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TECHNOLOGICAL PERSPECTIVES IN THE MACHINE-TOOL INDUSTRY AND THEIR IMPLICATIONS FOR DEVELOPING COUNTRIES

S. M. Patil

UNITED NATIONS

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TECHNOLOGICAL PERSPECTIVES IN THE MACHINE-TOOL INDUSTRY AND THEIR IMPLICATIONS FOR DEVELOPING COUNTRIES

LES PERSPECTIVES TECHNOLOGIQUES DE L'INDUSTRIE DE LA MACHINE-OUTIL ET LEURS INCIDENCES SUR LES PAYS EN DEVELOPPEMENT

PERSPECTIVAS TECNOLOGICAS DE LA INDUSTRIA DE MAQUINAS HERRAMIENTAS Y SUS CONSECUENCIAS PARA LOS PAISES EN DESARROLLO

ABSTRACT / SOMMAIRE / EXTRACTO

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ABSTRACT

The ability of the machine-tool industry to produce the multifarious types of machine tools necessary for industrialization profoundly affects the industrial and economic progress of any nation. Many developing countries have nevertheless lagged behind in establishing their capital goods industry in general and their machine-tool industry in particular.

Estimated world production of the machine-tool industry in 1979 was $22.7 billion. Of the 33 major machine-tool-producing countries, 22 developed countries accounted for 92 per cent of the total production.

In order to guide policy-makers in developing countries in the further development of this crucial sector, the present publication provides for a review of the machine-tool industry throughout the world in the context of developed and developing countries and of the technological trends in machine-tool design and manufacture, as well as production engineering. An assessment is made of the implications of these trends for developing countries.

On the basis of a forecast that, by about 1985, assembling jobs will be integrated into other production routines, making use of computer-aided manufacturing systems, that by about 1987 approximately 15 per cent of the total machine-tool production will consist of flexible production systems, that by about 1990 robots will attain human capabilities in final assembly sequences and that by about 1995 almost 50 per cent of the final assembly in the automotive industry will be achieved by programmable automation and robots, an analysis is made of possible action by developing countries to bring their programmes for the production of machine tools into line with some of the latest advances in technological developments in the industrialized nations.

SOMMAIRE

La capacité de l'industrie de la machine-outil à produire les divers types de machines-outils nécessaires pour l'industrialisation influe fortement sur le progrès industriel et économique d'un pays. Or de nombreux pays en développement sont en retard pour établir leur industrie productrice de biens d'équipement et en particulier celle des machines-outils.

On a estimé la production mondiale de l'industrie de la machine-outil en 1979 à 22,7 milliards de dollars. Sur les 33 grands pays producteurs de machines-outils, 22 pays développés assuraient à eux seuls 92 % de la production totale.

La présente publication passe en revue la situation de l'industrie de la machine-outil dans les divers pays — pays développés et pays en développement — et les tendances technologiques en matière de conception et de fabrication de machines-outils, ainsi que d'organisation de la production, et répond au souci de guider les dirigeants des pays en développement dans les efforts qu'ils accomplissent pour développer ce secteur d'une importance capitale. Il est procédé à une évaluation des incidences de ces tendances sur les pays en développement.

En partant de la prévision que d'ici à 1985, les tâches de montage seront intégrées dans d'autres tâches routinières de production faisant appel à des systèmes de fabrication automatisés, que d'ici à 1987, 15 % environ de la production totale de machines-outils sera effectuée par des systèmes de production polyvalents, que d'ici à 1990, les robots pourront assurer les séquences finales de montage aussi bien que des êtres humains et que d'ici à 1995, près de 50 % des opérations finales de montage dans l'industrie automobile seront réalisées par automatisation programmable et par des robots, on analyse comment les pays en développement pourraient orienter leurs programmes de production de machines-outils en fonction de certains des derniers progrès technologiques dans des pays industrialisés.

EXTRACTO

La capacidad de la industria de máquinas herramientas para producir los múltiples tipos de máquinas herramientas que precisa la industrialización influye profundamente en el progreso económico e industrial de cualquier nación. Ahora bien, muchos países en desarrollo se han quedado rezagados en la creación de una industria de bienes de capital en general y de una industria de máquinas herramientas en particular.

Se calcula que en 1979 la producción mundial de la industria de máquinas herramientas ascendió a 22.700 millones de dólares. De los 33 principales países productores de máquinas herramientas, a 22 países en desarrollo les correspondió el 92 % de la producción total.

A fin de orientar a los formuladores de políticas de los países en desarrollo sobre la manera de continuar el crecimiento de este sector crucial, la presente publicación estudia la industria de las máquinas herramientas en todo el mundo, tanto en los países desarrollados como en los países en desarrollo, las tendencias tecnológicas del diseño y la fabricación de las máquinas herramientas, y la ingeniería de producción. Además, hace una evaluación de las consecuencias de estas tendencias para los países en desarrollo.

Se pronostica que para 1985 aproximadamente los trabajos de montaje estarán integrados en otros procedimientos de producción mediante sistemas de fabricación equipados con computadoras; que para 1987 aproximadamente alrededor del 15% de la producción total de máquinas herramientas se efectuará mediante sistemas flexibles de producción; que para 1990 aproximadamente los robots podrán desempeñar las mismas funciones que el hombre en las fases finales del montaje; y que para 1995 aproximadamente casi el 50 % del montaje final de la industria automotriz se llevará a cabo mediante la automación programable y los robots. Partiendo de estos pronósticos, se analizan las medidas que puedan adoptar los países en desarrollo para poner sus programas de producción de máquinas herramientas en consonancia con algunos de los últimos adelantos de la evolución tecnológica de los países industrializados.

TECHNOLOGICAL PERSPECTIVES IN THE MACHINE-TOOL INDUSTRY AND THEIR IMPLICATIONS FOR DEVELOPING COUNTRIES

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Preface

According to one view, the most urgent task of developing countries is to meet the basic needs of the poor, using simple, small-scale appropriate technology. An opposing view is that modern technology and rapid industrialization alone can solve the problems of developing countries. Many countries in the third world consider the emphasis placed on basic needs to be an attempt to deny them the benefits of modern industry, and regard appropriate technology as backward technology that is particularly inappropriate at a time when some developing countries are becoming important exporters of industrial goods. It is also argued that such concepts perpetuate the existing international division of labour that allows developed market economies to undertake modern, highly productive industrial activities, while encouraging developing countries to concentrate on low-paid, less productive labour-intensive work. Such a debate, however, is meaningless. The crucial task of developing countries is to overcome their lack of technical development and raise the productivity of their labour to a level that would enable them to make progress towards the goal, set by the Second General Conference of UNIDO held at Lima, Peru, in March 1975, of achieving at least a 25 per cent share of world industrial production by the end of the twentieth century.

This study of technological perspectives in the machine-tool industry is designed to assist developing countries in the selection of appropriate modern machine-tool design and production technology. It consists of three parts: part I comprises a global review of the machine-tool industry, including a case study of the machine-tool industry in India; part II considers prospective technological developments in the machine-tool industry of developed countries; and part III discusses the implications for developing countries of technological developments in the machine-tool industry.

The study is based on replies to a questionnaire sent to leading machine-tool manufacturers, designers, production engineers, technologists, researchers and teachers in production technology and machine-tool users throughout the world. The annex contains an extract from a report of the Technical Policy Board of the Institution of Production Engineers, United Kingdom of Great Britain and Northern Ireland.

The study was prepared by S. M. Patil, acting as a consultant to UNIDO. The views expressed are those of the consultant and do not necessarily reflect the views of the secretariat of UNIDO.

EXPLANATORY NOTES

References to dollars ($) are to United States dollars, unless otherwise stated.

References to rupees (Rs) are to Indian rupees. In 1980, the value of the rupee in relation to the dollar was $1 = Rs 7.95.

The following forms have been used in tables:

Three dots (. . .) indicate that data are not available or are not separately reported.

A dash (—) indicates that the amount is nil or negligible.

Besides the common abbreviations, symbols and terms, the following have been used in this study:

AJM	abrasive-jet machining
CAD	computer-aided design
CAM	computer-aided manufacture
CHM	chemical machining
CMEA	Council for Mutual Economic Assistance
CNC	computer numerical control
DNC	direct numerical control
EBM	electron-beam machining
ECM	electrochemical machining
EDM	electron-discharge machining
EEC	European Economic Community
ENIMS	Experimental Scientific Research Institute of Metal-cutting Machine Tools
IBM	ion-beam machining
LBM	laser-beam machining
MDI	manual data input
NC	numerical control
PAM	plasma-arc machining
PM	powder metal
USM	ultrasonic machining
WJM	water-jet machining

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Part one

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I. Background

Objectives of the study

Steadily increasing production costs in developed countries have led to a corresponding expansion of demand for more highly productive and precise machine tools. The activity and technical standards of the machine-tool industry have therefore become an accurate index of the economic efficiency and productivity of manufacturing industry. Many machine tools currently in use are clearly recognizable successors of basic designs. Some, however, are completely new in conception and involve machining methods, normally electrical, whereby the intense concentration of power (emanating from electric sparks, electron beams or laser beams) on a small area of a workpiece causes the metal to melt and vaporize. Similar innovations involve the manufacture of turbine blades by electrochemical techniques, the electrolytic grinding of very hard metals and ultrasonic and abrasive jet machining.

In view of such rapid and innovative changes in the design and technology of machine tools, developing countries should thoroughly investigate the question of obsolescence in the machine-tool industry before acquiring foreign designs and technological know-how. The objective of this study is to provide an in-depth analysis of that question and to make a realistic forecast of machine-tool technology up to the end of the century. This would help developing countries to establish their own machine-tool industries on a proper basis, avoiding designs and technology ill-suited to their needs or likely to become obsolete in the near future.

Definition of a machine tool

A machine tool is a power-driven tool, non-portable while in operation, used for carrying out, individually or in combination, the operations of machining, forming and electrochemical processing of metals, wood, glass, plastic and similar materials. Machine tools range from simple drilling machines and lathes to complex, fully automated and computerized machines, machining centres with tool changers, multi-station machines, transfer lines and flexible machining systems capable of automatically producing work that meets the required standards of quality and quantity. Metalworking machine tools are required for the production of metalwork and a wide range of capital and consumer goods by the manufacturing and engineering industries.

There are at present two main types of machine tools, namely chip-removing and forming types. There are 10 main operations in the chip-removing process: turning, milling, planing, shaping, drilling, boring, gear-hobbing, tapping, broaching and grinding (cylindrical, profile, external, internal and flat). Like all machine-tool operations, the above ten processes depend not upon heat or pressure as do castings, forgings and stampings, but upon removing metal chips which range from the metallic gravel of planing to the fine dust of grinding and electrolytic, chemical, plasma and laser machining. The variants and combinations of these and a few other operations could result in hundreds of different kinds of machine tools.

The main category of forming machine tools includes all types of presses, forge hammers, explosion forming machines, welding units etc.

Importance of the machine-tool industry

Few, if any, products and services of modern civilization would exist if it were not for machine tools. However, despite its fundamental importance, the machine-tool industry has always represented only a small part of the total industrial output of developed countries, thanks to the efficiency and longevity of its products. The entire world machine-tool industry is in fact smaller than many individual corporations in the United States of America.

The ability of the machine-tool industry to produce the great variety of machine tools necessary for industrialization has a major impact on the economic and industrial progress of a country. Many developing countries have lagged behind in establishing their own capital goods and machine-tool industries. A few, however, have a sizeable capital goods industry and a large machine-tool industrial base, which has given them a big advantage over other developing countries. They are now able to substitute local production for imports of many types of capital and consumer goods, and some have reached a stage of development that enables them to improve their balance of trade through the export of a variety of industrial products.

Brief review of the world machine-tool industry

The world machine-tool industry, which consistently registered an increase in output from 1962 onwards, generally reflecting strong industrial growth among the main producers and users of machine tools throughout the world, suffered its first setback in 1974 as a result of the oil crisis. Rising oil prices, inflation and confusion in the world financial markets had their repercussions on machine-tool production during the rest of the decade. Production estimates of leading machine-tool-producing countries and areas in 1979 and data for 1978 are shown in table 1. These countries and areas also account for a major share of exports. World exports and consumption of machine tools have risen sharply since 1964, as may be seen from figures I and II. Figure III shows the growth in machine-tool production of the nine leading producers since 1966. The countries listed in table 2 consumed about 75 per cent of total world machine-tool production and accounted for about 93 per cent of world exports.

The share of production and exports accounted for by the leading machine-tool-producing developed countries is shown in figures IV and V.

The high degree of industrialization, the monetary strength and the flourishing economies of the nine biggest producers provide the basis for their strong machine-tool industries. Traditionally, these countries have accounted for 80 per cent of world trade in most industrial goods and for nearly all the technological innovations in the field of metalworking equipment. Their advanced designs and technological developments have to a large extent been achieved to meet their own requirements, namely increased production and productivity and the progressive saving of labour.

TABLE 1. WORLD MACHINE-TOOL PRODUCTION AND TRADE

(Millions of dollars)

	1979 (estimated)					1978				
	Production			Trade		Production			Trade	
Country or area	*Total*	*Cutting tools*	*Forming tools*	*Export*	*Import*	*Total*	*Cutting tools*	*Forming tools*	*Export*	*Import*
1. Germany, Federal Republic of	4 099.9	2 951.9	1 148.0	2 460.0	541.2	3 396.4	2 373.8	1 022.6	2 122.3	462.0
2. United States	3 890.0	2 940.0	950.0	660.0	1 060.0	3 004.3	2 205.7	798.6	560.2	715.3
3. Soviet Union	2 892.0	2 234.0	658.0	350.0	800.0	2 652.0	2 056.0	596.0	332.0	803.0
4. Japan	2 697.8	2 081.5	616.3	1 113.8	155.2	2 350.3	1 736.6	613.7	1 017.5	119.9
5. Italy	1 385.7	903.7	482.0	698.9	265.1	1 060.5	698.3	371.2	596.2	194.4
6. United Kingdom	1 106.4	872.3	234.1	468.1	574.5	821.4	639.1	182.3	426.0	399.2
7. France	918.1	586.2	331.9	479.8	352.4	723.0	535.7	187.3	382.7	289.6
8. German Democratic Republic	805.8	636.7	169.1	661.6	243.8	698.6	552.0	146.6	547.9	217.8
9. Switzerland	797.1	677.5	119.6	677.5	139.5	768.2	652.8	115.4	652.8	124.3
10. Poland	684.6	600.8	83.8	190.9	518.3	678.8	594.9	83.9	163.4	595.8
11. China	420.0	315.0	105.0	28.0	60.0	405.0	305.0	100.0	20.0	65.0
12. Romania	403.6	359.7	43.9	130.7	381.2	294.3	268.0	26.3	88.0	339.0
13. Czechoslovakia	357.2	285.9	71.3	265.0	166.3	363.4	295.1	68.3	246.2	170.2
14. Spain	313.1	219.9	93.2	216.2	82.0	232.2	161.8	70.4	147.6	90.1
15. Brazil	239.8	191.8	48.0	33.0	136.0	255.3	203.0	52.3	20.1	226.2
16. Yugoslavia	222.5	121.0	101.5	50.0	150.0	173.5	105.1	68.4	41.7	150.2
17. Sweden	199.7	131.2	68.5	156.7	101.7	166.4	105.5	60.9	138.3	109.5
18. China (Taiwan Province)	172.2	165.2	7.0	120.0	70.0	126.0	119.7	6.3	94.0	58.3
19. Austria	150.8	64.1	86.7	113.1	147.0	112.5	69.8	42.7	93.9	98.9
20. Republic of Korea	150.0	107.0	43.0	22.0	140.0	95.0	68.0	27.0	5.0	156.0
21. India	129.0	112.9	16.1	31.0	55.8	111.8	96.8	15.0	24.4	48.8
22. Belgium	127.3	44.7	82.6	110.5	126.3	114.0	40.0	74.0	99.0	113.2
23. Hungary	115.9	107.3	8.6	89.8	123.9	109.3	101.7	7.6	84.2	112.7
24. Canada	110.3	64.6	45.7	66.4	330.2	84.8	47.4	37.4	52.8	228.0
25. Netherlands	75.0	50.0	25.0	39.0	102.0	66.5	43.9	22.6	34.7	90.9
26. Argentina	62.0	24.5	37.5	12.0	75.0	60.0	24.0	36.0	12.0	60.0
27. Denmark	48.0	26.0	22.0	25.0	42.0	45.3	24.9	20.4	23.7	39.8
28. Bulgaria	30.0	30.0	—	15.0	25.0	30.0	30.0	—	15.0	25.0
29. Singapore	21.3	19.3	2.0	27.7	92.1	12.0	10.4	1.6	18.8	46.8
30. South Africa	20.0	7.4	12.6	3.9	112.3	14.9	4.6	10.3	4.0	80.5
31. Australia	18.0	9.7	8.3	1.1	155.4	18.5	9.9	8.6	1.1	106.7
32. Mexico	15.5	7.5	8.0	1.5	85.0	13.6	6.6	7.0	1.3	75.0
33. Portugal	14.3	6.1	8.2	4.6	38.9	10.2	4.8	5.4	4.0	14.8
Total	22 692.9	16 955.4	5 737.5	9 322.8	7 448.1	19 068.0	14 181.9	4 886.1	8 070.8	6 426.9

Source: *American Machinist*, February 1980

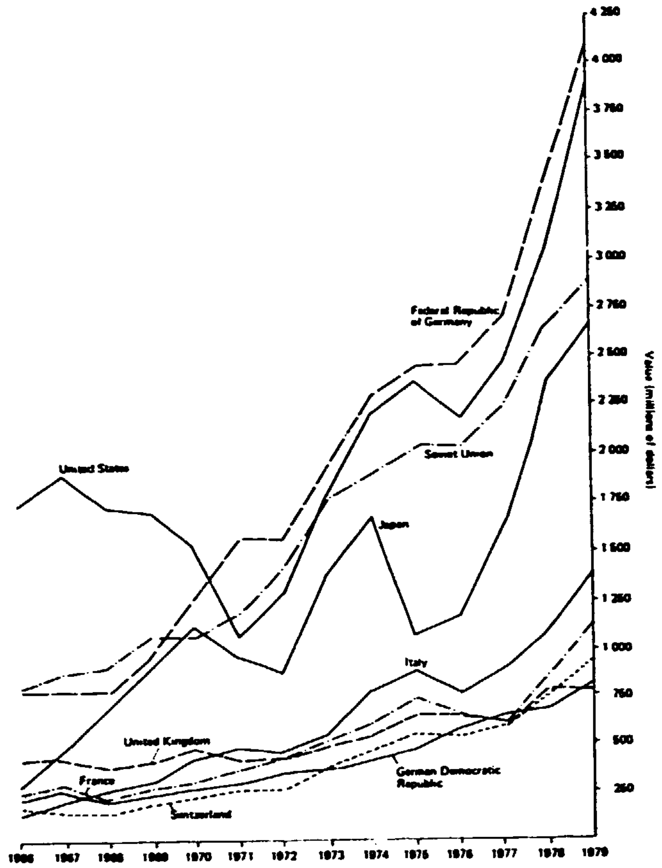
Figure I. World machine-tool exports

Source. National Machine Tool Builders' Associa... n.

Figure II. World machine-tool consumption

Source National Machine Tool Builders' Associatio..

Figure III. Growth of machine-tool production of the nine leading producers



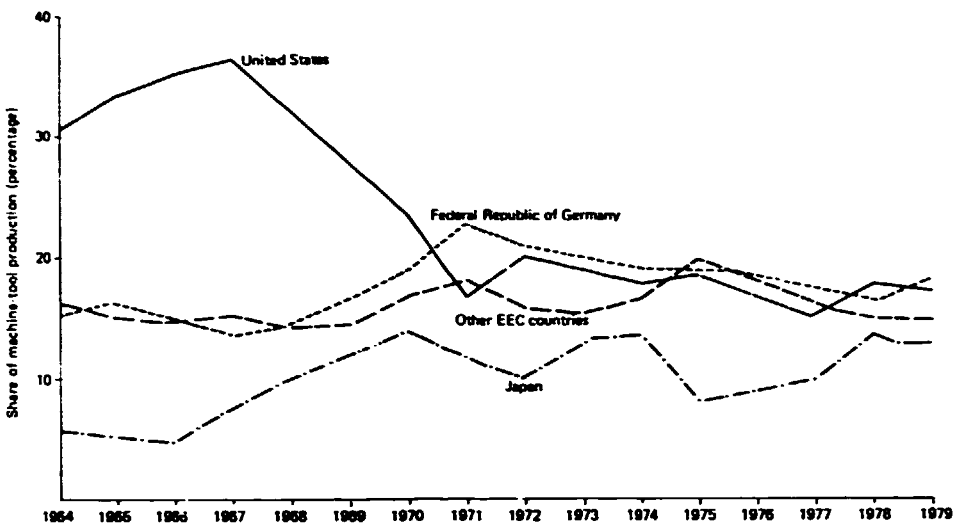
Source: *American Machinist*, February 1980

TABLE 2. LEADING MACHINE-TOOL CONSUMERS

Country	*Output (million $)* 1978	*Output (million $)* 1979	*Percentage change*
1. United States	3 159.4	4 290.0	35.8
2. Soviet Union	3 123.0	3 342.0	7.0
3. Germany, Federal Republic of	1 636.5	2 182.2	33.3
4. Japan	1 452.7	1 739.2	19.7
5. United Kingdom	794.6	1 212.8	52.6
6. Poland	1 111.2	1 012.0	8.9
7. Italy	658.7	951.9	44.5
8. France	630.2	790.7	25.5
9. Romania	545.3	654.1	20.0
10. Brazil	461.4	342.8	25.7
11. China	450.0	452.0	0.4
12. German Democratic Republic	368.5	388.0	5.2
13. Yugoslavia	282.0	322.5	14.4
14. Czechoslovakia	287.4	258.5	10.1
15. Canada	260.1	374.1	43.9
16. Republic of Korea	246.0	268.0	8.9
17. Switzerland	239.3	259.1	8.3
18. Austria	117.5	184.7	57.2
19. Spain	174.7	178.9	2.4
20. India	136.2	153.8	12.9
21. Hungary	137.8	150.0	8.9
22. Sweden	137.6	144.7	5.2

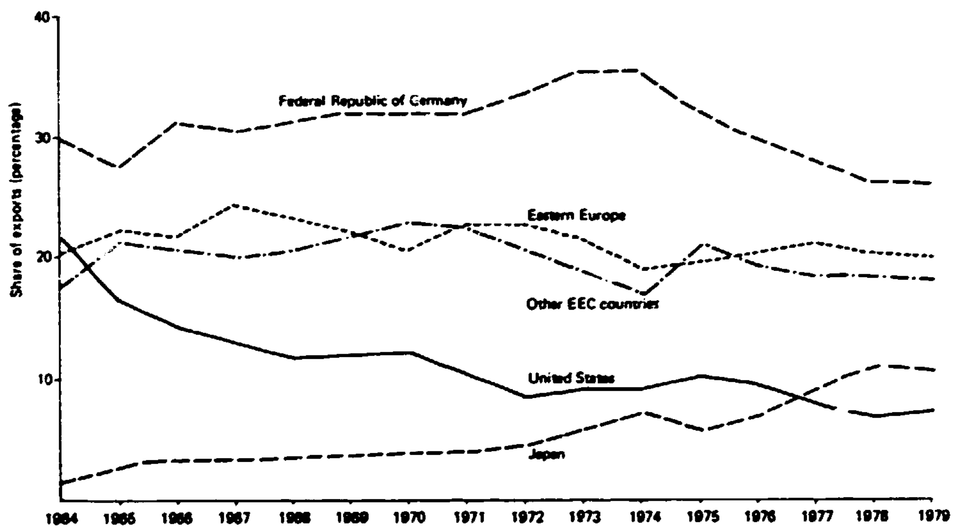
Source: *American Machinist*, February 1980

Figure IV. Share of machine-tool production of developed countries as a percentage of world output



Source: National Machine Tool Builders' Association.

Figure V. Share of machine-tool exports of developed countries as a percentage of world exports



Source: National Machine Tool Builders' Association.

Not only has industrial expansion in developed countries given impetus to the growth of their metalworking sector, but also their higher level of consumption demands that those growth rates be maintained to ensure continued affluence. However, judging from their present level of energy consumption, some apprehensions have been expressed that developed countries may not register the same rate of economic growth as envisaged before because their industries and technology depend upon depletable energy inputs such as coal and crude oil. But since developed countries have predominant technological power, resources and capabilities and the necessary infrastructure for research and development activities in almost all industrial disciplines, alternate energy sources may well be tapped by them much earlier than by other countries.

II. The machine-tool industry in some of the leading machine-tool-producing developed countries

The machine-tool industry in most developed countries has many common features. Nevertheless, the developments taking place are not quite uniform. For instance, some countries such as Switzerland specialize in producing high-precision machine tools, including jig boring machines, jig grinding machines, gear grinding machines and machine tools needed by the watch industry. The United States has specialized in producing very high-performance productive machines, mostly with numerical control (NC), computer numerical control (CNC) and direct numerical control (DNC) systems, for small-, medium- and large-batch production and mass production of single components (for example, transfer lines). Countries belonging to the European Economic Community (EEC), Japan and countries with centrally planned economies, such as Czechoslovakia, the German Democratic Republic and the Union of Soviet Socialist Republics, produce heavy-duty and high-production machines needed mostly for general applications at very reasonable prices. This explains why major machine-tool-producing countries have themselves been the principal importers of machine tools. It is very common to see Swiss grinding machines, jig-boring machines or gear-grinding machines in the Federal Republic of Germany, Japan, or the Soviet Union. On the other hand, France, Italy, Switzerland and the United States import substantial quantities of machine tools from the Federal Republic of Germany for particular applications. No developed country has ever attempted to be self-sufficient in machine tools. Some developed countries with centrally planned economies which experimented with the concept of self-sufficiency to an extreme degree had to give up eventually in order to improve the quality and productivity of their domestic products and equipment and also to compete in the world market.

The following brief accounts of the status of the industry in some of the leading machine-tool-producing developed countries should prove useful to developing countries.

Czechoslovakia

The machine-tool industry in Czechoslovakia consists of 47 manufacturing firms producing metal-cutting and metal-forming machines. The industry in Czechoslovakia dates back to 1905 and has a long tradition of building quality machine tools. The country has two major groups of manufacturers, one being the Engineering Technique Group and the other consisting of various national corporations. Czechoslovakia is a leading producer of machine tools in the Council for Mutual Economic Assistance (CMEA), second only to the Soviet Union and the German Democratic Republic.

Besides general-purpose machine tools, its industry is famous for machine tools designed for heavy use and for ordnance work.

Production and trade

The production, consumption and trade of Czechoslovakia in machine tools from 1975 to 1979 are reflected in table 3.

Czechoslovakia has traditionally traded with CMEA countries and with developed market economies. In recent years the volume of imports from the German Democratic Republic and the Soviet Union has increased. However, Czechoslovakia exports more machine tools than it imports, as reflected in table 3.

Technology

The Czechoslovak machine-tool industry is greatly assisted by the research and development carried out at the Research Institute of Machine Tools and Machining, Prague, and the Institute for Metal-forming Machine Tools at Brno. The principal directions of research activity are in the development of CNC for machine tools and modular manufacturing systems. Work is in progress on a fully flexible, automatic manufacturing system. This is to be achieved by means of a DNC

TABLE 3. THE MACHINE-TOOL INDUSTRY IN CZECHOSLOVAKIA: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

Year	Production	Consumption	Exports: Value	Exports: Percentage of production	Imports: Value	Imports: Percentage of consumption
1975	305.4	244.7	190.5	62.38	129.8	53.04
1976	337.9	260.7	190.2	56.29	113.0	43.34
1977	309.1	251.4	215.3	69.65	157.6	62.69
1978	363.4	287.4	246.2	67.75	170.2	59.22
1979	357.2	258.5	265.0	74.19	166.3	64.33

Source: American Machinist

system with a three-tier hierarchy of computers involving a central computer for systems control, with tool movements from a central magazine to tool sharpening, and intermediate computers (CNC) for control of the machining centres. A semi-automatic integrated manufacturing system consists of NC machining centres and standard NC machines, such as measuring machines and ultrasonic work devices, and other supporting equipment. The system is controlled by DNC computers developed in Czechoslovakia. Some of the new developments undertaken by the Research Institute at Prague are the following: an automatic system to sense tool wear and breakage in the automatic production system; and tool magazines for CNC machining centres to store large numbers of tools in a matrix formation. This represents an advance on the limited number of tools in the tool changer equipment currently provided with machining centres.

Federal Republic of Germany

The machine-tool industry of the Federal Republic of Germany rose from war-time devastation to a leading position in the world economy within two decades. Many attribute the economic miracle of the country to the dynamism and remarkable growth of its machine-tool industry, which was facilitated by two important factors. In the first place, most of the capital equipment of the country, like that of a number of European countries, was damaged during the Second World War. The rebuilding of the country hinged on making available capital equipment like machine tools for reconstruction. Secondly, the destruction during the war provided an opportunity to equip machine-tool plants with the latest machinery, thus combining the advantage of higher productivity with modern designs. These two factors together with substantial assistance from the United States under the Marshall Plan helped to rebuild modern machine-tool factories all over the Federal Republic of Germany and Berlin (West). The rapid reconstruction of the industrial base of Western Europe and the favourable conditions of expansion over a long period of time provided the ideal setting for the machine-tool industry of the country to grow into a powerful catalyst of industrialization.

Production and trade

Data [illegible]hine-tool production, consumption and tra[illegible]e Federal Republic of Germany from 1975 t[illegible] are shown in table 4.

TABLE 4. THE MACHINE-TOOL INDUSTRY IN THE FEDERAL REPUBLIC OF GERMANY: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

Year	Production	Consumption	Exports: Value	Exports: Percentage of production	Imports: Value	Imports: Percentage of consumption
1975	2 403.9	808.8	1 814.3	75.48	219.7	27.16
1976	2 410.6	909.4	1 738.7	72.12	237.5	26.11
1977	2 635.5	1 132.7	1 823.2	69.18	320.4	28.28
1978	3 396.4	1 636.5	2 122.3	62.48	462.0	28.23
1979	4 099.9	2 182.2	2 460.0	60.00	541.2	24.80

Source: American Machinist

The table shows a decline in exports as a percentage of production, which could be partly the result of currency realignments and partly of competition from countries with lower labour costs. Even in developed countries, the labour-intensive character of machine-tool manufacture persists despite impressive advances in automation. Nevertheless, the export sales of the machine-tool industry of the Federal Republic of Germany occupies the first rank, far ahead of other countries. This is mainly due to the technological strength, quality-consciousness and high degree of aggressiveness of its tool exporters.

Although the industry continues to rely primarily on exports, the role of the domestic market is growing. The impetus to develop higher-technology machines is expected to come mainly from home demand and from sophisticated export markets like that of the United States. During 1979 the increase in domestic demand was reflected in higher investments in industrial development projects. Continued product development is also required in order to compete effectively on the growing domestic market.

As reflected in table 4, imports of machine tools by the Federal Republic of Germany cover approximately 25 to 30 per cent of total consumption. This again proves the fact that the biggest machine-tool-producing and -exporting countries are themselves large importers of machine tools. Machine-tool imports of the Federal Republic of Germany are likely to rise because of the increasing cost of manufacture brought about by wage increases and lower working hours in its machine-tool industry. Japan and Switzerland are expected to increase exports of their products to the Federal Republic of Germany because of the almost steady cost of manufacture of machine tools in those two countries. Japan now ranks fourth among countries from which the Federal Republic of Germany imports machine tools.

Technology

The foremost position of the machine-tool industry of the Federal Republic of Germany is due to its technological strength in all spheres of machine-tool manufacture, ranging from simple lathes to the most sophisticated manufacturing systems incorporating robots and computers. Research and development support to the machine-tool industry is provided by continuous work done at machine-tool research institutes such as the Technische Hochschule, Aachen, and the Technische Universität, Berlin (West). The country has pioneered some of the major advances not only in electronics but also in many other fields, including product reliability and safety. More than 25 per cent of NC machine tools on display at the Third European Machine Tool Organization Exhibition at Milan, Italy, were equipped with controls produced by a firm of the Federal Republic of Germany in a joint venture with a Japanese firm. The two firms have forged ahead of other control manufacturers. Using their microprocessor-based CNC for lathes, the programmed workpiece contours and the machining sequence are shown on the graphic display in the same way as on an electronic drafting machine. The control system determines the necessary rough and finishing-cut sequences from infeed valves and it has the capability to display current cutting data.

The firms engaged in the joint venture have introduced two major new control systems, each using a 16-bit microprocessor and offering the option of bubble memory with 256,000-character storage. One of the systems, developed by the firm of the Federal Republic of Germany, includes an arrangement by which information can be presented on a display screen that includes some of the alarm and diagnostic functions.

Laser cutting has been added to NC. A firm in the Federal Republic of Germany has incorporated a laser into its punching machine, which floats on air supports when punching, but is lowered to a rigid foundation when laser cutting. The firm has been trying further to reduce noise in its punching machines by putting sound-absorbing casings around those components of the machine which produce the most noise. The principal source of noise is the cutting tool.

France

The machine-tool industry of France showed declining production up to 1977 because of progressively decreasing investments in machine tools by the French metalworking industries. In 1979, the French metalworking industry still did not provide hopeful indicators of higher investments. However, thanks to the export of high-technology products, the French machine-tool industry had not suffered a serious setback.

The French machine-tool industry is composed of small and medium-sized establishments. Consequently, even their competitiveness has been limited because they cannot muster the resources required to make major inroads on the export market or to rejuvenate the home market by offering customers the facility of payment by easy instalments.

The French industry is now striving to consolidate its position in the home and export markets by virtue of its high technology products.

