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TECHNOLOGICAL ALTERNATIVES FOR THE FABRICATION OF SEMI-FINISHED AND FINISHED PRODUCTS OF COPPER

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INTRODUCTION

The UNIDO Secretariat requested the author to prepare a study on "Technological Alternatives for the Fabrication of Semi-Finished and Finished Products of Copper." Present study was prepared in accordance with the relevant Terms of Reference and the main recommendations of the First Expert Group Meeting on the Non-Ferrous Metals Industries, held in Vienna, 18-21 March, 1985.

The scope of this study included

a) analyses of present and future markets of copper and copper alloys, basic trends of changes in intensity of use of copper in different groups of countries,

b) review of technical changes, substitutions and other factors affecting the demand on copper and copper based alloys,

c) examination of traditional and new technological routes for the production of copper and copper alloy wire, strip, sheet, tube, bar, casting and hot stamping indicating the most important advantages and disadvantages of the different technological options,

d) survey of the main trends of reseach being conducted in the various sectors of non-ferrous semi production, showing their aim.

On the basis of the analysis of the present situation and changing pattern of market, technological level and research works, recommendations are given relating to the selection of those technologies which seem to be more suitable for developing countries with the aim of promoting a steady self-reliant development in the said countries.

The presented analysis of the technological developments and alternatives is based on the relevant publications and the knowledge of Copper Industry of the consultant. So the results and recommendation might be amended and/or expanded during the Consultation Meeting through the contributions of copper expert colleagues.

I. CHANGING TRENDS OF COPPER CONSUMPTION

I.1. GENERAL TENDENCIES

The copper consumption of the world in the last decade has experienced and extremely dynamic growth.(Table 1.) Prior to 1946, the total copper production of the world is estimated to 72 million tons, while the cummulative copper consumption between the years of 1946-1980 amounted to 169 million tons - that is 3.2 times more than in all the years before 1946.
While the annual production in 1950 was as low as 2.5 million tons, the world total copper production in 1980 reached 7 million tons.
At the same time, however, the growth rate of the world consumption of refined copper seems to slow down, though it hasn't come a standstill inspite of the serious economic crisis experienced all over the world. (Table 2.)

Between 1950-1981 the growth rate amounted to 3.4 %. Within this period of time : it was 4.6 % in the 1950s, 3.5 % in the 60s and 2.1 % in the 70s within the circle of the non-socialist countries.

Much of the growth of production took place outside established centres of production. Accordingly, the share of major companies in the USA and Europe fell from 93 % to 45 %. In 1950 over the half the world's output was supplied from North American mines. Six companies, four of them in the USA, accounted for most of the value added in the world by the industry. From mines in the Western USA and Latin American subsidiaries, US firms accounted for two-thirds of the world supply and most copper fabricated products.

Estimated cumulative copper production prior to 1946,	72	million tons
Cumulative copper production 1946-1980	169	million tons
Ratio : 1946-1980/prior to 1946	2.3	
Annual production, 1950	2.53	million tons
Annual production, 1980	6.97	million tons

Table 1.

World production of primary copper

Growth rate of copper consumption :

1950 - 1981	3.4 % per year
1950 - 1960	4.6 % per year
1960 - 1970	3.5 % per year
1970 - 1980	2.1 % per year

Copper prices in real value :

1960 - 1970	+ 3 % per year
1970 - 1980	- 1 % per year

Table 2.

Refined copper consumption and copper price trends in the non-socialist countries

By contrast, these firms in 1983 smelted less than a fifth of the world consumption. New centres of production and smelting exist in the Pacific Basin (Australia and Japan) and within the USSR, while nationalised companies manage expanding industries in Africa (Zambia and Zaire) and Latin America (Chile, Mexico and Peru). Thus, currently over half the sources of new refined metal enters world trade. The developing countries supply most of the incremental tonnages behind the remarkable expansion of the world industry. Instead of one dominant centre, today there are four major fabricating centres.

Experts predict there will be an accelerated growth in the next 20 years outside the USA. By the year 2000, the "rest of the world" demands are expected to double.
On a regional basis, the annual growth rates required will range from 8-10 % in Africa and Latin America to 4-6 % in Japan and the East bloc. The USA and Europe, in contrast, are expected to grow at 2-3 %, well below the world's average rate of 4.6 %.

