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D02899

United Nations Industrial Development Organization

Distr.
LIMITED

ID/WG.87/7
17 August 1971

ORIGINAL: ENGLISH

Regional Seminar on Machine Tools
in Developing Countries of
Europe, Middle East and North Africa

Zlatni Pjasaci (Golden Sands) near
Varna, Bulgaria, 18 to 27 October 1971

THE POSSIBILITY OF INTRODUCING NUMERICALLY CONTROLLED MACHINE TOOLS IN DEVELOPING COUNTRIES 1/

by

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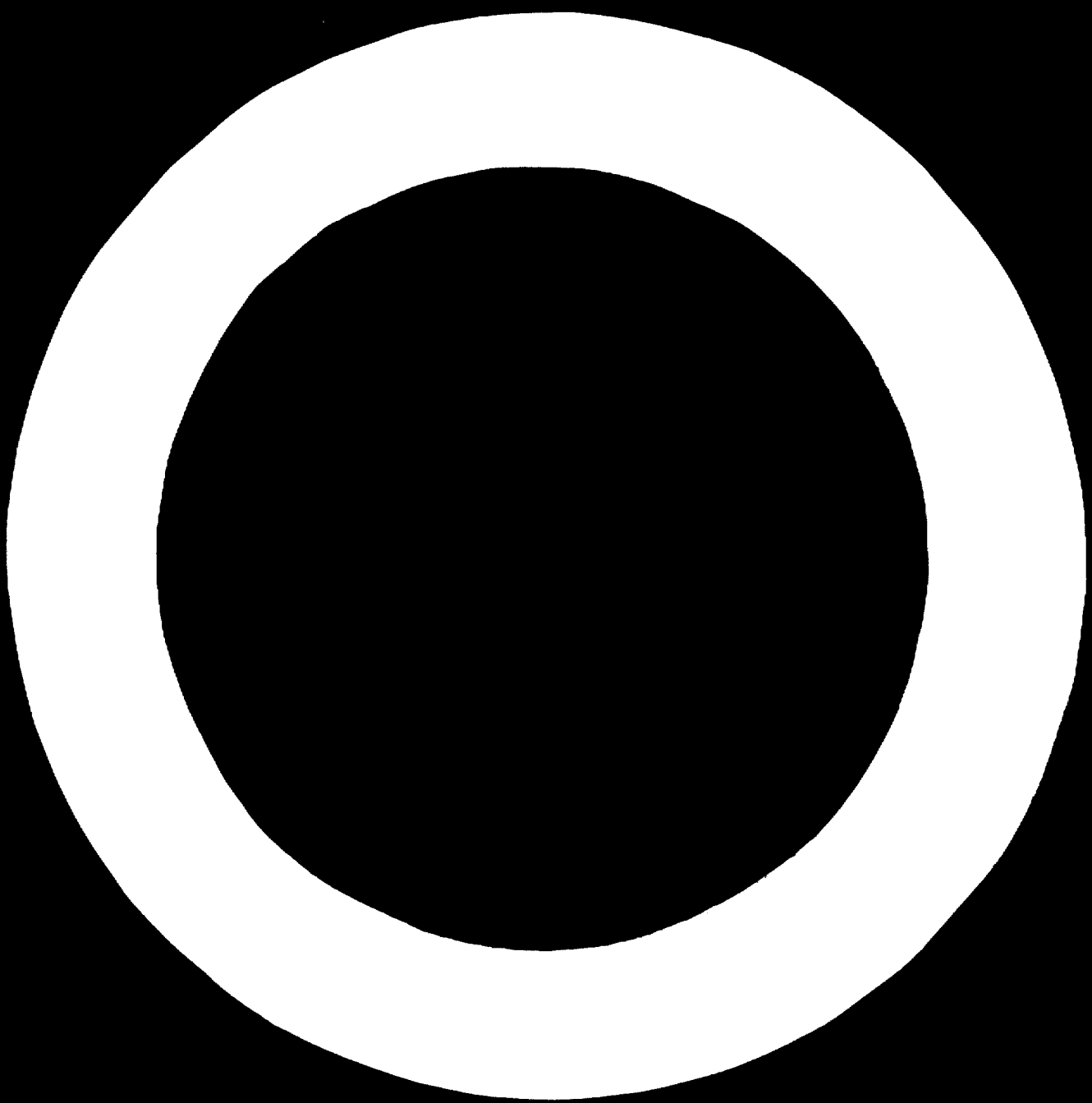

The numerical control of a machine tool is a device which provides for automation of a machining cycle on the basis of control information which it receives in the form of numerical data. This type of control, which represents a particular case of sequence control, is concerned mainly with the travel of moving parts like tool holders and work-piece holders, and a programmed sequence controlled machine tool may be equipped with or without numerically controlled displacements.

Numerical control represents an important improvement in sequence control of machine tools. Under this new technique, the travel of parts is no longer limited by stops which have to be adjusted with every change in the size of the work piece, but by the numerical control itself, which counts the extent of the movements as they are performed and stops them as soon as the desired dimension is reached. As soon as the tape carrying the control instructions has been set up, no other adjustments of the machine travel have to be made at the beginning of the manufacturing process.

<u>At present there are available:</u>

1. <u>With respect to information media</u>
   controls not using punched tape, with manual feed-in of data by means of switchboards (dial-in or plugboard type); in particular, jig boring machines with two co-ordinates using numerical definition and display of co-ordinates by selector buttons:
   controls using punched tape or magnetic tape (the information medium using punched tape is by far the most widespread).

2. <u>With respect to machines</u> (by increasing order of complexity Simple numerical display of dimensions read-out devices) on jig boring machines and large units in particular, an improvement which considerably simplifies the task of the operators;

- machines working with point-to-point or line motion control system, i. e. by means of discontinuous control (drilling, boring machines) and machining parallel to the axes (milling machines, for example).

  It should be noted that in the United States drilling machines (single spindle and NC turret drill) represent one fifth of the total of numerically controlled machine tools (3,221/16,500), while boring machines amount to 10% of this total (1,728/16,500), which goes to show the numerical importance of these two types of machines;

- Contouring machines, i.e. with continuous control (milling machines, parallel lathes . . .).

- Multi-purpose machines and machining centres with or without automatic change of tools.

To illustrate the above the figures 1 to 5b show various types of numerically controlled machine tools.