Production and trade

An improvement in the competitive position of the French machine-tool industry is hampered by a variety of factors. The majority of machine tools installed in French industrial establishments are comparatively old. It has been reported by the French Machine Tool Manufacturers Association that in 1979 only about 32 per cent of the installed machine tools were less than 10 years old, while it was 37 per cent in the Federal Republic of Germany, 39 per cent in the United Kingdom and as much as 60 per cent in Japan. The more disconcerting fact about the French machine-tool industry is that while home consumption is moving at a slow pace, the countries competing with France are progressively installing newer machines to sharpen their competitive edge in the world market. The production, consumption and trade statistics for France from 1975 to 1979 are shown in table 5.

As reflected in table 5, France had a surplus in its balance of trade in machine tools during 1978 and 1979. Its export efforts are not limited to a particular geographic region. The principal foreign customers of French machine tools in order of priority are: Romania, Germany, Federal Republic of, Soviet Union, Italy, Algeria. Efforts are also being made to penetrate markets in China, Mexico and Latin America more effectively.

French exporters to the EEC countries improved considerably because of increased sales to Belgium, the Federal Republic of Germany, the Netherlands and the United Kingdom. By way of comparison, Italy increased its sales to France. Among the other countries, it is important to underline the penetration of French machine tools into Spain, which is the ninth largest customer of France. Exports to the United States also registered an impressive growth and made the United States the seventh largest customer of French machine tools. The French machine-tool industry is also intensifying efforts to sell its products to Argentina, the Republic of Korea, and European countries with centrally planned economies. Switzerland has a surplus balance of trade in machine tools with France.

France has been importing high-technology and high-production machine tools mainly from the Federal Republic of Germany and the United States. High-precision machines are imported primarily from Switzerland. The French metalworking industry imported machine tools at the rate of 45 to 50 per cent of its total consumption throughout the 1970s.

Technology

The French machine-tool industry has high technological strength. The refinements on general-purpose machine tools are identical to those seen on machines offered by competitors, and France has not lagged behind in the field of NC and CNC controls or in the development of machining centres designed to meet the requirements of the French aerospace industry. Major French machine-tool companies have been exporting advanced machine tools to several other countries in addition to leading aircraft manufacturers. In 1979, there were 5,200 NC machines installed in the French metalworking industry, of which as many as 1,600 were CNC machines. A leading French firm is building a variety of industrial robots and special pallet loaders to assure a high degree of automation, for example in painting and welding. It has designed and built robots for applying lacquer, zinc paint, primer and mastic and for enamelling and metallizing. A seventh optional axis provides access to work areas inside auto-bodies. Another firm has produced a machine in which parts can be held in a central headstock for simultaneously machining both sides. Blanks are automatically loaded, centred, clamped, machined and ejected without stopping the spindle. A leading French manufacturer has started marketing an NC hone for engine sleeves, a 16-spindle

TABLE 5. THE MACHINE-TOOL INDUSTRY IN FRANCE: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

			Exports		Imports	
Year	*Production*	*Consumption*	*Value*	*Percentage of production*	*Value*	*Percentage of consumption*
1975	678.6	695.5	319.4	47.06	336.2	48.34
1976	657.2	732.7	272.2	41.42	347.7	47.45
1977	590.6	607.5	269.3	45.60	286.2	47.11
1978	723.0	630.2	382.7	52.93	289.6	45.95
1979	918.1	790.7	479.8	52.26	352.4	45.57

Source: *American Machinist*

progressive honing machine for hydraulic parts that maintains a tolerance of 2 μm, and a high-precision 16-spindle machine for fuel-injection-system parts, which features hydraulic expansion of the hone to hold tolerance to 0.5 μm at an output of 100 parts per hour.

Despite their impressive level of technical development, several of the above-mentioned high-technology products are not purchased by French customers because of the low level of investment in the country in modern machine tools. It has been suggested that the stagnation of investments in France has forced many French machine-tool manufacturers to open manufacturing facilities abroad, notably in the United States.

German Democratic Republic

The German Democratic Republic currently ranks eighth among world machine-tool producers and fourth among machine-tool exporters.

Even before the Second World War, Erfurt, Magdeburg, Leipzig and Karl-Marx-Stadt (Chemnitz) were important machine-tool-building centres. Since all those cities are now part of the German Democratic Republic, the country has become one of the leading producers of machine tools. The industry is concentrated in the south of the country around Karl-Marx-Stadt.

The German Democratic Republic produces quality machine tools suited for one-off, medium-scale, large-batch and mass production. It also produces custom-built machine tools for large manufacturing plants. Machine-tool manufacture assumes an important position in the economy, and about four times as many people are involved in the manufacture and marketing of machine tools than, for example, in the United Kingdom. At present, more than 80,000 people are employed in the machine-tool industry, the products of which include both metal-cutting and metal-forming machine tools.

The machine-tool industry of the German Democratic Republic is centrally planned and controlled. Overall responsibility for sales and marketing policy is determined by an export-import agency based in Berlin. The industry is divided into four *Kombinats* or manufacturing combines, each responsible for the manufacture of different groups of metalworking machine tools. One combine manufactures machines for the production of circular components (for example, lathes and grinders), while companies within another combine manufacture machines for the production of prismatic or housing-shaped components (for example, milling machines). The third combine concentrates on the manufacture of sheet metal, blanking and forming machines and equipment for processing plastics. The fourth combine manufactures tools, jigs, fixtures and maintenance machines.

Production and trade

Machine-tool production, consumption and trade figures of the German Democratic Republic for the years 1975 to 1979 are given in table 6.

Over 80 per cent of the machine-tool production of the German Democratic Republic is exported. The export range comprises a multitude of machine tools for turning, grinding, gear-cutting, milling, drilling, boring, planing etc. The country now ranks fourth among leading world exporters, and it imports only a fraction of what it exports, as reflected in table 6.

In general, three quarters of the trade of the German Democratic Republic is with other members of the Council for Mutual Economic Assistance (CMEA), about half of which is with the Soviet Union. The country also imports machine tools from the Soviet Union and other countries with centrally planned economies. Another important trading partner of its machine-tool industry is the Federal Republic of Germany.

TABLE 6. THE MACHINE-TOOL INDUSTRY IN THE GERMAN DEMOCRATIC REPUBLIC: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

			Exports		*Imports*	
Year	*Production*	*Consumption*	*Value*	*Percentage of production*	*Value*	*Percentage of consumption*
1975	582.2	268.8	507.8	86.77	191.4	71.20
1976	568.8	365.7	446.4	78.48	170.3	46.57
1977	641.4	218.7	596.6	93.00	173.9	79.52
1978	698.6	368.5	547.9	78.42	217.8	59.10
1979	805.8	388.0	661.6	82.10	243.8	62.84

Source: *American Machinist*

Technology

The German Democratic Republic regularly supplies high-quality machine tools to other CMEA members. The products range from general-purpose to computer control machines, and considerable importance is attached to the production of custom-built and NC machine tools. Most of the basic research and development work is conducted at the universities of Jena, Dresden, Berlin, Leipzig and at the Machine Tool Design and Research Institute in Karl-Marx-Stadt. Research work is also conducted in co-operation with countries such as Czechoslovakia and the Soviet Union.

The design excellence of machine tools produced in the German Democratic Republic may be attributed to the incorporation of modern components such as recirculating ball screws, direct-current drives and electronic linear position scales. It also produces linked production lines.

The German Democratic Republic is recognized as the leading machine-tool manufacturer in CMEA because of its pioneering work in improving the machining environment, productivity and accuracy. Nevertheless, in certain areas the level of applied machine-tool technology in the German Democratic Republic falls somewhat short in comparison with the standards of developed market economies. The country does not build CNC systems at present, although it can supply machines equipped with its own NC systems. It also supplies machines built for CNC and fitted with CNC systems produced by developed market economies.

Computer techniques are employed in production—for instance, tape preparation within the factory is done on a minicomputer. Moreover, NC machines are linked to a central main-frame computer—the German Democratic Republic makes its own minicomputers—by machine terminals. In some of its factories, an automatic parts store is used in conjunction with the transport system, and studies have been undertaken on the possibility of issuing all necessary tooling and fixtures for a job along with the components and then transporting them together round the system to the work station. Such an advanced production management system on the shop-floor has become almost a necessity in view of the serious shortage of labour in the German Democratic Republic.

Italy

The machine-tool industry in Italy was born at the beginning of the century and developed during the years between the two world wars, until in 1938 it was producing 28,000 tonnes of machines. Although activity was resumed immediately after the Second World War, pre-war production levels were not reached again until the late 1950s, with the development of the automobile and electrical domestic appliance industries. Between 1958 and 1963, production was quadrupled. While firms already operating in the sector were restructuring their production in accordance with the new technological requirements, many others launched for the first time into the production of machine tools.

After the crisis suffered by the whole Italian economy between 1964 and 1966, the year 1967 marked a second period of strong development for the machine-tool industry, again associated with a marked recovery of investment in durable consumer goods. During this period, stimulated by a sharp rise in the cost of labour, there was a growing tendency on the part of many Italian firms to produce more sophisticated, automated and numerically controlled machinery.

The Italian machine-tool industry has grown steadily since 1970. The success of the Italian machine-tool industry depends on the traditional structure of Italian companies. Firms with less than 500 employees account for 70 per cent of production. These firms have increased their investments and are planning to meet the higher demands of the home and export markets.

Since United Kingdom and United States studies indicate a revival of the boom for machine tools in 1979 and 1980, there is every likelihood of world investments in plant and machinery reaching over $20 billion, compared with $15 billion in 1977. The Italian machine-tool industry hopes to get a share of this bulk investment.

The Italian machine-tool industry has adopted a novel method of capturing new markets by establishing training and trading centres in third world countries. A national agency called the Italian M3 T has been set up in Rome. The name M3 T denotes the Italian machine tools, training and trading establishment which combines training and trading functions. The basis for establishing this agency was a report prepared by the Data Bank of Italy which is responsible for analysis and documentation. In the report, the number and types of machines which were most likely to find a market in Latin America were worked out as well as the training facilities to popularize Italian machine tools. Since one usually prefers the make of the machine on which one has been trained, the Italian machine-tool industry promoted the establishment of M3 T to attract new customers by setting up a training institute in Rio de Janeiro. The agreement was concluded with the Brazilian National Authority for Industrial Training for the delivery of programmable machines, NC machines and planning aids as well as for the training of Brazilian personnel in Italy and for deputing Italian instructors to Brazil. Financing for this project is provided by the financing branch of the Finanzaria Construttori Italiani Macchine Utensili (Italian Machine Tool Manufacturers Association). The training centre at Rio de Janeiro will demonstrate its capability in such a manner as to provide the most comprehensive training by using the best suited Italian equipment. This centre may prove to be a forerunner of many such centres in Latin America.

Production and trade

The development of trade in machine tools has been helped by the establishment of a few specialized institutions. The Institute for External Trade of Italy has been playing a major role. The Institute has been responsible for creating an awareness of the competition and the necessary dynamism to increase foreign trade by encouraging private initiative and gaining the support of financial institutions.

Production, consumption and trade figures from 1975 to 1979 are shown in table 7.

In the year 1975, the Italian Machine Tool Manufacturers Association conducted a detailed survey regarding the age of machine tools installed in Italian manufacturing industries. According to this survey, the average age of Italian machine tools in operation in Italy is 12.8 years, which is higher than that of only Japan. This clearly indicates that the industry has been successful in selling a considerable portion of its production at home, despite the adverse conditions of fresh investments.

A major worry of the Italian machine-tool industry is the labour problem. Pressure by the labour force has led not only to increased wages, but also to a reduction of weekly working hours to 36 or 38 hours.

During the 1970s Italy has had a steady positive trade balance in respect of machine tools, of which it is becoming one of the major exporters. The continuous good export performance of Italy may be attributed to the organizational support provided by Federexport, a national organization set up by the Ministry of Industries. The main countries from which Italy imports machine tools are the Federal Republic of Germany, Japan and Switzerland.

Federexport and the Italian World Trade Centre have concluded an agreement designed to support Italian foreign trade. The Italian World Trade Centre provides companies with a large number of services. Under the agreement, assistance is provided to small units which forego possible sales because of the risk of not recovering the full sale amount from the customer. This risk is particularly great in instalment plans. The problem has been largely solved by offering the companies better insurance coverage than that offered by commercial banks and insurance companies.

Technology

NC entered Italian machine-tool production on a large scale in the 1970s. The growth of NC was most dynamic because of the flexibility of CNC controls and miniaturization of their components. Microprocessors have added a further capability.

In the field of development, Italy has made important strides. In modern DNC transfer lines, the individual NC machines are only links in a system controlled by a central computer. These transfer lines are now employed in Italy for the production of various types of housings of heavy-duty vehicles, tractors and agricultural machinery. On this flexible production system, gearbox housings and components of agricultural machinery are produced. It has revolutionized the concept of transfer lines. Other impressive machining systems are automatic welding systems and an asynchronous assembly line for various types of motors.

TABLE 7. THE MACHINE-TOOL INDUSTRY IN ITALY: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

			Exports		Imports	
Year	*Production*	*Consumption*	*Value*	*Percentage of production*	*Value*	*Percentage of consumption*
1975	873.1	653.4	431.3	49.39	211.7	32.40
1976	750.9	541.8	365.3	48.65	156.2	28.83
1977	878.3	629.4	436.5	49.70	187.7	29.82
1978	1 060.5	658.7	596.2	56.22	194.4	29.51
1979	1 385.7	951.9	698.9	50.44	265.1	27.85

Source: American Machinist

In the field of controls, an Italian manufacturer has produced a control with a special two-level machine-operator dialogue system. During machining, communication of data takes place on a simplified level and advanced language is used only for programme editing. Another Italian firm has come out with a control unit that allows the machine tool to be employed as a motor-driven measuring machine.

In the realm of three-dimensional co-ordinate measuring instruments, new numerically controlled designs and models have been produced. These three-dimensional automatic measuring units function at high speed and accuracy. They are flexible and simple to programme and are designed to measure mechanical construction elements. A system has been patented in which motion along the axis is provided by a magnetic attachment. Stoppage in the measuring position is done pneumatically in order to improve rigidity.

An Italian firm has produced a line of co-ordinate measuring machines featuring software for automatic control by tridimensional inspection. The inspection cycle of a component can be programmed from an engineering drawing. Additionally, a complete inspection certificate can be printed out both during and after inspection procedures. A display helps the worker learn inspection operations and the unit has the capability statistically to process inspection parameters, calculate and display the relative averages and mean square deviations.

A flexible programmable controller with 12 controllable axes which can be extended to 24 has been developed. The positioning accuracy is ±0.1 mm in all straight-moved axes.

Japan

Even though Japan has been making machine tools for the last 100 years, it was neither a major producer nor a trend-setter until the early 1960s. Massive government assistance and dedicated research and development efforts, started after 1957, produced startling results by elevating Japan in 1972 to the fourth place in the world ranking of machine-tool-producing countries, surpassing leading nations like France, Italy and the United Kingdom.

The machine-tool industry of Japan is currently enjoying a complete recovery from the severe setback it suffered in the 1973 oil crisis, with a substantial increase in new orders received during 1978. This recovery reflects the successful efforts of the industry to meet the needs of machine tool users, with increasing modernization and efficiency as the yen rapidly appreciates on international currency markets.

The production of NC machine tools received positive support from the Government of Japan and national research laboratories as early as 1958. This factor, together with constant improvements in product quality, earned for Japan the reputation of being a supplier of quality machine tools and also helped to erase from the minds of many the impression of Japan as a supplier of cheap products which were poor imitations of those made in developed countries with market economies. The Japanese machine-tool industry has actively developed NC machine tools. This effort has not only met existing demand, but also helped to create new demand from user industries. Even abroad, reasonably priced NC machine tools built in Japan have drawn increasing attention from user industries. Japanese NC machine-tool builders are steadily strengthening their positions in machine-tool markets both in Europe and the United States.

The technical level of the Japanese machine-tool industry also continues to rise, with its current efforts to develop and build high-precision machine tools for use by aerospace manufacturers. This challenge is stimulating some innovative development in the Japanese machine-tool industry.

Production and trade

Japanese manufacturers continue to improve their efficiency and productivity by acquiring new equipment. They hope thereby to offset unavoidable cost increases for inputs such as energy and labour. In turn, machine-tool builders have stepped up development of newer and more efficient tools, with special attention being given to NC tools with labour-saving features. Production and trade figures from 1975 to 1979 are shown in table 8.

Exports represented only a small share of total production when Japan was enjoying high growth rates and strong domestic demand. In recent years, however, Japanese exports of machine tools have made impressive gains.

A major factor in the export success of Japan is NC equipment. NC machine tools exported in 1977 and onwards accounted for about 31 per cent of total exports. With the active entry into NC fields by almost all developed machine-tool-producing countries, competition among NC machine-tool builders has intensified considerably and led to substantial price reductions.

When NC machine tools made their appearance, the controls accounted for roughly 50 per cent of the price of machine tools. Now they account for only one third and the trend is towards continued falling prices.

TABLE 8. THE MACHINE-TOOL INDUSTRY IN JAPAN: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

Year	Production	Consumption	Exports: Value	Exports: Percentage of production	Imports: Value	Imports: Percentage of consumption
1975	1 060.4	824.6	359.1	33.86	123.3	14.95
1976	1 126.9	803.8	398.8	35.39	75.7	9.42
1977	1 602.8	1 074.2	616.4	38.46	87.8	8.17
1978	2 350.3	1 452.7	1 017.5	43.29	119.9	8.25
1979	2 697.8	1 739.2	1 113.8	41.28	155.2	8.92

Source: American Machinist

About a decade ago, almost a half of Japanese exports of machine tools went to the United States. However, in recent years the unprecedented economic growth in East Asia has changed the pattern of overseas customers, although the United States remains the largest market for Japanese machine tools. The Republic of Korea and other countries of East Asia accounted for 26.4 per cent of Japanese exports in 1978. The second biggest customer in the same year was the United States. European centrally planned economies accounted for 15.9 per cent and European market economies for 12.6 per cent of exports in 1978. Over 40 per cent of total Japanese production of machine tools were exported in 1979. As the demand for NC machine tools is mainly created in countries operating well-developed metalworking industries, Japanese builders give special attention to markets in the United States and the EEC countries.

Imports accounted for a large share of the machine tools used by Japanese industry in the early post-war years. They covered 57.7 per cent of the domestic consumption of machine tools in 1955 and fell to 45.1 per cent in 1957. In line with the progress achieved by Japanese technology, the share of imported machine tools gradually decreased over the years.

In 1966 Japan experienced its first transformation when imports fell below exports plus domestic consumption of indigenously made machine tools. Dependence on imports was drastically reduced by 1976, when Japanese imports of machine tools, valued at $75.7 million, were barely 9.5 per cent of total consumption. Imports dwindled again in 1977 to reach 8.17 per cent of consumption, amounting to $87.8 million. More than 90 per cent of domestic demand has been met by domestic production. Imports of machine tools during 1979 are estimated to have barely reached 9 per cent of total consumption. The principal suppliers of machine tools to Japan are the Federal Republic of Germany and the United States.

Technology

The technological level of Japanese machine tools in the 1960s was judged to be at least 10 years behind that of the Federal Republic of Germany, the United Kingdom and the United States. But the Japanese have very quickly bridged this gap by rapidly assimilating the modern technology designs of machine tools of almost all categories from simple lathes to sophisticated NC machining centres. The very fact that Japanese dependence on imports dropped from 57 per cent of total consumption in 1955 to barely 9.5 per cent in 1976 reveals the fact that Japan not only absorbed technology from other countries but benefited by the impressive innovations of its own research and development institutions. It is an accepted fact that Japan has established a big lead over other countries in electronics and machinery manufacture.

The technological strength of Japan in the field of machine tools becomes evident from the fact that NC machines accounted for 30 per cent of total production in 1979. The Japanese have made impressive progress, not only in the manufacture of advanced machine tools, but also in introducing many innovations in the realm of production engineering. Japan is the first country to evolve unmanned operations into working reality. This has been possible because of the outstanding work done by Japan on industrial robots capable of very high levels of judgement. Japan is leading the industrialized world in the use of robots. It is estimated that 10,000 robots are in use in Japan, as compared with 3,000 in the United States and 850 in the Federal Republic of Germany, the three of which are world leaders in robot technology.

Every major Japanese machine-tool builder emphasizes the machining centre (MC) in development and marketing efforts. The Ministry of International Trade and Industry indicated that the production of machining centres totalled a record 1,377 units in 1978, or 48.7 per cent higher than the previous year.

Behind this active production of machining centres is a market trend. Japanese machinery manufacturers are now turning out a wider variety of types and models of equipment in small batch quantities. Even in automobile manufacturing, which is noted for mass production, there is a movement towards producing a broader variety of cars to satisfy diversified consumer needs. NC machining centres appropriately fill this need. They are designed to meet various machining needs even in small quantities. Besides, unmanned operation is facilitated by most of the machining centre models, which results in substantially less dependence on hard-to-obtain skilled workers. The Japanese machine tool industry has pioneered these advances to its great advantage not only in the domestic market but in the export markets of the world.

Poland

In Poland there are about 25 factories producing machine tools The Polish machine-tool industry was completely rebuilt after the Second World War. Current investment in the machine-tool industry of Poland is estimated to be higher than that of France or Italy. In terms of money invested in the machine-tool industry, Poland ranks only behind countries such as the Federal Republic of Germany, Japan, the Soviet Union and the United States. It has recently established both technological and economic contacts with the Federal Republic of Germany to produce high-precision machine tools. Companies in the Federal Republic of Germany have entered into co-operation agreements with the Polish machine-tool industry. Formerly, much of the production equipment consisted of machines from Czechoslovakia, the German Democratic Republic and the Soviet Union, but Polish industry has begun to install modern equipment made in the Federal Republic of Germany, France, Italy and the United Kingdom.

Production and trade

During 1979, Poland was among the eleven leading countries of the world in the production of machine tools. The production of the Polish machine-tool industry almost doubled in the years 1974 to 1979. Polish production, consumption and trade of machine tools from 1975 to 1979 are shown in table 9.

Switzerland

The machine-tool industry of Switzerland has established a world-wide reputation for its quality and precision products. Instead of manufacturing the whole range of machine tools, Switzerland has always concentrated on specific product lines, such as high-precision lathes, precision-grinding machines, gear-grinding, sliding-head automatics, jig-boring machines, electron-discharge machines with wire-cutting and fine-blanking presses. The Swiss machine-tool industry has held the front rank in these product lines. The industry consists of a large number of small and medium shops, although there are a few which could be described as large-scale units.

Production and trade

About 90 per cent of the products of the Swiss machine-tool industry are metal-cutting, and the other 10 per cent metal-forming machine tools. Swiss production, consumption and trade in machine tools from 1975 to 1979 are shown in table 10.

TABLE 9. THE MACHINE-TOOL INDUSTRY IN POLAND: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

			Exports		Imports	
Year	*Production*	*Consumption*	*Value*	*Percentage of production*	*Value*	*Percentage of consumption*
1975	422.8	698.4	125.8	29.75	401.4	57.47
1976	510.0	877.9	152.3	29.86	520.2	59.25
1977	583.4	968.8	151.4	25.95	536.8	55.41
1978	678.8	1 111.2	163.4	24.07	595.8	53.62
1979	684.6	1 012.0	190.9	27.88	518.3	51.22

Source: *American Machinist*

TABLE 10. THE MACHINE-TOOL INDUSTRY IN SWITZERLAND: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

			Exports		*Imports*	
Year	*Production*	*Consumption*	*Value*	*Percentage of production*	*Value*	*Percentage of consumption*
1975	535.9	220.2	380.8	71.06	65.1	29.56
1976	535.6	134.4	455.5	85.04	54.3	40.40
1977	580.3	163.8	493.4	85.02	76.9	46.95
1978	768.2	239.3	652.8	84.98	124.3	51.94
1979	797.1	259.1	677.5	85.00	139.5	53.84

Source: American Machinist.

Switzerland has traditionally exported machine tools to all the industrialized countries of the world, and recently it has stepped up its exports to China. Its exports have registered significant growth since 1975 and stand at above 80 per cent of total production.

Swiss machine-tool imports are mainly from: France, Germany, Federal Republic of, Italy, Japan, United Kingdom, United States. Although imports cover about 50 per cent of consumption, they are equivalent to less than 20 per cent of production.

Technology

The Swiss machine-tool industry is supported by many private and national institutions engaged in research and development of machine tools. Examples of high-technology machine tools produced by leading Swiss manufacturers include the following: CNC jig-boring machines, CNC lathes, machining centres, copying lathes, CNC wire-cutting machines, precision grinders, a wide range of gear-hobbing machines, gear-grinding machines and machines for the watch and instrument industries.

Switzerland has produced major innovations in precision machine tools needed by its horological industry. The sliding-head automatics developed in Switzerland, known as Swiss automatics, are available in full CNC versions.

The Swiss machine-tool industry is moving into the areas of highest precision by an imaginative integration of the measuring function on its machine tools. This effort is supported by solid innovations in mechanics and instrumentation.

Union of Soviet Socialist Republics

The machine-tool industry in the Soviet Union ranks third in the world. Yet the Soviet Union is a major importer and one of the foremost consumers of machine tools. The machine-tool industry in the Soviet Union was one of the very first to be put on a firm foundation after the Russian Revolution for the industrial development of such a vast country. The machine-tool industry was formerly concentrated in the areas around Moscow and Leningrad, but has now been deliberately spread throughout other areas, except for the vast expanse of Siberia.

Production and trade

The Soviet Union has progressively increased its production of machine tools since 1974 and has consistently occupied the third rank in world production behind the Federal Republic of Germany and the United States. The production, consumption, export and import of machine tools together with percentages of exports and imports in relation to total production and consumption are shown in table 11.

Most machine-tool exports of the Soviet Union go to CMEA countries. The leading customers are Bulgaria, Czechoslovakia, the German Democratic Republic, Poland and Romania. The Soviet Union also exported sizeable quantities of machine tools, largely as part of barter trade, to developed market economies.

The Soviet Union is also a big importer of machine tools. It imports mostly from: France, German Democratic Republic, Germany, Federal Republic of, Italy, Japan, Switzerland.

Technology

The Soviet Union has the widest research and development base, perhaps next only to the United States. The foremost research and development organization, the Experimental Scientific Research Institute of Metal-cutting Machine Tools (ENIMS), located in Moscow, and machine-tool

TABLE 11. THE MACHINE TOOL INDUSTRY IN THE UNION OF SOVIET SOCIALIST REPUBLICS: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

			Exports		*Imports*	
Year	*Production*	*Consumption*	*Value*	*Percentage of production*	*Value*	*Percentage of consumption*
1975	1 984.4	2 286.6	187.8	9.46	490.0	21.43
1976	2 010.0	2 489.0	235.0	11.69	714.0	28.69
1977	2 201.9	2 821.4	280.5	12.74	900.0	31.90
1978	2 652.0	3 123.0	332.0	12.52	803.0	25.71
1979	2 892.0	3 342.0	350.0	12.10	800.0	23.94

Source: American Machinist.

institutes at various universities in Moscow, Leningrad, Kiev and Yerevan are actively engaged in research on various aspects of machine-tool technology. Some of the important research work in machine tools in the Soviet Union is in the area of precision machine tools. Extensive research and development work is being done on the static rigidity, dynamic stability and thermal stability of machine tools and their effects on working accuracies, and standards have been evolved in this regard. Instruments for measuring accuracy of spindle rotation over the whole range of working speeds have been developed and put into practical use.

Means of calibrating standards of length have been developed. Linear ruling machines, permitting a line reproduction accuracy of 0.3 μm and a ruling error of 1 μm over 1 m are being produced. Line standards are calibrated with the aid of a comparator with a maximum measuring error of under 0.2 μm.

A laser interferometer has been developed for reproducing the standard of length. A very high order of measuring accuracy has been achieved by splitting the laser beam into two half beams, one of which is used to compensate for thermal distortion errors. Measurements are made possible with an accuracy of 0.02 μm. The laser interferometers are used in the manufacture of ultra-high-precision measuring systems, line-standards calibration instruments and feedback transducers for high-accuracy, closed-loop NC systems.

Research work is being conducted in the design and construction of basic machine tools, such as high-precision machines for the generation of master helical bevel gears of the ENIMS kinematic system, and a machine for gear-hobbing with direct motor drives for hob and the gear blank (without gear drives).

One of the major areas of research and development undertaken at ENIMS in close co-operation with the industry is the automation of production processes, employing NC machine tools and industrial robots that constitute elements of complete automatic manufacturing systems.

The development of new wide-range transistorized generators for electron-discharge machining (EDM) has improved machining accuracy by one or two classes, increased productivity two to three times, and resulted in a reduction of electrode consumption by a factor of 10 to 15. EDM machines with table sizes up to 16,000 sq cm for processing large forgings and drawing dies have been developed. New methods of EDM with oscillatory rotary copying motion for the manufacture of large moulds and dies and a method combining ultrasonic and electrochemical machining (ECM) for the machining of carbide heading dies and drawing dies have been developed.

Laser-beam machines for processing diamond dies have been developed and produced. Research work is in progress for the application of laser-beam machining for turning hard-to-work metals.

Computer control is applied for production planning, scheduling, workpiece transport and location, machining, inspection, quality control, machine tool supervision, fault-finding, partial resetting and so on.

The Soviet Union is now engaged in designing new equipment to speed up the production of automatic machines using minicomputers. The emphasis on the production of NC and CNC machines is evident from the fact that the Soviet Union is a leading producer of NC machine tools as shown in table 12, which compares Soviet production with the NC machine-tool production of other developed countries.

The research emphasis is to considerably increase the output of special tools and automated lines and also to increase the use of modular design of automated lines. The Soviet Union is currently engaged in the large-scale production of automated manipulators controlled by computers. The development of such robots obviously reflects Soviet interest in establishing an impressive lead in space and nuclear research.

TABLE 12. NUMERICALLY CONTROLLED MACHINE TOOLS: WORLD PRODUCTION IN 1977

Country	*NC machine-tool units*	*Value (million $)*	*All machine-tool units*	*Value (million $)*	*NC units as a percentage of all units*	*NC value as a percentage of total value*
France	576[a]	80	64 320	580	0.90	14
Germany, Federal Republic of	1 885	. . .	256 911	2 619	0.74	. . .
Italy	710[a]	. . .	. . .	850	. . .	. . .
Japan	5 436	300	147 731	1 564	3.82	20
Soviet Union	6 300	. . .	. . .	2 300	. . .	. . .
United Kingdom	607[a]	47	65 552	701	0.93	7
United States	4 221	491	273 819	2 350	1.55	21

Sources: National Machine Tool Builders' Association, *Handbook 1978-79*; *American Machinist*, February 1980.

[a]Figures correspond to 1976.

The Soviet Union is also developing superhard materals and alloys, in addition to natural and synthetic diamond tools for NC machines.

United Kingdom of Great Britain and Northern Ireland

The machine-tool industry of the United Kingdom, after a post-war boom, started to decline as a result of inflation and reduced investments in its engineering industries. The orders received by the industry could keep factories going for hardly six months in 1976 and seven months in 1977, and very little improvement occurred in the following years. As a result, there was a large-scale retrenchment of labour and several companies went out o. business. The industry was able to survive only because of its exports.

The United Kingdom is attempting a qualitative change in its production instead of relying on a quantitative expansion. Some experts feel that if this is not done, then the élite work-force in the machine tool industry may migrate to other sectors, which would be certainly harmful to the economy because of the importance of the machine-tool industry. The biggest problem of the manufacturing industry in the United Kingdom is the lack of ability to compete with overseas competitors both at home and abroad.

Production and trade

United Kingdom production, consumption and trade of machine tools from 1975 to 1979 are reflected in table 13.

Table 13 shows that United Kingdom machine-tool imports as a percentage of domestic consumption is steadily increasing when compared to those of the Federal Republic of Germany, Japan and the United States. The major sources of United Kingdom imports are the Federal Republic of Germany, Italy, Japan and the United States.

Technology

The United Kingdom was one of the first countries to incorporate NC technology into machine tools. United Kingdom CNC machines have established a good reputation. The United Kingdom is perhaps the first country to incorporate the advances of space science into its machine-tool controls. A machine-tool producer in the United Kingdom has incorporated a microprocessing unit developed in the United States for space exploration as the brain behind its numerical control system. The unit is made up of several microprocessors and possesses much higher diagnostic characteristics than the other known CNC systems. The industry is actively engaged in

TABLE 13. THE MACHINE-TOOL INDUSTRY IN THE UNITED KINGDOM: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

			Exports		*Imports*	
Year	*Production*	*Consumption*	*Value*	*Percentage of production*	*Value*	*Percentage of consumption*
1975	728.3	618.5	363.0	49.84	253.3	40.95
1976	645.5	583.5	319.2	49.45	257.2	44.08
1977	587.9	525.8	300.4	51.10	238.3	45.32
1978	821.4	794.6	426.0	51.86	399.2	50.24
1979	1 106.4	1 212.8	468.1	42.31	574.5	47.37

Source: *American Machinist*

developing hardware and software for programmable controllers and sophisticated industrial robots.

United States of America

The machine-tool industry in the United States is located predominantly in the north-east and north-central parts of the country. In terms of numbers of employees, this branch of industry is relatively small and characterized by many small and medium-sized firms, although the United States has the largest machine-tool units of all developed market economies.

The outlook for the United States machine-tool industry is good. Machine-tool builders are adding shifts, expanding operations and taking other measures designed to meet demand for more sophisticated equipment. However, despite increased production, the industry faces delivery delays and backlogs have climbed to record levels. In 1979, the total industry backlog was worth over $2.5 billion.