Copper consumption is affected by several factors.
A further increase - beside its favourable properties - can be explained by the fact that while in the 60s the copper price has increased by 3% p.a. in real value, in the 70s an annual price decrease of 1% can be observed. For the aluminium this tendency was of the opposite, so copper became a relatively cheap metal.
The growth of copper consumption in various countries is very well explained with the theory of "intensity of mineral use" (IU). Defined as an economy's apparent consumption of copper devided by its gross national product (GNP), IU rises in the early stages of industrialisation

as a function of GNP per capita, but peaks and falls at higher level of GNP per capita. Thus the shape of an economy's IU curve would form an inverted U with less developed countries on the rising portion and advanced economies on the falling portion.
So in medium and low-industrialised countries the copper consumption is increasing with the GNP, the development of industry and standard of living. From copper consumption point of view, the highly developed countries, although at different points of time, but got saturated. In the USA, this saturation set in before the Second World War, while in the West European countries it took place about the end of the 60s or in the early 70s. Thereafter the copper consumption per unit product of industry shows a declining tendency.

From the per capita copper consumption data (Table 3) it can be seen that in the non-socialist countries the average copper consumption is 2.5 kg/capita/year. There are, however, tremendous differences between the individual countries or groups of countries, while the annual consumption is 8.6 kg/capita in the highly developed countries, it is only 0.3 kg/capita in the developing ones. There are significant differences even between the western countries.

During the p. t two decades an enormous increase can be observed in the copper consumption of certain developing countries, for example in Brazil the annual copper consumption/capita has become fourfold between the 60s and 80s and amounted to 2 kg, and in South-Korea it raised as high as 4 kg/capita/year from almost zero.

Countries	1960 year kg/capita	1980 year kg/capita
Altogether	1.8	2.5
Developing countries	0.1	0.3
Developed capitalist countries	5.6	8.6
Belgium	8.3	31.0
Brazil	0.5	2.1
France	5.3	4.6
Great Britain	10.7	7.3
Hungary	2.8	4.6
Italy	3.7	6.9
Japan	3.2	11.8
Soviet Union	3.0	5.1
South Korea	-	4.0
Spain	1.3	3.6
USA	7.2	8.7
West Germany	9.7	12.1
Western Europe	5.7	7.4

Table 3.

Per capita copper consumption in the highly industrialized- and in the developing countries

The copper consumption data of the different industries (Table 4.) show that the major consumers are electrification and electric engineering industries. These branches of industry apply for 45-55 % of the total consumption. For that reason, an extensive increase can be observed in those countries where the industrialisation has just been started, such an example is Brazil, where electrification and transport took a tremendous development, or Korea and Taiwan, where electronic and electrotechnic industries swept ahead at high speed taking over the role of textile industry.

I.2. SUBSTITUTION AND TECHNICAL CHANGE

A) DECREASE OF COPPER INTENSITY

The following four factors are influencing the dilution of copper intensity:

1) Economy in the use of copper and copper alloys through advances in fabricating techniques and in the design of the finished products.
   Examples for that include thinner-walled and lighter gauge copper tube for plumbing system, finer brass strip for car radiators, miniaturisation in the whole field of electrical and electronic circuits and components, use of clad-metals for coins, ammunition, etc.

   New alloys with better mechanical and physical properties are fostering this type of material saving. Copper is being replaced by improvements in designs, such as multiplexing via pulse code modulation to upgrade capacities in junction circuits and trunk lines.

2) Substitution of alternative materials with similar physical properties to copper.

Industrial Sector	USA	W.Europe	Japan
Electrical Engineering, Electronics	46.3	54.3	52.0
Building Construction	15.9	15.5	8.8
Transport	10.1	10.7	17.1
Industrial Appliances	18.8	14.0	15.0
Consumer Goods	8.9	5.5	7.1
T o t a l	100.0	100.0	100.0

Table 4.

Consumption of Copper in Various Industrial Sectors of Some Highly Developed Countries

Power transmission systems offer an example in which the switch away from copper cable to aluminium cable took place despite aluminium's inferior conductivity and rising price relative to copper. The switch occured because the final cost per unit of power transmitted via the aluminium systems fell below that of copper installations (Newcomb, Toward a dynamic theory of substitution and technical change, AIME, 1976.)

More currently, the switch to composite materials and aluminium radiators in automobiles reflects the technical change to high-temperature combustion, which aids emission control and also eliminates weight. The overall result is a high-performance automobile with lower variable and fixed costs for the user. The elimination of conventional radiators may be a part of the system redesign.