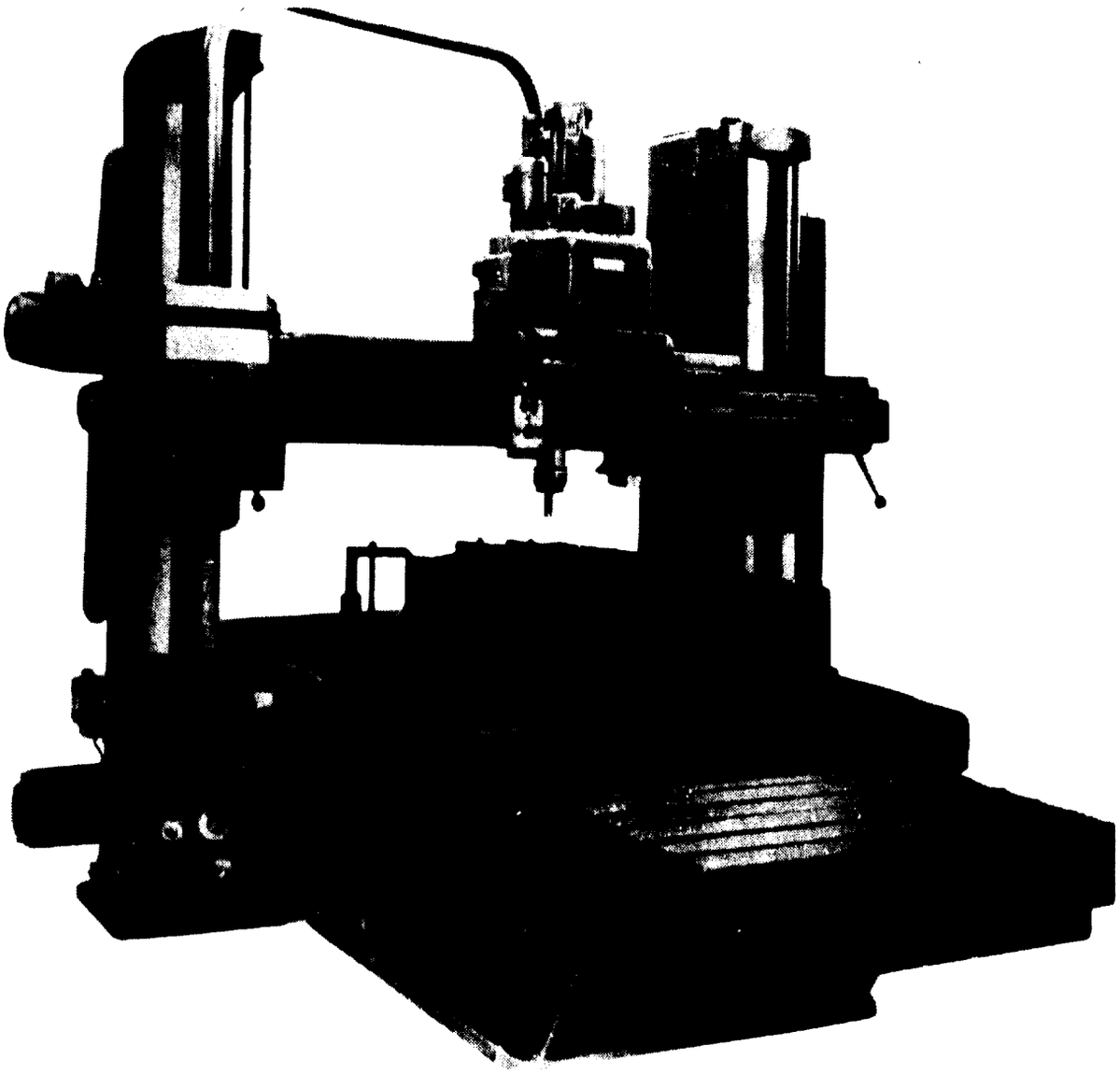

Figure 1.

Numerically Controlled Boring - Drilling Machine
(Two axesand manual display of co-ordinates)