An ominous sign for the machine-tool industry is the fact that the operating rate of the metalworking industry is currently estimated at 76 per cent and decreasing. In metalworking, the problem is the automotive industry, which is operating at a little more than half of its capacity. But the automotive industry accounts for only 20 per cent of the output of the metalworking industry. The machinery, electrical machinery and aircraft segments, which represent more than one half of the total output of the metalworking industry, are still operating above 80 per cent. This fact should more than allay the pessimism of United States machine-tool manufacturers as a result of the current United States economic recession. But in order to survive the recession, machine-tool manufacturers should proceed with the extensive product development that has been undertaken.

Production and trade

United States production, consumption, exports and imports of machine tools, together with percentages of exports and imports in relation to total production and consumption from 1975 to 1979 are shown in table 14.

Machine-tool exports represent an important factor in the United States trade balance but are a small proportion of the total amount of production, partly because the United States itself needs to replace old machine tools currently used by the metalworking industry. In fact, the United States was in 1979 the top consumer and importer of machine tools in the world, and this appears perhaps natural if the age and quantity of machine tools installed in the country are considered.

According to statistics published in 1978, the United States has the lowest percentage of machines under 10 years old (31 per cent) and the highest percentage over 20 years old (34 per cent) of the following group of developed countries: Canada, Germany, Federal Republic of, France, Italy, Japan and the United Kingdom. United States exports as a percentage of total production are decreasing, as may be seen from table 14. However, the United States may be leading other countries such as the Federal Republic of Germany and Japan in exporting high technology machines. United States exports of metalcutting machine tools increased by 11 per cent in 1979, with notable gains registered in exports of horizontal machining centres, vertical boring machines, horizontal boring-drilling-milling machines, electrical-discharge machines, threading machines and multi-station transfer machines. Metalforming machine-tool exports rose by 24 per cent in 1979, with increases in almost all product types.

Many of the machine tools imported by the United States come from Japan and the Federal Republic of Germany. During 1979 Japan supplied over one third of total United States imports

TABLE 14. THE MACHINE-TOOL INDUSTRY IN THE UNITED STATES OF AMERICA: PRODUCTION, CONSUMPTION AND TRADE

(Millions of dollars)

Year	Production	Consumption	Exports: Value	Exports: Percentage of production	Imports: Value	Imports: Percentage of consumption
1975	2 451.7	2 201.7	576.6	23.15	317.6	14.42
1976	2 169.3	1 941.1	546.5	25.15	318.3	16.40
1977	2 440.7	2 389.5	452.1	18.52	400.9	16.78
1978	3 004.3	3 159.4	560.2	18.64	715.3	22.64
1979	890.0	4 290.0	648.8	16.97	1 043.8	24.71

Source: American Machinist.

of machine tools, followed by the Federal Republic of Germany with 19 per cent. United States machine-tool imports were for many years lower than exports, but deficits in the machine-tool trade balance occurred for the first time in 1978 and continued in 1979.

Technology

The machine-tool industry of the United States now uses machines incorporating the latest technological features such as NC, CNC and DNC, and the industry is shifting its emphasis from individual machines to complete manufacturing systems based on computer-aided manufacture (CAM). It should be noted that NC machines accounted for 34 per cent of shipments in 1975 and the percentage is steadily increasing. The United States produced as many as 5,688 NC machine units during 1978.

A new array of system elements—matching centre, computer-aided operations, minicomputers, adaptive controls, automated diagnostics and microprocessors—is at the service of machine-tool builders. In addition to accelerating change in modern manufacturing, they are producing a fundamental transformation in the nature of manufacturing engineering. The production of labour-intensive general-purpose machine tools is declining, and requirements for such machines are being met by imports. In the coming years, the machine-tool industry of the United States will emerge as the major supplier of integrated, flexible production plants to retain its lead in the world market. The secret behind the success of the United States machine-tool industry lies in its ability speedily to convert technological innovations into production realities.

The industry is now growing rapidly, with swift transitions in product design and application and revolutionary changes in both the nature of its products and the structure of the industry. Nevertheless, there are some deficiencies in the United States machine-tool industry, as pointed out by the Machine Tool Task Force Report on Machine Tool Technology.[1] It states that co-operation between industry, the academic community and Government is not as strong in the United States as in some other countries, notably the Federal Republic of Germany and Japan. Lack of co-operation in the United States appears to have been due to a variety of reasons, such as anti-trust concerns, the diversity of user industries, the many small specialized and diverse companies of the industry, the individualism of various companies and the general adverse relationship that exists between the groups. The report also notes that the United States is the only major developed country that does not have a machine-tool institute, which in other countries often becomes the focal point for common technology interests. Yet another rather surprising observation is that many good ideas come out of research laboratories in the United States, but buyers are slow to adopt them because they are reluctant to risk using a new technology.

The outstanding technological breakthrough in production engineering pioneered by the machine-tool industry in the United States has been the organization of the manufacturing process through a computer-aided system called the flexible manufacturing system. This new method relies on the following three distinguishing characteristics: potentially independent NC machines; a transport mechanism; and an overall method of control that co-ordinates the functions of both machine tools and the transport system so as to achieve flexibility. Within this broad scope, there are a number of individual approaches towards striking a balance between high output on the one hand and great flexibility with concomitant reduction in volume of output, on the other.

Yet another revolutionary change in computer-aided manufacturing in the United States is the introduction of computer graphics, which may be defined as a human-oriented system that uses the capabilities of a computer to create, transform and display pictorial and symbolic data. Computer graphics are widely employed in the United States manufacturing industry for geometric modelling, including NC programming, preparation of drawings, calculations, assembly studies and work planning.

[1] *American Machinist*, New York, October 1980.

III. The machine-tool industry in some of the leading machine-tool-producing developing countries

Argentina

The machine-tool industry in Argentina was set up immediately after the Second World War. By 1971 there were 94 establishments accounting for a total production of 13,000 tonnes of machine tools.

In Argentina there are three main groups of machine-tool manufacturers. The first group consists of large companies with more than 100 workers. The second category has between 50 and 100 workers, and the third consists of small-scale units employing less than 40 workers.

Argentina now produces many types of general-purpose machine tools and a few NC machine tools. In addition to 12 manufacturers in the large- and medium-scale production sectors, there are a number of ancillary units feeding the parent units with a variety of mechanical, electrical, hydraulic and pneumatic components. Most of the machine-tool-producing units are located at Buenos Aires and Cordoba.

Because of high levels of inflation in 1978 and 1979, there was practically no investment in the machine-tool industry. Capital investment in other sectors was also paralysed. The rate of inflation was 127 per cent in 1978 and 150 per cent in 1979. This helps to explain the poor rate of growth of the machine-tool industry in Argentina from 1977 to 1980.

Production and trade

Table 15 gives the statistics for production, consumption, exports and imports of machine tools from 1974 to 1979.

Most of the machine tools exported by Argentina go to other Latin American countries under the Latin American Free Trade Association arrangement for customs-free exports.

Argentina has traditionally imported more than 50 per cent of its machine tool requirements. In 1979, for the first time, its imports exceeded domestic production, as reflected in table 15.

TABLE 15. MACHINE-TOOL PRODUCTION AND TRADE OF ARGENTINA, 1974 TO 1979

(Millions of dollars)

Year	*Production*	*Consumption*	*Exports*	*Imports*
1974	40.0	53.5	7.0	20.5
1975	42.0	70.9	9.7	38.6
1976	50.5	79.0	10.0	39.0
1977	60.0	102.0	15.0	57.0
1978	60.0	108.0	12.0	60.0
1979	62.0	125.0	12.0	75.0

Source: American Machinist.

Technology

The machine-tool industry now produces a wide range of general-purpose machine tools and a few NC machines. The large manufacturers possess adequate technology and modern equipment, and produce machine tools such as automatic lathes, milling and grinding machines, heavy-duty presses and a variety of other types for production and maintenance.

Brazil

The Brazilian machine-tool industry is the biggest in Latin America. In 1979 it occupied fifteenth place in the world ranking of machine-tool-producing countries.

As in all other developing countries, the manufacture of machine tools was taken up in an organized manner only after the Second World War. Most of the manufacturing units are concentrated in and around São Paulo, but recently new units have been established in other regions.

The Brazilian machine-tool industry began to manufacture NC machine tools in 1975. The projected development of the metalworking industry in Brazil from 1968 to 1980 is shown in table 16.

TABLE 16. DEVELOPMENT OF THE METALWORKING INDUSTRY IN BRAZIL

(Base: 1968)

Year	*Production (percentage)*	*Locally added value (percentage)*	*Increase of added value (percentage)*	*Machine tool (thousands of units)*	*Labour (thousands of workers)*
			Metal products		
1968	100	100	100	—	—
1971	134	61	231.8	69.6	165.7
1975	198	60	188.5	91.6	218.1
1980	170	59	257.4	122.7	263.1
			Non-electrical machinery		
1968	100	100	100	—	—
1971	144	61	142.7	70.7	152.0
1975	212	59	202.1	92.3	198.5
1980	285	56	275.2	131.3	255.3
			Electrical machinery and equipment		
1968	100	100	100	—	—
1971	136	57	134.7	75.0	167.1
1975	192	56	185.7	96.5	208.0
1980	285	56	275.2	131.3	255.3
			Transport equipment		
1968	100	100	100	—	—
1971	137	47	137	90.9	227.3
1975	192	48	205	114.9	294.6
1980	285	48	302	147.2	368.0

Source: Institute for Economic and Social Planning (IPEA).

Production and trade

The production, consumption, export and import statistics for Brazilian machine tools from 1974 to 1979 are shown in table 17.

The 13 major Brazilian machine-tool producers account for 90 per cent of machine tools exported by Brazil. Traditionally, exports have accounted for only a small share of the total production. Brazil exports mostly simple machine tools such as lathes, milling machines, grinding machines and a few power presses.

The value of machine-tool imports into Brazil has always been more than 50 per cent of domestic machine-tool production, as reflected in table 17.

TABLE 17. MACHINE-TOOL PRODUCTION AND TRADE OF BRAZIL, 1974 TO 1979

(Millions of dollars)

Year	*Production*	*Consumption*	*Exports*	*Imports*
1974	113.3	175.8	6.0	70.5
1975	137.0	206.0	14.0	83.0
1976	222.5	386.8	10.7	175.0
1977	282.9	441.9	11.2	170.0
1978	255.3	461.3	20.1	226.2
1979	239.8	342.8	33.0	136.0

Source: American Machinist

The high cost of imports in recent years can be directly attributed to the purchase of advanced technology machines, gear grinders, special transfer lines etc. needed by Brazilian engineering industries. The reliance on imports of such sophisticated machines is likely to decrease as the domestic machine-tool industry starts producing advanced technology machines.

Technology

The Brazilian machine-tool industry launched a programme of restructuring in 1974. Under this programme, many of the machine-tool manufacturing firms were expanded to produce a large number of machine tools, to raise the quality of their products, to increase productivity and to enter the sophisticated field of NC machine tools. This restructuring was mainly done to enhance the technological strength of the industry. A special Research Institute of Technology was started in the University of São Paulo to provide the industry with the necessary know-how for designing and producing sophisticated NC machine tools. The Institute conducted in 1974 a survey to highlight the technical performance and standards of quality in manufacture. The Institute has been responsible for making recommendations to the metalworking industry on methods of solving specific manufacturing problems and in matters of selection of machine tools for specific purposes. The Institute is now engaged in designing and building machine tool prototypes either at the request of manufacturers or on its own initiative. The standards established by the Institute in the manufacture and testing of machine tools are on a par with international standards.

The Government of Brazil is providing a number of incentives for economically sound and technically advanced projects with a view to modernizing the production methods of the Brazilian machine-tool industry.

From the stage of co-operation with internationally established machine-tool manufacturers, the industry has moved to the design of almost all types of general-purpose machine tools and a selected number of NC machine tools. The strength of the Brazilian machine-tool industry is evident from the fact that it is sustaining the biggest automobile industry of Latin America.

China

The machine-tool industry of China has been expanding over the last decades. In 1949 about 1,600 machine tools were produced, and by 1978 the figure had risen to 183,000 units.

China currently has approximately 30 large-scale machine-tool plants and more than 40 small and medium-size plants manufacturing almost all types of general-purpose machine tools and some advanced designs. The industry employs about 500,000 workers. Efforts are being made to foster the machine-tool industry all over the country, but production still tends to concentrate heavily in the east, north and north-east of China. Most of the larger plants are located around Beijing and Shanghai.

Production and trade

China can meet almost all its current machine-tool needs, but it must increase the variety and improve the designs and quality of its products, particularly high-precision machines and instruments. Among the 269 new machine tools planned for 1981 are numerically controlled jig-boring machines, universal and external grinding machines and different types of horizontal boring machines. This is part of the modernization programme initiated by the present leadership of China.

Chinese machine-tool production and trade from 1974 to 1979 are shown in table 18.

TABLE 18. MACHINE-TOOL PRODUCTION AND TRADE OF CHINA, 1974 TO 1979

(Millions of dollars)

Year	*Production*	*Consumption*	*Exports*	*Imports*
1974	140.0	172.0	3.0	35.0
1975	300.0	351.0	4.0	55.0
1976	315.0	360.0	5.0	50.0
1977	355.0	395.0	10.0	50.0
1978	405.0	450.0	20.0	65.0
1979	420.0	452.0	28.0	60.0

Source: American Machinist

Technology

The Chinese machine-tool industry is behind that of developed market economies in two main areas, namely co-ordination of research and development activities, on the one hand, and production technology, on the other. Plants operate at inefficient levels with virtually no inventory control. A major weakness is in organization and plant management. Many of the plants are vertical operations, with the majority of components made within the main factories. With such a system, it is difficult to improve efficiency through specialization.

The machine-tool industry of China is nevertheless moving forward. Some of its basic universal models of general-purpose machine tools are being exported to developed market economies, with the considerable advantage of low prices. The China Machine Tool Exhibition held at Hong Kong in 1977 displayed export products such as gear-shaping and gear-grinding machines, cylindrical grinders, optical profile grinding machines, lathes and other items.

China has built up a basic foundation in technology. Its technical experience in the strict definition of mother machines, such as jig and horizontal borers, planomillers, and various gear-cutting and finishing machines, is superior to that of many other developing countries in East Asia.

On the other hand, with regard to engine lathes, universal millers, radial drilling machines and other production machines, most of the designs are old and the production system is inefficient. Such general-purpose machines should be strategic export products for the Chinese machine-tool industry, which has just started on a full-scale export drive. Its lack of development in the field is therefore particularly critical.

Mexico

The manufacture of machine tools in Mexico began in 1959 in a small stamping-press factory.

TABLE 19. THE MACHINE-TOOL PARK IN MEXICO

	1960		1970		1980	
Type of machine	*Units less than 5 years old*	*Percentage of total*	*Units less than 15 years old*	*Percentage of total*	*Units less than 25 years old*	*Percentage of total*
Metalworking	13 677	87.3	73 148	84.7	174 283	24.7
Lathes	2 820	18.0	17 011	19.7	38 711	18.8
Milling	531	3.4	4 066	4.7	9 384	4.6
Drilling	980	6.3	[illegible]	10.4	30 246	14.7
Grinding	830	5.3	317	8.5	17 485	8.5
Presses	1 206	7.7	7 106	8.2	18 606	9.0
Other	7 310	46.6	28 648	33.2	59 851	29.1
Woodworking	2 000	12.7	13 062	15.3	31 390	15.3
Total	15 677	100.0	86 210	100.0	205 673	100.0

Source: Institute for Economic and Social Planning (IPEA).

Soon new plants started production of engine lathes and milling machines of different specifications. The country now has many enterprises engaged in the production of metalworking machine tools, including turret and automatic lathes, surface and cylindrical grinders and drilling machines. The major types of machine tools produced in Mexico are divided into the following three categories:

Metal-cutting	*Metal-forming*	*Woodworking*
Engine lathes	Presses	Planers
Automatic lathes	Drop forges	Saws
Drilling machines	Shearing machines (guillotines)	Edgers
Grinders		Lathes
Saws	Bending and rolling machines	Shapers
		Tenoners
		Drilling machines

The industry receives strong government support in the form of fiscal incentives and technical assistance. It has undertaken joint ventures involving firms from Czechoslovakia, the Federal Republic of Germany, Italy, Switzerland and the United Kingdom.

Apart from the products of joint ventures, machine tools produced in Mexico are mainly imported designs under licence from companies located in countries such as France, Switzerland, the United Kingdom, the United States and Yugoslavia. The boost given to the Mexican economy by the petroleum industry will help the domestic machine-tool industry to expand rapidly.

A breakdown of the machine-tool park in Mexico according to estimated product age, is given in table 19.

Production and trade

The machine-tool production of Mexico is so limited that most of its requirements are met by imports. Domestic production covers mostly general-purpose machine tools like lathes, drilling machines, knee-type milling machines, turret and capstan lathes and a variety of shears, presses and forging machines. Production, consumption, export and import figures for the years 1974 to 1979 are given in table 20.

TABLE 20. MACHINE-TOOL PRODUCTION AND TRADE OF MEXICO, 1974 TO 1979

(Millions of dollars)

Year	*Production*	*Consumption*	*Exports*	*Imports*
1974	2.0	224.0	—	222.0
1975	4.5	249.0	—	244.5
1976	5.0	195.0	—	190.0
1977	6.0	86.0	0.3	80.0
1978	13.6	87.3	1.3	75.0
1979	15.5	99.0	1.5	85.0

Source: *American Machinist*.

The modest volume of Mexican exports of machine tools is mostly exported to Latin American countries under arrangements with the Latin American Free Trade Association.

Mexico imports mostly sophisticated machine tools from the Federal Republic of Germany, Japan, the United Kingdom and the United States.

Technology

Manufacture continues to develop with strong government support in the form of fiscal incentives and technical assistance. There are many joint ventures involving firms from Czechoslovakia, the Federal Republic of Germany, Italy, Switzerland and the United Kingdom. The Industrial and Finance Company of the Government of Mexico is promoting the development of the manufacturing industry, including the machine-tool industry.

Republic of Korea

In 1979 there were 199 machine-tool-building firms in the Republic of Korea.

The machine-tool production of the Republic of Korea in 1975 was so small that the country was not even included in the world ranking of machine-tool-producing countries. But within three years, by 1978, it ranked twentieth, ahead of India. Such remarkable growth may be attributed to the national plan drawn up by the Government in 1973 to strengthen the machine-tool industry. A major industrial complex was built by the Government and many foreign investors were welcomed. The machine-tool industry is now in a position to manufacture not only the full range of general-purpose machine tools, but also sophisticated items like CNC lathes, machining centres and NC boring and milling units.

The industry enjoys full government support through various funds, including the following:

(a) People's investment funds, involving saving by the people in order to promote the construction of heavy industries;

(b) Machinery industry funds to support promotion of the machinery industry;

(c) Foreign currency funds to promote the domestic production of machines;

(d) Funds to support medium and small companies;

(e) Export support funds.

The Government also grants the following tax concessions:

(a) Reduction of or exemption from taxation for important machinery industries;

(b) Preferential tax on funds for technical developments;

(c) Exemption from customs duty on machines and facilities which cannot be produced domestically;

(d) Exemption from tax on funds for improving facilities of medium and small companies.

To promote foreign investment in joint ventures, the Government offers the following incentives: investment permits; guarantee of remittance of dividends and principal; exemption from import approval laws; and guarantee of remittance of royalties on licence contracts.

Production and trade

Production figures for the period 1976-1979 show the remarkable rise of the industry and its promise of further growth in future. The production, consumption, export and import of machine tools from 1976 to 1979 are shown in table 21.

TABLE 21. MACHINE-TOOL PRODUCTION AND TRADE OF THE REPUBLIC OF KOREA, 1974 TO 1979

(Millions of dollars)

Year	*Production*	*Consumption*	*Exports*	*Imports*
1976	10.0	100.0	—	90.0
1977	57.0	185.0	—	130.0
1978	95.0	246.0	5.0	156.0
1979	150.0	268.0	22.0	140.0

Source: Metalworking-Engineering and Marketing, March 1980.

The machine-tool exports of the Republic of Korea have risen substantially from the almost negligible results recorded in 1977.

A number of Japanese machine-tool companies have established licence production agreements with builders in the Republic of Korea, and some of the machines produced are exported to Japan.

The Republic of Korea imported $90 million worth of machine tools in 1976, accounting for 90 per cent of its machine-tool requirements during that year. However, the remarkable growth of its domestic industry has gradually reduced its dependence on imports. The country imported machine tools worth $140 million in 1979 which was about 50 per cent of the domestic consumption of machine tools.

Technology

Even though the machine-tool industry of the Republic of Korea owes its success to foreign co-operation and a large number of joint ventures, especially with firms in Japan and the United States, the industry is spending heavily on research and development. The country now manufactures a very wide range of metal-cutting and metal-forming machine tools. Sophisticated NC machine tools are built by many manufacturers in the Republic of Korea. One firm is making horizontal machining centres and NC lathes with technology obtained from a Japanese firm. A United States firm is co-operating with a manufacturer in the Republic of Korea to make cylindrical grinding machines. Another manufacturer makes ball screws and nuts for NC machines and has designed its own NC lathes. The lathe has been interfaced with a Japanese industrial robot to develop its automation and productivity. Another producer has developed its own special-purpose machines to machine cylinder blocks, and others co-operate with Japanese firms to make high-precision engine lathes and advanced designs of milling machines.

Many technical universities in the Republic of Korea carry out research and development work for the machine-tool industry. Private builders have also invested substantially in research and development to remain competitive.

IV. Case study of the machine-tool industry in India

A case study of one of the developing countries which has striven hard to establish its own machine-tool industry over the decades may serve as a useful example for those developing countries which are also trying to set up or develop their own machine-tool production. The study may reveal some salient aspects such as the experience in building machine tools, infrastructural needs, direction of growth, initial hurdles to be overcome and, above all, the vital importance of the deliberate decisions and support of the Government for establishing the industry. Other details such as structure, technological needs, development of local designs and production engineering for the sustained growth of the industry could serve as guidelines.

Industrial base of India

If one takes the historical development of industry as a whole since the beginning of the Industrial Revolution in the United Kingdom over 200 years ago, one can see a distinct pattern of development. Whether in the United Kingdom or any other industrialized country, the general pattern seems to have been to lay greater emphasis on the consumer goods industry. It is only after considerable development of the consumer goods and the consumer durables industries that a country usually develops a sufficiently large market for capital goods, the natural consequence of which is the development of the capital goods industry. In the United Kingdom, about seven to eight decades had to elapse between the Industrial Revolution in the textile industry and the emergence of the engineering industry as a major component of the capital goods industrial sector. The United Kingdom emerges as the workshop of the world only around 1840.

The case of developing countries, however, appears to be somewhat different in the present context of their limited industrial development. Can they leave their engineering and capital goods industry to market forces alone and develop them after a sufficiently large demand has been generated by their domestic consumer goods industry? Furthermore, could they afford to leave their capital goods industry to grow in a natural and unplanned manner, or will they have to plan the capital goods industry systematically, providing for its growth, the essential inputs and infrastructure—both physical and fiscal? The answers to these questions obviously depend upon the natural resources, availability of infrastructure and, more importantly, the political policy decisions of the country concerned. However, by considering the example of some developing countries that have already established a strong base for their own capital goods industries, including a machine-tool industry, some justification may be found for deliberate government policy decisions designed to establish and develop in a planned manner a domestic capital goods industry in general, and a machine-tool industry in particular, as a top priority in overall planning for industrialization. As an example, the case of India is considered below.

Relying on the historical experience of industrialized countries, immediately after independence in 1947 many Indian economists and others from abroad suggested that India should concentrate first of all on consumer goods industries and wait a few decades before setting up capital goods industries, including the machine-tool industry. The answer given to such advisers was that they had ignored the most vital aspects of overall development, namely that the neglect of the basic and capital goods industrial sectors would only create a situation in which the desired increase in the volume of consumer goods, including consumer durables, could not take place for lack of the steel, machine tools and other capital goods needed to produce them. Furthermore, it would have meant delaying the development of a capital goods industry by several decades. The country and its political leaders therefore decided during the 1950s to launch a major effort to develop basic metal industries including steel, machine tools and other capital goods industries at the beginning of the process of Indian industrialization.

The industrial situation of India in 1947 had the following four basic features:

(a) There was, strictly speaking, no capital goods industry, although a few engineering shops had been established primarily to supply the needs of the Indian railways, and two steel mills produced approximately 1.5 million tonnes of steel per annum;

(b) The entire infrastructure needed for industrial development, including power, water, transport and off-site facilities, was lacking;

(c) The level of Indian agriculture was depressed, unit output low and the labour-land ratio adverse. Neither was there any system of inputs designed to achieve increased fertility and output without the extensive use of land resources;

(d) There were no other avenues of gainful employment besides agriculture. This led to depressed levels of income, consumption and saving.

The independent Government of India therefore took policy decisions with the following objectives: to develop the capital goods industry; to improve agriculture; to enlarge the manufacture of mass consumption goods and create employment opportunities in industry; and to develop the infrastructure for rapid industrial development. The Government, as the principal instrument of social and economic change, determined development strategies designed to ensure an intersectoral balance in the allocation of resources. The five-year economic plans were based on such an approach.

The concept of planning adopted by India involves the identification and classification of options in terms of relative weight, and the selection of appropriate processes and sectors of development.

One of the fundamental decisions taken by the Government of India at the initial stage of development was that the Indian economy should be structured on the mixed economy pattern, which meant that while there would necessarily have to be a massive and progressively dominant share of Government in economic development, there would also be a legitimate, definite and significant place for private initiative. In what manner these two lines of activities could be synthesized at different times and at different stages of development has been the principal objective of the planning exercise in India.

The emergence of the public sector in India as the principal instrument of economic development has thus come about, and in the industrial field it is playing an important role side by side with the private sector. It has totally geared itself to the task. As a result, a great deal of progress has been achieved in the capital goods industry. For example, steel plant equipment and heavy electricals—from a variety of machine tools and industrial machinery to process equipment of diversified character and high precision—are being manufactured in India. It is not as if development in this sector has been exclusive to the public sector. In fact, a number of large, medium and small-scale private enterprises were encouraged by preferential financing, a network of fiscal relief and infrastructural promotion to accelerate and promote the effort to achieve self-reliance and near self-sufficiency in the capital goods sector. As a result, except for a few items of industrial machinery of high precision and complexity which are either not economically viable to manufacture or so technologically intensive as to be extremely expensive to be built in India, the country has become practically self-reliant so far as concerns the capital goods sector.

Large investment has been made in the engineering industries for diversifying production in the public and private sectors and for securing better utilization of capacity. New machinery manufacturing capacity has been created for various industries.

In petrochemicals, the main development has been in capacity and production of basic intermediates required for synthetic fibres, plastics, aromatics, dyestuffs and related industries. There was a substantial investment in other industries like power and newsprint.

Indian industries now produce a wide range of textiles of different fibres (natural and man-made), leather and leather goods, rubber products, drugs and pharmaceuticals, construction materials, a large number of organic and inorganic chemicals and electrical and non-electrical goods.

The industrial capacity of India today encompasses the entire spectrum of manufactured products. These range from simple engineering goods and consumer durables such as bicycles, automobiles, refrigerators, radios, air-conditioners and television receivers to sophisticated machine tools, industrial plant and machinery, transmission towers and power-station equipment, industrial machinery of a highly specialized nature for cement plants, textile mills, sugar factories, refineries, fertilizer plants, petrochemical plants, steel mills, and also technology-intensive products such as aircraft, ships, nuclear equipment and satellites. Production of all these inputs of vital importance to the economic development of the country has been an essential feature of the emerging industrial structure of India, which makes it one of the 10 highly industrialized countries of the world.

Development of the Indian machine-tool industry

During the 1930s, various Indian companies began to manufacture reasonably good-quality machine tools such as sliding, surfacing and screw-cutting lathes, single-pillar drills, shaping machines and hack-saws. The machines were able to find a ready market and output was approximately 100 units per annum before the Second World War.

Although wartime demand gave considerable impetus to the growth of the Indian machine-tool industry, the structure and organization of the industry were not strong and specialized enough to enable it to undertake the production of machine tools and compete against imported foreign machine tools in the post-war years. In view of the serious decline in the industry after 1945, as reflected in table 22, the Government of India decided to intervene and help the industry to establish itself on a strong footing. As a first step, it planned in 1949 to set up a modern machine-tool factory and entered into a co-operation agreement with a leading Swiss producer. This led to the birth of a major public-sector machine-tool concern in India. The Government of India also provided much financial and fiscal assistance to private-sector machine-tool companies and allowed them to acquire modern designs and technical know-how from reputable machine-tool manufacturers abroad. The industry received special technical assistance and guidance from the Director General of Technical Development within the Ministry of Industry, who also closely monitored the growth of the industry. In addition, one of the important incentives that the Indian machine-tool industry received from the Government was that imports of machine tools were restricted and imports of types produced locally were totally banned.

TABLE 22. MACHINE-TOOL PRODUCTION OF INDIA, 1941-1950

Year	Value of imports (millions of rupees)	Production: Number of units	Production: Value (millions of rupees)	Production value as a percentage of import value
1941	6.8	—	—	—
1942	5.7	273	0.6	10.5
1943	5.4	1 713	6.4	118.5
1944	15.3	2 170	7.8	51.0
1945	18.2	3 699	11.2	61.5
1946	18.3	2 820	9.1	49.7
1947	36.8	1 400	4.6	12.5
1948	41.4	1 691	5.5	13.3
1949	42.0	2 240	4.7	11.2
1950	24.9	1 130	2.9	11.6

Source: Indian Machine Tool Manufacturers Association.

As a result of these and other measures, the Indian machine-tool industry increased its output and imports began to decrease. During the first five-year plan commencing in 1950, the industry consolidated the production of a number of general-purpose machine tools, many of them manufactured under licence from abroad. The product range covered various types of geared-head centre and capstan lathes, milling machines, drilling machines, radial drills, grinding machines etc. of modern design.

Besides the two major production units in the public sector, 15 large and medium-scale firms in the private sector produced a variety of general-purpose machine tools. Of particular significance, however, was the growth of small-scale units manufacturing machine tools, which in 1958 numbered 344. Machine-tool production and import statistics from 1951 to 1960 are shown in table 23.

TABLE 23. MACHINE-TOOL PRODUCTION OF INDIA, 1951-1960

Year	Value of imports (millions of rupees)	Production: Number of units	Production: Value (millions of rupees)	Production value as a percentage of import value
1951	25.0	2 834	4.7	18.9
1952	22.1	4 488	4.4	20.1
1953	31.3	2 961	4.4	14.1
1954	38.6	1 544	4.7	12.2
1955	52.9	3 064	6.8	12.8
1956	83.7	3 016	10.8	12.9
1957	146.4	4 033	23.5	16.0
1958	144.2	5 465	34.1	23.6
1959	163.3	4 434	41.6	25.5
1960	209.4	5 980	58.6	28.0

Source: Indian Machine Tool Manufacturers Association.

The 1960s were a decade of rapid growth for the Indian machine-tool industry. It was largely during this period that the machine-tool-producing units in the public and private sectors entered into numerous co-operation agreements with manufacturers of machine tools in Europe, Japan, the United Kingdom and the United States, in order to widen the base of production and to add new products. New designs such as combination turret lathes, single-spindle automatics, multi-spindle automatics, vertical turret lathes, gear shapers, gear hobbers, precision copying lathes, multi-tool automatic lathes, drum turrets, horizontal boring machines, broaching machines (vertical and horizontal types), front chucking machines, single- and special-purpose machines, transfer lines and heavy-duty hydraulic and mechanical presses were taken up for production to meet the growing needs of the metalworking industries. It was during this period that the Indian machine-tool industry laid the foundation for the manufacture of almost all types of general-purpose machine tools. In addition to general-purpose machine tools, the production of special-purpose machine tools under licence from a well-known firm abroad was also started to cater to the needs of the automobile, tractor and armament industries in particular, and other branches such as diesel engines and electric motors. The programme of diversification within and outside the field of machine tools was primarily aimed at building the necessary resilience into the industry so that it could face any spells of recession without becoming paralysed.

The Indian machine-tool industry achieved a high ratio of production to total consumption in 1970. From a mere 23 per cent in 1961, domestic production as a percentage of total consumption of machine tools rose to 71 per cent during 1970.

During the late 1960s, 66 firms accounted for 90 per cent of the total output of machine tools. The three public sector units alone accounted for more than 50 per cent of total production, and continued to do so when this study was prepared.

By 1970 the Indian machine-tool industry was participating in major foreign exhibitions and becoming conscious of the need to produce advanced-technology machines and update the quality and versatility of its products. Statistics regarding production, imports, exports, consumption and share of production in consumption are given in table 24.

TABLE 24. THE MACHINE-TOOL INDUSTRY IN INDIA: PRODUCTION, TRADE AND CONSUMPTION, 1961-1970

(Millions of rupees)

Year	*Production*	*Imports*	*Exports*	*Consumption*	*Production as a percentage of consumption*
1961	73.3	242.2	—	315.5	23
1962	104.0	260.4	01.1	363.3	29
1963	167.8	315.0	01.0	481.8	35
1964	209.8	344.4	01.2	553.0	38
1965	254.8	349.3	01.4	602.7	42
1966	284.8	429.9	06.6	708.1	40
1967	254.7	394.0	06.7	642.0	40
1968	206.3	362.5	18.6	550.2	37
1969	266.8	189.9	29.5	427.2	62
1970	372.3	183.0	27.9	527.4	71

Source: Indian Machine Tool Manufacturers Association.

The Indian machine-tool industry continued to make steady progress during the 1970s, achieving a real growth rate of 8 per cent from 1973 to 1979. Statistics on machine-tool production, consumption and trade during the 1970s are given in table 25.