Fuel economy legislations have resulted in a trend towards smaller vehicles and the drive towards higher efficiency will accelerate copper's replacement with aluminium, alloy steels and plastics.

In the highly developed countries at present, copper is being replaced by aluminium/steel-core cable in power transmission, by aluminium in magnet wire, transformers, and switch-gear. In construction, copper can be replaced by PVC tubing, and in transport by the trend to thinner walled and narrower tubing of aluminium, steel or plastic. These materials and a variety of new systems permit increasing substitution for copper in hydronic thermal aplications.

Materials substitution may take place at more rapid rates in the highly industrialised countries because most research is done there, replacement trends are pushed without as much concern over quality problems, and because markets are more open to imports.

3) Development of new techniques requiring other materials.

In the future fibre optics is expected to replace a part of the copper coaxial cables in telecommunications. This new technology is not taking over because it is replacing a scarce and expensive raw material - though this was a factor in its inception - but mainly because it is technically superior. It has many advantages over copper cable; it is much more compact, it is immune to electrical interference, there is no risk of electrocution or explosion as it carries no electric current, and it is extremely difficult to tap. One over-riding advantage though, is its efficiency. A fibre optics system carrying 2,000 telephone channels would need signal boosters only every 8 km, as opposed to the conventional system's 2 - 4 km.

Fibre optic systems using glass fibres as conductors, can carry far greater volumes of traffic than equal-sized copper cables.
Microwave towers, satellites and wave-guide systems also replace long-distance communication systems using copper.

4) Structural changes in industry

For instance a shift to road building at the expense of house building in the construction sector may dilute the copper intensity in this area.

B) NEW APPLICATIONS OF COPPER

Beside the above mentioned factors "diluting" the copper intensity in the different branches of industry, there are several new fields of application for copper and its alloys.

P.T.Gilbert of Yorkshire Imperial Alloys presented a review of the use of copper and copper alloys particularly copper-nickel, in marine engineering. Widespread use of copper alloys for marine applications could be attributed to the fact that such alloys had good corrosion resistance, efficient thermal conductivity, anti-fouling properties, and could be welded without difficulty. Copper alloys could be used to produce tubes and plates for condensers, heat exchangers, and evaporators in power stations.
Copper alloy and aluminium bronze tubes and plates are also used in desalination plants, petroluem refineries, and petrochemical plant.
The main materials for seawater piping systems for ships, offshore oil and gas platforms, and petroleum plants are aluminium bronze, copper-nickel and aluminium-bronze.

T.J.Glover of Inco Europe claims that it had long been established that copper and its alloys could prevent fouling of ships' bottoms. An increase in the surface roughness of ships' hulls due to corrosion and marine bio-fouling reduced speed and increased fuel consumption.
It is generally accepted that the efficiency of a hull is reduced by 1% for every 10 microns increase in roughness. Copper-nickel could reduce surface roughness because it was resistant to seawater corrosion and offered permanent fouling resistance. The hull of a ship the Copper Mariner, was built with copper-nickel hull in 1977 and after four years the corrosion rate was 0.05mm and the amount of fouling was negligible. However, the fact that cupro-nickel was about ten times more expensive than mild steel had somewhat prohibitive.

Use of copper for roofs and building expanded in recent years in several countries. This metal has been adopted more and more for wall cladding, too.

There is a huge potential market for super-conductors. The ratio of pure copper to the volume of super-conductor employed is about 1:20. The copper is extruded and drawn as a composite with niobium-titanium alloy.

Solar technique and heat pumps are spreading more and more due to the improved design of appliances. These devices can save a fair amount of energy using copper tubes - as the heart of the system - the heat exchanger. The efficiency of the system being a very important factor is attributed to the high thermal conductivity of copper.

Electric urban passenger systems are growing throughout the world. Compared to the 11 kg of copper used in conventional vehicles, all the electric vehicle system now available used sometimes as much as three times more for individual vehicles and up to ten times more for integrated public transport systems using back-up generation and transmission. Nearly half of the metro system's copper is used in the overhead cables, and the rest in substations and trains. Main-line railways can take up to 5 tons in each train and 6 tons in each substation.

There are a number of growth areas for electric transport : battery electric vehicles, hybrid vehicles using electric-augmented petrol or diesel engines, and tracked and dual-mode vehicles.

Some brass alloys have very unique properties. One of them is the copper-zinc-aluminium shape memory alloy. It returns to its original shape at a specific temperature, and is used as activating part of switches and other devices , e.g. opening and closing windows at elevated temperatures. Other brasses damp noise so they are used as machine parts in low noise applications.
A very bright perspective is opening for the application of these alloys.