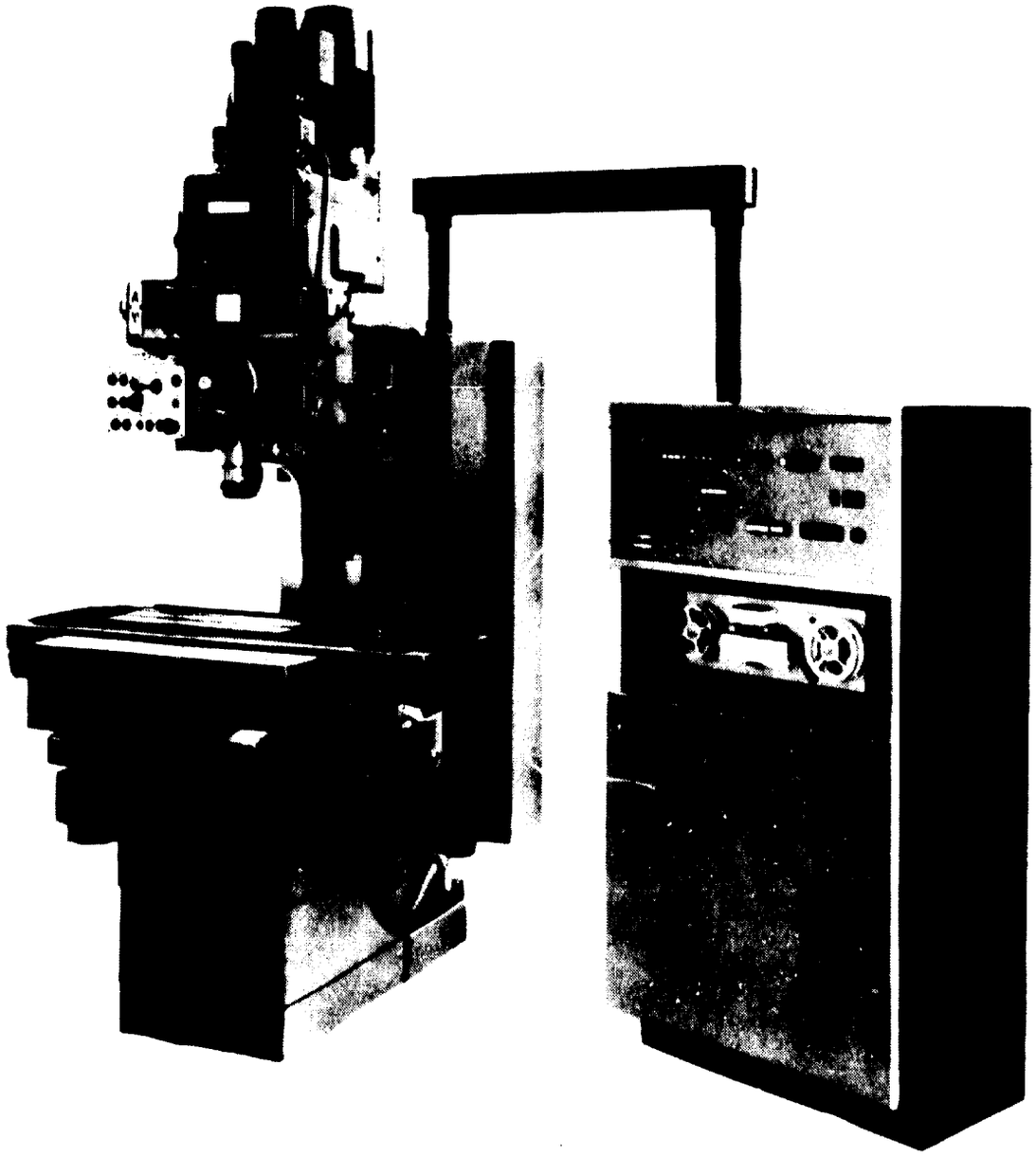

Figure 2.

Numerically Controlled Boring - Drilling Machine
using punched tape

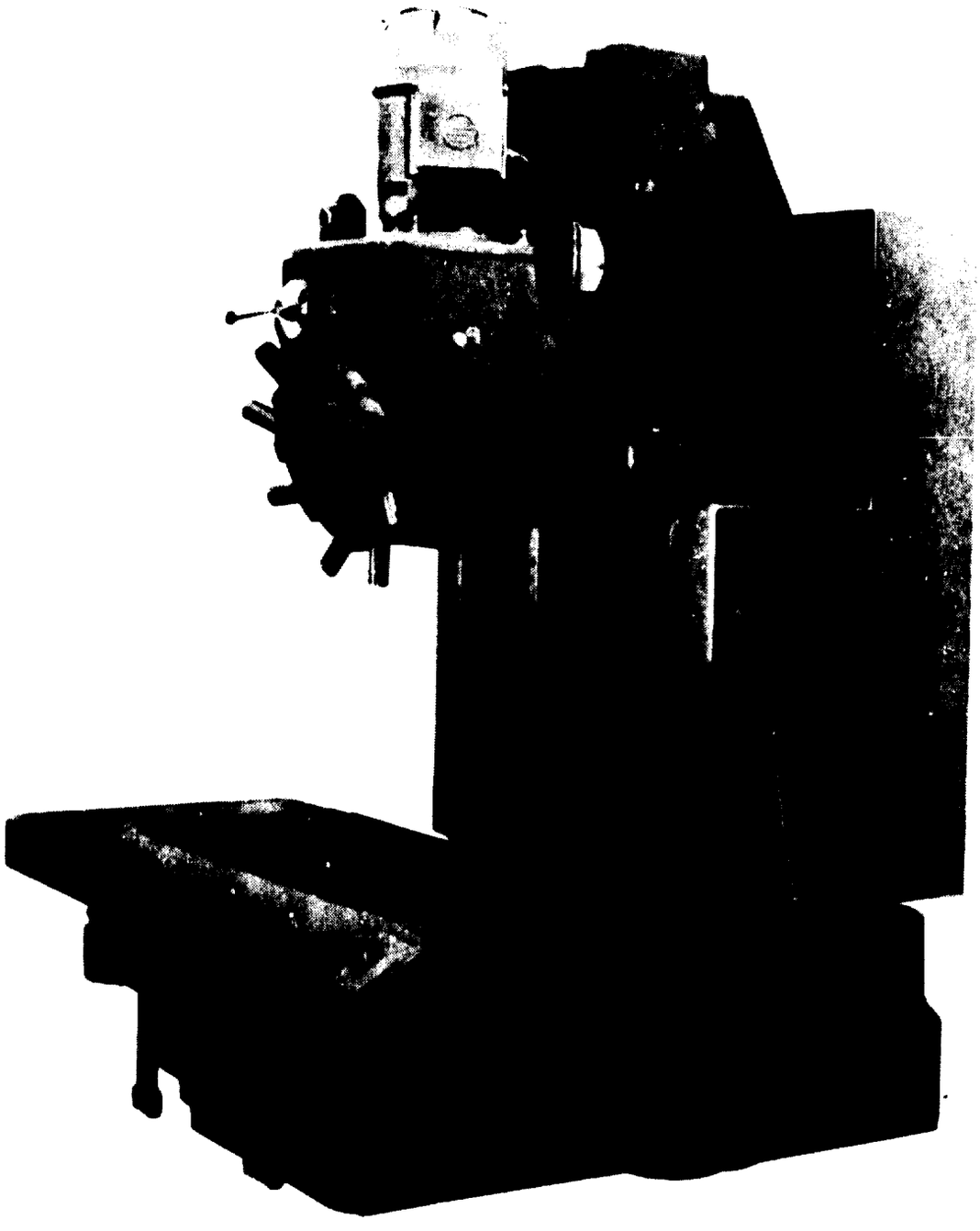

Figure 3.

8-Spindle Turrethead Milling - Boring - Drilling - Tapping Machine
with
numerical control of the longitudial and transverse displacements
of the table and plain sequence control of the vertical displacement
of the spindlehead by adjustable mechanical steps.