During the 1970s production steadily increased and there was a comparative reduction in imports. Figure VI shows the growth in production and exports and the gradual decline in imports of machine tools from 1945 to 1979. The percentage of domestic production rose from 70 per cent to 86 per cent of consumption, as may be seen from figure VII.

The Indian machine-tool industry currently exports mainly centre lathes, turret and capstan lathes, radial drills, single-column pillar drilling machines, kne -type milling machines, cylindrical grinders, surface grinders, tool-sharpening machines and power presses.

TABLE 25. THE MACHINE-TOOL INDUSTRY IN INDIA: PRODUCTION, TRADE AND CONSUMPTION, 1971-1979

(Millions of rupees)

Year	*Production*	*Imports*	*Exports*	*Consumption*	*Production as a percentage of consumption*
1971	502.5	217.0	30.5	689.0	73
1972	494.6	236.4	21.0	710.0	69
1973	622.6	286.7	36.9	872.4	71
1974	884.4	294.6	71.2	1 107.8	80
1975	1 040.3	440.5	81.8	1 399.0	74
1976	1 168.5	444.9	169.2	1 444.2	81
1977	1 095.7	357.2	136.6	1 316.3	83
1978	1 210.5	400.0	205.0	1 405.5	86
1979	1 544.3	—	210.0	—	—

Source: Indian Machine Tool Manufacturers Association.

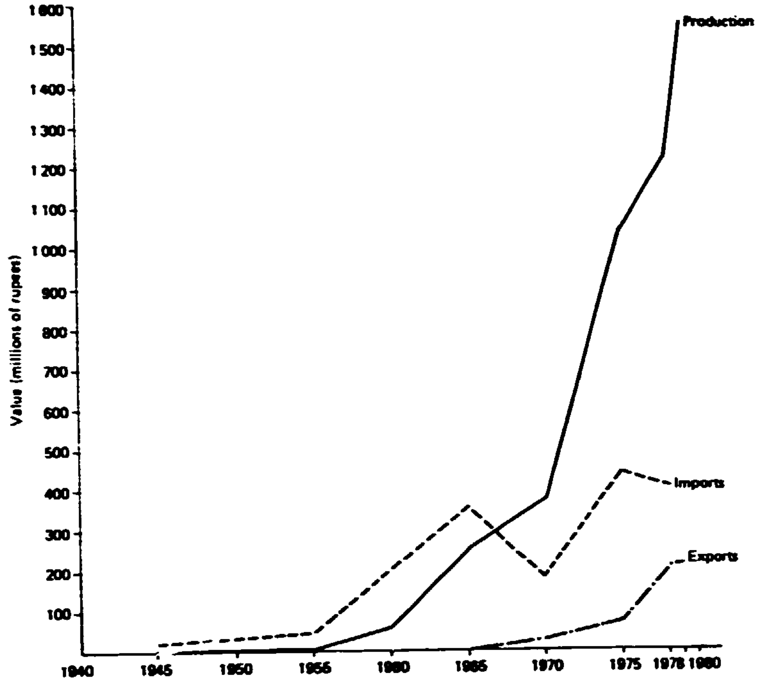
A significant feature of the export performance is that even small-scale units are producing machine tools for export in addition to manufacturers in the medium- and large-scale sector.

Indian machine tools are exported not only to developed countries like the Federal Republic of Germany, the United Kingdom and the United States, but also to developing countries of Africa and Asia. The machine-tool industry has demonstrated its ability to sell in the highly competitive world market. In the past, exports were channelled mainly through foreign agents and importers. But now more interest is being shown by reputable foreign manufacturers who are approaching Indian machine-tool builders to have machines built in India for export to overseas markets. In addition, leading firms have their own network of world-wide export branch offices through which they import their machine tools and distribute them to the dealers in the respective countries. They maintain fully fledged, factory-trained teams of service engineers and hire mostly local personnel to carry out the selling operation.

In addition to the export of machine-tool products, the Indian machine-tool industry has started in a modest manner to export its engineering services and management consultancy. The leading machine-tool manufacturers have undertaken to establish turnkey machine-tool projects abroad, mainly in the Asian and African countries. Their expertise is also being used by foreign countries in setting up machine-tool training centres, in-factory training of foreign manpower in skilled trades, and in engineering disciplines like planning and shop supervision of manufacturing processes.

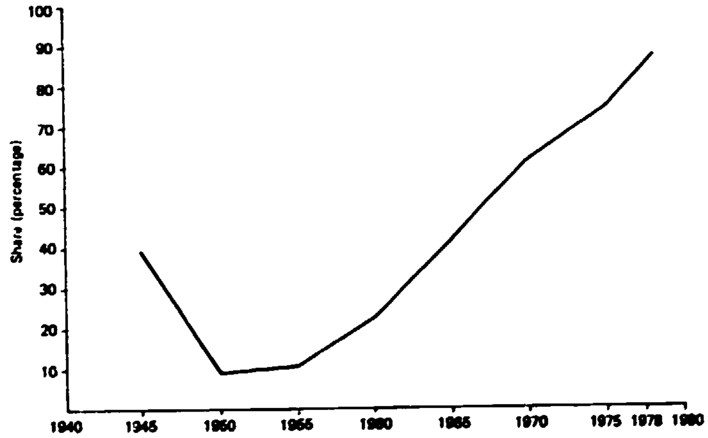
The invisible export of software expertise in machine-tool technology could contribute substantially to the foreign exchange earnings of the Indian machine-tool industry as a whole.

Figure VI. Growth of machine-tool production, imports and exports of India



Source: Invention Intelligence, New Delhi, April, 1980.

Figure VII. Share of domestic machine-tool production consumed in India



Source: Invention Intelligence, New Delhi, April 1980.

The Indian machine-tool industry produces a range of advanced-technology machine tools. It began to manufacture modern NC machine tools during the 1970s, and is currently in a position to offer NC and CNC turning centres, CNC vertical machining centres with automatic tool changers and NC turret machining centres. The production of NC and CNC machine tools led to the production of the software packages required for the optimum utilization of the machines. During the 1970s the industry also began to produce EDM machines and gun-drilling and deep-hole boring machines.

Structure of the industry

There are about 125 large and medium-scale establishments currently manufacturing machine tools in India, with an installed capacity of approximately 17,500 machine tools per annum.

In addition to the large establishments, the small-scale manufacture of machine tools, accessories and allied equipment has expanded rapidly. The small units produce knee-type milling machines, planing machines and some unsophisticated models of grinders. The name Batala lathe has almost acquired a special connotation in the

Indian context. Batala in the Punjab is the home of hundreds of small units producing a variety of machine tools which sell for a fraction of the price of machine tools produced by the larger establishments. Its success demonstrates that the production of machine tools need not be confined to capital-intensive large factories but could be spread over a large number of small units to produce the components and to assemble them at a central facility. The low wages and the reasonable overheads are responsible for the lower prices of the products. If modern designs, refined production technology and quality-consciousness can be introduced into the sector, then larger units can concentrate solely on the production of sophisticated machine tools and equipment and acquire from the small sector the necessary components for modern designs. This is already happening in the Indian machine-tool industry.

The development of ancillary industries to relieve the larger units from the responsibility of making all required components has become established in India. Several industrial estates have been started by the provision of essential infrastructure such as buildings, power and water supplies to innumerable entrepreneurs by large-scale manufacturing houses, state governments or the Government.

The ancillary industries not only help the parent industry to meet the techno-economic necessities of the competitive market, but also permit the diffusion of ownership and management. The importance of ancillary industries was first realized in India when the bicycle manufacturers of the Punjab made use of the products of ancillary units and succeeded in producing quality bicycles at a much lower cost than those made by large-scale units elsewhere in India.

The machine-tool industry in India established ancillary units in the early 1960s, and the advantages accruing to the parent units were evident from the fact that subsequently more ancillary units were started all over the country. In 1979, there were 95 industrial estates in the country catering to the needs of larger manufacturing units. Ancillary units currently account for about 25 per cent of the machine-tool industry. Their position will become increasingly important with the growing reliability and technical ability of the units to produce complicated components with the required accuracy. Already signs are evident that the development of ancillary industries will continue in future because of the unmistakable advantages of inter-dependent industrialization which will serve the needs of not only the industry, but also the community in terms of larger employment potential, enhanced purchasing power and broad-based ownership conferred by a competitive economy.

The invisible export of software expertise in machine-tool technology could contribute substantially to the foreign exchange earnings of the Indian machine-tool industry as a whole.

Research and development

Although some leading machine-tool manufacturing companies in India had their own design and development departments by 1960, organized design and development activities in the field of machine tools seem to have begun in 1965. Within less then a decade, Indian research and development engineers and production technologists were able to design and produce general-purpose machine tools and to undertake the design of more sophisticated tools.

Co-operation agreements with foreign machine-tool manufacturers were necessary in the beginning to speed up the process of growth of the domestic machine-tool industry and as an essential component for the training and development of engineers, technicians, designers, planners, managers and skilled operators. But the large-scale import of technology and know-how in such a vital field could not continue indefinitely, except on a selective basis, because foreign sources could not always be relied upon to respond positively where more modern and sophisticated export-oriented designs and production technologies were concerned.

The Indian machine-tool industry was aware not only of the need to establish in-house research and development activities, but also of the useful role of institutionalized research and development, particularly for the benefit of small and medium-scale units. Hence the industry attached considerable importance to institutional research and development leading to the design, construction and testing of new models and prototypes of machine tools, and to improved production processes and engineering systems.

The Government of India took the initiative in the matter of institutional research and development and in 1965 set up the Central Machine Tool Institute at Bangalore to act as a nucleus for institutional research and development. The Institute was established by the Government of India in co-operation with the Government of Czechoslovakia. During 15 years of its existence the Institute has developed several machine tools with domestic technology and, more importantly, trained hundreds of machine-tool designers and production technologists for the industry. A number of machine-tool manufacturers, particularly in the medium- and small-scale sectors, have taken advantage of the expert services rendered by the Institute.

The activities of the Institute have grown both in scope and content. Besides undertaking designs and development assignments and conducting training courses for machine-tool designers, technologists and production engineers for the machine-tool entrepreneurs, it has widened its facilities to carry out research in the testing of machine tools, machining technology, metrology and numerical control systems.

An NC Centre is being established at the Institute by the Government of India under the United Nations Development Programme (UNDP) to provide assistance to the metalworking industry in all areas related to numerical control. Training personnel from user industries, demonstrating the technology of manufacture using numerical control, advising on the selection of NC equipment, and undertaking development work in the field are some of the items on the programme of work of the Centre. So far, over 300 industry-sponsored participants have attended its courses.

The Centre undertakes the machining of parts on NC machines to demonstrate quality consistency and the economics of machining. For this purpose the Centre is equipped with a 5-axis machining centre, a 3-axis milling machine, a 2-axis cylindrical grinder and two NC lathes. A minicomputer and a co-ordinate measuring machine have also been installed.

Personnel from industries can bring in their parts, programme them, edit the programme, plot it on a co-ordinate plotter, tool up the machine, use the tape for actual machining and produce the parts in a limited quantity to ascertain repetitive accuracies, manufacturing times, economics etc.

Companies intending to acquire NC machines can utilize the facilities of the Centre for trial machining and decide on the specifications of the machine they intend to buy. Consultancy services are also offered in the selection of NC machines, control systems, part programming languages, post processes, supporting and maintenance aids etc.

As regards development activities, a CNC system using a microprocessor-based computer is in its final stage of assembly and development. A microprocessor-based tape preparation system to punch and edit the tapes has just been introduced, and the first few units are being supplied to users. The Centre is also considering the development of the software needed for computer-aided manufacturing (CAM).

The Centre is expected to evolve conceptual designs, up-to-date peripherals, controls and in-process gauging systems, and to build and test prototypes exhaustively before the commencement of serial production. A systematic modernization of existing machine-tool designs, bringing them up to the latest international standards, is also one of the main activities of the Centre.

As is common elsewhere in the developed countries, large manufacturers of machine tools in India are continuously strengthening their in-house research and development in machine-tool design and production technology. For instance, Hindustan Machine Tools Ltd. is putting up a separate building to house its entire research and development department.

The Government of India has introduced certain new measures of importance to the industry. A new law states that no imports of designs and technology by an individual manufacturing concern will be permitted unless the enterprise proves to the satisfaction of the Government that it has its own strong research and development base, and that the company will not only absorb and adapt the imported technology, but also strive to depend on its own research and development efforts for future innovations and improvements in design and technology. Many fiscal incentives have also been granted for the promotion of research and development activities in the manufacturing industries.

In spite of the impressive strides made by the domestic machine-tool industry, an ever-widening technology gap is separating India from developed machine-tool-producing countries. In fact, the Indian machine-tool industry is currently at a crossroads, with one route leading to highly productive, automated machine tools and advanced computer-aided manufacturing systems, and the other route leading to a labour-intensive approach which, according to one view, could mean stagnation for the entire industry. One way of putting the Indian machine-tool industry on a more modern footing could be through the high-technology metalworking and capital goods industries, particularly transports, communications, power generation and armaments, which will require even more highly sophisticated machine tools and production technology in future.

Part two

Prospective technological developments in the machine-tool industry in developed countries

V. Background

This study is designed to be pragmatic, not theoretical. No attempt will be made to forecast technological trends in the machine-tool industry using mathematical techniques like those of Project Delphi.[2]

In order to deal with the subject comprehensively, the following aspects have been considered: machine-tool mechanics and design; cutting tool materials and tool technology; machine-tool control systems; non-conventional machining processes; metal-forming machine tools; manufacturing systems and production engineering; automation in production technology.

It is interesting to compare the forecasts made in 1970 by Eugene Merchant, author of a study on Project Delphi survey methods, and by the International Institution for Production Engineering Research with what has actually occurred over a period of 10 years. Such a comparison is made in a report by the Technical Policy Board of the Institution of Production Engineers, United Kingdom, on current and future trends of manufacturing management and technology in the United Kingdom. The annex contains an extract from this report with forecasts of trends from 1984 to 1996.

Because machine tools are the most important means of industrial production, the development of production technology depends directly and uniquely on the development of modern machine tools. In this survey of the latest developments in machine-tool technology, therefore, the vital link between modern machine tools and the development of production technology will be considered.

The great changes taking place in metalworking may be attributed to the rapid developments in machine-tool design and technology, control engineering and production concepts. Developments relating to, *inter alia*, new materials, cutting tools and a new generation of drives are not only influencing the concept of machining, but also adding a new dimension to the methodology of machine-tool design.

New forms of production organization such as the concept of fully or partially flexible manufacturing systems are emerging. At present, by far the most important form of modern technology is computer-aided manufacture (CAM). It has already proved its ability to improve production possibilities more than all known forms of production technique put together. For this reason, machine-tool-based production technology is becoming increasingly integrated with the computer.

Machining efficiency is the crucial requirement of a machine tool. Research on the maximum obtainable reduction in machining time and the maximum achievable accuracy and surface finish in machining is taking place throughout the developed world. But the emphasis is currently on the possible reduction that can be obtained in preparation and operation time and in various non-machining times. Many new technologies covering the fields of machine rigidity, drives and controls have helped considerably to reduce both non-cutting and preparation times, especially with the development of new controls and positioning devices. The need to reduce the operation time has led to the search for better tools and designs of machine tools having higher speeds and power.

The design of modern machine tools is based on the combination of several technologies. The design of structure, drive and control and the basic design methodology demand a close interaction of mechanical, electrical and electronic engineers, in addition to metallurgists and others from a variety of specialized disciplines. The design of machine-tool structures is undergoing a quiet revolution. The requirements of high rigidity, light weight and good damping characteristics are forcing designers to evolve new designs using alternative materials and new configurations. The present trend is towards structures using combinations of metals and non-metals to ensure proper thermal stability, static and dynamic stiffness and favourable wear and noise characteristics.

The development of new cutting-tool materials is compelling designers to devise drives of high speed and reliability. Noise considerations are restricting the use of gear drives at high speeds. Silicon-controlled-rectifier DC motors are being developed and bearing systems are undergoing many changes. The requirements of high speeds, increased stiffness, high accuracy and reduced noise are favouring the application of hydrostatic bearings on a much wider scale.

[2]Project Delphi was the name of a study sponsored by the United States Air Force in the early 1950s. It sought to obtain expert opinion mainly through questionnaires.

Modern controls are being constantly refined to meet the demands of higher productivity. The remarkable tempo of development in micro-electronics and semiconductor technology is adding new capabilities to numerical controls, and the latest microprocessor-based CNC systems demonstrate a level of reliability which was considered impossible only a few years ago. Fault diagnosis, remote diagnostics and self-checking routines have improved to such an extent with the advent of microcomputers that unmanned operations appear to be the next goal on the manufacturing horizon.

Spurred by diverse consumer demand, manufacturing is showing a shift from mass production to large-volume production with a built-in flexibility for quick change-over from one component spectrum to another. The user industries are demanding finer part accuracies, tolerances and assembly requisites to meet the demand for high accuracies of end-products. The urgent need of the manufacturing sector for multi-function machines to reduce production time and ensure high accuracies of machined components is responsible for the birth of versatile machining centres. The concern of the manufacturing sector to humanize the working environment is forcing designers to view ergonomics as an essential component of machine-tool design. The need to conserve material is dictating a shift from cutting to forming. The threat of an energy crisis is forcing a keener attention towards energy management in metalworking. All these challenges are changing the very foundation of the design and manufacture of machine tools.

A great many structural changes are expected to take place in the production engineering industries of developed market economies as a result of innovative technological developments, in particular in information technology. In the past, advances in production engineering often had much to do with breaking down operational sequences into smaller steps, standardizing the motions and relating them to people. However, as a result of modern information technology, a reorientation of industrial production is conceivable and already visible in some developed market economies. It is characterized by greater operation flexibility in handling customer requests and by a reduction in the monotony and one-sidedness of jobs. Apart from the new requirements to be met by production engineering as a result of changing user and worker demands, an innovative boost is expected to be given to production engineering, above all by modern semiconductor technology.

VI. Machine-tool mechanics and design

There can be no instant transformation into an era of noiseless machine tools with high metal-removal rates, ultra-precision and 100 per cent uptime. Instead, there are signposts pointing to the paths that might be taken in improving the capabilities of metalcutting machines. This in itself is an important contribution to the state of the art of machining. Spectacular advances in the capabilities of modern cutting tools could double cutting speeds from both roughing and finishing and double feed rates in cutting. Taken together, these offer potential time reductions of 50 to 70 per cent, and a further reduction of perhaps 50 per cent is possible if roughing and finishing can be combined into single-pass machining at an increased depth of cut. Depending on the application, such savings could increase overall output by 15 to 300 per cent.

Each of the above possibilities, however, adds to the challenge of machine-tool design, requiring higher spindle revolutions per minute, faster feed mechanisms, larger torques and forces, significantly greater horsepower and much increased static and dynamic stiffness.

In the design of a machine tool, the major elements of importance are the structure, drive, guides etc. As previously indicated, the design of a machine tool should reflect the confluence of several engineering disciplines. The latest trends bear testimony to an integrated approach to the design of every major element of a machine tool. The design trends in structures, guideways and bearing surfaces, spindle systems, feed drives, accuracy aspects in design and computer-aided design, are briefly outlined below.

Structures

A century of trial and error has led to iron in its present form, but both methods of design and products may not be adequate for tomorrow. Even iron may be replaced.

The principal design parameters of the machine-tool structure are as follows: stiffness-to-weight ratio, natural frequency and damping from the standpoint of dynamics, dimensional stability and the long-term stability influencing the retention of accuracy of alignments. Another important parameter arising from ergonomic considerations is the accessibility for loading and unloading the job. This is an important parameter in view of the importance attached to automated loading. This is particularly evident in the slant bed design of modern lathes. The search for cheaper alternatives to cast iron has spurred research on the use of welded structures, concrete and even granite for use in the machine-tool structure.

Fabricated steel structures

The need for lighter and stiffer structures has prompted designers to evaluate fabricated welded construction for beds and columns and also for modules which are used in a variety of combinations. Increased stiffness offered by the welded structures used for columns and cross-beams of vertical boring machines is almost 30 per cent over that of cast iron. In addition to the advantages of light weight and increased stiffness, these welded structures are cheaper than cast iron.

Concrete

Reinforced concrete is even cheaper than welded structures, with the added advantage of possessing excellent damping properties. Some manufacturers in the United States are using concrete to make beds of NC turning machines. These structures consist of a sheet-metal casing braced internally by steel rods and filled with concrete to which the machine tool is permanently glued. A special type of concrete which expands on curing is used. The bed of the machine is a closed box section, cast iron in which sand and core are left behind to achieve a high coefficient of structural damping. This assures a statically and dynamically stiff structure which facilitates a high metal removal rate, high precision and an excellent surface finish in NC machines.

Granite

Future machine-tool beds and bases may well be made of stone, particularly from granite because of its strength and easy availability. There is a diamond-turning machine in the United States in which granite is used as both the machine base and the measurement base. It is claimed to be the first ultra-high precision lathe, having straightness errors within 0.025 μm and positional displacement errors within 0.013 μm at all points, thus permitting turning with mirror polish in a single operation. Granite appears to be the most suitable material for such high-precision machines because of its low thermal expansion (7.2×10^{-6} per °C) and an excellent damping rate at 15 times more than that of cast iron or fabricated steel structure. In spite of all these advantages, the cost of processing granite for use as a machine base is still very high.

Guideways and bearing surfaces

New design concepts are now being tried to ensure the longevity of machine accuracy, to reduce periodic maintenance and provide for easily replaceable guideway elements that do not require costly and time-consuming scraping. Recent innovations in guideway technology have resulted in the development of glued-on and fixed-on guides.

Glued-on guides are built with hardened or nitrided steel strips of 10-12 mm thickness which are bonded on the properly prepared base structure by using bonding agents like epoxy resins. The fixed-on guides are designed with case-hardened or nitrided steel guides which are bolted or dowelled on to the precision-milled, ground or hand-scraped locating surface of the welded or cast-iron machine bed or base. This is likely to be the basic design approach for the guideways and bearing surfaces of machine tools in the future.

The cost of such guideways is much less than even the conventional precision-milled or hand-scraped guides. They facilitate easy replacement of worn-out guides, considerably reducing the down time of the machine. The mating part may be of cast iron or any self-lubricating or tribologically compatible material.

Rolling-element guideway bearings

In high-precision machine tools and NC machines, there is a marked increase in the application of rolling-element bearings for guideways. By careful grading of precision rollers (or balls where a lighter load is to be carried), and by careful calculation of the mean loading per element, a very high-precision motion can be achieved by virtue of the elastic averaging effect. Some modern jig-boring machines use hollow rollers in the vee-flat in a semi-kinematic configuration. In this case, the hollow roller serves to help the averaging effect, and being slightly over square by about 50 μm, an excellent viscous damping is achieved by the shearing of the oil film in the vee-way across the flat ends of the rollers. With this type of bearing, a coulomb friction of less than 0.003 is achieved, ensuring that even under heavy cutting loads a heavy workpiece can be positioned with an accuracy of 1 μm.

Hydrostatic oil bearings

The main advantages offered by hydrostatic oil bearings are high stiffness, low friction, high viscous damping and very high averaging effects exhibited by the all-fluid film bearings. During operation there is no metallic contact. This ensures high life and accuracy of the bearings, which are used in machine tools primarily where very high cutting forces associated with high metal removal are encountered, and yet medium accuracy and good finish are required. The main disadvantages of hydrostatic oil bearing are their high cost due to the need for auxiliary equipment such as pumps, resistors, and filters, and the need to control very precisely the clearances in the necessarily over-constrained bearing gaps. The temperature rise in the bearing is directly proportional to the clearances, and in very high-precision applications it is desirable to control the temperature of the oil in the scavenging and recirculation process, if necessary by refrigeration.

Aerostatic bearings

Application of air bearings is now prevalent, especially for high-precision, high-speed grinding machines. The error-averaging effect of the air film compensates for errors of circularity in the spindle and the bearing bore. By using these bearings, the roundness error on the finished product is considerably reduced. The maximum roundness error of a spindle with air bearings so far achieved on a high-production grinding-machine is 0.00025 mm. The most important advantage is that the thermal warm-up normally encountered in spindles with rolling-element bearings does not exist. Air bearings used in grinding spindles afford a higher quality of form and finish. For much heavier metal removal using large formed wheels and inplunge grinding operations, a combination of air and oil hydrostatic bearings are now successfully used to achieve a higher bearing stiffness and better viscous damping under heavy loads.

An ultra-precision surface-grinding and slitting machine incorporating externally pressurized air bearings for both wheel and spindle, and linear bearings for the X and Y motions of the machine, has been developed in the United Kingdom.

Spindle systems

The thermal energy dissipated in the machine spindle-head during operation leads to considerable thermal dilation which causes spindle drift and spindle droop. These thermal problems can be overcome by controlling and stabilizing the operating temperatures of the spindle head and by keeping it cool through refrigeration. The cooling is done in such a way that a temperature of 20° to 25° C is maintained.

Drift and droop compensation is very important in the case of boring and jig-boring machines. The modern trend is to compensate the boring spindle assembly in such a manner that whatever the projection of the spindle, the tool position does not drift or droop. Such compensation is now possible with hydrostatic bearing systems and with pressure feedback in respect of a built-in reference.

Feed drives

Automatic and NC machines now demand high acceleration or deceleration and a steady state of operations of the feed drive systems. The innovations in semiconductor technology, servo-drives, electrohydraulic systems and high-energy magnetic materials have led to the development of a new breed of feed drives. Electrohydraulic and total electronic servo-drives dominate the field at present, although the electrohydraulic versions are being phased out because of their low response time, actuation delay and associated problems of noise, heat and cost. Modern NC and EDM machines are fully equipped with electronic servo-drives.

The present generation of high-performance drives incorporates one of the following: DC permanent-magnet direct-drive torque motors; DC permanent-magnet servo-motors; electric and electrohydraulic stepper motors; AC variable-frequency motors; brushless DC motors; and wound field DC motors.

The DC permanent magnet systems are the most commonly used because of the attainable band width and good performance at low speeds with added benefits of less heat, noise and low cost.

Even in Japan, where electrohydraulic stepper motors have hitherto been widely used, because of the simplicity of electronic control, permanent-magnet DC motors are slowly replacing them.

The permanent torque motors are a special brand of DC control motors. They have a pancake form and develop high torque at low speeds without becoming overheated. The permanent magnet field does not allow heat dissipation while the motor is on stand-by. Because of these characteristics, they can be directly coupled to the load, offering a very high coupling drive stiffness and even zero backlash with careful mechanical design. These torque motors are highly reliable and durable.

Mechanical drive elements

Along with the direct drive DC servos and torque motors, the most commonly used mechanical drive elements are recirculating anti-friction screws and nuts. However, the hydrostatically lubricated nut and lead-screw systems have recently found increased application in the machine-tool field because of lower rumble, higher stiffness and low friction. Although the hydrostatic nut and screw systems are more expensive, they provide higher reliability when used in the servo-drive system along with DC torque motors and grating transducers.

Accuracy of design

The design of modern machine tools is aimed towards a high accuracy of the machined components. In this context, not only the earlier-mentioned aspects of stiffness of structures, suitable assembly configurations, required stiffness and reliability of drives, sensitivity of slide motions and thermal stability should be achieved, but also an integrated approach should be adopted for the design of the machine and controls.

In view of the enhanced performance requirements of modern machine tools, the design should satisfy a dual purpose. A machine tool has to be able accurately to machine the component and even take over the function of inspecting the machined job. Hence the added function of measuring has necessitated the incorporation of a number of measuring devices and systems on the machine tool. Among these, the most commonly used are the inductive scale, absolute digital or incremental-type shaft encoders and laser interferometers associated with digital read-outs.

Although the vast majority of servo-positioning aids used in NC and CNC machines are the indirect type of transducers such as shaft encoders, the direct types such as inductive scales and moiré fringe gratings are finding increased use because of their higher precision. In a new instrument developed in the United Kingdom, the interpolation of moiré fringes from optical gratings is obtained by a scanned photodiode array which makes possible a very fine resolution from a transmission grating with 100 lines per millimetre. This resolution is close to that obtained by laser interferometry, but at a fraction of the cost.

Modular construction

A distinct trend towards the modular construction of machine tools is already evident. This trend is strengthened by the need of the metalworking industry to machine a wide range of parts in small and large batches, with an ability to change over quickly from one part family to another. This can be done best by a system which allows various configurations of machining systems to be built up from a range of standard modules rather than by the use of inflexible machine parts. Considerable success has been achieved in using modular units for building grinders for high-volume production, but a wider application of the concept to embrace lathes, milling machines, drilling machines etc. has yet to be established. However, as more industries turn to group technology, it is expected that machine-tool builders will increasingly adopt this concept of machine building.

Other technical factors encouraging modular construction include the move towards higher speed and power, variable spindle drives, interchangeable tool turrets and direct-drive feed units. The first three factors have led NC lathe designs to a concept where the drive motor, gear box and spindle units are separated to limit thermal problems and to isolate sources of vibration. The same considerations are seen in modular grinder designs.

Builders of machine tools also stand to gain by adopting a modular design concept. Short lead times, flexibility in final machine configuration, low inventory and larger batch quantities lead to savings of cost and time in machine-tool building. The builder can offer machining systems tailored to meet customers' needs with a possibility of adding more modules when required. All these considerations are prompting a move towards modular design of machining systems.

Computer-aided design

Engineering design involves the use of scientific principles, technical information and imaginative manufacturing instructions to make an engineering product from engineering drawings. Every industry and engineering company evolves its own particular design methods and procedures. A fairly typical design method is as follows: functional specification; preliminary rough design; cost estimates and design analysis; final design; detail design; and drafting. In the modern state of development, computers are being widely used in engineering design. This has led to the development of a new discipline known as computer-aided design.

Conceptual design

The first two aspects of design, namely functional specification and preliminary rough design, may be regarded as a conceptual part of the design process. It is essentially a creative activity that depends upon the ingenuity, innovative qualities and feel of a designer, based on experience and creative ability. Computers have considerable limitations as aids to conceptual designing. Nevertheless, many computer methods are valuable means of expediting the design process. Computer retrieval of design information is one of them. The designer spends a considerable amount of time searching for information from catalogues, standards, research papers, oil designs etc. Computer-managed data banks are available in certain fields to cater to the needs of the designer. The designer can have access to such data banks through multi-access channels, even from a remote place through computer terminals and the telephone network. In-house, minicomputer-based information retrieval systems are also valuable in computer-aided design.

Cost estimates and design analysis

After the conceptual stage comes the stage of cost estimates and design analysis. This stage uses the computer to the maximum extent. Calculation of forces, deflections, stresses, variations of a proposed design and cost estimates can be performed with a high degree of accuracy by the computer.

At this stage the recycling of information is done to alter the rough design and to reanalyse and re-estimate to arrive at a cost-effective and optimum design. If a computer is not available at this stage, the designer usually remains satisfied with one or two trials and waits for the performance report on the design after the prototype is manufactured and tested.

The availability of multi-axes and time-sharing computers and intelligent peripherals such as visual display and graphics terminals have simplified matters. The multi-access and time-sharing facility allows the user to communicate directly with a distant computer, send data or instructions through a visual display graphics terminal, and immediately receive back the output on the terminal screen in graphical form. If the designer is not satisfied with the output, then some of the input parameters may be changed either through the keyboard or in the form of graphical input by using a light pen on the graphic screen and instructing the computer to reprocess. The cycle can be repeated until the required result is achieved. By this method, the user and the computer can work together, modifying and improving the design and correcting errors without having to wait for the print-out. This development in computer technology and graphics represents an essential part of computer-aided design.

Computer-aided drafting

Once the design parameters and shapes are established through the conceptual and analysis phases, the next step is the production of engineering drawings, which is mainly a drafting job. The development of automated drafting machines, both drum and flat bed types—has made drafting easier. Once the various design data are fed to the computer in the form of co-ordinates, the data can be transformed into an analog drawing by operating the drafting machines as computer peripherals. Computer software is available to deal with two-dimensional and three-dimensional views, automatic dimensioning of part drawings and assembly drawings.

High-speed machining

Expected improvements in cutting-tool materials allow an increase in the limits of material removal rate, in maximum speed (5,000-6,000 rev/min) and feed by an average factor of about 2, and in power by a factor of almost 4. This requires specific efforts in the development of faster and more powerful machine tools in all categories and extensive research and development efforts in spindles, bearings, drives, slides, motors, transmissions, chucks, tailstocks and structures. Work on these aspects is being carried out in the laboratories, research institutes and machine-tool industries in developed countries.

It is estimated that in 1979 the cost of metal removal in the United States exceeded $60 billion. If special techniques like high-speed machining could reduce that expenditure by 1 per cent, the savings obtained would be considerable. Given the amount of money spent on metal removal in all developed countries, even a marginal saving obtained by high-speed machining could release a large amount for new investments.

Along with an increasing awareness and enthusiasm to share the new technology, all the leading research and development establishments working on the subject of high-speed machining in developed countries agree that the machine tool should have the following combination of attributes:

(a) Stiffer structures to allow not only higher cutting forces (higher material removal rate), less deflection (better accuracy), a resistance to chatter (better surface finish), and reduced tool wear, but also, when their design is optimized, the use of less structural material, thus reducing costs. Many parts made today by a rough cut followed by a finished cut should be suitable for machining in one pass with a stiffer machine tool. An improved ability to understand, analyse, test and quantity structural behaviour and parameters, both statically and dynamically, is needed. Research and development work is therefore being carried out in the following areas: theoretical and experimental analysis of structural characteristics such as shifting weights and cutting forces; experimental and computation methods for static and dynamic stiffness; damping mechanisms; foundations and vibration testing;

(b) To achieve high spindle speeds, the spindle bearings should be designed to handle the expected loads and speeds. A forward-thrust bearing of hydraulically pre-loaded bearing is considered necessary to prevent a loaded spindle from being pulled out of its housing;

(c) The machine should be provided with a protective cover to safeguard the operator and other personnel on the shop-floor from flying chips and broken cutters;

(d) All tooling should be balanced for speed and the tool inserts firmly anchored for protection;

(e) The advantages of increasing the number of cycles per unit time in high-speed machining are best achieved with an automatic tool changer;

(f) Automatic work-loading and unloading devices are essential;

(g) Faster feed rates involving table speeds of 800 rev/min are considered necessary. However, the table construction may have to be modified to reduce the amount of mass moving at the higher speeds;

(h) Rapid contouring consistent with table feed rates requires a rotary table with a table speed of at least 5 rev/min;

(i) Heavy-duty gripping chucks are essential and should be designed, especially for high-speed turning, to counteract centrifugal forces and withstand cutting forces.