Summing up the disquieting and reassuring tendencies in copper consumption, one can easily note that there is still a good potential for future growth especially amongst developing countries where electrical and electronic sectors, construction and transport are expanding fast. and copper intensity is still only a fraction of the same of the highly industrialised nations.

II. COPPER WIRE ROD MANUFACTURING

Copper's major field of application according to Table 4. is the electrical sector, where the high electrical conductivity, good physical properties, relatively high strength and corrosion resistance of copper are of great importance. In this sector copper is overwhelmingly used in the form of wires, cables, magnet wires, etc. Growing quality requirement and efforts of decreasing production costs resulted in revolutionary changes in the main technological routes.

Up to 1965, the standard processes involved the separate operations of wire bar casting, hot rolling and pickling. Although during this period the technologies were steadily advancing, particularly with respect to rolling mills and introducing continuous casting of oxigen-free billets, significant contraints were imposed by the discrete nature of the bars /typically weighing about 100 kg/, as well as the need both to reheat the bars for hot rolling and to relatively short lengths of rod during drawing.

Within the last decade, this procedure has largely been displaced by continuous processes. These feature the tandemisation of operations spanning melting of a cathode in-feed and coiling of bright rod in length, in effect, restricted only by the available handling facilities. Bearing in mind the relatively short time during which this dramatic change has occured, it is remarkable that by the end of 1984, the number of continuous processing units for re-draw rod, either installed or expected to be installed was around 100.

The success of the continuous processes is mainly due to bold innovations and improvements in design of equipment.

An important contributory factor has been the steady increase in the availability of high-purity cathode copper from electrolytic refineries. This situation has promoted the development of furnaces for the continuous melting of cathode, for direct transfer to a holding furnace associated with a continuous casting machine. Consequently, it has become possible to produce copper rod of both the tough-pitch variant and virtually oxygen-free, suitable for the most critical electrical conductor applications.

A) CONTINUUS-PROPERZI

The Properzi non-ferrous metals casting process was developed first for zinc and lead, and was later adapted to produce aluminium rod. In 1960 the company built its first copper rod caster, which had a capacity of 10 tph. This plant was sold to the USA's Southwire. A second caster was installed in the USSR in 1962. As rolling torques and loads are similar for aluminium and copper casting, Properzi was able to draw on its experience in aluminium rod casting in the development of the copper caster.

The "second generation" of copper casters was developed in the mid-1960s. These casters had capacities of 25 tph. Three were installed in Sweden, Greece and Italy. This range of casters was particularly aimed at high-capacity producers. Following requests from smaller producers, Properzi developed a "third generation" of casters which had smaller capacities and required low capital investment. Costs were reduced by the replacement of continuous shaft furnaces with reverbatory furnaces.

This new range of casters, including the modified "second generation" casters, had capacities ranging from 5 to 30 tph.

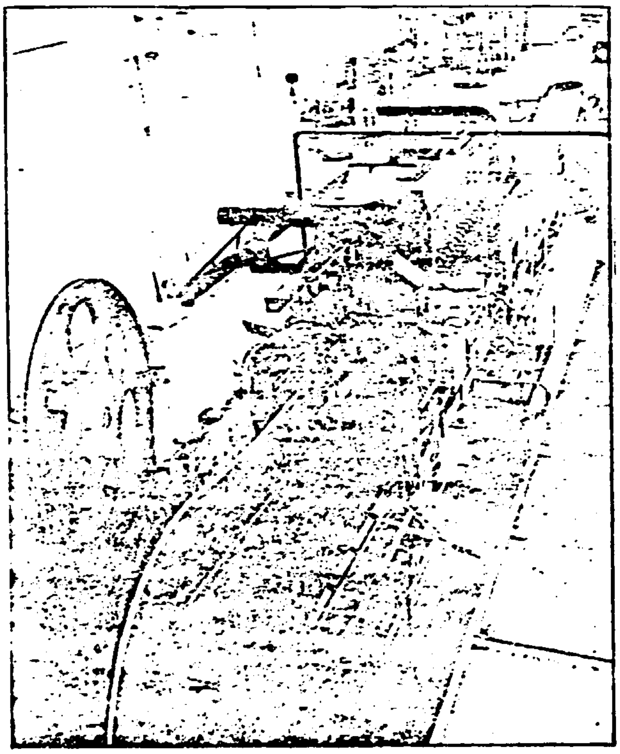


Figure 1. A Continuus-Properzi continuous copper rod casting line

There were two main types : casters with capacities up to 10 tph with either one or two reverbatory furnaces (designed for small and medium-sized producers); and casters with capacities over 10 tph with vertical shaft furnaces.