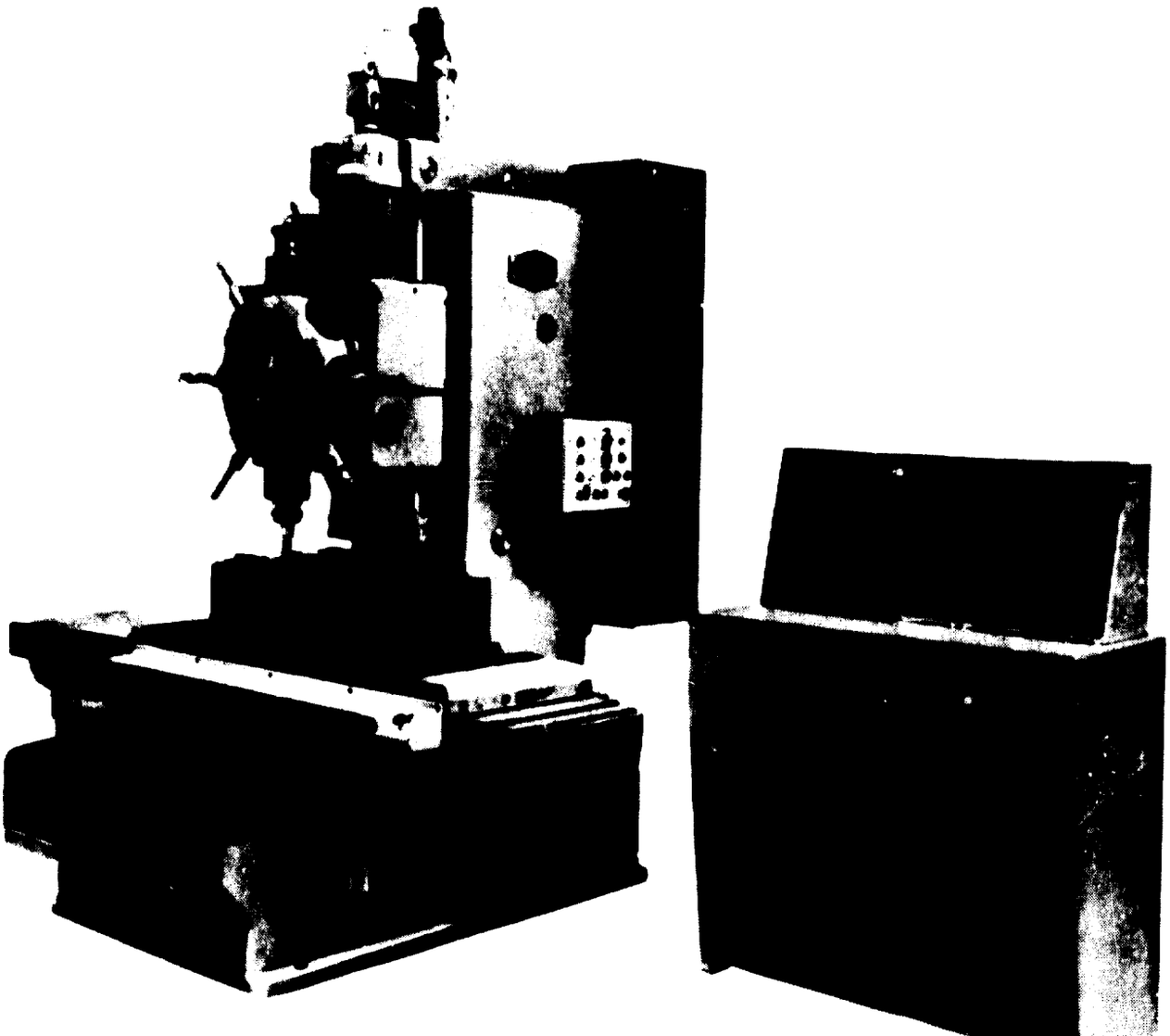

Figure 4.

8-Spindle Turrethead Milling - Boring - Drilling - Tapping Machine
(Three axes controlled table and spindle-head movements)

Figure 5.