Knowledge about chatter has improved and there are now several emerging techniques that allow diagnosis and remedy when chatter occurs. However, a consensus or good understanding has yet to be reached, and further research work in this regard is being carried out in developed countries. It would be ideal if eventually chatter-free machine tools could be designed.

The life of machine tools today is satisfactory, provided the machine tools are properly maintained. Reliability can be improved by careful and thorough testing, better compiling and analysing of failures to guide redesign, duty-cycle recording (to determine how often and how much a machine tool was overloaded), regular condition monitoring, and better protection against dirt, chips or fluids for all covers, switches or seals.

Energy utilization has not been a major problem since machine tools use relatively little (0.5 to 2 per cent) of the total plant power, compared with heating and air-conditioning or heat-treatment. Turning equipment off when not in use and other simple steps can be helpful in conserving energy. However, newly designed machine tools should provide opportunities to improve energy efficiency, for instance, in mechanical transmission of power or in electrical drives.

Detailed evaluations and surveys are being conducted by machine-tool-producing developed countries in chip removal and disposal, reliability and failure modes, and seals, covers and devices to prevent dirt, chips, dust or liquids from reaching moving slides, bearings and switches. The removal and disposal surveys are concerned with modern sensors, future materials and unusual approaches, such as building a machine tool upside-down to allow chips to fall. There is little valid data on failure modes, failure rates or component reliability under different duty cycles or operating conditions. Work in these areas is in progress. Research work is being conducted to identify the weak links in machine-tool reliability and to improve preventive maintenance and specification or acceptance tests. An objective evaluation of designs of covers and seals for guideways, lead screws, racks and bearings can allow longer life, better reliability and less maintenance. Considerable research is being carried out in these areas in many developed countries.

Among the other features of machine tools designed for high-speed machining, mention should be made of a facility to programme the cutter paths to obtain the advantage of high feed rates, sensors employed for dimensional control and surface finish, and compensation devices to offset thermal distortions. Vibration and chatter can be catastrophic at high and ultra-high speeds. The success or failure of high-speed machining depends to a large extent on the cutter balance. Considerable research work is in progress to solve these problems.

Ergonomics, noise and safety

Even though technology is progressing towards unmanned machine operations and unmanned factories, there is nevertheless concern for the health and safety of the industrial labour force. Recent years have witnessed a greater emphasis on ergonomics, safety and noise considerations in machine-tool design. It is aimed at providing operators with pleasant working environments, both from physical and aesthetic points of view. This is seen as an important method of retaining skilled labour in manufacturing and preventing its migration to other areas such as service industries. Recent recommendations on acceptable shop noise levels and mandatory safety regulations point to an increasing obligation of the machine-tool builders to meet even more stringent regulations in the future.

Proper ergonomic (operator-machine relationship) design is important especially on manually operated machines. Easy identification of controls, low operating forces, logical grouping and pleasing colour schemes are the major considerations. New concepts are emerging to design a lathe which can be comfortably operated by a seated person, thereby stressing the importance attached to the operator's comfort in the design of modern equipment. With the increasing international trade in machine tools, the trend towards visual communication between human beings and machines through symbols is increasing. Recent work in evolving an internationally recognized code of symbols even for NC and other electronic control systems is a positive proof of this trend.

Present recommendations limit the level of noise to which an operator is exposed to 90 decibels over an eight-hour shift. Machine-tool designers therefore have to design machines with noise levels of 85 decibels or less. So far, efforts have been directed towards containment and not noise reduction. New designs are striving to reduce the absolute noise levels of machine tools to 80 decibels. This is expected to have a major impact on machine-tool design. Hydraulic and gear drives and pneumatic systems are giving way to quieter, smoother, electrical drives and electronic controls. Non-metallic panels for guards, covers, trays, access doors etc. are used to reduce noise radiation from sheet metal surfaces. Drive paths are made short and stiff with a minimum number of transmitting elements and controlled clearances throughout.

Operator safety is an important aspect of machine-tool design and construction. While regulations are more stringent for metal-forming equipment, metal-cutting machine tools are also subjected to mandatory safety regulations both in the case of simple manually operated machines and NC and similar advanced machine tools. Guards and seals to protect the operator from chips, coolants and other hazards have already reached a point where there are often limiting factors in quick loading and unloading. This is especially true of grinding machines designed for abrasive machining. These conditions point to new machine configurations in the years ahead.

Future machines may evolve along lines where the guarding is distributed between the machines and the operator rather than being confined to the machines totally. Possible solutions lie in partial curtailment of the working zone, allowing quick and easy access while the operator is placed in an enclosed control station. The use of closed-circuit television can become popular as a visual link between the operator and the machining zone, with remotely operated systems for scanning the work, gauging and inspection when required. Doubtless such methods will be applied only where the machine and production situations lend themselves to reasonably long operation without operator intervention.

Another solution that is likely to be used is to substitute robots for loading and unloading operations while the operator is sufficiently removed from the machine to avoid hazardous conditions. Such concepts are bound to appear on future machine tools since safety considerations will not be allowed to impair to any extent the productivity of the machine.

Energy management in metalworking

About 1 hp (750 W) of power is needed at the spindle of a machine tool for producing mild steel or cast iron chips at a rate of 16 cm^3/min in milling, drilling or turning. The power required is more in some other alloys and less in materials that could be machined more easily. In other words, it takes about 12 Wh to turn out a pile containing 16 cm^3 of chips. This in itself does not appear very expensive, but it should be remembered that the energy required concerns only the material cut from the workpiece, and does not include the energy fed to the spindle drive to overcome mechanical losses of gears and bearings and also the electrical losses within the spindle drive motor. In addition, the following energy requirements should be considered: the energy input into the coolant pump, the axis drives if it is an NC machine, the cooling system or heat exchanger, the line of compressed air and the lighting for the comfort of the operator, refrigeration, heating, cooling etc.

In most of the production modes, the actual metal-cutting accounts for only 30 per cent of the time the job is on the machine, but energy is consumed 100 per cent of the time. Hence it may be easily surmised that the overall energy efficiency of the operation is at its maximum when the maximum amount of energy is used for cutting or forming the job, because this is precisely the time when machine utilization is at its maximum and the productivity of all energy-consuming components reaches a peak. Though this has not yet been achieved, it is the goal of every management because the total energy input per workpiece is minimized and provides the highest energy efficiency.

The adoption of a manufacturing philosophy that boosts productivity, whether computer-based or not, also leads to a higher level of energy efficiency. The choice of cutting tools that increases metal removal rates or ensures longer tool edge life or reduces the machine down time for tool changing also facilitates and increases both productivity and energy efficiency. In spite of a higher rate of energy consumption, an increased spindle horsepower put into the workpiece raises the energy efficiency by giving a larger share of energy for doing the real job. The modern trends towards higher productivity in machine tools is basically meant to enhance the energy efficiency.

The price of industrial energy is about triple what it was in 1967. Energy costs are increasing at a rate of approximately 15 per cent a year and economists are not forecasting a slowing down of this rate even if the current rate of inflation is brought under control. Perhaps the most important factor in machine use, however, is reliability in terms of machine performance and uptime.

Design is often a creative compromise of conflicting requirements. Clever design can increase the output, reduce down time and enhance universality, or the flexibility to handle different workpieces and materials. Considerable research is being carried out on easier chip disposal, improved systems of automated workpiece loading and unloading, safety, ergonomics, energy conservation, faster tool and workpiece clamping and cutting with more than one tool simultaneously.

VII. Cutting-tool materials and tool design

The performance of cutting-tool material in a given machining application is mainly determined by the following three important properties: wear resistance necessary to enable the cutting tool to retain its edge and shape cutting efficiency; hot-hardness necessary to enable the cutting tool to retain its cutting ability and hardness at high temperatures developed at the tool chip interface; and toughness necessary to enable the tool to withstand forces, to absorb shocks associated with interrupted cuts and to prevent the chipping of the fine cutting edge.

Wear resistance and toughness are two interdependent characteristics, a gain in one resulting in a loss in the other. Whereas high-speed steel starts rapidly to lose its hardness at temperatures above 40° C, carbides, ceramics and diamond retain their hardness at very high temperatures.

Several other properties such as coefficient of thermal expansion, thermal conductivity, grindability, weldability, hardenability, dimension stability and freedom from distortion after heat treatment are important. The coefficient of thermal expansion determines the influence of thermal stresses and shocks on materials. Carbides have lower coefficients of thermal expansion than high-speed steels and develop lower thermal stresses, but they are more sensitive to thermal shocks because of their brittleness. With increasing thermal conductivity, the heat produced in the tool chip interface is rapidly dissipated. As the wear resistance of a cutting tool improves, the grindability generally decreases and the grinding costs are increased.

Until 1900 machining was performed by using either plain high-carbon steel or air-hardening steel. Shortly after 1900, high-speed steel was introduced and it has since undergone many modifications. The cast cobalt-base tools introduced around 1915 are employed for machining operations at much higher cutting speeds.

The next notable improvement in tool materials came with the introduction of cobalt-bonded sintered tungsten carbide produced by the powder metallurgy technique. The addition of titanium, tantalum and niobium carbides to basic tungsten carbide vastly enhanced the range of application of carbides. This material used in the form of small inserts, either brazed or clamped to steel shanks, proved extremely popular. Further research and development work in the field of sintered carbides yielded superior varieties of carbides having a thin hard layer of titanium carbide or titanium nitride on a basic carbide substrate. With this development of coated inserts, a 50 to 80 per cent increase in the cutting speed over that of conventional carbides was achieved. Many new types of coated tips with multiple layer coatings are also being introduced.

Shortage of tungsten has, however, led to the development of many non-tungsten cutting-tool materials. Among them the most promising are solid titanium carbide and titanium nitride. Ceramic tools exhibit very high hardness and abrasive resistance, facilitating the use of higher cutting speeds. However, their application has been limited owing to their brittleness and lack of strength. A new tool material consisting of columbium, tungsten and titanium permits a 60 per cent increase in cutting speed in comparison with tungsten carbide. Cubic boron nitride with a hardness second only to that of diamond permits speeds five to eight times faster than that of tungsten carbide and can be used to cut hardened materials. Polycrystalline diamond bonded to tungsten carbide substrate is now successfully employed for machining non-ferrous materials.

Tool materials

Cast alloys

High-speed steels were unsurpassed until the introduction of cast cobalt-base alloys. Cast alloys are produced with certain combinations of tungsten, chromium and cobalt having extremely high red-hardness, wear resistance and toughness. Since the coefficient of thermal expansion is the same for both steel and these alloys, the two materials can be brazed or welded without the danger of inducing stresses. The cast alloys bridge the gap between high-speed steel and carbide and to some extent are still being used in the metalworking industries.

Cast alloys have properties intermediate between high-speed steels and cemented carbides. They are less tough and more wear-resistant than high-speed steels, and are used at surface speeds above those of high-speed steels and below those of carbides. Other important characteristics are high red-hardness (ability to retain edge hardness up to 760° C), a low coefficient of friction, excellent resistance to corrosion and high resistance to shock and impact.

The cast alloys are used for machining cast iron and malleable iron, alloy steels, stainless steels, non-ferrous metals, bronze, graphite and plastics. The shock and impact resistance of cast cobalt-base alloys allows them to perform better than carbides on interrupted cuts.

Cast alloys can be used in multiple tooling on automatic screw machines and multi-spindle bar automatics, where not all operations require the surface speeds of either high-speed steels or carbides. Carbides are used on large diameters and cast alloys on smaller diameters. Cast alloys are also used to cut small diameter jobs.

Cemented carbide

The first major breakthrough in the development of tool materials came in 1926 with the advent of cemented carbide for metal-cutting. Earlier, cutting-tool materials were mostly produced by molten metallurgy methods and depended on proper heat treatment for hardness and other properties. Their performance was therefore greatly affected by the attendant cutting temperatures. The carbides now produced by powder metallurgy techniques display very high red-hardness (ability to retain their cutting edge up to about 100° C) and wear resistance and can be operated at very high cutting speeds when compared with high-speed steels.

Initially, straight tungsten carbide with cobalt as the bounding material formed the basic constituent of cemented carbide, which was well suited for the machining of short chipping material like cast iron. Later the range of application was considerably extended by the addition of carbides of titanium, tantalum, niobium etc.

The extent to which carbides have spread is borne out by the fact that at present in developed countries 300 to 400 carbide varieties are marketed by various tool manufacturers.

Partly because of low tensile strength and high costs, carbides were originally used as small tips for inserts brazed to a tougher and less costly steel shank material. The cost of carbide has now come down appreciably and is only a fraction of what it was some years ago. Still, it is invariably used along with steel shanks on which it is clamped or brazed except in the case of very small tools. Though simple and cheap, the brazing process is now disappearing since it has certain drawbacks. Brazing, even carefully done, may subject the carbide to internal stresses owing to the different coefficient of expansion of steel and carbide. These stresses alone may not be large enough to damage the tips, but when coupled with normal cutting stresses, they may cause failure of the tip. Regrinding of brazed carbide tips is also a problem because the grinding stresses may cause cracking of the tip. The geometry and finally the performance of the carbide tools depend on the skill with which brazing is done and grinding is carried out. These problems assume greater importance when multi-point tools like milling cutters have to be sharpened and the relative positions of the cutting edges must be accurately maintained. In addition, some of the newly developed grades of carbides are difficult to braze. Recently introduced coated carbides are not suitable for brazing because the subsequent grinding removes the coating.

The concept of the throw-away insert overcomes the disadvantages of the brazed tool and offers considerable economy, higher productivity and operational convenience. Elimination of regrinding and other troubles associated with poor grinding, accuracy of tool geometry and reduced tool inventory are some of the advantages offered by these tools. Since regrinding costs are completely eliminated, they can be subjected to the maximum wear at higher speeds than those used as brazed tips. With the use of pre-sintered chip-breaking on throw-away inserts, better chip control is achieved.

A shortage of tungsten has led to the development of many non-tungsten cutting-tool materials. Among them the most promising are the titanium carbide and titanium nitride tool materials, which have greater solubility in the bonding materials used, nickel and molybdenum, than tungsten carbide has in cobalt. This results in high strength of materials with good resistance to chip tool welding and reduced friction between the chip and the tool. Because of their higher thermal conductivity, temperatures produced at the cutting point are lower. They have a very low density, about one third to one half that of tungsten carbide alloys, and this leads to low heat absorption, which is a critical factor for extended tool life. They also have a transfer rupture strength comparable to that of tungsten carbide, exhibit higher hot-hardness and do not form a built-up edge on their rake faces, consequently producing a good surface finish on jobs.

Titanium carbides and titanium nitrides have been used to bridge the gap between tungsten carbide and ceramics for finishing and precision machining operations at speeds as high as 450 m/min and with light to moderate feeds and cutting depths. These could also be used on high-temperature alloys with poor machinability and on hard alloy steels.

The potential for major development in carbide cutting-tool material depends primarily on the availability of cobalt. The supply of this essential material is controlled by Governments, and a cut-off would hinder development efforts in carbide tools.

Coated carbides

In the case of conventional cemented carbide grades, a compromise has been sought between wear resistance and toughness. In principle, increased wear resistance also means reduced level of toughness and vice versa. The emphasis in the development of cemented carbides is therefore on improving wear resistance while retaining adequate toughness. This has led to the development of coated carbides in which a microscopic layer of wear-resistant material (titanium carbide, titanium nitride) is chemically coated over a tough carbide substance to attain a single grade of carbide having the property of both high wear resistance and toughness.

Coated carbides are rapidly changing the composition of cutting tools. Such tools account for approximately 25 per cent of carbide-insert use, a figure may increase to 80 per cent depending on material conditions. However, if these tools are to be used at their optimum capacity so as to provide full economic return, machine spindle speeds, horsepower and feeds will have to be increased. That is already being done in the designs of machine tools produced in developed countries. In micrograin carbide, the particle size of the carbides is reduced to submicrograin level. It is found that micrograin carbides exhibit significantly higher traverse rupture strength at any given hardness level than conventional carbides. They are used for severe metal-cutting operations requiring a higher strength than those of conventional grades of carbides. They are recommended for applications where high-speed steel or cast alloy tools are too fast, or where cutting speeds are slow for carbides, or where carbides fail by chipping.

Because of their high strength, coated carbide tools are being extensively used with positive rake angles in machining high-nickel-base alloys (super alloys). They are also recommended for cut-off tools, since the slow speed encountered towards the centre of the bar does not affect these tool materials, and for form tools.

Ceramics

Among the numerous ceramic tool materials available, the best results are obtained with aluminium oxide combined with small quantities of various other oxides. Ceramics are hard and have a high degree of compressive strength even at elevated temperatures. They have a good abrasive resistance to cratering and a low frictional co-efficient, and they are not sensitive to the higher range of temperatures encountered in practice. Ceramic tools can retain their cutting-edge hardness up to about 1,400° C and exhibit uniform strength up to 1,220° C. Because of these properties, they are being used in developed countries for cutting tough material at high speeds and at higher temperatures as compared with other tool materials. However, the relatively low transverse rupture strength of ceramics—about one half to one third of carbide—is a serious limitation which has been restricting their wider applications to that of uninterrupted cuts.

Ceramics, having higher hot-hardness and greater resistance to wear, are employed for increasing productivity and lowering costs. Ceramics provide good surface finish and quality and eliminate finishing operations like grinding. Cast iron, noted for its abrasive characteristics, can be machined to a smooth bright finish using ceramics. Heat-treated steel as hard as 65 Rockwell "C" can be finished by ceramic tools up to 0.5 μm surface finish, often eliminating the grinding operation with considerably improved tool life vis-à-vis the carbide. High-temperature alloys such as hastalloy, stellite and Monel metal can also be machined using ceramics. Ceramics are used for special turning, long tube boring, cylinder liner boring etc.

Ceramic tools have the potential to increase cutting speeds by a factor of 5 to 10, but their toughness will have to be increased before they can be widely used. The wide use of ceramics would require some refinement in machine-tool technology. During the next five years, ceramics will continue to make progress, but at as slow a rate as that experienced during the past five years.

Ceramics and cermets have been used for cutting tools for the last 20 years and have secured a definite place, within limits, in metal-cutting. Many of the earlier aluminium oxide ceramics are no longer available, because they are not good enough to compete with the more recent hot-pressed, high-purity aluminium oxide inserts.

Of more significance, however, is the so-called cermet material containing 15-30 per cent titanium carbide in addition to aluminium oxide. There are a number of producers of high-quality materials in this class that compete in the high-speed cutting range.

In addition to the more conventional cermets, there have been others in which additives, such as molybdenum and molybdenum carbide or tungsten carbide, have been used with aluminium oxide instead of titanium carbide. None of these has yet proved viable as a cutting tool. Extensive research is being conducted in this area by the cutting-tool manufacturers.

Diamond

Diamond, because of its high modulus of elasticity, chemical inertness and exceptionally high hardness, is ideal for obtaining fine surface finish and accuracy. Though the initial cost of diamond is high when compared with high-speed steel or carbide tools, the cost per piece machined with diamond is invariably much lower.

Diamond is chemically inert and takes a high polish. Because of this property, chips do not adhere to its surface when machining non-ferrous and non-metallic surfaces. Diamond has high hot-hardness but excessive heat causes it to crack, and oxidation of diamond starts at about 800° C. An abundant supply of cutting fluids should therefore be used without interruption and light feeds should be employed. The diamond cutting edge is extremely smooth, keen and accurate. It is completely free from sawtooth irregularities inherent in a carbide tool, and hence the modern trend is that the diamond tool is employed more for precision application.

Diamond is extremely brittle and it chips or fractures if it is not properly handled. It should be used on machines with minimum vibration or chatter and protected from shock loading.

Diamonds of various forms are used in many industrial applications such as grinding wheels, dressing tools, drawing dies, hones, lapping compounds and cold drills. As a cutting tool, diamond is mainly used for machining the following: non-ferrous metals like aluminium, brass, copper, bronze and other bearing materials; non-metallic materials like epoxy resins, hard rubber and glass; and precious metals like gold, silver and platinum. In light-alloy pistons, nearly all surfaces are diamond-turned and bored, especially where higher silica content is involved. Sintered bearings, which cannot be machined by other tool materials, are machined by diamonds. Commutators are turned with diamond tools to give them a smooth surface with clean boundaries. They are generally used for finishing cuts and are not recommended for ferrous materials. Polycrystalline diamond is used for machining glass, reinforced plastics, eutectic and hyper-eutectic aluminium alloys and other materials having hard and soft structures which prevent interrupted cuts. They are also used in milling.

Columbium-titanium-tungsten alloy

A nitrided refractory metal alloy consisting of 50 per cent columbium, 30 per cent titanium and 20 per cent tungsten has been developed by a company in the United States.

Untreated inserts of the alloy having a hardness of around 200 Brinell are nitrided in a nitrogen atmosphere at a very high temperature. The surface hardness of the finished insert is greater than that of ceramic and, towards the centre, softer than steel. Because of its non-homogeneity, application of the alloy is limited to throw-away inserts.

The alloy cuts very cool. It has excellent thermal shock resistance, high hardness and toughness. It also exhibits excellent resistance to diffusion and adhesion wear (chip welding). It is claimed to give three to five times more edge life than conventional carbides.

The alloy is recommended for roughing, semi-roughing and finishing cuts in turning, facing and boring. It operates in the speed range of 250 to 500 m/min on steel of 200 Brinell. It is not generally applied to milling, parting-off or for operations using form tools.

Cubic boron nitride

Next to diamond, cubic boron nitride is the hardest substance known. It consists of atoms of nitrogen and boron with a special structural configuration similar to diamond. Cubic boron nitride is successfully used as a grinding wheel on high-speed steel tools providing good surface finish, precision and high output, and also on titanium, stainless steel and stellites. The second application includes grinding of hardened steel lead screws, splines, threads and ball and roller-bearing parts. Because cubic boron nitride cuts cool, grinding defects such as burrs and thermal shocks are not produced. It is also used for grinding the slideways of cast iron beds and housing-type components.

Tool design

Chip breaker

Long and unbroken chips produced while machining ductile materials are difficult to handle and injurious to the operator. The sole purpose of the chip breaker is to break chips into convenient sizes for easy disposal and to protect the machine surface from rubbing against chips. Various chip breaker designs and configurations have been conceived to obtain effective chip control.

Various types of chip breaker and inserts are the external chip breaker, and moulded chip insert and the variable-width chip breaker. The moulded chip breaker design evolved with the advent of centre-lock-type tool holders. In this design the chip breaker grooves are formed at the sintering stage. They are built in single-, double-, triple-, multiple- and variable-width configurations. The variable-width chip breaker consists of an insert with a varying groove to enable the insert to handle a wider depth of cut.

Tool geometry and configuration

The land angle inserts have been designed for the use in heavy roughing and light finishing cuts. A new land geometry was first evolved in the United States. In the design adopted the chip leaves the rake face very quickly, thus reducing the chip-tool contact length and transferring very little heat to the insert. This reduces the cutting temperature and results in improved tool life. Another advantage is that by avoiding the back wall of the chip groove, cutting forces are reduced and the metal removal rate is increased. The chip breaks with a natural curl and facilitates improved chip control at both ends of the feed range, which helps in easier programming of NC machines.

Wave-shaped insert design

The single-sided negative insert in this design is provided with a wave-shaped edge geometry having double chip-breaking grooves and a mini-chip breaker near the nose radius to compel the chip to curl against itself. This wave-shaped cutting edge provides a positive angle of inclination and reduces cutting forces. In this design the axial and radial forces are reduced to 20 and 30 per cent respectively, and the tangential force by about 10 per cent vis-à-vis the standard negative insert. The insert also helps to use positive or negative rake for negative rake tool holders.

Tooling system

The inherent disadvantages of indexing throw-away inserts directly on the NC machine tool led a United States firm to design a new tooling system. This system provides for rapid tool changes, with tool holders held in place by a ball-lock mechanism. It involves the concept of quick indexing of a cartridge-carrying insert. The compact design of the system affords space for 12 tools on a 6-station turret, thus doubling the tool capacity.

Another system combining a high performance insert with a reliable coated carbide has been developed. It has a new carbide insert geometry and a multi-faced coating, designed for extremely tough machining applications. Its land-angle shape allows freer cutting and very high metal removal rates, and the coating allows for heavy interrupted cutting, past runout and scale. The clean rake surface presents lower resistance to chip flow and thereby encourages higher feed rates. It has high chip-controlling ability along with the natural advantages of using high-speed rates to reduce unit power consumption.

Qualified tool holders

The positioning of the cutting edge in both X and Y axes is especially important when using automatic, copying or NC machines. Normally, tool positioning error is doubled in turning because of the tool cutting on diameters. Since many NC centres have a programmable resolution of 0.002 mm, and since closer tolerances are insisted upon in precision machining, greater attention is paid to accurate tool setting. Another critical requirement is repeatability in positioning the tool in automatic tool changers. To respond to these requirements, qualified tool holders are designed where certain critical nominal dimensions are qualified over the specified radius of the insert within about ±0.05 mm. The qualified tool holder eliminate the need to size every tool individually. Roughing cuts can be taken without the need for a trial. In qualified tool holders all control dimensions are nominal for both manual and computer programming. Besides eliminating the present presetting stand, the set-up time is greatly reduced by using qualified tool holders.

Major constraints in tool design

Chip control is normally accepted if there is no danger to the operator and no damage to the workpiece, and if the chips are small enough to handle easily and safely by either manual or automatic means. These are important in the case of NC machines, where chips can cause much damage and interrupt production. The need to bring chips under control may lead to over-control when extremely tight, dark-blue chips are formed, or when inserts cause severe chatter or break prematurely. This may be avoided by achieving a lower metal removal rate, but the vestiges of over-control will still remain in the design.

Increased metal removal rates through an increase in feed rates appears attractive, but it is beset with many problems. An increase in the depth of cut or speed poses several problems. In the case of depth of cut there are limitations. For example, if the depth of cut is doubled, twice as much power is required at the tool point. If power and rigidity are available, then an increase in depth of cut can be effective. But the wider chip may be either too difficult to break or may become too crowded or deformed. This will require even more power than originally anticipated.

Even though modern machine tools cut much faster, there are some limitations to increasing speed. Tool life deteriorates drastically with speed because of the significant increase in abrasion and temperature on the flank, rake face and nose radius of the insert. Flank wear is the most important cause of the end of tool life. By understanding the interrelationships between speed and feed, productivity increase and tool life can be balanced. The real key is the feed rates, but these are again limited by the insert geometry. Designers must therefore continue the search for the ideal geometry, optimum speeds and feeds and material characteristics to meet production requirements.

VIII. Machine-tool control systems

A spectacular new art of manufacturing, based on the changing nature of the information stream that runs a manufacturing enterprise, is emerging in developed countries. In the past, human beings were both the translators and transmitters of information. The operator was the ultimate interface between the design intent as incorporated in the machine drawing or instructions and the functioning of the machine tool. Human beings used mental and physical abilities to control the machine tool.

However, computers are increasingly becoming the translators and transmitters of information, and numerical control is perhaps the most representative example of the kind of control that plugs into a data stream with the minimum of human intervention. Historically, numerical control has been the most significant development of the electronic revolution as it affects manufacturing engineering.

The possibility to store information at a low cost and to compute and regulate on the basis of stored information has considerably automated the production cycle. Storage, computation and machine regulation is done according to the principle of digital technology, that is by employing a large quantity of evaluated symbols with elements of semiconductor technology. In other words, the building blocks of modern electronics hold the key to control technology. The following basic aspects of machine-tool controls are important to the user and manufacturer alike: operation and programming; operation safety; cost; flexibility and extendability; and integration and standardization.

A numerically controlled machine tool is a machine which grinds, drills, turns and cuts according to a predetermined programme. Its work cycle is recorded on perforated cards or tapes or on magnetic tapes. Commercial production of NC machine tools began in the United States as long ago as 1952. Their application was limited, but during the past decade they have become significantly more sophisticated, compact and cheap, partly because of the silicon chip and the associated micro-electronic technology.

Though initially numerical controls were built to prove their efficacy in machine control, many of the above factors associated with the new art of manufacture were not considered. But now numerical control is no more an engineering curiosity. It has come to occupy an important place in the very concept of production engineering. The development of NC, rendered possible by the remarkable growth in semiconductor technology and digital science, is designed to make it an invaluable tool of production, due attention being paid to its reliability and cost.

A decade ago, numerical control was a means of automatically controlling machine movements with the help of coded numerical instructions. These instructions were contained in a punched tape. The coded tape was the heart of NC, with the responsibility for controlling the sequence of machining operations, machine positions, spindle feeds and rotational directions, as well as many other functions like control of the coolant pump. But in the last ten years, NC has changed considerably. Transistors have given way to integrated circuits. Advances in computer technology have helped to replace all logical hardware. Decision circuits have been superseded by executive software in the form of minicomputers. The NC guided and controlled by computer has given birth to computer numerical control, which is the heart of modern machining centres. Part programming, inter-active computer graphics, adaptive control, microcomputer codes, servo-mechanisms, human engineering and on-line diagnostics have been added to the establishment aspects of process planning.

Computer numerical control systems

The architecture of the CNC system is entirely different from a conventional hard-wired system. The concept of CNC is akin to the digital computer concept. Every digital computer has the following three major parts: the central processing unit, which does the arithmetic and logical operations; the memory, which stores the data to be processed; and the control instructions and peripherals, which form the link between the computer and the outside world. For CNC, the machine and various other items of equipment to be controlled form the peripherals.

The major components of the CNC system include the computer and the executive programs, data-handling, controls for machine axes, magnetics etc.

All functions for controlling the operations of NC machine tools are synthesized by the logic designer by evolving a combination of logic modules consisting of gates, flip-flops, counters, shift resistors etc., along with the necessary peripheral devices.

Different approaches, using the same type of logical elements as the basic hardware, may be employed to obtain the same end-results. This gives rise to a non-standard system design requiring for each system a large variety of spares and a large inventory. It was therefore realized that efforts had to be made for standardizing the system design of the hardware. The evolution of large-scale integrated circuit technology brought NC system designs closer to this achievement. The design was done around a computer capable of meeting the requirements of any machine. The computers used in such NC systems are either minicomputers or microprocessor-based computers with a standardized hardware architecture. Other peripheral devices are kept unchanged, but the corresponding interface circuits are modified to cope with the new type of hardware. The requirements of each individual machine tool are met by a software program called the executive program, which is a part of the control. It contains the command logic which determines how the control is to perform its functions such as operating the tape reader, translating the program tape and sequencing the machine tool. In other words, the controller's own logic is actually a computer program instead of specialized electronic circuits. The hardware remains standard and fixed with the different design approaches. But software, once successfully developed, needs no maintenance. Hence standardized system design is achieved with a minimum of maintenance requirements.

A computerized controller needs fewer electronic components and fewer circuit interconnections. The tape reader, which is the most vulnerable equipment in a workshop environment, is removed from on-line operations during machining, thus leading to improved reliability.

The number of printed circuit boards are reduced and the same control may be used for a three-axis machine or a five-axis machining centre. This reduces the inventory of spares for single or several CNC units, even if different machines are involved. Personnel training is reduced because only one system has to be maintained and serviced. Rectifying a malfunctioning of the system is much easier in the computerized system because of diagnostic programs. Even a less skilled person having a basic knowledge of operation can isolate a problem down to a subsystem or the card level.

Computerized control systems offer more flexibility since modification of the software program is simpler, quicker and cheaper than in the case of the hardware of a conventional NC system. This facilitates the inclusion of additional features by increasing the software in standard building-blocks. Though it may involve a marginal modification, it is less costly to make a CNC system compatible with the unique problems and practices of any shop. Newly developed options can also be added after installation to upgrade the equipment. This facility eliminates the danger of premature obsolescence, although rapid progress in electronics indicates that machine-tool controls become obsolete in three to five years. Part programs are stored in the computer memory and then made available for machining. This feature is particularly helpful in repetitive production. Execution of short blocks is not limited by the reader speed because the access time for the data stored in the memory buffer is negligible.

A new part program can be actively generated or an existing part program can be modified inside the computer memory. This simplifies changes in geometry, feed, speed and optimization during try-out. The time for tape-proving and debugging is thus reduced, and production time considerably increased.

The computer and the properly designed software have made increased sophistication of CNC control possible. In conventional NC, this increase in sophistication necessitates more hardware with a consequent rise in costs.

All the machine axis irregularities may be measured and inserted in the control software so that in subsequent programmed operations the absolute accuracy of movement is maintained. It is thus possible to produce a part which is even more accurate than the machine itself. This feature facilitates programming, optimizes machining conditions and achieves consistent surface finish and accuracy.

To reduce the machine set-up time and compensate for tool wear, the offset data can be stored in the memory and called at any appropriate time. Use of thumb-wheel switches for storing data as in hard-wired controllers is eliminated. Virtually an unlimited amount of offset information can be provided.

In the case of tool breakage, the machining operation can be stopped and the tool changed without destroying the programmed data.