In 1977 Properzi developed a "micro" mill which was capable of cold rolling from a diameter of 8-16mm down to 1.5mm at a speed of 45 metres per second. The mill was designed to replace the traditional drawing process for small-diameter copper rod.

At present there are four standard Properzi copper casters which are built by Continuus-Properzi : Model Cu/2500-8/19 has a capacity of 25 tph and produces 6.35-8mm dia rod; Model 7E-Cu/1800-8/13 has a capacity of 14 tph and produces 8mm dia rod; Model 6E-Cu/1400-8/13 Mini has a capacity of 7 tph and produces 8mm dia rod; Model 6E-Cu/1400-8/13 Mini/S has a capacity of 4 tph and produces 8mm dia rod.

In the casting plant, the well-established two-wheel casting process is utilised. The lower casting wheel and the upper "idle" wheel are both encircled by a continuous steel belt which closes the ring mould fitted to the periphery of the lower wheel, to form the casting chamber and determine the shape of the bar . The casting ring mould has an outside diameter of 1,500mm.The caster's cooling system includes two headers which are fitted with separately adjustable valve sprays to allow variations in cooling.

The cast bar is guided through a conveyor on to an automatic shear unit which is fitted with a pinch roll to feed the shearing head. The bar is cropped continuously and cropped ends are collected in a water cooling tank. Immediately downstream of the shear unit is a trimming unit.

Following trimming, the bar passes through a brushing unit. This unit is fitted with four rotary steel wire brushes which remove the thin surface oxide layer and any burrs left by the trimming process. The bar is then fed to the rolling mill by means of a pinch-roll.

B) THE SOUTHWIRE PROCESS

The first Southwire Continuous Rod (SCR) line completely designed for copper went into operation at Carrollton, Georgia, in 1965, a development of the company's copper bar caster, which had its first run in March 1963. Over the years the system has been improved by continuing development of the shaft furnace, molten metal handling, casting, rolling, pickling, coiling and packaging of coils, and can be designed to meet the requirements of individual customers.

The normal run circle for a SCR copper system is 16-40 hours , with changeover time for new belts of about 30 minutes. Raw material is charged into a melting ASARCO shaft furnace, and the molten metal is then transferred to a holding furnace, by means of a covered launder. Again via a launder the molten copper flows to the pour-pot mounted on the casting machine, from which it is transferred by the pouring spout to the grooved periphery of the casting wheel. A steel band encloses much of the wheel's circumference, thus forming the casting cavity in which the molten metal solidifies. After solidification, a cast bar leaves the cavity by means of an adjustable stripper shoe mounted on the casting machine above the casting wheel which extracts the casting from the wheel during start-up.

An extractor conveyor then alters the movement of the bar from the vertical to the horizontal plane, so that the bar