Machining Center with Tool-changer

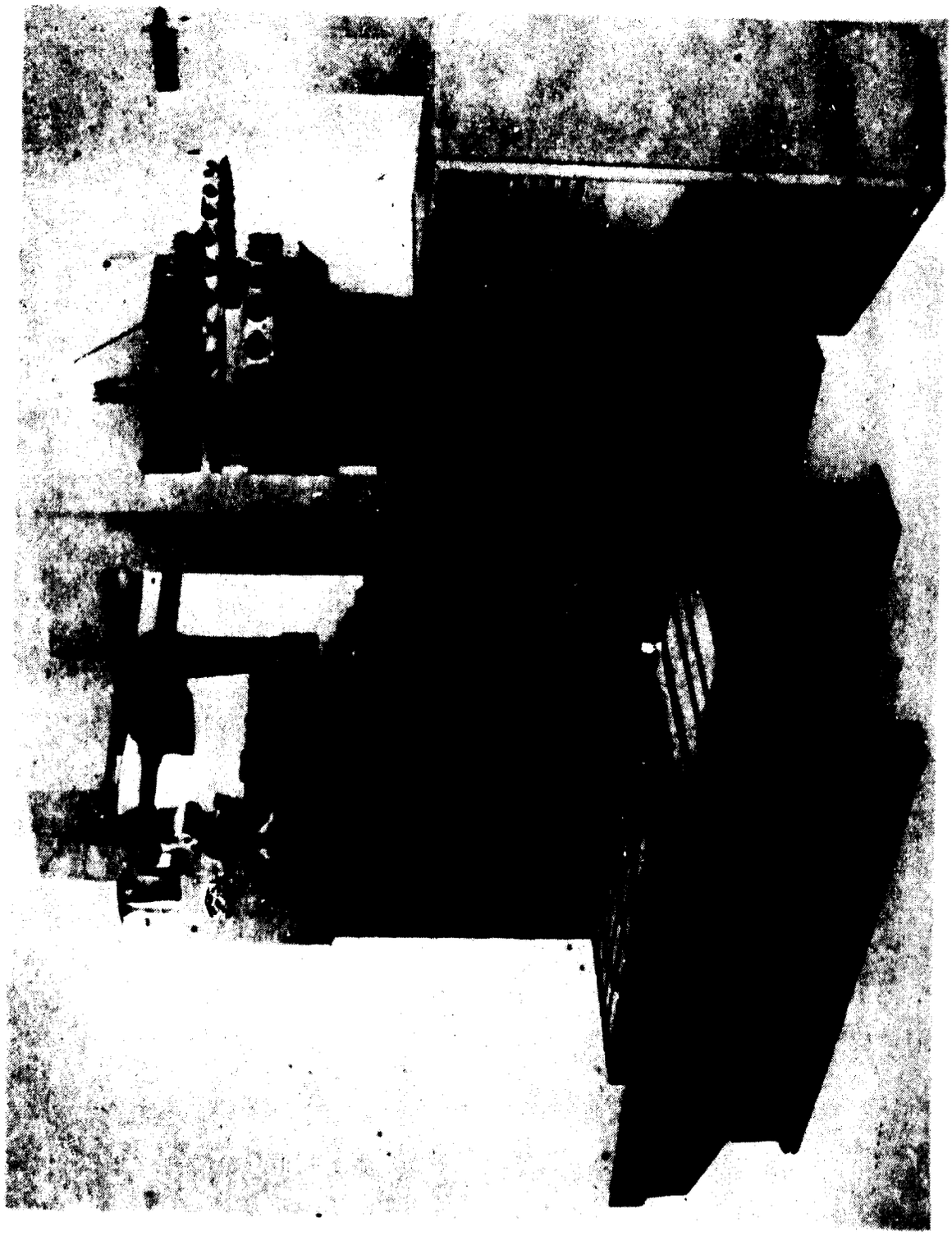

Figure 5 a.

Machining Center with Tool-changer

The above refers solely to metal cutting machine tools but we should not overlook forming machines working by deformation without chip removal. For numerical control has also made its appearance in this field; for example we may quote:

- punching presses, section shearing and punching machines working without prior marking out of the piece to be machined (angles, for example) and without template;
- press brakes for automatic preselection of bending angles by setting of the stroke;
- cutting off presses: on one and the same machine, for example, the numerical control ensures the linear positioning of a cross carriage table carrying the sheet to be cut and the directional positioning of the turrethead holding the tools;
- tube bending machines: a first operation is performed for setting purposes by a specialist. Errors due to the flexibility of the tubes can then be automatically corrected during the following operations; for this purpose, the deviation is measured on the first piece, the necessary correction is computed, carried out and then incorporated in the control programme of the machine.

Numerical control provides automatic operation of machines, while eliminating jigs and fixtures and other expensive tooling. It makes it possible to pass rapidly from one manufacturing process to another by a simple change of the programme tape and the useful running time of the machine goes from 20 to 70 % approximately.

Numerical control increases the flexibility, versatility and performance of the machines to which it is applied.

In view of the progress already achieved in industry, gains in production must now be sought not in a reduction of cutting time (which is proportionately not very great in the complete

manufacturing cycle of a product - only a few percent *) but in a reduction of waiting periods due to passing from one machine to another, of time spent in loading, setting, inspecting and unloading of work pieces. It is in these areas that numerical control can prove its real value.

It is important to note that automation by numerical control is intended mainly for small and medium scale production. Mass production manufacturing processes, on the other hand, have long since been automated thanks to transfer machines and special machines designed in each case for the machining of a specific part.

Precisely because of its advantage, numerical control has found its place first in the aeronautic and aerospace industries for the machining of intricate and urgently needed parts which it would have been difficult to machine by the usual conventional methods. The machines used, however, are very expensive (contouring machines, machining centres).

It must be noted that numerical control of machine tools is progressing only very slowly in the other sectors of mechanical engineering at the present time. Most manufacturers are reluctant to scrap jigs and fixtures and conventional machine tools in excellent working condition or not yet amortized in order to acquire numerical control equipment at whatever price, so that the newer types of equipment will make their way only very gradually.

The main obstacles are basically the high price of the equipment and the fact that it is difficult to prove to customers that the first machines will pay off in the long run.

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*) Time of the complete cycle = 100
Waiting time = 80 to 95
Time on machine tools = 5 to 20
Cutting time (20 to 30% of the time on machine tools) = 1 to 6

In an article in Metalworking Production of May 4, 1970, the experience of three American firms is described: CATERPILLAR TRACTOR, INTERNATIONAL HARVESTER and DEERE and CO., manufacturers of agricultural equipment. Those firms took a very long time to adopt numerical control. CATERPILLAR bought its first machine in 1959. This purchase was made as an investment and in order to make a start in getting practical experience of numerical control (to become familiar with numerical control which cannot be learnd from papers in technical reviews, it is essential to possess a machine).

Three months were required for CATERPILLAR TRACTOR to incorporate this first machine in the production line, and it was only beginning with the third machine that the difficulties of putting them into operation were more easily overcome.

Although the first machine was bought as early as 1959, numerically controlled machine tools really began to be used effectively only after 1964.

Today this company considers that, thanks to numerical control, they have reduced costs of production and improved the quality of their manufactured product.

Similarly, DEERE and CO. bought its first numerically controlled machine tool in 1959, but really started to used numerical control on any considerable scale in 1963 only.

At the present time, the figures for the numerically controlled machine tools owned by these three firms are as follows:

CATERPILLAR TRACTOR	:	350 numerically controlled machine tools; (turnover : 2 billion dollars)
INTERNATIONAL HARVESTER	:	120 numerically controlled machine tools; (1969 turnover : 2.6 billion dollars 12 programmers)
DEERE and CO	:	26 numerically controlled machine tools; (1969 turnover : 1 billion dollars).

The N/C machine tool situation from the points of view of manufacture and use was approximately the following in 1968, in several industrial countries taken as examples:

T A B L E I

1968 Park of NCMT:

Machine tools	NCMT park	total park	%
USA	14,740	2,800,000	5
GB	2,100		
FRG	1,000		
FRANCE	350	500,000	1.5

The percentage of NCMT as compared to conventional machine tools thus appears to be relatively low.

T A B L E II

Number of NCMT manufactured in 1968:

		N C M T	total number of machine tools manufactured	%
	Number	Value		
USA	2,875	$364,000,000		20
GB	550	[illegible],000,000		8
FRG	440			
FRANCE	154	F 66,700,000 $ 12,120,000	F1,400,000,000	5

The relatively slow development of the use of NCMT which the above tables bring out is, moreover, generally true. It is enough to look at the measures which the Ministry of Technology (MINTECH) in Great Britain has seen fit to take with a view to promoting the use of machine tools with NC.

Trial period scheme:

Potential users are given the possibility to try out these machines at little cost in their own workshops.

Preproduction scheme:

Placing of preproduction orders with NCMT manufacturers with an opportunity for the user to receive one of these machines for trial without having to incur any expense for purchase, and with the possibility of buying it later at a reduced price if he finds it useful.