The present trend is to use a programmable machine interface where a machine interface ladder network can be programmed in software. This has helped the machine-tool builder to eliminate a considerable number of relays, contactors and timers that are used in machine electrics and magnetics. Changes in the interface do not require corresponding hardware changes. The ladder network can be displaced on a cathode ray tube. This feature is an extremely valuable tool in debugging the machine interface program.

enhancing the reliability of the system. Since a great deal of hardware is in CNC systems, diagnostics is a very important tool for correcting the faults that appear in the course of operation in the hardware circuits of the systems. Since a computer used in a CNC system has the ability to perform different tasks under different programs, a proper program can be written to make the computer work like a circuit tester instead of an NC controller, thereby providing a diagnostic program.

Manual data input controller

The latest trend in simplified CNC control of individual machines has led to the microprocessor-based manual data input (MDI) control system. MDI controls go beyond digital readouts by adding slide drives, while advancing microelectronics technology puts new skills at the disposal of the machinist. Among the synonyms for MDI controls are such terms as tapeless NC, memory NC and operator program NC. These terms are as valid as MDI. Many MDI controls can be converted into conventional NC systems by plugging in an optional tape reader. Most present-day NC systems incorporate program editing features that make them fully capable of accepting manually input part programs.

Most of the well-known NC machine builders have brought out this type of CNC system. In the MDI system, the operator has a choice of, on the one hand, making the program by manually machining the first part to record the machine slide and tool movements automatically, or, on the other hand, using the keyboard for input of work cycle commands from a program sheet on the basis of the part drawing. Since this does not make use of the punched tape, the tape reader which is normally a source of trouble is totally eliminated. If required, the part programs located in the system memory are transferred to a magnetic cassette for permanent storage. One firm provides a plug-in cartridge having random access memory with a nickel cadmium cell. An editing facility is also provided to make any part changes in the program. MDI systems are lower in price and smaller in size than the conventional CNC system. The only limitation of the MDI at present is that the controls are made for machines with up to only three axes. These controls are ideal for adoption on machine tools built in developing countries.

Direct numerical control

Direct numerical control is an extension of the CNC concept. In DNC, a central computer controls simultaneously a number of NC or CNC machines. DNC, according to the definition of the Electronics Industries Association, is a system connecting a set of numerically controlled machines to a common memory for part program or machine program storage, with a provision for on-demand distribution of data to machines. The DNC system has provision for collection, display or editing of part programs, operator instructions or data related to the numerical control process. Though the concept of DNC is not new, it has yet to spread widely in the manufacturing sector. There are also many shortcomings that need to be overcome in the systems. However, the main reason for the DNC not becoming so popular is the initial high cost of investment. Another reason is that a universal DNC system with a wide range of applications has not been created. The possibility of using the DNC system for maximum productivity has yet to be proved.

DNC level I and level II are the two schemes of DNC systems currently in use. Some firms offer a DNC minicomputer that stores all machine data post-processed for a specific machine on a master disc file. The minicomputer sends the machine data on a real time basis to each NC machine interfaced to it. In this case, no stand-alone NC system for the NC machine exists. There is a limitation on the number of NC machines interfaced to one minicomputer as the computer works on a real-time basis. One major disadvantage of this system is that if there is a malfunction in the minicomputer, then all the NC machines connected to this computer will be affected. To overcome this drawback, use is made of a stand-by minicomputer that can take over in the event of malfunctioning in the DNC minicomputer. The other remedy is to switch to the DNC level II system, where each NC machine has its own stand-alone CNC system. These individual CNC systems receive data from the DNC minicomputer. Here, even if the DNC minicomputer fails, the machines can be operated with the help of their independent CNC systems. If the individual CNC systems are provided with floppy-disc data storage, then a considerable amount of data can be transferred from the DNC minicomputer to these systems.

DNC offers several operational advantages. The tape reader, which is usually the most downtime-prone component of a machine control unit, is bypassed. Secondly, a program in a computer storage is much easier of access for use in operation, for revision or editing, or for quick and easy interaction between the programmer and the machine tool. The same computer that directs the operation of a machine tool can also be used for auxiliary purposes such as down-time recording, performance tabulation, real-time machine status and other operational items of interest to management. An advance design DNC unit can also be utilized to sense operating conditions and make modifications in programmed instructions. DNC requires programmers and supervisors with a thorough knowledge of the system to exercise full and optimum control. DNC systems can be extremely effective when combined with the best systems know-how, but the initial cost is still great, and very high-quality software support is needed.

Recent trends in numerical control of machine tools

The use of a general-purpose minicomputer and related software as part of control systems is being discontinued. Control systems built with microprocessors and dedicated software are the basic constituents of the CNC system.

Microprocessors are currently used in two configurations. One involves a bit-slice design for constructing microcomputers which in all respects fulfil the function of a minicomputer and for microprogramming. The designer of a CNC system is thus offered the flexibility to formulate his or her own macro-instruction sets. Hence it is now possible for many builders of NC systems to change over from the minicomputer to the microcomputer version without changing the software of the system. A number of major producers have changed over to microprocessor-based systems while keeping the same software that was developed for their minicomputer systems. This has proved very economical, since no additional investment is required on software development.

The second configuration of the microprocessor-based CNC system involves the use of three 16-bit microprocessors with specific functions assigned to each of them, for example, part calculation, axes drive and I/O interface. A similar system uses three 16-bit microprocessors, one each for axis drive, front panel interface and central processing unit. In this design, the central processing unit co-ordinates the tasks between the microprocessors.

In the earlier CNC systems, magnetic-core memory was used as the main memory of the system. This provided a non-volatile memory but was more expensive and also temperature-sensitive. Hence it is now replaced by semiconductor memories, such as the random access memory. Since these are volatile, a battery back-up is provided to retain the information in the memory in case of main power failure. Random access memories are now available in 16-bit configurations in a single chip. Other types of memory chips, such as the read-only memory, the program read-only memory and the erasable and programmable memory, are used to store the management and control information. These are non-volatile memories. The latest trend is to store the system-executive software in program read-only memories. Formerly, this software was on punched tape and was loaded through the tape reader into the main memory, but quite often the stored information was lost because of electrical disturbances in the workshop environment or a power failure. A CNC system developed in the United States uses a floppy disc for storing executive software. It is non-volatile and has proved very useful.

The development of computer technology has made possible the introduction of NC machine tools which themselves had drastically changed the technology. Further improvements in controls are foreseen, such as those designed to increase their capability and their memory to allow more functions to be monitored and controlled. Rapid progressive electronics causes machine-tool controls to become obsolete in three to five years. There will be new, complex, high-performance controls as well as simpler low-cost versions suitable for less complex parts and versions compatible with manufacturing systems.

Computers have proved themselves in stand-alone machine-tool controls. CNC units are replacing hard-wire NC, and programmable controllers are replacing hard-wired relay logic. Computer reliability has been remarkable, and controls have helped to increase machine uptime and the time needed to correct failures. A modular control design that allows for add-on capability with additional functions can improve flexibility and reduce costs. In addition to the central processing unit, the use of more computers is expected, with functions such as the following: supervisory computers in the DNC or machining system comprising several machine tools; an aid to optimization and shop performance, in the form of a small hand-held computer or microprocessor or a small personal computer; and a tie-in of machine tools to a computer-assisted comprehensive operations-control system in the company.

Some of the methods of improving machine-tool control units include the following: use of integral adaptive controls; features to assist or speed up accuracy measurement of the machine tool; using the computer and display already embedded in the machine tool for training of operators or maintenance personnel; novel schemes of error compensation; additional diagnostics; devices to reduce set-up efforts and time, such as tool-set stations or feeler probes placed in the tool holder with automatic adjustment for tool wear or fixture positions; on-the-machine inspection of geometry or surfaces with automatic correction; keeping record of machine utilization or cutting-tool life; self healing or self-repair after diagnosing a certain failure such as a broken drill; and development of the ability to modify a program on the shop-floor or record the events of the last minute or two prior to a failure.

Standardization of interfaces or language and data communications is an important concern, like terminology and maintenance methodology. Strong efforts are being made to evolve a set of standards.

Interactive graphics, a powerful emerging technology, is playing an increasing role by providing visual displays for monitoring and command or control at each step in the manufacturing process, from design to cutter motion and interaction and the complete manufacturing systems. Improvements through three-dimensional modelling of parts and clearer communication between the devices and the operator are undergoing further intensive investigation.

Verification of input data prior to running a program on a machine can be very cost-effective in batch production of complex parts. The spin-off benefit is to prevent production machine tools from being used extensively for tape checking.

Adaptive controls, although studied for about 15 years, have found only limited applications. Improvements in understanding the cutting processes, the variation of cutting conditions and more reliable sensors need to be developed. Good sensors for tool wear and breakage, geometric dimensions or contours, preferably of the non-contact type, and demonstrations of specific complete adaptive control systems have not yet been perfected.

There is a need to develop more and better sensors, techniques for identifying intermittent errors and diagnosing more of the mechanical failures through signature analysis or other techniques. Novel diagnostic approaches are also needed, such as those making it possible to predict a failure and permitting orderly shut downs of operations rather than unscheduled emergency stops.

Future NC systems will be microprocessor-based and provided with computer graphic display. With computer-aided design the use of this graphic display will be extended to the NC systems, resulting in the interactive graphic CNC system. One firm has already brought out a microprocessor CNC for turning machines with automatic programming and interactive graphic display. In this system the cathode ray tube can display the appearance of the finished part, the programmed tool part, the actual position value, the system parameters, program data, tool offsets and diagnostics. A paging facility is provided for viewing long programs on the cathode ray tube display.

Automatic programming is another feature of CNC to attract users of NC machines. The post-processor is built into the software of the system. The operator need only enter the basic dimensions of the workpiece, the codes for the tools used, the offsets, feeds, speeds and some simple instructions through the keyboard. The built-in software does the necessary computation, calculates the arc centre and programs itself.

In the field of diagnostics for maintenance of CNC systems, remote diagnostics will be commonly employed in future.

Two such remote diagnostic facilities are currently offered to NC users in the United States. Remote diagnostics involve the use of a telephone to transfer digital information between a malfunctioning CNC system and the central computer used for diagnostics on the premises of the manufacturers. The central computer is able to make a multitude of analyses and checks on both the control unit and the machine elements, thus rapidly pin-pointing solutions to malfunctions and also spotting potential sources of failure. The system acts as an expert on the shop-floor, talking the same language as the equipment, eliminating communication problems and delays in problem-solving, and saving expenses by the travelling field service engineers. This facility can also be extended to other countries by using a satellite communications link.

Electronics from the most sophisticated computer to the circuitry in a simple drive or a sensor have introduced versatility to manufacturing technology. Advances in electronics are expected to increase cost-effective production.

Electronic control, for example, will change the concept of a stand-alone machine and allow the machine to function as part of a system. The machine cycle will be altered either by remote command or by conditions sensed on the machine, such as a process variable or the position of a surface.

Machine performance will be monitored by electronic sensing devices. The information thus obtained will be useful for diagnostic analysis as well as for management decision-making on machine utilization.

To be useful, however, machine feedback will have to be communicated to someone besides the machine operator, and so control at the machine will involve the additional responsibility of a communications terminal. Electronic technology, such as the data transmission and line protocol, will help create an information flow that will make the machine an integral part of the manufacturing system.

Knowledge of software design and system integration will then become necessary in manufacturing plants. A good software designer, for example, will be able to maximize hardware utility and create flexible systems that others can repair and alter. A systems integrator should understand and determine how all the elements work in relation to each other.

At present there is no general consensus on what the responsibilities of the systems integrator should be, or whether it is even a necessary function. Its value will have to be determined, however, before complex systems can be developed and implemented.

Producing NC tapes through voice command is already a reality. A speed processor that converts a programmer's analog voice signal into the digital language of the computer permits part programs to be generated by vocalizing the data.

A system introduced in 1979 incorporates large custom-integrated circuits and the latest techniques in electronics such as high-speed microprocessors and bubble memories. It is capable of operating a robot, thus eliminating the need for a separate NC system for the robot, and it uses only about half the parts of the system it replaces. Another system which will reduce the number of parts still further through the use of very large-scale integrated circuits is being developed.

Soon microprocessors will start replacing wheels, gears and mechanical relays in a variety of control applications, because it is more efficient to move electrons around than mechanical parts.

Machine design

More sophistication is now built into machine tools to machine a part in a single set-up. Simple two-axis lathes have given way to four-axis lathes and turning centres. Similarly, four-axis and five-axis machining centres are replacing three-axis milling machines. Automatic tool changers with large tool magazines and chains to store up to 70 tools or more are a standard feature of the modern machining centre. The contouring table is now used as the fourteenth axis of a machining centre instead of an indexing table. Pallets are used to reduce workpiece set-up time.

Turret lathes are now the most common NC machines. The present trend is to have a single combination turret which can hold tools for both internal and external diameter turning. However, much care is required in planning the tool layout and to ensure that there is no interference between the tools and the chuck while machining the internal and external diameters. Production centres are available on which all basic machining operations like turning, boring, drilling and milling can be done in one set-up. A spindle can also be indexed and moved up and down to do many milling jobs.

Control systems are now being built as an integral part of the machine tool itself. Builders of CNC systems now offer control systems in the form of different modules, so that a machine-tool builder can buy only the modules required and accommodate them in their machine structure. By this modular concept, it is possible to eliminate bulky stand-alone enclosures, to amplify machine electrics and to avoid having long interface cables. This concept has cut down the cost of NC machines.

IX. Non-traditional machining methods

The increasing use of difficult-to-machine materials, such as hastelloy, Nitralloy, vespalloy, nimonics, carbides, stainless steels and heat-resisting steels in the aerospace, nuclear and communications engineering industries and for the manufacture of military hardware has spurred the development of non-traditional machining methods. Conventional machining processes have become inadequate to machine these materials according to rigid quality standards and economic production requirements. In addition, the machining of such materials into complex shapes is difficult, time-consuming and sometimes impossible.

Non-traditional machining techniques have overcome some of the machining difficulties. The non-traditional methods are classified according to the nature of the energy employed in machining, namely thermal and electrothermal, chemical and electrochemical and mechanical.

In the thermal and electrothermal methods, the thermal energy is employed to melt and vapourize tiny bits of work materials by concentrating the heat energy on a small area of the workpiece. By continued repetition of this process, the required shape is machined. These methods include electron-discharge machining (EDM), laser-beam machining, plasma-arc machining (PAM), electron-beam machining (EBM) and ion-beam machining (IBM).

The chemical and electrochemical machining methods involve a controlled itching or anodic dissolution of the workpiece material in contact with a chemical solution. These processes include chemical machining (milling and blanking), electrochemical grinding, honing and deburring.

In the mechanical methods of non-traditional machining, material is primarily removed by a mechanical erosion of the workpiece material. The mechanical methods include ultrasonic machining (USM), abrasive-jet machining (AJM) and water-jet machining (WJM).

Non-traditional machining processes are applied to all metals and alloys. This is in contrast to the conventional machining processes which vary in their application depending upon the strength and the hardness of the material. Among the non-traditional processes themselves, there is a good degree of variation in respect of their application on different work materials.

The application of non-traditional machining processes is also influenced by the shape and size of the workpiece to be produced, including holes, through holes and cavities, pocketing, surfacing, through cutting etc.

The other parameters of comparison between conventional and non-traditional machining, on the one hand, and among the non-traditional machining methods, on the other, are, with regard to material removal rates, the power consumed and the accuracy and surface finish that can be achieved.

Non-traditional machining processes cannot at present completely replace conventional machining methods of metalworking. They also do not offer the best solution for all applications. They should only be viewed as complementing conventional metalworking methods. The suitability of any of the non-traditional machining processes for a specific application should be judged from the standpoint of increased reliability of the process, better assurance of quality and the ability to machine workpieces which cannot be machined easily by any conventional methods.

Electron discharge

The EDM process involves a controlled erosion of electrically conductive materials by the initiation of a rapid and repetitive spark discharge between the electrode tool (usually a cathode) and work piece (anode) separated by a small gap of about 0.01 to 0.50 mm known as the spark gap. This spark gap is either flooded by or immersed in a dielectric fluid. The spark discharge is produced by the controlled pulsing of direct current between the workpiece and tool. The dielectric fluid in the spark gap is ionized under the pulsed application of the direct current, thus enabling a spark discharge to pass between the tools and the workpiece. Each spark produces enough heat to melt and vaporize a tiny volume of the workpiece material leaving a small crater on its surface. The energy contained in each spark is discrete and can be controlled so that the material removal rate, surface finish and tolerance can be predicted.

EDM equipment manufacturers offer a variety of machine tools, ranging from small machines to large units resembling heavy presses. The chief influencing factors on the design of EDM equipment are the number of components to be produced in one set-up, accuracy required, size of workpiece, size of electrode and depth and orientation of cavity.

Nearly all EDM machines consist of a base, a column and a head. The column is fixed to the base and supports the head. A co-ordinate table which supports the workpieces is usually mounted on the base. Machines with fixed work-tables are also available. A dielectric tank is constructed around the table and provided with an automatic level controller. It is also equipped with safety devices to shut down operation in case the temperature exceeds a certain limit.

Workpieces can be mounted on the machine table (fixed or co-ordinate types) with suitable work-holding fixtures. However, it should be ensured that there is a good circulation and flushing of the dielectric fluid. It is sometimes convenient to hold the workpieces on suction and injection pots with a built-in arrangement for circulation of dielectric fluid. Manufacturers of EDM equipment supply suction and injection pots and rotary tables providing for circulation of the dielectric fluid through the workpieces. EDM is well suited to make intricate dies, and a heavy-spindle EDM machine has been developed for the manufacture of fine dies mainly needed in the watch and instrument industry, with CNC control.

Wire-cut EDM is a comparatively new concept. A small-diameter wire is used as the electrode to produce intricate shapes in steel plates. The table of the machine is provided with numerical control to perform complex motions required by the workpiece. The speed rate in this process is constant, but should any abnormal conditions in the spark gap occur, the machine table stops until favourable conditions in the spark gap are restored. The travelling-wire EDM machines are extremely well suited for the production of extrusion dies, blanking dies and punches, press tools and sintered compacting dies.

Impediments to easy EDM machining may be summed up by the following three main types of problem: poor flushing in tight quarters; slow-cutting at fine finish settings; and preferential wear on the leading edge of the electrode, where it is usually least tolerable. In the final stages of finishing a complex cavity, it is not uncommon for all three to occur at once.

Of special interest to EDM users is the development of the electro-orbiting attachment, which promises to solve all three of the above-mentioned problems. Simply by stirring the electrode around in the cut, the device facilitates flushing, which improves cutting rates at the low current settings used to produce the finest finishes. An added touch of sophistication, an orbit that expands as the electrode plunges into the cut, distributes wear between the leading edge and the sides of the electrode. The development of orbiters has been an elaboration of these basic ideas. Highly sophisticated orbiters are currently available, manufactured in Japan, Sweden, Switzerland and the United States, all having electronic CNC systems. Orbiters are made either as an attachment to the vertical ram or as a table-mounted device that orbits the workpiece. Long electrode life, better flushing and finer finishes are among the claims made by the EDM orbiter manufacturers.

Electrochemical process

Electrochemical machining (ECM) is the controlled removal of metal by anodic dissolution in an electrolytic medium in which the workpiece is the anode and the tool the cathode. Two electrodes are placed close together with a gap of about 0.5 mm and immersed in an electrolyte which is normally a solution of sodium chloride (common salt).

Under ideal conditions and with properly designed tooling, ECM is capable of holding a tolerance of the order of ± 0.02 mm or even less. Repeatability of the ECM process is also very good. This is largely due to the fact that the tool wear is virtually non-existent. On a good machine, tolerance can be maintained on a production basis in the region of ± 0.02-0.04 mm.

Tooling design is the key to successful application of ECM. There are two aspects of the design of ECM tooling. The first is the determination of the tool size, and the second is the appropriate machining conditions necessary to produce the required shape.

The ECM technique poses no significant threat to conventional machining because the economics of application of ECM are justified only in specialized areas where conventional machining is not feasible. One of the main applications of ECM is machining difficult-to-machine materials and complex-shaped parts in the aerospace industry.

Electrochemical drilling is extensively used for drilling the cooling holes in gas turbine blades. The chief advantage of this process is that the burr-free holes can be made in thin workpieces. Deburring by the electrochemical method is slightly different from ECM, since the tool and the workpiece are placed in a fixed relative position with a gap of 0.1-1.0 mm. The tool is positioned near the base of the burr. Specially built machines for deburring are now available on the market.

In electrochemical grinding, a metal-bonded grinding wheel impregnated with diamond abrasive is the cathode and the workpiece the anode, as in ECM. The wheel is submerged in the electrolyte, which is usually an aqueous solution of sodium nitride, so that it is the wheel rather than the work that is wetted. In fact, abrasive grains on the suface of the wheel act as paddles that pick up the electrolyte and cause pressure to build up at the work area.

Although the basic operating principles of electrochemical grinding and ECM are the same, there are differences in application and methods of functioning. Whereas in ECM the tool never touches the workpiece, in electrochemical grinding the metal-bonded grinding wheel lightly touches the workpiece. The metal removal is largely brought about by electrochemical action and only 10 per cent of the volume of material is removed by abrasive action of the wheel. The process therefore is ideal for grinding carbides, carbide tools and work of complex shapes.

Chemical process

Chemical machining (CHM) is the stock removal process for the production of desired shapes and dimensions through selective or overall removal of material by controlled chemical attack with acids or alkalies. Areas from which material is not to be removed are protected from attack by masking. Nearly all materials, from metals to ceramics, can be chemically machined. There are two types of chemical machining, namely chemical blanking, which is used for cutting or stamping parts from thin sheet materials, and chemical contour-machining or chemical milling for selective or overall metal removal from a thick material. The CHM process is employed where blanking or metal removal is difficult or impractical by conventional machining processes because of material hardness, brittleness, size of part, complexity of shape or thinness of the part.

Chemical blanking is used chiefly on thin sheets and foils. In most applications, photo-resist (photo-sensitive masking) is used to define the location on the workpiece at which the material is to be etched.

One of the major applications of chemical blanking is in the manufacture of burr-free, intricate stampings. Typical chemically blanked parts include laminations for electric motors and magnetic recording heads, slotted spring discs, gaskets, meter parts, camera parts, fine screens, and helicopter vent-screens.

Chemical milling is primarily used to machine preformed aerospace parts to obtain a maximum strength-to-weight ratio. Employing this method, aircraft wings and fuselage sections are made with integral stiffeners of optimum cross-section throughout their entire length. Chemical etching is used to engrave highly intricate details on nearly any metal and to produce printed circuit boards.

Ultrasonic process

Ultrasonic machining (USM) is a process in which a cutting tool oscillates at high frequency, about 20,000 Hz, in an abrasive slurry. The tool has the same shape as the cavity to be machined. The high-speed oscillations of the tool drive the abrasive grain across a small gap of about 0.02-0.10 mm against the workpiece. The impact of the abrasive is solely responsible for the material removal. The method is chiefly employed to machine hard and brittle materials, which are either electrically conducting or non-conducting.

USM is particularly useful in micro-drilling holes of up to 0.1 mm. The size is limited only by the strength of the tool, the size of the abrasive particles and the methods adopted for circulating the abrasive slurry. A tool as large as 85 mm in diameter is used on a machine with a capacity of 2.5 kW. Larger holes can also be cut by trepanning. The depth of hole obtained is limited by the tool wear, slenderness ratio of the tool and the ease of supplying the abrasive slurry to the working gap. Depth-to-diameter ratios of up to 10 are quite common.

Abrasive jet

Abrasive-jet machining (AJM) is the removal of material from a workpiece by the application of a high-speed stream of abrasive particles carried in a gas medium from a nozzle. The AJM process is much finer and the process parameters and the cutting action are carefully controlled.

The process is used chiefly to cut intricate shapes in hard and brittle materials which are sensitive to heat and have a tendency to chip easily. It is also used for deburring and cleaning operations. AJM is inherently free from chatter and vibration problems. The cutting action is cool because the carrier gas serves as a coolant.

Aluminium oxide is the preferred abrasive in the majority of applications. Silicon carbide is also used in certain cases. The abrasive particle size is a dominant factor in AJM, and the best results have been obtained with a particle size in the range of 10-15 mm. Dolomite (calcium magnesium carbonate) of 200 grit size has been found a suitable abrasive for light cleaning and etching. Sodium bicarbonate is used for extra-fine cleaning operations. Glass beads of different diameters, 0.3 to 0.6 mm, are used for light polishing and deburring.

The major field of application of the AJM process is in the machining of essential brittle and heat-sensitive materials such as glass, quartz, sapphire, semiconductor materials, mica and ceramics. The AJM process is used in drilling holes, cutting slots, cleaning hard surfaces, deburring, scribing, grooving, polishing and radiusing. Delicate cleaning, such as removal of smudges from antique documents, is also possible with AJM.

Laser beam

A laser is a device that converts electrical energy into a narrow beam of light energy. Laser-beam machining (LBM) is a machining process in which the work material is melted and vaporized by the laser beam. The heat produced in small areas where the laser beam strikes can melt almost any known material. A very wide range of materials can be processed by means of lasers. Complex shapes can be cut with extreme accuracy and reproducibility. Single-batch or production quantities may be programmed direct from component drawings, thus eliminating the delays and costs associated with tooling up.

The ability of the laser to cut material is virtually unaffected by properties such as hardness, brittleness, electrical and thermal conductivity, heat resistance, magnetism, flammability etc. Extremely hard nickel cobalt alloys cut as readily as mild steel, and ceramics, timber, rubber, leather, asbestos and plastics can all be cut with lasers.

Laser-cut components feature an excellent surface finish and normally no rework is necessary. This results from the highly localized thermal input. Thermally insulating materials exhibit no heat effect at all adjacent to the cut, and metallurgical disturbance to sheet metal is comparable to that occurring at a sheared edge. Acrylics cut by laser feature a polished appearance, while timber has a darkened edge which enhances the grain.

As the cut is only 0.1 to 0.22 mm, the intricacy of shape does not fundamentally limit this process, and often complex shaped components which would defy manufacture by conventional means can be produced.

The costs and delays associated with press-tooling are eliminated by laser cutting. Savings may therefore be made when relatively low batch production or prototype work is involved. Slots, holes, cut-outs and contoured shapes may be achieved without reliance on existing tooling.

The quality of plastic, metal or wooden lettering manufactured for the sign industry by this process is unsurpassed. Laser cutting of plywood has for some years been a reality in the packaging industry.

The laser beam is used in metrology. Spherical test parts for diamond-turning optical machines used in the manufacture of critical optical surfaces are fragile. A non-contact laser sweep-gauge prevents surface damage while testing diamond-turned spherical contours. Laser beams are also used for testing the alignment of slideways and straightness of parts to a very high degree of accuracy. Laser interferometers are commonly used for this purpose in the machine-tool industry.

The laser can be used for cutting as well as for drilling. The material removal rate in LBM is comparatively low, of the order of 4,000 m^3 per hour. The holes drilled by the laser are not round. In order to overcome this difficulty, the workpiece is rotated as the hole is laser-drilled. Other problems associated with laser drilling are the taper and the recast structure in the heat-affected zone. Taper of 0.5 mm per 10 mm drilled depth can be sometimes expected. In order to achieve the best possible results in drilling, the material must be located within a tolerance of ± 0.2 mm of the focal point. Therefore, when machining thicker materials, the focal point has to be moved down the hole as it is drilled.

LBM is at present suitable only in exceptional cases, for example machining very small holes and cutting complex profiles in thin hard materials like ceramics. It is also used in partial cutting or engraving. Although LBM is not a mass material removal process, because of its rapid repetitive machining characteristics and ease of control it may be used in mass micromachining production. Other applications include sheet metal trimming, blanking and resistor trimming.

Electron beam

Electron-beam machining is a metal removal process in which a pulsating stream of high-speed electrons produced by a generator is focused by electrostatic and electromagnetic fields so as to concentrate the energy on a very small area of work. As the electrons impinge on the work with velocities exceeding one half the speed of light, their kinetic energy is transformed into thermal energy and they vaporize the material locally. The process takes place in a vacuum chamber (10^{-5} to 10^{-6} mm of mercury) to prevent scattering of electrons by collision with gas molecules.

While electron beams are beginning to be used extensively for welding, their machining applications are still restricted. EBM is generally limited to drilling extremely small holes and cutting narrow slots or contours in thin material to close tolerances.

The electron beam has gained a very wide application in welding. Since the electron beam can be focused to an extremely small diameter (0.25 mm and lower), the melting and fusion can be confined to a thin slice of workpiece. The main attraction of EB welding is its ability to make clean deep welds with very little heating in the surrounding metal.

Electron-beam welding has proved highly useful in repair work. Defects in castings, for example, can be corrected in the final stages of machining without the risk of distorting the machined casting. Another attractive feature of EB welding is that dissimilar hard materials can be welded together, such as carbon steels to stainless steels, and ferrous to non-ferrous metals.

Plasma arc

Plasma-arc machining is a material-removal process in which the material is removed by directing a high-velocity jet of high-temperature (11,000°-30,000° C) ionized gas on the workpiece. The relatively narrow plasma jet melts the workpiece material in its path. Because of the high temperatures involved, the process can be used on almost all materials, including those which are resistant to oxy-fuel gas-cutting.

The obtainable cutting rates in PAM are 250-1,700 mm/min, depending upon the thickness and material of the workpiece. For example, a 25-mm-thick aluminium plate can be cut at a speed of 750 mm/min, while a 6-mm carbon-steel sheet can be cut at 4,000 mm/min. The use of water injection can increase the cutting rate in carbon steel to 6,000 mm/min for a 5-mm-thick plate.

PAM is chiefly used to cut stainless steels and aluminium alloys. It is preferred to oxy-fuel cutting because it produces comparatively smoother cuts and is free from contamination.

Ion beam

Ion-beam machining or etching is generally classified among the thermo-electric processes along with electrobeam, laser-beam, plasma-arc and electrical-discharge machining. Unlike most of these techniques, however, IBM does not depend on the heating of materials to the point of evaporation. Instead, it removes material by sputtering of ions. This sputter etching mechanism is basically simple. A stream of ions bombards the suface of the target material. Each bombarding ion dislodges surface atoms by transferring kinetic energy from itself to the atoms.

The use of IBM to remove material has found only limited application. It is applied mostly in micromachining (etching) of electronic components such as computer memories, figuring optical surfaces and the precision fabrication of fine wire dies in refractory materials. The IBM process is also used for the disposition of a thin film of material, particularly in electronics industries.

Water jet

Cutting brittle, soft or sticky materials, fabrics, felt, rubber or honeycomb structures or readily inflammable materials is often possible only with considerable outlay or not possible at all using conventional cutting methods. A water jet accelerated to over twice the speed of sound opens entirely new possibilities for cutting such materials.

The jet-cutter system has been successfully used in Europe and the United States, particularly in the aircraft industry, for the following materials: leather, plastics, rubber, paper cardboard, corrugated cardboard, plywood, mineral and wood fibreboards, textiles, insulating materials, metal foils, glass and carbon fibre, reinforced plastics, ceramics and asbestos.

The high pressure jet-cutter process provides a number of significant advantages over traditional methods. The water is completely dustless as the water jet binds the material being cut. Material loss is minimized, the width of cut being less than 1 mm and in some instances as small as 0.1 mm, as in the case of corrugated cardboard.

In some production processes, high-pressure water-cutting has advantages over the laser-beam method because no heat is developed during the cutting operation. This eliminates the danger of fire or explosion and the problem of heat-induced damage to materials.

In addition, high-pressure water jet systems enable the cutting process to be guided at close tolerances in all three planes, with no formation of edges on the material and no development of side pressure when cutting curves.

The jet-cutter comprises a pump unit and a cutting unit. The pump unit develops a high-pressure water jet that is carried through a tube to the cutting station via an accumulator. The pressure may be varied from 1,000 to 4,000 bar, which enables the operator to select the optimum rate for cutting a particular material. The cutting involves a table compatible with the production process, to suit the width and type of material, and a nozzle fitted with a diamond orifice jet of extremely small aperture. The water medium does not require any purification and can be drawn directly from the main supply. It is also possible to reclaim the used water. The velocity of the jet causes a natural vacuum at the point of cutting. The cutting dust is extracted and removed with waste water. As cutting forces can only occur in the direction of the jet, it is possible to execute complicated shapes without deforming the material. As a result, cutting soft elastic or sticky materials is just as easy as cutting fabrics or honeycomb structures of the most simple shape.

The water jet cuts without generating heat. This is important, for example, in the case of synthetic fibre fabrics when the structure of the fabrics may not be modified at the point of cut. The absence of heat and the absence of any form of sparking is extremely important when working with readily inflammable materials.

The quality of cutting is excellent, and as a result of the minimal slit width hardly any material is lost. The cut is generally without any burr formation on the back of the workpiece, thus eliminating the need for deburring.

Automatic tracking accessories enhance the jet cutting capabilities. One example is the unit for cutting car upholstery leather to required patterns. This unit can at present cut up to eight layers of leather simultaneously at a speed of 10 m/min.

A number of hot spots in aeroplanes require high-temperature-resistant materials for items such as washers, baffles, insulators and engine brackets. An aircraft manufacturer in the United States which made many of these parts from asbestos could not comply with government safety regulations regarding the use of that material. As a result, the company installed a cutting system that uses a high-pressure stream of water, a jet-cutter, which allowed production to continue. The localized vacuum system created in the cutting area reduced dust emission to well within the regulations. Besides the environmental benefits, the company achieved a number of manufacturing improvements, including savings in labour and materials, a better quality of cut and increased capacity for multi-shape cutting.