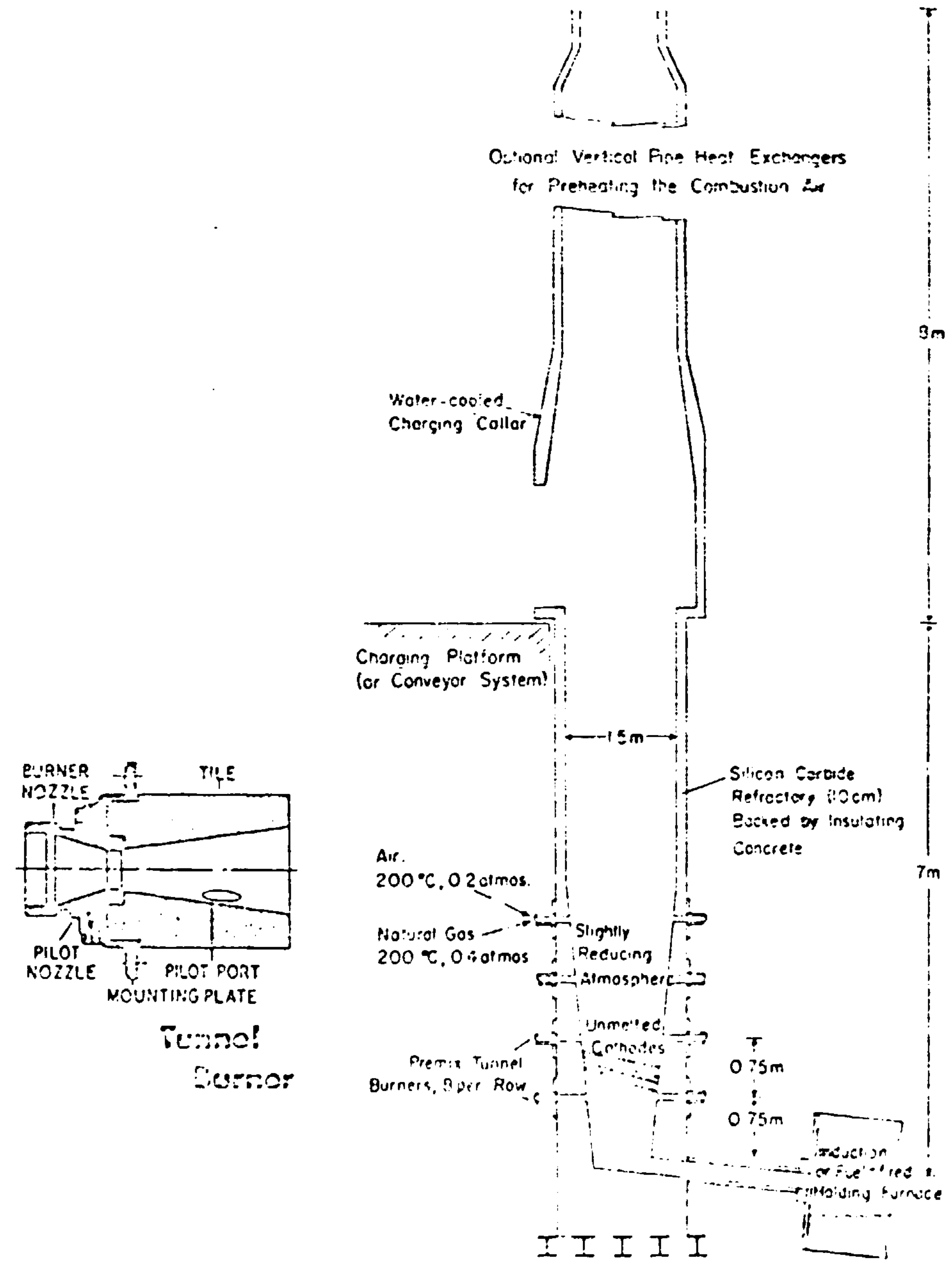


Figure 2. Diagram of ASARCO shaft furnace and tunnel burner

will be in the proper orientation for subsequent processing. Pneumatically operated presser rolls are lowered on to the bar as it passes over the extractor conveyor and pinch rolls, which maintain tension in the bar and to guide the lead end into an in-line shear, are positioned at the end of the extractor conveyor. The in-line shear squares the lead end of the bar and, upon start-up, crops the cast bar into lengths suitable for remelting until the physical and metallurgical quality of the bar are suitable for rolling.

After passing a bar handling and loop control table, to sense and correct variations in casting and rolling speeds, the bar enters a preparation device consisting of four scribing knives and four wire brushes, and then a pinch roll unit which positions and feeds it to the first stand of the rolling mill. During its passage through the mill the rod is protected from oxidation through a soluble oil protective atmosphere which also cools it, though the solution is kept at an elevated temperature to prevent overcooling.

On leaving the mill, the rod is subjected to a 3-phase in-line pickling process, which occurs as it travels within a compartmentalised delivery tube. In phase one, a mild acid solution is circulated through the tube to remove light oxide on the rod as it leaves the last finishing stand, while phase two consists of water rinsing, cooling the rod and removing any acid residue, with pressurised spraying boxes and air wipers. The third phase prevents surface oxidation by a water-soluble wax coating applied automatically. Hydraulically-driven pinch rolls then direct the rod to the coiler, with the diameter of each coil being determined by the rotational speed of the coiling head.

C) OUTOKUMPU CASTING PROCESS

In 1969, an upwards casting system was developed and a copper caster incorporating this system was brought on stream in 1970.