NCADS (Numerical Control Advisory and Demonstration Service)

Two bodies are financed by the Government under this third plan:

(a) PERA (Production Engineering Research Association) for point-to-point machines,

(b) RAE (Royal Aircraft Establishment) for contouring machines - available to firms interested in NC in order to help them in choosing machines likely to meet their needs, to assist in the solution of problems involved in programming and technology in general, as well as to inform them on the practical use of NC in the various aspects.

The Federal [illegible] and Scientific Development is about to take similar measures starting at the end of 1971, - production scheme, in particular - with the same purpose in view. to promote the introduction of NCMT in the small and medium scale mechanical engineering industries. Furthermore, a body designated as ADETA (Association pour le Développement de la Programmation Automatique), partly financed by the Government, intends to act as adviser to potential users of NCMT in the same way as PERA and RAE.

A recent survey ran in France among fifty firms where N/C machine tools are in operation, has given the following results as regards the park of these firms:

T A B L E III:

N C M T	park composition		
	today		forecast for the near future
	number	%	%
boring drilling machines	24	30	4
milling machines	7	6	5
multifunction machine tools without tool changer	42	48	50
machining centres with tool changers	6	7	13
lathes	11	10	24

These figures show the importance of N/C drilling and boring machines in the first steps towards NC. The survey showed too that most of the firms, by lack of adequate means, resort presently to manual programming.

I do think the situation is exactly the same in several other countries and my opinion is that one must bear in mind that the above mentioned points represent the first mandatory steps towards N/C.

P R O G R A M M I N G

Another important problem is to be considered in the field of numerical control is that of programming.

NCMT may be programmed either manually or automatically.

Manual programming is most extensively used by small firms or by companies with few NCMT. On the other hand computer programming (automatic programming on computer) is expanding rapidly for contouring machines and with users owning a large number of NCMT.

Numerical control by itself does not solve all problems. The user must be provided with a language which enables him to engage in a dialogue with the machines.

In simple machining operations, this dialogue takes place by means of coded signals carried on a punched tape.

In more complicated cases, this coding soon becomes impossible to handle. Job preparation then calls for a symbolic language making it possible to describe in clear the desired machining instructions. This language is then processed on computer, producing a punched tape which corresponds to the code used.

Data processing facilities (computers) carry out specific operations only be receiving specific instructions designed for them, but on the other hand, programming of machine tools is effected by means of languages (designed for the machining problems to be solved) which are not understood by data processing facilities. It is thus necessary to make use of a device, called a post-processor, which converts the data supplied by the computer into a form which can be understood by the machine tool.

The Process of computer programming is basically as follows:

(a) the programmer of the planning department describes the different phases of machining using an appropriate symbolic language(APT)*;

(b) the programme of the part to be produced is punched on a card and fed into the computer where it is translated into machine language with the help of a processor;

(c) the general solution is translated into a language understood by the particular machine tool for which it is intended by means of a sub-programme called a post-processor;

(d) the instructions for the machine tool are punched on tape (or recorded on magnetic tape).

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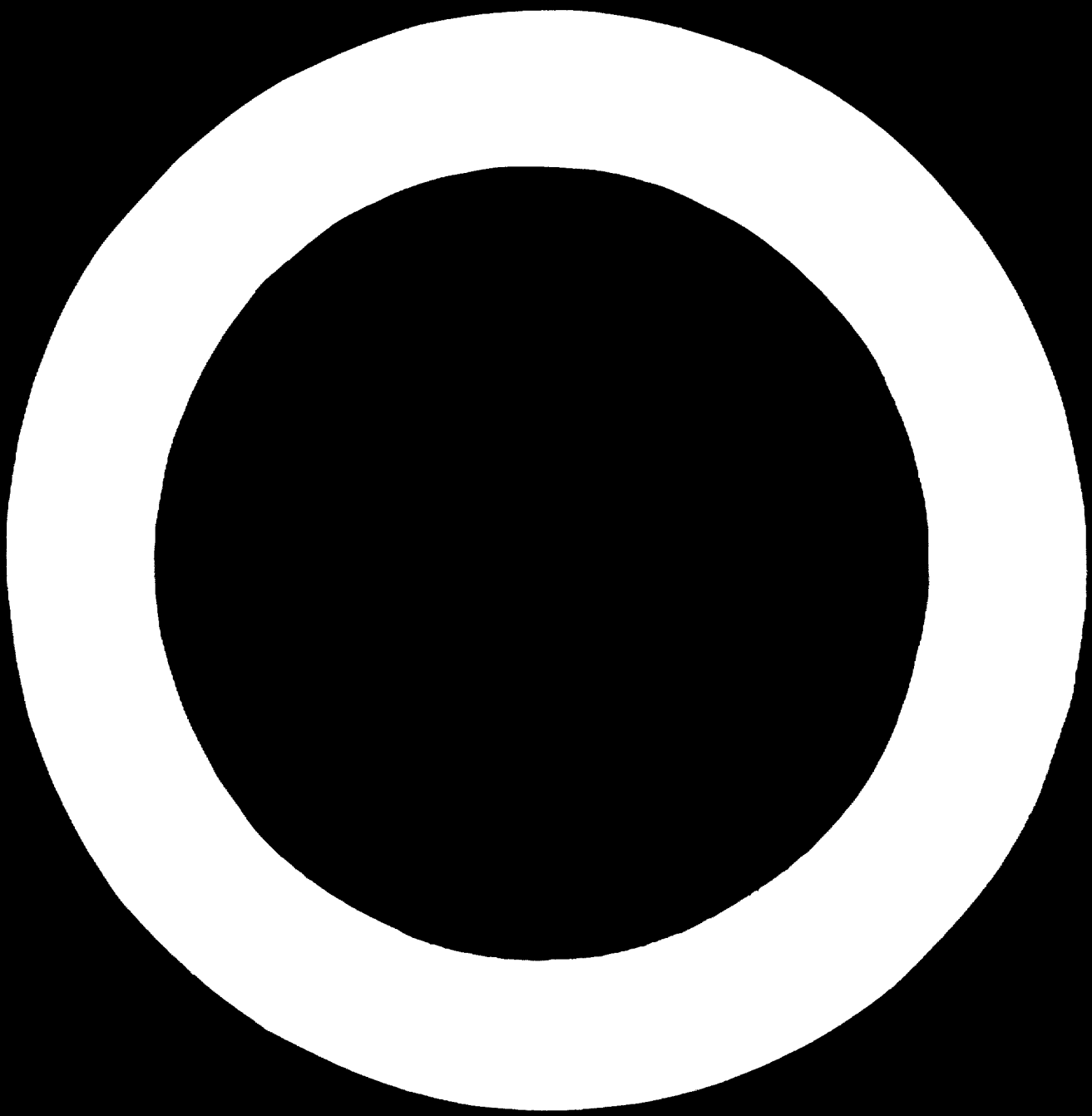
*) APT = Automatically Programmed Tools: a programming system developed for contour milling with several axes and high capacity computer.