X. Metal-forming machine tools

Down to the third quarter of the twentieth century, metal-cutting has dominated over metal-forming in the metalworking industries. The share of production of metal-forming machines as a percentage of world machine-tool production was barely 10 per cent during the 1940s and 1950s. However, the present concern to conserve materials, the rising cost of energy and the need to explore new routes of production have given metal-forming considerable significance. Metal-forming machines such as mechanical and hydraulic presses (single-column open-back inclinable types, heavy-duty, straight and double-column types and forged types), press brakes, shears and guillotine machines represented more than 25 per cent of total world machine-tool production during 1979. There are signs that this share will rise to 30-33 per cent by the end of the century.

The plastic deformation of metals takes place in two ways: by bulk deformation and by incremental deformation. Until 1960 metal-forming machines, mainly conventional forges and presses, were built to accommodate workpieces formed by the bulk deformation process. However, incremental deformation processes are currently finding wider application. These are to a certain extent non-traditional forming methods. They include helical rolling, ring rolling, spinning and flow-forming. These non-traditional methods and other high-speed forming techniques such as fine blanking and NC punching powder metallurgy are partly responsible for a discernible shift from cutting to forming.

Forming methods

High-speed forming

A great deal of interest is now being shown in various methods of forming metal at very high speeds. Considerable development efforts on a wide variety of processes have resulted in some high-speed forming techniques which have become important in industry by replacing conventional methods.

The development of new high-strength alloys combined with the need to produce parts of more complicated form has increased the problems associated with forming on conventional presses. Many manufacturers would prefer to form parts rather than use the often wasteful cutting methods, but the high capital cost of conventional forming machines, dies and tooling has precluded their use for all but mass production purposes. The possibility of cheaper equipment has thus stimulated interest in high-speed methods.

The main customers for the heavy-duty high-speed presses are the automobile industry and agricultural machinery manufacturers, including lawn and garden equipment manufacturers. In highly sophisticated sectors, the aerospace industry will soon manufacture many of its sheet metal components with the help of computers. Super-plastic forming and diffusion bonding are some of the metal-forming manufacturing processes in the aerospace industry. Titanium at a temperature of 900° to 950° C makes a workpiece so pliable that it can be formed into complex shapes at low pressures, usually 10 bar. At 140 bar bonding is possible. Although the hot isostatic press is still at the laboratory research stage, it has a greater potentiality and could be designed for the production of several tonnes of aerospace components per day. It has been recognized that the process of forming by means of a hot isostatic press is a fast-growing technology with an increasing potential in both the aerospace and non-aerospace fields.

Normally, a press brake is designed with an allowance for deflection under load. Engineers frequently confronted by press-brake application in which bends are required at loads less than or greater than normal have come up with a design that permits precise bends to be made under either of these conditions. It eliminates the need for dies shimming, a lengthy and troublesome procedure.

Development engineers in the United States have designed and built a stamped-steel automotive exhaust manifold that weighs 60 per cent less than its cast-iron counterpart. Weight reduction, hence energy-saving, was the main objective, but faster engine warm-up and noise reduction are additional benefits. Many automobile manufacturers are closely following developments in stamped engine components.

Internal combustion engines will never be stamped out like wheel covers, but in eight to ten years from now most of their components could be products of press-working shops. Moreover, the exhaust manifolds and piping ahead of the catalytic converter could consist of stampings even sooner.

The automobile industry uses a great many presses which are continuously being improved in design. Their greater capacity (1,500-5,000 tonnes), suitable also for deep-draw metal-forming operations, give greater production and higher quality of pressed components such as bodies, doors, panels and bumper stamping for cars and trucks built with advanced designs of safety accessories. However, more sophisticated application of forming presses is seen in the aircraft, space and armament industries. In the production of military hardware, new technologies are being used in the assembly line of transfer presses to produce cartridge cases of higher calibres.

Cold-forging

The cold-forging of steel has attracted attention as a method of improving the utilization of material in the manufacture of engineering components. Although the process is still not regarded as a means of producing components difficult to make by other methods, cold-forging is now receiving much more attention as a result of the rising cost of material and the low recovery price of swarf. In cold-forging, usually the starting billet is progressively changed in shape until the final form is achieved. This involves different deformation processes combined in an arbitrary sequence. The basic sub-processes involved are extrusion, upsetting or heading, drawing, ironing, swaging, expanding, threading and form-rolling. Some of these are briefly described below.

Extrusion

Extrusion is a particularly versatile manufacturing process in which the cross-sectional area of the billet is reduced during deformation. Symmetrical products which are variants of the basic shapes like rods, tubes and cans are readily made. Material may be deformed at one end or both ends of a billet, simultaneously or sequentially. Depending on the conditions, material may flow preferentially in one direction, and this flow may have to be stopped after that part of the desired shape has been achieved, so that material may flow in the less-preferred direction to complete other parts of the desired shape. Flow is rarely restricted in all directions because billet volume (weight) may vary and excess volume may result in unacceptably high tooling stresses or even tool failure.

Upsetting and heading

In upsetting, a billet is subjected to compressive deformation, generally in the direction of its axis, to enlarge the cross-section area over a part or the whole of its length. In heading, the enlargement is confined to one end of the billet and is basic to the production of fasteners. A punch moving along with the die axis upsets that part of the billet which protrudes from the die into a form determined by the geometry of the mouth and the punch head. In general, lengths up to about 2.5 billet diameters can be upset without bending in a single blow, up to about 4.5 billet diameters in two blows and up to 6.5 billet diameters if a sliding punch supports a part of the billet during upsetting. Cracking is avoided if the maximum upset diameter does not exceed 2.5 billet diameters in free upsetting or 3-4 billet diameters in heading of mild steel.

Ironing

In ironing, the product, solid or tubular, is pushed through a die and its external diameter is reduced. Because the product is not wholly constrained by the tooling, the reduction in diameter which can be achieved is limited by the onset of buckling in the solid product, tearing of the base in the tubular product and by the upsetting of the product material immediately ahead of the die. The process has been extensively used to produce stepped shafts used in electric motors and tubular components of large length-diameter ratios.

Press equipment and tooling

Each operation involving a change of shape of billet material requires appropriate tooling, which may be set up on a single press in batches or in separate presses with the components produced on an in-line basis. If demand exists, a series of presses may be linked for automatic feeding and transfer along the line. Alternatively, all the forging operations may be undertaken in a single tool containing the necessary stations mounted in a single press of sufficient capacity to perform all operations in a single working stroke. In this case, a transfer feed is provided to convey the partly formed billet from station to station. Where small components or fastener type products are required in very large numbers, these can be formed in multi-station, progressive cold-heading machines which perform the above functions at a very high speed.

The working parts of cold-forging tools comprise a punch or punch-mandrel, a container consisting of a shaped insert and one or more pre-stressing rings and an ejector. Much more is now known of the stress distribution in items of tooling following extensive experimental research and analytical studies. This has considerably aided tool design and provided a better basis for assessment of tool life.

At present the manufacture of tooling items by the conventional machining of bar material produced by powder metallurgy shows greater promise than the manufacture of individual tooling items by the direct compaction and sintering of powders, although the latter route is also being pursued.

Fine-blanking presses

A part made by the blanking process is essentially a finished part. A triple-action sturdily built press exerts forces on equally sturdy specially designed tooling and, with precision unattainable on conventional presses, shears a part with smooth-edge contours from stock as thick as 20 mm. The part may be pierced, counter sunk, bent or coined. It may become flatter. Offsets may be formed in it without loss of dimensional accuracy. Most important, many if not all secondary operations that may have been required to produce it by previous conventional methods are bypassed. The real advantage of fine blanking is the time and money it saves.

The Swiss discovered these compelling advantages in the early 1940s, when they succeeded in stamping sheet metal into office machine parts with tooling that firmly held the stock around the punch perimeter and had a very small punch-to-die clearance, much less than in tools for conventional stampings. Edges were sheared smooth throughout full stock thickness, and removal of small burrs on part edges was a very minor operation.

The fine-blanking process has gained rapid acceptance in Europe, and not only in the office equipment field. Its cost- and energy-saving capabilities were strong incentives in Europe, as they are now for most of the world.

Fine-blanking works because punch-to-die clearance is very small compared with that normally used in conventional press-working, and the forces exerted by sturdy triple-action presses produce a blanking action that amounts to cold extrusion. Tooling is normally designed so that the punch-to-die clearance is about 1 per cent stock thickness or about 0.5 per cent on each side of the part. For some of the heavier fine-blanking operations, involving, for example, parts that are 10-12 mm thick, the clearance can be as small as 0.0004 mm. An interference fit (negative clearance) is never used.

By means of fine blanking, press builders and tool makers have produced parts with precise contours and flatness. The process will not usually flatten distorted stock, except in areas that are coined or if the counterpunch is shaped properly.

Burrs produced by fine-blanking are small and easily removed by such methods as belt-sanding, disk-grinding or tumbling. Sanding is generally used for large, heavy and flat parts, especially those that are long and narrow. Such parts must not have any bends or projections on the burr side. Small fine-blanked parts, either flat or three-dimensional, are usually deburred in tumbling equipment.

Semi-piercing, in which stock is not punched through, is one of the fine-blanking practices. Coining is a variation of semi-piercing that is also prevalent in fine-blanking work.

Tolerances

The dimensional accuracy of a fine-blanked part depends on the quality of tooling and the thickness, strength and quality of the stock, as well as on the size and configuration of the part. In general, tolerances could be very close to ± 0.0008 mm for external dimensions and internal holes and flatness, and ± 0.0004 mm per 25 mm for coined parts. Closer tolerances are possible under special conditions. The figures given are for steel, while tolerances are somewhat larger for aluminium or brass. Tolerances in conventional press-working by contrast are three to four times larger.

The operation of fine-blanking presses involves three movements, the stroke, length and force of which can be separately controlled or preset. The presses are built to withstand the substantial forces—many of them diagonal—inherent in the process and to support their tooling in precise alignment.

The larger presses are completely hydraulic, but the main blanking action in a line of presses in the smaller tonnage range from 25 to 350 tonnes is powered primarily by mechanical means.

Fine-blanking tools are usually of the single-stage compound type, although progressive tooling is required for certain jobs. Providing guidance and positioning of the main and inner form punches, the tooling is more rigid than compound tools for conventional press-working because the forces brought to bear on the workpiece are higher.

Overall clearance between the punch and the die in fine blanking is another point of difference between fine-blanking and conventional press-working. In the latter, it can be as large as 10 per cent of the material thickness, compared to 1 per cent in fine-blanking. And since a die opening and punch sides in fine-blanking tools are not tapered, but are straight and remain so for their full life, part uniformity can be maintained. In fine-blanking, the press is an accessory to the tooling, which is the key element in the process of producing a clean cut through the entire thickness of stock, with no distortion except for a slight turnover at the tool entry edge and a small, easily removed burr at the exit edge.

Innovations in punching by numerical control

Flat metal was first punched using NC in 1955. This innovation had far-reaching consequences, leading to major changes in machinery for producing holes and contoured cuts in sheet metal plates and structural steel members. It also affected the operation of companies that bought such equipment, boosting their manufacturing efficiency.

Everyone, including manufacturers of controls, tooling and auxiliaries, benefited from the adoption of NC by the metal-punching industry, just as builders and users of metal-cutting machinery have reaped the fruits of NC since its introduction in developed countries. The widespread acceptance of this type of punch press control stimulated new press designs and improvement on earlier designs. In recent years, it has led to hybrid machines that not only punch but also cut by plasma arc or laser beam and even perform such functions as milling.

Computerized numerical control (CNC) entered the metal-punching field in 197' and provided even greater benefits. CNC drastically reduces NC programming time and effort and production cycles. It manipulates the punch-controlling numbers electronically, performing such tasks as optimization of punching instructions and other such number-juggling that an eight-track punched tape could never do. Although CNC is more expensive than NC, most punch-press manufacturers now offer it as a standard feature. If it is optional, most customers usually take it and most users with just an NC punch press eventually buy it.

NC or CNC punching machinery differs from conventional mechanical, hydraulic or pneumatic presses in that the workpiece is positioned under a basic punch that is gripped by a turret bushing or an adapter in a single-station type of press. Die sets of the type used in conventional press-working operations, often complex and costly, are not used. Workpieces can be the size of a small barn door, far larger than the largest now accommodated by open-back-inclinable and straight-side presses. Four-column platen presses with unitized tooling might handle large expanses of sheet metal, but for most jobs the set-up time and cost would make them costly to operate.

The strongest advantage of NC punching equipment is the adaptability of its workpiece positioning mechanism to that kind of control. Moreover, the beam lines that fabricate structural shapes and flats use NC for X-axis motion and punch actuation, and some use it for tool-shifting as well.

None of the beam lines uses it for tool changing, however. For such machinery, NC can govern handling systems beyond the punching stations, increasing efficiency because the workpieces are often long and heavy.

The third category of NC punch press designed for punching, and frequently for drilling, long lengths of thick plates uses NC to govern not only the X-axis motion but also the Y-axis positioning of the tooling.

On most sheet metal and plate machines, however, NC not only governs the X- and Y-axis positioning of the workpiece and actuation of the punch, but also selects the correct tooling at the right moment in the punching programme on presses with automatic tool changers. These machines represent a new generation of metal-working machines.

All punching machines, including the NC models, are composed of the following basic elements: a punching mechanism, a workpiece positioner and a structure on which they are mounted and operate. Beyond this fundamental definition, however, almost all makes and models differ from one to another.

Powder metal technology

The powder metal (PM) method of forming finished to almost-finished components is gaining popularity in the manufacturing industry. More and more parts in the instrument, aerospace and automotive industries are exploiting this technique. PM carbide tools, high-speed cutting tools, low-cost PM brass and liquid phase sintering are some of its applications. Test results on aluminium PM parts compacted by means of shock waves have proved successful, and parts which could not be made in one piece with conventional PM compacting techniques are being injection-moulded. These and other innovative techniques in PM and injection moulding could be employed to produce many difficult-to-machine complex parts.

Non-traditional forming processes

Instead of the brute force used in bulk deformation techniques, the incremental deformation techniques employ force purposefully and skilfully. These non-traditional forming presses are helical rolling, ring rolling, spinning, flow-forming and rotary forging. Of these processes, rotary forging, spinning and flow-forming are now the most popular.

Rotary forging

Rotary forging involves two opposed rotating, circular, contoured dies aligned on a single axis. One of the dies is prevented from making an axial movement and is offset at a fixed angle in relation to the other die which can move easily. A circular billet compressed between the two dies can be indented over a limited area by means of an axial force. Subsequent rotation of the two dies in conjunction with continued compression causes the plastic deformation produced by the progressive indentation through the billet. Once the workpiece achieves the required shape, compression ceases and the axially moving die is retracted. The resulting component reflects the shape of the dies, and the deformation mode produces a multidirectional grain-flow-structure which is not produced by conventional processes.

A recent variation of this technique, with a vertical axis, is known as rocking-die forging. It consists in its basic form of a wide-angled conical upper platen, located with its apex inverted in the die holder. The die holder has its longitudinal axis offset to the vertical axis by a small angle. In turn, the die holder is seated in a bearing and is usually constrained only to rock about the vertical axis.

By using this process in practice, a wide variety of component shapes have been forged, the complexity of shapes being determined by the configurations of both the dies. The components that can be manufactured by this process are mostly disc-type, such as clutch discs, pulley sheaves, gear-wheel blanks and inertia wheels. The job thickness in this process can be as low as 6 mm to as high as 200 mm, and diameters may range from 25 mm to more than 1,000 mm.

The increasing emphasis on noise limitation in the manufacturing field has led to the development of various types of noiseless riveting processes for assembly operations. Impact riveting has the inherent disadvantages of shock and vibrations leading to unpleasant noise levels depending on the size, hardness and the ratio of the spread to the diameter of the rivet. In impact riveting, the rivet head is deformed beyond its elastic limit, destroying its molecular structure. The spring-back action after impact often leads to loose assemblies.

Rotary cold-forming methods of riveting, because of the continuous and gradual spreading of the material, are practically noise-free and are credited with a number of advantages. Rotary cold-forming methods may be classified as roller-spin riveting, orbital riveting and radial riveting. Of these, orbital and radial riveting methods are similar to cold-form rotary forging, except that the shapes and the forces involved are comparatively small.

Roller-spin riveting

The roller-spin-riveting head consists of two split rollers mounted on an axis held in a holder. When the holder is rotated under vertical pressure, the head is formed gradually. Even though this process produces more uniform heads compared to impact riveting, the surface finish produced is not of high quality because of the difference in the contact velocities at different radii of the rollers.

The tooling in this process is expensive and tool wear rapid. The size requirements may pose problems in places of restricted accessibility.

Orbital and radial riveting

Orbital and radial methods of riveting are similar and involve a characteristic wobble motion of the tool. In orbital heading the tool is held in a freely rotating spindle, the axis of which is positioned at an angle, usually 3° to 6° to the axis of the housing, so that the spindle axis intersects the axis of the housing at the face of the tool. The rotation of the housing provides a circular orbital motion to the top of the tool. With this movement and the tool in contact with the rivet head, the face of the tool gets a wobbling motion without any relative rotation. As the tool comes in contact with the workpiece, it makes a line contact starting from the periphery and moving towards the centre. During this process, a wave of material mass moves ahead of the line of contact, the amount of material mass depending on the pressure applied. Because of very low friction, the heat produced in this process is negligible and the resulting surface is free from tearing marks. As only a minute quantity of material is displaced in each revolution, the axial pressure required is only about 10 per cent of that required in impact-forming of the head.

The radial riveting method is similar to that of orbital riveting except that in this process, the rivet head is formed by the movement of the tool point along a series of cylindrical loops that overlap tangentially at the centre to produce a rosette pattern. In the radial riveting head, the tool is not free to rotate as in the case of the orbital riveting head, but it makes a point contact compared with the line contact in the orbital method. Consequently, the pressure needed to form the rivet head is 10 to 20 per cent less than that in the orbital method. Hence this process is specially useful for small and delicate parts.

Metal spinning

In conventional spinning, which is basically a manual operation, a ring of the circular blank of thin-gauge material is formed to the desired shape of the finished utensil. While there is a change in the diameter of the blank and finished vessel, there is practically no change of thickness between the formed side walls and the base. During the process, the flow of material follows the laws of equal surface area and equal material volume. However, the process is slow in comparison with deep drawings, and for consistent operations requires highly skilled operators. This process is highly suited for ductile materials such as soft aluminium and its alloys.

Future of forming

Metal-forming is bound to attract greater attention in the future because of the growing concern to conserve material and restrict energy input to optimum levels. Forming is increasingly preferred because it not only makes a more prudent use of material, but also has in-built possibilities of better control over material properties.

The future of forming is bright because it allows reductions in machining sequences which are otherwise inevitable in metal-cutting. The newly developed high-precision die-casting and -forging techniques, precision-blanking and sheet-metal-working methods and advances made in powder metallurgy, fine-blanking, NC and CNC punching, investment castings and cold extrusion, and explosive, electrohydraulic, electromagnetic, compressed-gas, water-hammer and fuel-combustion forming are offering production managers more economical routes of production. Even though tooling costs of metal-forming machines are high at present, future research efforts may bring them down, particularly through the use of NC and CNC in the manufacture of dies and tooling.

XI. Technological trends in production engineering

The following three major factors have combined in the last decade to advance manufacturing to its present stage: the increasing cost and shortage of skilled labour; the higher productivity and automation (including NC) of new machines offered by machine-tool builders; and the availability of reliable low-cost computers.

Average lot size has decreased in recent years, even in traditional mass production industries such as the automobile industry. Today, the emphasis is on high volume rather than mass production. The latter implies millions of identical parts while the former means production at the same high rates but with the ability to adapt to customer preferences. To meet higher performance standards and safety and ecological regulations, manufacturing tolerances are becoming finer. All these factors have enhanced the importance of optimization technology in manufacturing.

Computers in manufacturing

Computer monitoring or control of plant operation is the most significant trend in the metalworking industry. Computers are used to solve scientific and engineering problems related to product design and production engineering, ensure the flow of parts and assemblies, control inventories and monitor production operations. Scheduling is computer-controlled, the objective being to keep machines and production lines as fully loaded as possible in order to receive maximum return on company investment and facilities.

Probably the biggest advantage of computers in metalworking plants is their ability to keep track of what happens on a real-time basis. Alerted by computers, management is able to make decisions when they are needed and when trouble occurs. The managers are able to study metalworking operations in their plants in greater detail to find where process improvements—better flows of parts and materials between machines and tools, better allocation of manpower and brainpower—will pay off.

Computer-aided design and manufacture are making it possible to transfer all the routine functions in manufacturing operations to the electronic computer, vesting in it a limited supervisory control and using its data-processing capabilities to optimize the manufacturing operations. Electronic control of manufacturing operations is advancing as rapidly as development of software will permit.

Emphasis is currently on linked machines, integrated systems and computer-aided manufacture. The stand-alone NC machine and groups of NC machines are now widely used for batch manufacturing. Future CAM systems will probably be formed by linking first one and then several CNC machines with automatic work handling or robotics with overall control by means of hierarchical computer systems. The next logical progression will be linked multiple systems of this type with automated assembly, which could possibly be the forerunner of an unmanned factory.

Direct numerical control of NC machines from a central computer has played a less prominent role while recent attention has been focused on a systems approach to batch manufacturing, namely flexible manufacturing systems and unmanned manufacturing systems. All the integrated CAM systems are aimed at batch manufacturing, have a high level of materials handling and have integrated control systems. Hence they can be considered an extension of DNC systems with the inclusion of management information systems, work transport and possibly tooling transport systems.

In Japan, the United States and several European countries with centrally planned economies or developed market economies, commercial DNC installations and integrated work transport systems have been introduced.

Integrated manufacturing

An integrated manufacturing system is one that combines a number of hitherto separate manufacturing processes so that they can be controlled by a single source. The chief benefits are as follows: reduction in lost time caused by inter-stage movement of the components being made; improved machine tool utilization, reduction in manpower; reduction of work in progress; and greater flexibility of component batching and loading.

At present, the majority of systems developed have concentrated on the machining processes involved and, in particular, the manufacture of prismatic parts. A truly complete integrated manufacturing system would require the same degree of co-ordination and control to be applied to other major operational areas, that is, production of rotational parts, fabrication and assembly.

However, the main concern has been with the application of this type of manufacture to small batch production, which represents a significant proportion of manufacturing output in almost all countries. It has been estimated that the difference in cost between mass production and small batch production of the same components can be as much as 30 to 1, and an appropriate expression of the cost target for integrating manufacturing systems could be the mass production of one-offs.

Integrated manufacturing systems of some form for machining components have been in commercial use for about two decades in developed countries and existed in experimental form for some years before that. Early systems included manually operated standard machine tools, fed by automatic means from a common source, as well as a limited number of machining centres coupled with palletized loading and unloading.

The real breakthrough, however, depended on the design of reliable, comparatively low-cost control systems that became available in the late 1960s. From this point on, it was possible to design systems which would achieve a sufficiently long mean time between breakdowns to make them economically attractive.

Production could now be accurately planned through a complex system of machining operations, and the manual content was reduced largely to that of inspection of parts and tooling to maintain the standards of accuracy and finish demanded by the specification of the component. The machine-controlled environment on and off the shop-floor could yield efficiencies not previously considered attainable in this type of production.

Because of the high operating efficiencies leading to greater tool-cutting time, a group of eight machines can be equated to 100 conventional machines in output, especially on small batches up to 50 parts. The average number of machines in a system varies between five and nine machining centres, though in the United States 70 have been included in one system. With high operating efficiencies (in some cases over 90 per cent), the output from a single system can be as high as 4,000 pieces per month on a three-shift basis, thus giving to the batch production of small quantities the volume outputs of mass production equipment.

Computer-aided manufacure

A CAM sy em is a closed-loop regulating system, the primary input dimensions of which are demand (requirements) and product idea (creativity), and the primary output dimensions of which are finished components (finish-assembled, tested and ready for use). It represents a combination of software and hardware involving production methodology, planning and control, and the choice of production aids including machine tools. It can be realized by systems engineering methods and offers a possibility of total automation through flexible and adaptive means. The most important aid to achieve this goal is the computer. This is the basic concept guiding the development and application of computers for integrated production.

In other words, CAM is a conglomerate concept where the ability of the computer is used at every stage of manufacture by evolving a cellular structure. Though this type of manufacturing may appear related to the transfer-line concept, CAM has the flexibility, unlike transfer lines, to alter the type of product and the product flow sequence from machine to machine. The alteration of product flow sequence is done in such a manner as to keep the idle time of any machine to the minimum. Such flexibility is achieved because of the monitoring and control exercised by the central computer.

The flexibility offered by new hardware and software is encouraging a shift from fixed-programme mass production facilities to variable-programme automation. It is now realized that the best benefits of computer control are only obtained in a kind of group technology where the machines are linked by automatic transfer systems and the computer keeps a continuous track on a variety of components as they go through the manufacturing cell.

The DNC computer is now extended to handle management functions within the manufacturing cell such as scheduling, inventory, materials management, budgetary control and reporting. The integration of a number of such manufacturing cells into a single manufacturing facility through a central computer will complete the cycle giving rise to the integrated manufacturing system. Such systems are required to have a hierarchical line of computers at different levels. Information and feedback from various cells go back to the central large computer, which possesses software capable of programming the whole operation for the optimum utilization of resources. The addition of automatic warehouses, assembly, test and dispatch systems is also proceeding, leading to the possibility of automated unmanned manufacturing.

Technological evolution

As a result of the long-range economic and social factors influencing industry, a number of developed countries have drawn up plans under which priority is given to the development and application of CAM systems and computer-optimized and automated machine tool systems. Governments, universities and industrial establishments are working as a team towards this objective. Even though the realization of fully computer-integrated production systems is the long-term plan, there is a clear awareness that the change from present industrial methods, know-how and machines is an evolutionary process. The applied strategy, therefore, consists in developing and applying individual, practical and economic measures in the form of short-term research, development and application programmes having the following main characteristics:

(a) The measures taken should result in adequate gains to justify their adoption and to produce profits on the invested capital to finance the next stage of research and development;

(b) Each step should be a link in the chain to achieve the final goal of fully computer-automated, optimized and integrated production.

Among the various programmes undertaken in developed countries, the following are noteworthy:

(a) Creation of software modules by developing individual modules which can be coupled with one another quickly at a later date to produce a complete software programme suitable for various production applications;

(b) Development and application of production calls for hierarchical computer systems and flexible production systems;

(c) Comprehensive computer-controlled operations of machine tools and computer monitoring of production processes by means of NC, computer-integrated controls, DNC and hierarchical computer systems;

(d) Studies of computer-controlled industrial robots for automatic manipulation of workpieces and tools, and of the operation of machine tools and production aids of various types;

(e) Development and application of computer-controlled flexible production systems evolved on the concept of automatic production cells.

Flexible machining systems

Flexible manufacturing systems have three distinguishing characteristics: potentially independent NC machine tools; a transport mechanism; and an overall method of control that co-ordinates the function of both machine tools and the conveyor system so as to achieve flexibility. The main purpose of such systems is to integrate the various functions in the same machine tool to form a flexible manufacturing cell that is a module of a flexible manufacturing system.

Each flexible manufacturing cell is an autonomous module, the functions of which are supervised and controlled by a microprocessor-based computer. The various functions of the individual cells are as follows: supply of blanks, tools, gauges and devices; use of clamping devices for identification, selection, transport, orientation, loading, positioning, clamping, declamping, interlock supervision and other step-by-step operations; automatic execution of operations such as measurement of the workpiece, adjustment of clamping devices, material handling and positioning, and automatic monitoring by sensors of interlocks, lubrication failure, tool breakage and other malfunctions.

Each cell basically caters to a particular machining process like turning and milling. The different cells are connected by transport devices into a flexible manufacturing system, and the co-ordination of the simultaneous activity of all the cells is accomplished by the process computer hierarchy so that from raw material to end-product the complete production process is automated.

An alternative concept of a flexible machining system envisages a manufacturing cell which performs various machining processes like turning, milling and boring as a part of one individual cell In this case, the material-handling functions are reduced. An existing stand-by robot or integrated robot handles the workpiece and the measurement device.

Maximum utilization of the cutting capability of the machine tool is ensured by an adoptive control. Suitable sensors to monitor process parameters are incorporated in the manufacturing system. The CNC system integrates the whole control strategy for utilization of installed capacity, reduction of idle time and monitoring the thermal effects of component accuracy.

Several manufacturing cells linked by a transport system, additional handling devices and an automated storage and retrieval system for the workpiece, tools etc. can lead to the concept of an automated factory. The most advanced stage of optimization would involve a hierarchical organization in which all cells at a higher level are controlled by a centralized DNC-type computer and all production groups are linked to a mini-computer, providing a basis for complete on-line optimization of material flow, scheduling, routing and full automation of production.

Computer-integrated flexible manufacturing systems are thus gaining increasing acceptance and importance in batch production. Of the approximately 50 flexible manufacturing systems developed up to 1979, about 40 have been put into operation, nearly 70 per cent of them intended for prismatic components.

Flexible manufacturing systems based on group technology or cell production principles using NC machines and gauging equipment are now being installed with robot handling devices and palletized conveyor supply units to machine families of parts.

Development is also proceeding with the automation of metal-forming machines using minicomputers and microprocessors. Programmable turret punches, auto-controlled guillotines and shears, and manipulative equipment are in use. Robot developments applied to metal-forming operations will enable a considerable degree of automation in this class of piece-part manufacture. It is now possible to construct metal-forming production cells with the aid of robots that will blank, pierce and bend a family of components using a common stock material.

The manufacture of piece-parts, whether forged, welded, sintered or similarly processed, is being automated with the use of robots. The automation of assembly operations remains problematical, except for flow-line manufacture. But robotic and computer developments will have a considerable impact on these operations in the immediate future.

Group technology

One of the methods of solving the problem of conflict between productivity and flexibility in the computer-integrated flexible manufacturing system is group technology, which is a progressive management concept employed in an engineering industry within the framework of an integrated manufacturing system. The application of group technology in a purposeful manner can result in economic benefits of mass production even in large and medium batch production. In addition to streamlining production through the rationalization of components, it also helps to establish better co-ordination between the production wing and other functions like design, methods and sales engineering. The fact that more than 80 per cent of the engineering industries of the world are engaged in medium and small batch production should give the concept of group technology a new significance.

Traditionally laid-out production lines based on functions such as turning, drilling and boring, lead to many production delays because of inherent limitations in production control. A group technology-based production system organizes the production facilities in self-contained and self-regulating groups, each of which undertakes complete manufacture of a family of components with similar configurations and manufacturing characteristics. The different cells of the group technology system virtually function as small factories within the main factory. This assures reduction in throughput time, work in progress, inventory, setting time, work handling, jigs and fixtures etc. This concept improves design rationalization, job satisfaction and production control. NC shops are at present major areas where group technology is employed. But with a shift from hard-wired NC to software-based controls like CNC, much of the essence of group technology will trickle down to the software.

Computer control and inspection of machine tools

The evolution currently taking place in the direction of computer control and inspection of machine tools represents the most progressive field of development of modern machine tools. It is aimed at exploiting the enormous potential of NC through computer-based control, DNC and the hierarchical computer system. This potential is steadily increasing in scope as a result of the advances continuously being made in the field of computer technology.

More and more minicomputers are being used at the work-place. Because of the linkage between the work stations, the trend is towards a decentralized computer, which allows a partial separation between data processing and the control function. This is especially true of computer control of machine tools. The computer has thus become the most modern device for error diagnosis and correction on modern machine tools.

The future trend will be towards the development of methods which facilitate automatic correction of malfunctions. The computer, as soon as it detects conditions that may lead to an error, will alter machine parameters in such a manner that the error will not actually take place. In case of malfunctioning, the computer will send a command for the replacement of the defective electrical or mechanical module. Thus it is now possible to operate machine tools without operating personnel.

Metrology and inspection

Metrology is going through a revolution brought about by the integration of electronics with the science of measurement. Developments in inspection and gauging equipment are aimed at matching the high production rates of modern machine tools and meeting the requirements of finer measuring resolution and higher accuracy. A large degree of automation is also being built into these systems for compatibility with automated manufacturing systems.

Major trends in gauging and inspection equipment point towards an increase in speed and accuracy of measurements. Systems using opto-electronics and electrical contact to replace electro-mechanical probes have been specially developed, and there is a clear trend towards remote sensing of size using lasers and similar devices.

A complete shift to digital display of information in most measuring equipment, including such devices as hand-held micrometers, is now evident.

Different devices are being integrated with measuring centres, especially in post-process inspection equipment. Applications of minicomputers and output devices such as plotters, printers and cathode ray tube displays have been developed to enable inspection equipment to achieve rapid and accurate processing and presentation of metrological information.

An increase of two orders of magnitude in accuracy has been obtained in the resolution of measurement. With the advent of the job-shop laser, it is now possible to measure distances down to 0.01 μm.

Progress in measuring techniques has been so rapid that the resolution and accuracy of gauging have reached limits governed by the inherent instability of the machine and workpiece system. The stress on machine design to achieve higher final part accuracies is now greater. The drive towards even higher part accuracies continues, justified on the grounds of lower rejections, requirements of automatic assembly, longer final product life, legislation to reduce noise levels and the needs of related technology such as integrated circuits.

The development of compact and reliable electronic probes has made possible in-process gauging on transfer lines and other automatic manufacturing systems. Systems are being developed to use this capability in the adaptive mode to correct job or tool setting to achieve the required size. Automatic gauging systems are also applied on equipment used for automated assembly. Modular automatic inspection systems have already been developed to fit automated production lines ranging from automobile to bearing manufacture. These modules can be combined to suit gauging requirements on a wide variety of parts and to incorporate devices to load, transfer, index and unload parts and segregate them into acceptable and rejected lots.

Assembly and materials handling

Assembly, with its high labour content, is an area holding potential for profitable automation. Mass production industries in developed market economies have made considerable progress in this direction.