In this casting process, cathodes are melted in an induction furnace and the molten copper is charged into a holding furnace through a launder. From this furnace metal is drawn continuously through a vertical die cooler. A cooled graphite mount-piece is positioned into the melt and the upper end of the die is encircled by a water-cooled copper jacket. Cast strands are cooled as they are drawn upwards and are coiled into 2-3 tonne coils by coilers located at the end of each strand. The submerged die withdrawal unit is located above the holding furnace and the die coolers are fitted to a horizontal steel support. Two pairs of pinch rollers for each strand pull the cast rods through the coolers. The diameter of a cast strand can vary from 8-25mm depending on the required dimensions of the finished product.

After the casting operation, the unpickled rod is bright, unoxidised, and ready for cold working. Cold working is undertaken on a specially-designed tandem line where several rollers are installed behind one another. Since the rod reductions are small, the wire is worked gently in order to prevent rolling defects, which are prevalent in hot rolling. Cast rod can also be further processed by means of drawing. The rod diameter determines whether cold rolling or drawing is most suitable.

An important characteristic of this casting process is that speed of rod withdrawal is limited. Consequently, to maintain economic output levels, a caster has a number of strands working simultaneously.

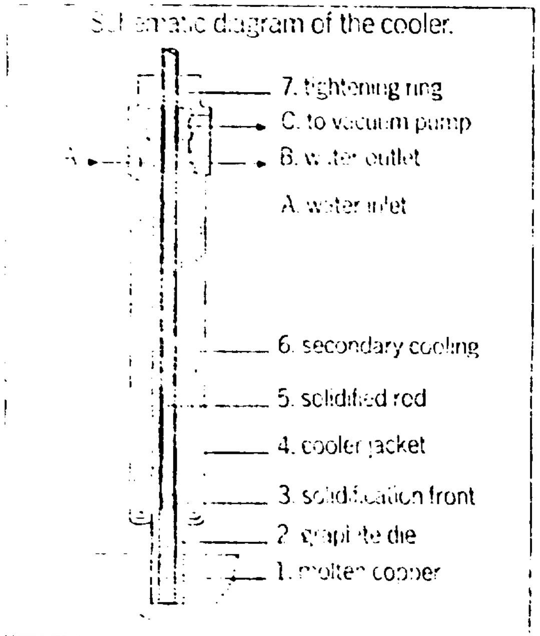
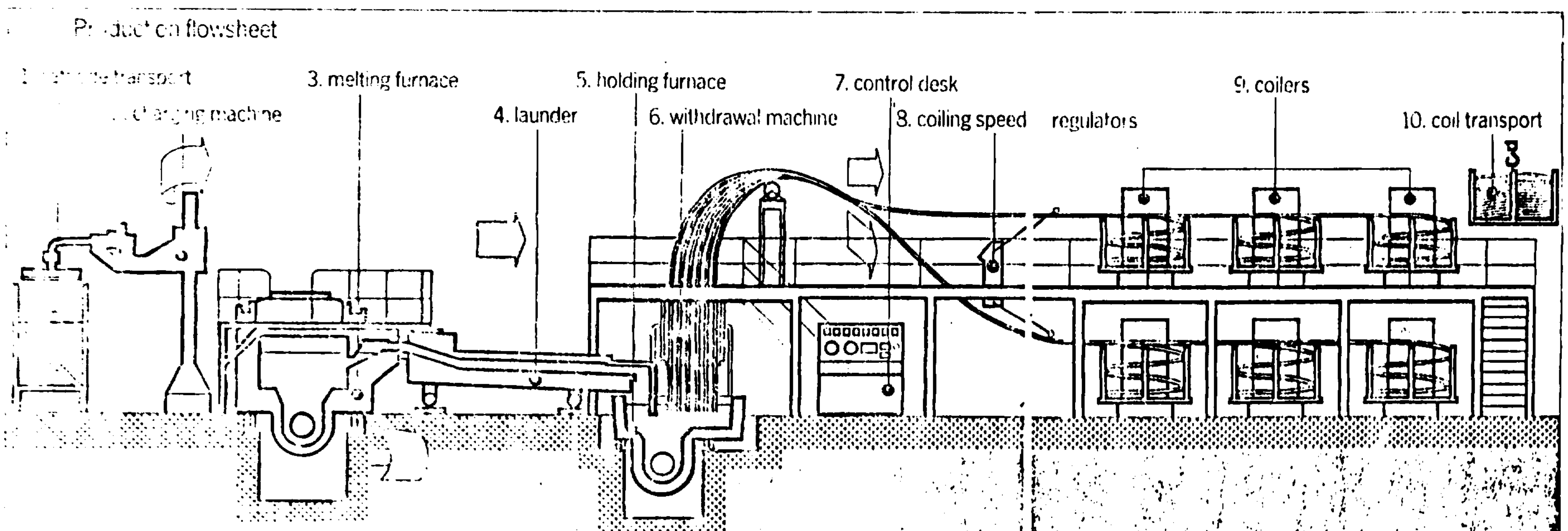


Figure 3. OUTOKUMPU upcast system



A pricipal advantage of the process is that complex equipment is not required as the process is very simple. This makes it possible to build and operate economically very small plants. It is also possible to add strands to a caster to increase capacity.