Languages of the APT type require powerful, high-capacity computers which are not always available to the user and whose hourly price is in any event very high.

In France, the first users - aircraft manufacturers - have followed the lead of the United States and have adopted the APT language but this language makes it necessary as has already been pointed out, to use high-power computers which are not yet very widespread in industry; thus, when NC was introduced into other fields of mechanical engineering, it was quickly realised that this language was too complex for most mechanical parts. (In the United States moreover IBM has found it necessary to develop ADAPT for two dimensional contouring).

In view of this, a simpler language called IFAPT - derived from APT as its name indicates - has been designed in France. More recently, this simplification has gone much further with the development of "mini-IFAPT", a language which is intended for a broader range of users and which concerns only the programming of point-to-point machining and that of machining parallel to the axes. Mini-IFAPT has the great advantage of requiring only a low-capacity computer.

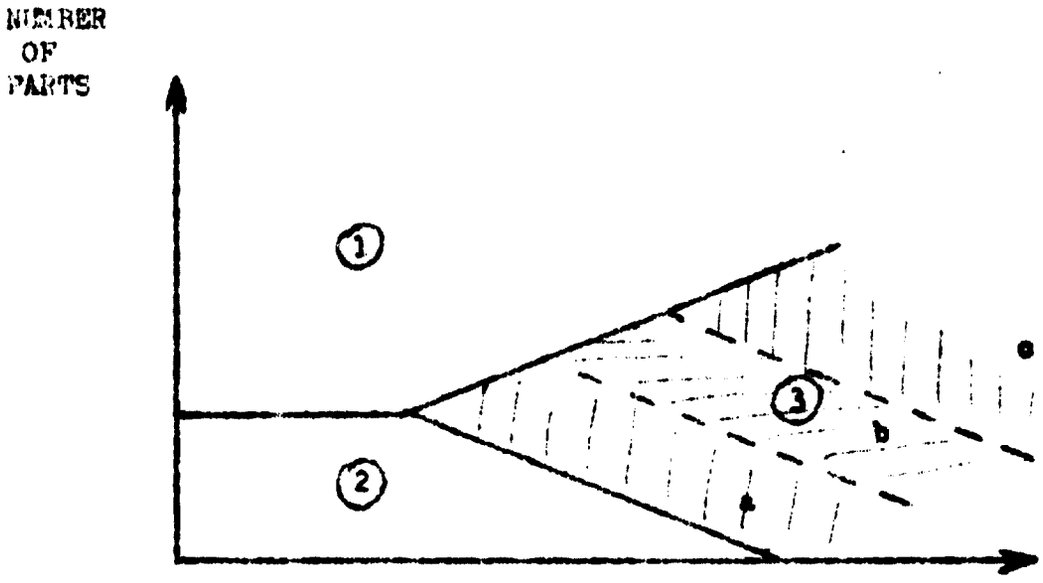
With the same aim in mind, PERA in Great Britain has developed the "PICNIC" language, intended essentially to simplify the work of most users of NCMT.

Research is now going forward throughout the world directed, it would seem, towards the development of specific programmes better adapted to the manufacturing processes of each firm as well as towards developing aids to manual programming.

In any case, we witness in Europe and the whole world a complete absence of standardization and a real Tower of Babel in programming languages. Therefore, it would seem appropriate for the developing countries to be cautious and to wait for all this to shake down, confining themselves for the time being to manual programming alone. A "wait-and-see" policy seems to be what is called for.

FIGURE 6

"Complexity - Number of Parts - Machine Tool" relation
(field of application of NC versus number of parts to be machined and their complexity)



(1) Zone of transfer - machines and special machine tools

(2) Zone of conventional machine tools without special tooling

(3) Zone of NC
- a) one spindle
- b) multispindle
- c) with tool changer

Numerical control is justified if :

- production is small or medium sized and preferably repetitive;
- the parts to be machined are not too simple (fig. 6);
- a high rate of use of the machine is foreseen (a shift of eight hours work per 24 hours is completely insufficient since the machine and its amortization represent a heavy expenditure).

On the basis of profitability studies, it is obvious that NC is most suitable for those countries where labour is scarce and expensive. This is therefore not a promising point of view from which to judge the advisability of applying NC in the developing countries.

The main advantages of NC which may be considered relevant in the case of these countries are :

- the reduction of setting up time;
- the elimination of jigs and fixtures;
- the improvement of quality (reduction of inspection and of scrap);
- economic production processes possible on a smaller scale, which involves a reduction in inventories;
- greater accuracy and better repeatability;
- substantial reduction in human errors;
- the possibility of using less skilled labour.

But if it is no longer necessary to employ highly skilled machine operators, on the other hand, programmers are required for the preparation of the job which raises the problem of training in addition to which there is the problem of the maintenance of new complicated and expensive equipment (electronic control circuits).

In the case of the developing countries, it seems that a first stage should consist in setting up a pilot workshop.

A clear distinction should be drawn here between contouring control and the two other systems: point-to-point and line motion.

Continuous path control, or contouring control, a costly and complex system, seems, for the time being, to concern only a small

sector of industry: indeed, it is designed for firms which are usually in the forefront of progress and which, for the most part, have no need to be sold on the idea. The special case of this type of control, moreover, involves problems completely different from those relating to the point-to-point system.

The point-to-point system, much simpler and considerably lower in cost, corresponds - and herein lies its real value - to 80 % of the needs of industry. It is quite clear that, in the initial stage, all effort should be concentrated on this type of control. Furthermore, it is important to note in this connexion that the use of the point-to-point system of numerical control, like that of machining parallel to the axes, does not necessarily require the use of electronic computers: in simple machining operations which are quite common in many workshops, manual programming is fully justified.*) This should make the introduction of NCMT possible in a certain number of enterprises without excessive difficulty. This initial stage would certainly have the result, after some period of trial and error, of subsequently facilitating the use of machine tools for production purposes requiring more sophisticated programming.