So far, automated assembly has been applied only to subassemblies. Even in the automobile industry, automated assembly has been applied only to subassemblies like the rear-differential axle and brake-drum. There is, however, a continuing search for methods to extend automatic assembly to whole products. Modern systems integrate assembly, inspection and testing into one automatic process. Automobile engine assembly is one area that has seen the application of such concepts with the process being controlled and monitored by computer.

Future design of automatic assembly equipment will also incorporate gauging, which will have a special impact on the electronics industries. Attempts are being made to use such systems in mechanical assembly when parts become jammed together or deformed without the knowledge of the operator.

Controls for assembly machines have also experienced considerable development. Programmable controllers are commanding many assembly machines, surpassing even computers and hard-wired controls in a number of applications.

Substantial progress has been made in recent years in the development of fasteners. New bolts, screws, nuts and rivets make assemblies easier, faster, cheaper and adaptable to automation. The newest concept is a system which sets bolts under a kind of adaptive control that shuts down the fastener driving tool when a preset torque—rotational angle combination—is reached.

Industrial adhesives are taking over many areas now served by mechanical fasteners. Techniques of adhesive bonding, originally developed for aerospace applications, may produce revolutionary changes in mechanical assembly.

Materials-handling systems are being integrated increasingly with operations in the plant. Computers are obvious tools for application in such systems. Foundries will be a major target for automated computer-controlled materials-handling systems in the years ahead.

XII. Automation and future trends in the machine-tool industry

Robots

Robots have been on the industrial scene since the early 1960s, but the first models were large and designed mainly for tedious, difficult and hazardous tasks.

Thanks to modern micro-electronics technology, robots have computers that enable them to learn a succession of tasks and versatility that promises to render obsolete a good deal of what is currently thought of as automation. Robots in fact represent the latest advance in automation, whether programmable or flexible. As distinct from the automatic mechanism, a robot generally has a multiple degree of rotary and linear freedom that can be actuated individually and simultaneously to give a close approximation to the physical motions of a human being performing the same tasks.

Whereas the earliest robots were controlled by programmes set with limit switches, modern robots are programmed by a minicomputer to which they are temporarily attached. Robots have been developed which can be automatically programmed or taught a sequence of movements by a human operator who guides the robot through the sequence.

Robots are at present applied in a wide range of tasks, including loading and unloading machine tools and presses, removing parts from die-casting machines, the handling and transfer of materials, especially in foundry and forge, welding, painting and simple assembly operations.

Prototype robots with rudimentary sensory feedback are already functioning in some countries. The use of television and holographic techniques is having a major impact on the development of robots capable of seeing and recognizing three-dimensional objects, especially when the objects are presented to the robot in a random orientation.

The computer program is the key to turning robots into assemblers. More advanced robots can be told what to do by typing the instruction on a computer keybord in a language that includes about 100 English words. Eventually, the evolution of robot language will make it possible to give robots more complicated instructions.

Having effectively eliminated the need for skilled operators for most machining operations in the 1960s and 1970s, machine-tool builders in developed countries are trying to evolve reliable unmanned machining systems capable of substantially boosting machine-tool throughput, ensuring strict adherence to stringent quality control standards, minimizing in-process inventories and guaranteeing production rates.

Automation, leading to unmanned factories, is technologically feasible in industry, yet its effect on people could cause insoluble social problems. The widespread use of unmanned factories may therefore come about only gradually, although the scope for unmanned operations under certain circumstances will increase in developed countries.

Future prospects

In the United States, the Society of Manufacturing Engineers has made series of forecasts on the future of production technology and machine tool development. The forecasts summarized below seem to be of particular interest.

About 1985

Assembling jobs will be integrated with the other production routines making use of computer-aided manufacturing systems. At least 25 per cent of the firms representing a cross-section of the metalworking industry in developed countries will apply software systems for the automation and optimization of various stages of production planning, for example, machining sequence, selection of suitable machine tools, clamping devices, sequence of operations, tool selection and optimal cutting conditions.

About 1987

About 15 per cent of total machine-tool production will not consist of single-purpose machines, but will make up component blocks of flexible production systems where the manipulation of workpieces between individual work stations will be done automatically and controlled by a central computer.

About 1990

The advanced development of sensors will help robots attain human capabilities in final assembly sequences. Computer-aided design techniques will be employed for the design of 50 per cent of the newly designed production aids.

About 1995

Almost 50 per cent of the direct work in the final assembly of automobiles will be achieved by programmable automation and robots.

About 2000

Based on these forecasts, it is presumed that even before the end of the century, many changes in machine tools and production technology will take place involving computers, including computer-aided design, fully integrated computer-aided manufacture and automatic assembly making extensive use of modern robots.

Part three

The implications for developing countries of technological developments in the machine-tool industry

XIII. The technology gap and its implications

Technological factors

The great progress taking place in the metalworking and capital goods industries in developed countries may be attributed to the following: the evolution of modern machine-tool mechanics and design, cutting-tool materials and tool geometry, machine-tool controls and manufacturing systems. By contrast, the newly industrializing countries have made insignificant progress in those areas, and the least developed countries, with little manufacturing industry, none at all.

Machine-tool mechanics and design

In the field of machine-tool mechanics and design, developing countries lag far behind. The majority of the machine tools being produced in those countries have been licensed from transnational corporations. It is unlikely that the licensed designs would in all cases be the latest designs, because if the latest designs are the main export items of developed countries, the licensors would not easily agree to transfer the designs and know-how to build them elsewhere. Even if it were possible to obtain the agreement of the licensors to grant manufacturing rights for some of the advanced designs of machine tools, it would take a large amount of resources to be invested by the licensee in licence fees, royalties, production facilities and, above all, extensive training of technical and production personnel to enable them to master the whole process of producing the sophisticated machine designs. More important is the fact that in developing countries, a sufficiently large volume of demand cannot be expected for highly sophisticated machines.

Highly advanced designs are developed to meet specific demands of the machine-tool-using industries such as the aerospace, aircraft, automobile, armaments and engineering industries. In some cases, machine-tool manufacturers receive guarantees of purchase and payment of adequate prices for the development of advanced machine-tool designs. In the absence of growing and advanced machine-tool-using industries in developing countries, there could be no sizeable demand for highly complex and costly machines and equipment. Furthermore, advanced designs are continuously undergoing changes that require close co-operation between producers and users before the final versions are obtained. In developing countries the repetition of similar experiences on a large scale cannot be expected.

Although computer-aided design is catching up in some of the newly industrializing countries, it is restricted to applications such as bed and column design calculations, gear drives and the design of main spindles. Computers are mainly employed for checking the designs of machine elements and unit assemblies after the prototypes have been built on empirical designs. Facilities for such work are far too limited and may be available only at machine-tool research institutes and universities teaching machine-tool technology.

It is essential to update the manufacturing methods employed in the metalworking industries of developing countries, so as to generate sufficient incentive, scope and demand for modern machine-tool designs, particularly numerically controlled machines, machining centres etc., which could be integrated into modern manufacturing systems in the metalworking industry.

The experience of developed countries has been as follows: improvement in manufacturing systems takes place in the machine-tool-using industries through the availability of advanced and highly productive machine tools; and the advanced designs of machine tools are made available to the using industry if there is sufficient demand for them. Hence, the technological gap in the machine-tool industry could narrow if modernization takes place in the production technology employed by the metalworking industry, which is the main customer for machine tools.

If their metalworking industries were given the correct incentive to grow modern and productive, developing countries would in the course of time be able to narrow the technological gap in machine-tool mechanics and designs. But taking into account the market situation, the resources available and, above all, the great technological advances taking place in developed countries, the gap in machine-tool technology between developed and developing countries will probably be difficult to bridge before the end of the century.

Cutting tools

Some developing countries, mostly the newly industrializing ones, use hard or extra-hard advanced cutting tools for certain applications. Transnational corporations having set up their own factories or entered into joint ventures in developing countries are able to provide advanced types of such tools, including sintered carbide tools, tungsten carbide, coated carbide and throw-away carbide tip-tools for use in conjunction with the more advanced high-powered machine tools.

Ceramic tools, special tools needed for machining centres and high-precision diamond tools, the use of which is highly restricted in developing countries, are imported where necessary.

Extensive use of high-speed tools, particularly for machining steelwork, is a common feature of metalworking industries in developing countries. Carbide tools are primarily used for machining cast-iron components. However, for certain applications; carbide tools and cutters for machining steelwork are used. For instance, tungsten carbide tools and cutters are commonly applied in single- and multi-spindle automatics, transfer lines and similar advanced designs of machine tools used in machining steel components.

Machine-tool controls

One of the major technological gaps between developed and developing countries is in the area of micro-electronics. There has been growth in the electronics industry in some developing countries, mainly to meet the requirements of entertainment, communications and armaments production. Though the use of computers for office purposes is comparatively well-established in some developing countries, the industrial application of modern computer technology is almost non-existent.

In developed countries, the main instrument of change is the microcomputer, which consists of complex circuits on a button-size chip of silicon. A medium-strength microcomputer can perform 100,000 calculations per second.

Some of the machine-tool-producing developing countries have also started producing NC machine tools, but the controls belong to the older generation in which coded tape forms the core of NC. In developed countries, however, CNC has become the core of NC machines and machining centres.

Controls of this type, including minicomputers, are not manufactured in developing countries, although some imported CNC-controlled machining centres are used. The machines come with the executive programmes developed by manufacturers in the form of standardized system designs.

The manual-data-input-type of control system is used in some developing countries on centre lathes, knee-type milling machines, drills etc. However, modern manual data inputs employed in developed countries are microprocessor-based, and such controls are not currently produced by developing countries.

The few found there are imported and suffer from the lack of adequately trained programmers.

Manufacturing systems

The absence of the latest computer-integrated manufacturing systems in developing countries is the result of their lagging behind in areas such as computer technology, advanced designs of machine tools, including CNC or DNC machining centres, minicomputers, microprocessors and highly advanced cutting tools usually associated with sophisticated types of machine tools. Although the large-scale introduction of robots into the manufacturing systems of developing countries may be physically impossible and even undesirable in view of the existence of a large unemployed labour force, robots could to some extent be employed in specific tasks that are usually impossible or undesirable for human beings to perform. But without the strong support of computer science, this cannot be achieved.

Metal-forming

With regard to metal-forming presses, some developing countries are manufacturing conventional types of open-back-inclinable and parallel frame presses with hydraulic and mechanical drives and shears and press brakes. In certain cases these items amount to as much as 50 per cent of the total national production of machine tools. Heavy-duty hydraulic and mechanical types of conventional presses, mainly used in mass production industries, are being made in some developing countries, but the hydraulic aggregates and other accessories are still imported from developed countries.

The technology gap between developed and developing countries with regard to metal-forming presses is widening each year. This is more apparent in the case of non-traditional forming methods such as helical and ring rolling, spinning and flow-forming. In developed countries, considerable research and development is being carried out with the aim of producing parts consisting of high-strength alloys formed into complicated shapes, for example by means of powder metallurgy. Developing countries are also lagging behind in the production of cold-forging and extrusion presses, and fine blanking and punching presses.

One of the main bottle-necks in metal-forming is the manufacture of complicated dies and tooling. For this, high-strength alloy steels must be used as raw materials to be machined on sophisticated machine tools such as CNC continuous-path vertical or horizontal machining centres.

Another piece of sophisticated equipment of the high-speed metal-forming industry is the transfer line press for automatic and progressive operations on transfer line, both in forging and forming. In this case, a transfer feed is provided to convey the part from station to station. Although some sheet-metal-forming transfer line presses are manufactured in the newly industrializing countries, heavy-duty and progressive forge presses are still imported.

Non-traditional machining

In the area of non-traditional machining systems, developing countries have made very little progress. One reason is that the metal-working processes have a relatively restricted field of application. Moreover, the development, and in particular the application, of many of the technologies has yet to be perfected even in developed countries.

A survey of developments taking place in this field in developing countries shows that only the following processes are employed in the metal-working industries in some newly industrializing countries: electron-discharge machining, electro-chemical machining and electron-beam machining. Of these, EDM and EBM welding have found greater usage than the others. In EDM, the wirecut process is becoming increasingly popular mainly in the production of high-precision die and press tooling, for instance, in the horological and instrument industries. EBM welding technology is receiving greater attention, particularly in more advanced industries, such as the aircraft, aerospace and atomic energy industries. However, apart from very simple EDM and ECM machines, equipment continues to be imported in small numbers by developing countries.

XIV. Economic implications

It is not possible for any country, whether developed or developing, to become completely self-sufficient in machine tools. It is also unnecessary and economically undesirable. The 10 largest machine-tool-producing developed countries are themselves the biggest importers of machine tools. This type of interdependence, in which a country imports its own requirements of machine tools and yet specializes in producing certain types of high-precision items, is a special feature of the global machine-tool industry. Some of the CMEA countries, which at first aimed at becoming completely self-sufficient, had to abandon the attempt and now import large quantities of specialized machine tools from developed market economies. This was necessary in order for them to improve the quality standards of the products of their metalworking industry and compete in world markets.

It is sometimes argued that production technology employing a comparatively large labour force could be as efficient as highly advanced labour-saving technology. However, labour productivity in developing countries is very poor compared with labour productivity, that is, output (added value) per worker per annum, in developed countries.

Furthermore, productivity improvements are not entirely the result of workers working harder and better. Productivity improvements largely arise from the efficient use of material and capital resources. In modern industry this is possible mainly through better management of resources employing improved and advanced technology.

The insufficient development of the machine-tool and manufacturing industries of developing countries is one of the main reasons for their poor industrial and economic growth.

Over 90 per cent of world manufacturing industry is in developed countries. Unless there is a massive transfer of modern technology from developed to developing countries, the latter will remain in a state of permanent economic weakness. Such a transfer would enable developing countries to develop their own technological capability to produce a surplus of manufactured goods, machinery and engineering products which could compete on world export markets.

It has been estimated that in India alone, 10 million jobs must be created every year from now to the year 2000 to cope with population growth and the backlog of unemployment. With more than 650 million people, India has a gross national product two fifths the size of that of the United Kingdom, which has only 60 million people. The same is true for many developing countries of Africa and Asia. Part of the problem is that most developing countries depend heavily on agriculture, with more than half their products coming from this sector which employs at least two thirds of the labour force. The main object of the policy-makers and Governments of developing countries should be to relieve agriculture of this heavy concentration of labour by introducing mechanization and to a large extent diverting labour to industries. This is only possible through rapid industrialization using modern and productive technology.

Industrialization in developing countries has been very uneven. Some of the middle-income countries have made considerable advances in industry. Several of them have nearly one quarter of their workers in the manufcturing sector, which is as much as some developed countries at present. Other countries show little change. In many of the poorest countries, less than 5 per cent of the work-force is engaged in the manufacturing sector. It would be highly misleading to present developing countries as invariably poverty-stricken. Even among the low-income countries some progress has occurred, and the newly industrializing countries have achieved remarkable growth rates. Argentina, Brazil and Mexico have an established industrial base which has increased rapidly in recent decades. The economy of Brazil, for example, will at current growth rates rival in size that of the Federal Republic of Germany by the year 2000. Brazil is also an important trading partner and thus a stimulus to growth for other countries in the South. The Republic of Korea has great potential for industrial and economic growth made possible through the use of modern production technology. Several other developing countries have also become significant centres of industrial production.

XV. Guidelines for the development of the machine-tool industry in the developing countries

A distinction must be made between newly industrializing and other developing countries when considering measures designed to promote the machine-tool production of developing countries.

The guidelines presented in this chapter concern primarily those developing countries which have a very limited industrial base.

In the beginning, developing countries will have to depend on imported designs, which should be simple, modern, relatively labour-intensive and suitable for smaller batch production. It may be possible to obtain such designs and the necessary manufacturing know-how more advantageously from newly industrializing countries.

During the initial period of dependence on imported designs and know-how, developing countries should take steps to build up a scientific infrastructure and make use of local potential. The establishment of machine-tool design and production technology institutes should therefore be a top priority. The institutes could be assisted by, or set up in co-operation with, well-known international machine-tool design and research institutes. A group of design experts in the institutes could design suitable machine tools, build prototypes and carry out the necessary tests. They could then offer the design licences to interested entrepreneurs. Designs could also be sponsored by entrepreneurs. With increasing experience, machine-tool-producing units could begin to design machine tools on their own. Government-financed machine-tool design and research institutes, on the other hand, could switch over to developing more advanced designs to meet the growing demands of the metalworking industry. It may still be necessary to require manufacturers to have their machine tools tested exhaustively and perhaps even graded by machine-tool design, research and production technology institutes.

Production units

Cast-iron foundries and pattern shops

Developing countries should give priority to setting up foundry facilities to produce high-quality cast-iron components such as beds, columns, arms, base plates, gear boxes, headstocks and tailstocks. In view of the large workforce available, the heavy castings could be hand-moulded, perhaps using sand-slingers. The sand-conditioning plant, core-blowing equipment, melting cupolas, core- and mould-drying ovens etc. need to be highly automated. However, the training of floor and machine moulders, core-makers, metallurgists etc. is essential for producing quality castings and keeping foundry product rejects to a minimum.

Pattern shops could be a captive operation of the centralized foundries. The making of pattern and core boxes is a skilled job requiring specially trained workers.

Forge shop

The percentage of forged parts in the production of machine tools is much less than cast-iron components and requires the establishment of only a few central forge units. Drop hammers and furnaces are the main items of plant and machinery needed in forge shops. The dies and tools may have to be procured from outside or from the central tool-room service units.

Rolling mills

Mild steels, carbon steels, alloy steels and sheet steels are the essential raw materials required in the production of machine tools. The proportion of steels is generally less than that of castings, both ferrous and non-ferrous. The latter nevertheless remain a vital raw material for the manufacture of machine tools and machinery. Whether a developing country should develop its own iron and steel industry depends upon various factors. Undoubtedly, it is advantageous for a country to develop its own iron and steel industry if the necessary raw materials are available. However, many small developing countries that have not reached a high level of industrial development and lack the necessary infrastructure and essential raw materials, such as iron ore, coal and gas and adequate electric power, but have a small-scale demand for steels of various types and sizes, would be well-advised to import the small quantity of steels initially needed for the nascent machine-tool and machine-building industries. It would also be advisable to set up rolling mills in which various operations, from steel scrap melting to rolling several sizes of bars (including alloy steels), angles, channels etc. could be undertaken. Using modern technology, for example the continuous casting (concast) machine and mills of adequate size and capacity, small rolling mills could turn out the required sizes and quantities of steel raw materials of different sizes and sections, and even alloy steels and carbon steels partly meeting the needs of the machine shops engaged in the manufacture of machine tools and machinery.

Central tool room

Machine-tool production units are not complete without a tool room facility. In all developed and newly industrializing countries, tool room facilities are commonly adjoined to each manufacturing unit. This is necessary in order to maintain a degree of flexibility and self-sufficiency and to meet the specific needs of each manufacturing unit. But the difficulty that may be encountered in developing countries concerns the availability of both highly skilled labour and experienced and resourceful tool designers. Moreover, plant and machinery for tool rooms could be expensive. For these and other reasons, including fuller utilization of capacity, developing countries should set up central tool-room facilities as an adjunct to the machine-tool complex. The central tool-room equipment should include jig borers, universal tool-room milling machines, and precision thread-cutting facilities. The unit may have to be equipped with facilities for making high-speed cutting tools with furnaces and baths for heat treatment of high-speed steels. Precision equipment for grinding and resharpening of tools such as carbide tools, hobs, reamers and taps is a common feature of most tool rooms. The tool room unit should be staffed with competent tool makers and designers who can design and make jigs, fixtures, special tooling for the machine shop and other production units, including forge shops, rolling mills, sheet metal shops and even foundries and pattern shops.

Ancillary shops

Ancillary shops such as those for heat treatment, plating and sheet-metal-working could be largely captive units of the machine-tool production units. These could be of large or medium size depending upon the load from the parent machine-tool units. The main point is that these independent activities could be run more efficiently with a degree of specialization.

Structure of the industry

Separate plants with 100-200 employees should be established to produce different types of machine tools. This is advantageous for many reasons, the major ones being the greater degree of rationalization, larger batch sizes and, above all, the technical specialization. The number of employees could be even less if the major operations or units such as the foundry, heat treatment, tool room facilities and training centres are separate but common elements in the production of different types of machine tools in different units. There also should be a possibility of further decentralizing production by farming out certain items and accessories to ancillary industry.

Production technology

In assessing and selecting a suitable production technology, it must be ensured that the technology is capable of producing quality products at reasonable costs.

The choice of production technology depends on the stage of industrial development of a developing country. Industries in developing countries have been established mostly in co-operation with developed or newly industrializing countries. In many cases, the industries have been established on a large scale, without paying sufficient attention to the importance of developing small-scale and ancillary units. There has also been a high degree of self-sufficiency in the vertical planning of industrial units. Some of the heavy and capital-intensive processes may be best conducted within one establishment, with little scope for the decentralization and distribution of work content among small and medium-scale enterprises. But this is not necessarily the case with many items of machinery, including machine tool and other mechanical and electrical engineering products. The production technology employed could give considerable scope for setting up a number of small-scale and ancillary units dispersed throughout the country, to which simpler parts or accessories and ancillary items could be farmed out. Such a pattern of decentralized production and labour-intensive technology will also serve the desired objective of providing employment opportunities and achieving the maximum dispersal of industrial activities.

Production process

The process of machine-tool production may be classified into the two broad categories of component manufacture and assembly and testing operations. With regard to machinery, whether electrical or mechanical, once the designs have been determined, subsequent processes, in particular manufacture of components and assembly and testing operations, are similar to machine-tool production.

In the case of component manufacture, there are normally two broad types involved: ready-made, externally purchased items such as electric motors, switch gears, clutches, ball-bearings, oil rings, circlips, limit switches, machine lamps, and lubricant and coolant pumps; and items that are manufactured to specifications from castings, forgings and steels, the category on which this study focuses.

In developing countries components should be manufactured using general-purpose machine tools and production aids such as jigs and fixtures. Since the batch quantities are small, there is no need for highly rational, advanced special-purpose machine tools. Component manufacture requires the training of skilled turners, fitters, grinders, milling machine and jig-boring operators etc. in central training centres. They should then be transferred to production shops for on-the-job training before they are entrusted with skilled tasks such as boring headstocks, grinding spindles, thread-cutting screws and nuts, scraping bedways, and cutting and grinding gears.

It takes a long period of experience to assemble modern types of general-purpose precision machines. Assembly operators have to be even more skilful than machinists, since some of the machining inaccuracies of components have to be corrected in assembly by appropriate filing and scraping.

The assembly operation is normally divided into two main parts, namely sub-assembly and unit assembly on the one hand, and final assembly on the other. Suitable assembly fixtures, test beds, control equipment etc. must be provided so that sub-assemblies and unit assemblies may be tested before sending them on to final assembly.

The testing of machine tools is a specialized task. There are international test charts and specifications, for example the Schlesinger charts, which require the testing of machine tools by specially trained technicians.

Quality control is an essential aspect of machine-tool production. Suitable instruments such as micrometers (inside and outside), thread gauges, snap gauges, go and no-go gauges and vernier calipers are used to check components passing through various stages of machining. Sub-assemblies and unit assemblies also have to be rigidly tested on specialized test beds designed for particular unit assemblies, so that when they are sent to final assembly, they should not only fit properly and lend themselves to easy assembly, without much alignment or fitting work, but also the machine tools, at the final inspection stage, should conform to the specifications of the alignment and performance tests.

Separate plants with 100-200 employees should be established to produce different types of machine tools. This is advantageous for many reasons, the major ones being the greater degree of rationalization, larger batch sizes and, above all, the technical specialization. The number of employees could be even less if the major operations or units such as the foundry, heat treatment, tool room facilities and training centres are separate but common elements in the production of different types of machine tools in different units. There also should be a possibility of further decentralizing production by farming out certain items and accessories to ancillary industry.

ANNEX

CURRENT AND FUTURE TRENDS OF MANUFACTURING MANAGEMENT AND TECHNOLOGY

The forecasts presented below were drawn from a report by the Technical Policy Board of the Institution of Production Engineers, United Kingdom. The report, entitled "The Way Ahead", was based on a survey conducted by means of questionnaires. The methods used derive from those of a project, known as Project Delphi, sponsored by the United States Air Force in the early 1950s. The forecasts refer to the United Kingdom, unless otherwise specified.

1984-1985

1. Computer-aided manufacture will use a network of graphics terminals to inform management on the shop floor of the situation of any product and some will convey set-up and operations instructions.

2. NC machine tools will normally use floppy disks instead of paper tape.

3. The cost of part programming will be reduced by one third by means of computer aids on interactive pre- and post-processing and expanded data bases. Computer graphics will be in use for CAD and CAM by about 5 per cent of all companies.

4. Computer-aided material-handling systems integrated with manufacture will be used by a small (2 per cent) but growing number of companies.

5. Smaller companies will have only 1 per cent of their work designed by computer interactive graphics.

6. About 10 per cent of all manufacturing industry will have a considerable amount of automatic inspection (on line) with diminishing post-manufacture inspection. This process will extend well beyond engineering products into such areas as textiles, paper and box or can manufacture, and will experience continuous development.

7. The proportion of companies using integrated CAD and CAM for both product and tool design will be as follows:

	1984-1985 (percentage)	*1990 (percentage)*
Japan	10	20
United Kingdom	5	10
United States	10	25

8. Managers expect working hours to be reduced to 38 per week.

9. Workers will be consulted in at least 30 per cent of all companies engaged in manufacture.

10. Office staff will work under some form of productivity scheme, though this is considered difficult to establish.

11. Computers will be used by the majority of manufacturing units, especially those with at least 250 employees. Most processing plans will be done by computer, thus reducing management paperwork.

12. About 50 per cent of manufacturers will have costing and machine scheduling on computers. This information will be available to managers on request by means of visual display units.

13. Minicomputers and microcomputers will be used to assist both physical movement and information in materials handling.

14. In precision turning and grinding, in-process sensing of finish and dimensions will reduce scrap by 25 per cent and eliminate much post-manufacture inspection.

15. It should be possible to predict and specify the surface finish needed to give the required wear life in rotating shafts or sliding surface.

16. Adaptive control strategies for metal removal by turning, rolling or grinding will be available and these will be adopted by 10 per cent of the industry.

17. Both paint spraying and automatic welding by robots will be widespread (up to 40 per cent of the industry).

18. Lasers will be used for in-process (non-contract) control of accuracy.

19. The structure of most new machine tools will be composite to avoid vibration and to give stiffness and thermal stability and reduce noise.

20. In the United States many industries (up to 10 per cent by 1987) will use group technology.

21. Lasers will be used for cutting and welding in both the United Kingdom and the United States.

22. Software systems will be developed to predict costs based on part definition only.

23. About 75 per cent of United States assembly systems will have automatic inspection.

24. By 1985 direct labour in car final assembly will be replaced by programmable automation (probably up to 30 per cent).

25. Part storage and retrieval in the United States will be automatic.

1986-1987

1. In the United States 10 per cent of all machining will be done by group technology by 1987.

2. Working hours will be reduced to 36 per week.

3. The knowledge will be available to use the computer to indicate whether it is economical to employ group technology for any particular part.

4. In larger firms 50 per cent of all the process paper-work for manufacturing will be computer-generated. As a result, there will be a 25 to 30 per cent reduction in machine-tool part programmers, and more CAM will lead to more CAD.

5. About 20 per cent of all printed circuit board and electronic manufacturers will use part classification and coding systems.

6. About 50 per cent of electrical wire harnesses and automotive harnesses, insofar as they exist in their present form, will be designed by CAD.

7. Automatic assembly will have penetrated into 20 per cent of mass-production companies.

8. The Japanese predict coding of sheet metal parts for classification by 20 per cent of companies.

9. A harmonized scheme of working for most of the work force will exist. There will be few hourly paid workers, but flexible hours of work for office staff will not extend to production workers in general.

10. There will be a considerable extension of all types of standards as a result of EEC regulations and health, safety and consumer protection, and also for manufacturing reasons.

11. Most NC machines will have dedicated micro-computers.

12. Spark erosion will have developed and become the dominant method for tool making.

13. About 20 per cent of mass-production companies will be using dedicated automatic assembly and modular robots will make equipment prices competitive, with specially designed single-purpose automatic assembly equipment. These will be in small quantity until 1990.

14. In the United States 50 per cent of new machine tools manufactured will have NC.

1988-1989

1. In the field of electronics manufacture the industry is expected to be a leader in the application of computer-aided ideas. CAD and CAM will be applied by 50 per cent of the industry.

2. Computer programs for die-making control and optimum design will exist.

3. By 1989 about 75 per cent of all CAM systems will be relying on distributed computing system concepts. Only 10 to 20 per cent of the systems will rely on control or main frame computers.

The percentage breakdown of the different systems in use will be as follows:

	NC	*CNC*	*DNC*
Japan	30	40	30
United Kingdom	10	80	10
United States	20	50	25

4. There is considerable doubt as to whether any large proportion of NC machines will employ conversational interrogation based on set menus from the shop floor, since control would probably be lost in large units. Some specialized small units may use this for jobbing work.

5. In the United States 20 per cent of manufacturers will have a computer model of their operations.

6. About 20 per cent of mass production industry will use dedicated automatic assembly robots.

7. Central computers will control 80 per cent of in-process and finished parts inventory.

1990-1991

1. It may be necessary to ration energy and certain raw materials, particularly metals

2. About 10 per cent of all special tools and fixtures will be designed by interactive computer graphics.

3. About 25 per cent of all machined parts will be designed by interactive computer graphics in the larger companies and 10 per cent of the results will be introduced through CAM.

4 About 10 per cent of all machining operations and some types of fabrication will be made by group technology or cell operations in the larger companies. This procedure has not always been economic for foundry or fabrication.

5. About 50 per cent of process plans will be computer generated in the larger companies.

6. The development of optical scanning of drawings and digitizing will put CAM data into data bases for either retention or subsequent processing. Some engineers question the economics of this development.

7. Classification of laser (optical) scanning of labels for inventory control will be used by 10 per cent of companies in materials handling.

8. About 25 per cent of set-up and operations instructions will be conveyed on video screens from computer graphics to the shop-floor supervisors.

9. Seventy-five of all conventional NC equipment will have been replaced by CNC or more probably DNC equipment.

10. About 20 per cent of all small-batch companies will use programmable robots for some forms of automatic assemblies, but usually not when the batch size is less than 50.

11. Paper tape will be largely superseded by CNC video display units with floppy discs or diskettes capable of supplying job operations, graphics and set-up data instructions to the operators.

12. In the United States the work week is expected to decline to 32 hours and 50 per cent of the work-force will be skilled.

13. About 50 per cent of the work-force in manufacturing will be skilled largely in computer maintenance.

14. In the United Kingdom and the United States 20 per cent of industry will have combined materials and process planning by computer-aided control.

15. In Japan, the United Kingdom and the United States, by 1990 methods development will be performed by computer for 33 per cent of such work. This also applies to the development of standards and for process control.

16. In the United States 75 per cent of simple program-controlled equipment will be replaced by multi-stored programs and multi-processor control.

17. About 20 per cent of the industry will use adaptive control strategies for metal removal (turning, grinding and milling).

18. There will be a marked reduction of noise from machine tools—possibly 85 dB will be mandatory.

19. Robots should be able to assemble families of parts (as opposed to single items) because optical identification will be possible.

20. About 30 per cent of assembly will be made by structural adhesives.

1992-1993

1. About 10 per cent of smaller companies (with a staff of less than 1,000) will employ group technology or cell manufacture, although size is not a major criterion.

2. About 20 per cent of industry will have a computer model of manufacturing operations.

3. About 25 per cent of all manufacturing units will have computerized:

(a) Control of stock;

(b) Automatic identification of items;

(c) Use of pallets to convey through the whole process (possibly a year or so later than *(a)* and *(b)*).

4. Facilities will be generally available for automatic sensing and replacement of broken or worn tools.

1994-1995

1. Robots will be installed in 50 per cent of industry where CAM is used.

2. About 25 per cent of machined parts will be designed by computer interactive graphics even in firms with less than 1,000 employees.

3. Working hours will reduce to 32 but it is unlikely that a four-day week will ever be adopted. Small companies will use group technology for 10 per cent of all machining operations.

4. About 20 per cent of all machine tools installed will have the following characteristics:

(a) Automatic loading, unloading and transfer;

(b) Sensing and changing tools for wear or breakage;

(c) Complete monitoring and recording by computer.

5. In smaller firms, 50 per cent of process planning and manufacturing paperwork for parts and assemblies will be done by computer, and 30 per cent in companies with 50 workers only.

6. Feedback (on-line) sub-systems will sense and correct deviations (back to the part standards) in 25 per cent of manufacturing firms.

7. Operations in the manufacturing process will be modelled by 25 per cent of companies in 1995, and perhaps by 20 per cent even by 1992.

8. About 20 per cent of machine tools supplied will incorporate co-ordinate measuring (probably of a non-contact nature) and feedback control to adjust deviations.

9. The percentage of special tool and fixture design by computer graphics will be 25 per cent.

10. Up to 25 per cent of all smaller companies (staff of 1,000 or less) will have fully adopted CAM. This will also be the case when batch sizes are normally as low as 50.

11. Industrial robots will be integrated into CAM systems in 50 per cent of companies engaged in assembly, moving etc. This may occur rather later in very small units.

12. Most of the manufacturing work-force will have to become highly skilled in diagnosis and maintenance of automatic machinery and computers.

13. Firms will hold information and motivating sessions to maintain staff morale.

1996

1. About 25 per cent of machine tools will form part of a versatile machining system with automatic part handling between machines with central process control.

It is considered that any results beyond this year would be unreliable.

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