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*) Manual programming is quite sufficient for parts that require simple machining operations (drilling, tapping, line motion milling and plain turning as long as the number of instruction blocks carried by the punched tape does not exceed a reasonable limit. The second step is a resort to programming aids such as small computers to determine the dimensions for machining, repertory-type of standard machining sequences....

C O N C L U S I O N S

In the particular case of the developing countries, it would be wrong, in our opinion, to want to take shortcuts. Some preliminary action, however, would be useful, especially with a view to preparing the ground for the future. This action might take two forms:

(a) It might be possible to establish an official organization, a kind of pilot workshop, which might or might not be part of an already existing machine tool technical centre, whose role would be to provide information about numerical control and to prepare in advance to assume the role of a training body, and, in due course, of an adviser to the first users so as to provide guidance and assistance with programming and the starting up of production.

(b) It might also be possible right now to consider using NCMT of the simpler types (manually programmed drilling machines, for examples); in drilling jobs the numerical data are not difficult to determine, they can be prepared manually and punched on tape. This initial use might take place in vocational schools to train technical programming staff as well as in a certain number of workshops whose production lends itself to the use of NC (small batch production).

NC will certainly have a role to play in the developing countries since it will provide them with more versatile machines for varied small scale repetitive production.

Much is being said today about new leaps forward in the mechanisation and automation of mechanical engineering:

- integration of interpolators in machine tools (DNC - direct numerical control);
- use of computers to optimize machining conditions;
- use of adaptive controls *) to make machines self-adapting to the job they are required to perform;

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*) An adaptive control is a system that uses sensors to gauge a machine's feeds and speeds or other factors and then feed back data to optimize feeds and speeds and the cutting rate.

- direct transition from the engineers' design to the instructions controlling the machine tool without passing through the previously unavoidable intermediate stage of conventional technical drawings and blueprints (one day the stage may be reached where man, now capable of giving instructions in writing to machine tools, might confine himself to giving them purely verbal orders).

All these prospects for the future should not, however, make us lose sight of the current problem of making proper use of the opportunities offered by numerical control of machine tools here and now.

This problem concerns a technique which is a reality, not something in the future but a tool which is already in our hands and from which we must endeavour to derive the greatest benefit for the good of all.

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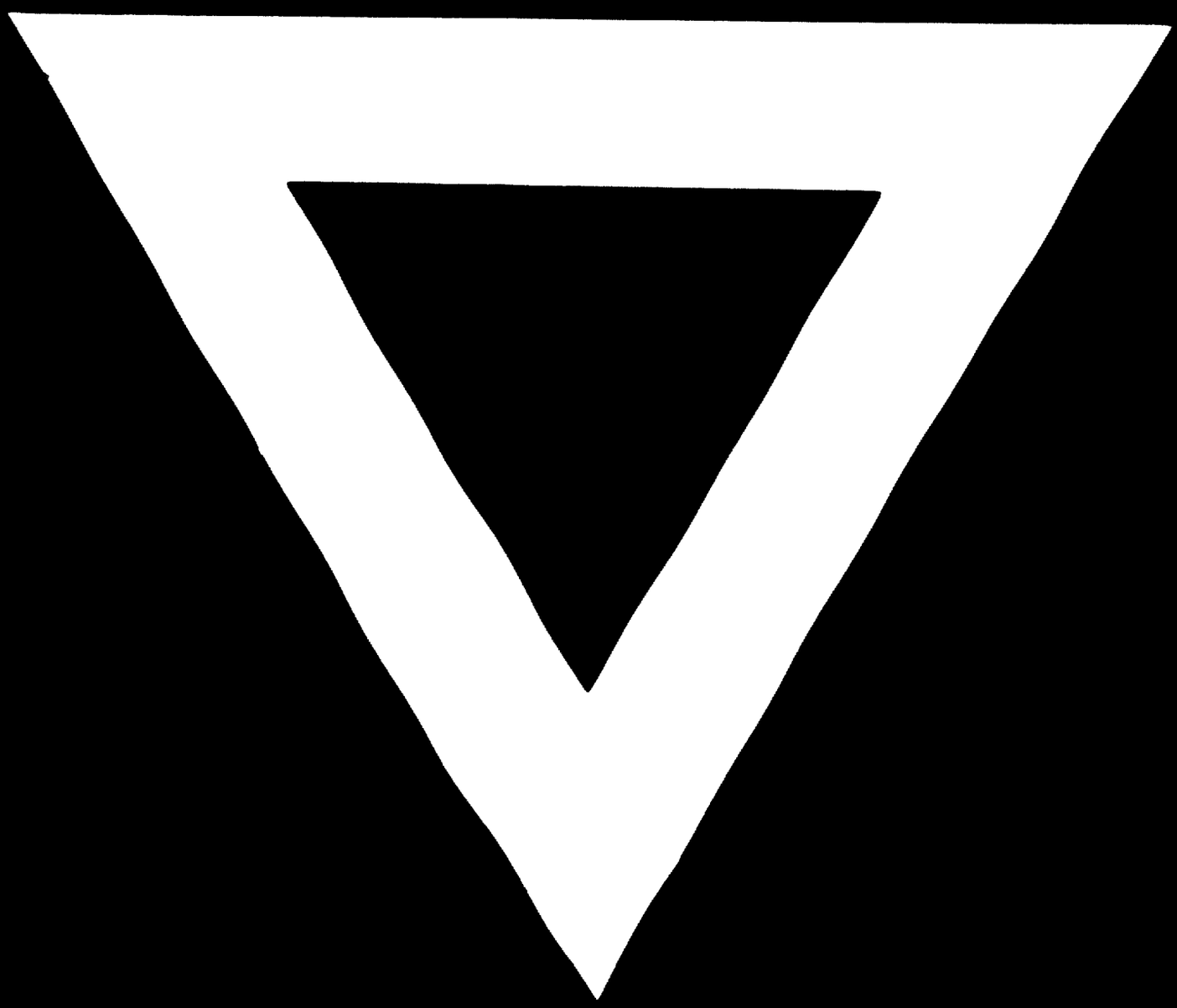

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