The casting line is completely automated and a 12-strand caster, for example, producing 2 tph can be controlled by one operator. Plant capacity is dependent on the number of strands, but as an approximate guide, each strand of a caster can produce 1,000 tpy. At present, there are some 20 Outokumpu casters in operation worldwide with capacities ranging from 3,000 to 30,000 tpy.

Outokumpu has production-scale experience in : oxygen-free copper (HCOF, DLP, and DHP copper), brasses, nickel-silvers, bronzes, copper-nickel alloys, precious metals and alloys, zinc, cadmium. The shapes and dimensions of the up-cast products can be varied over a wide range; not only rods (wires) but also tubes, strips, and various special profiles can be cast. The use of multi-strand machines makes the casting of small cross-sections economical. The smallest dimensions cast are : wire 3 mm diameter, strip 4 mm thick, tube of 20mm OD, 1.5mm wall thickness.

The production capacity of a plant depends on the dimensions of the product, the number of strands, and the rate of withdrawal, the latter generally being dictated by the nature of the metal.

Different types of furnaces can be used. Normal channel-type induction furnaces are used for oxygen-free coppers and certain alloys. Coreless induction furnaces are used for precious metals and some difficult alloys. Resistance and gas-heated furnaces can also be used if required.

D) SECOR CASTING PROCESS

Clecim, the plantmaking subsidiary of Creusot Loire, began development work (as Secim) on a copper rod casting process in 1975-76. A 10-tph prototype caster was built in that year and following a testing period of 18 months an order was placed by Australia's Copper Refineries of Townsville, Queensland, for a 25-tph rod caster. This caster, which incorporates the patented grooveless rolling procedure (RER), developed by Copper Refineries, was brought on stream in late 1977. The trademark for the Secim rod casting process is Secor.

More recently Cosim, Clecim's Spanish subsidiary, has built a Secim rod caster at the Oviedo plant of SIA Santa Barbara. This Secor line has a capacity of 10.5 tph and was fully operational at the end of 1982, two months after the start of the commissioning period.

Secor process description

In both the Secor plants which have been built so far, molten copper is supplied from an Asarco shaft furnace. It then passes through a launder into a holding furnace, and then into a pouring furnace, from which it flows through a spout into the caster. Slag traps are incorporated in the two launders. The pouring furnace can be controlled either manually or automatically to feed the caster at a constant rate. Automatic pouring is achieved by means of a "bubble" tube which is immersed in the tundish of the caster and fed continuously with nitrogen or argon.

The caster is of the wheel-and-belt type and top-pouring is practised. After cooling in the mould, the cast bar is passed from the casting wheel to an exit table which feeds the rolling mill. To avoid problems in the event of re-start in casting following any breakdown, the cast bar does not pass above the casting wheel.

Pinch rolls are on the exit table, which are synchronised with the casting wheel speed, take the weight of the bar to prevent bar tension at the wheel exit. The pinch rolls convey the bar to the edge trimming unit and entry shear. The trimming unit removes any fins on the belt side of the bar and chamfers bar corners. The entry shear crops the bar at start-up until the cast bar is suitable for rolling. The shear also disposes of rod in the event of a cobble. Cropped bar sections are cooled on the crop bar conveyor and stacked for remelting.

Prior to rolling, the bar passes through a pre-pickling and scale-breaking chamber. The bar is rolled using grooves to form a round then grooveless rolls (Copper Refineries' RER system) to form a flat before the final round pass. The non-twist rolling mill has cantilever stands grouped in blocks of 2-3-4 or 5 stands. An intermediate shear is installed on the mill to reduce downtime should a cobble occur. Cooling in the mill is achieved by circulating coolant from a central station. After rolling, the rod passes through a cooling tube where it is cleaned with non-acid solution. The rod is drawn through the cooling tube by exit pinch rolls and fed through a waxing unit to the coiler. The wax prevents tarnishing of the clean finished rod. A guillotine shear is positioned in front of the coiler to cut the rod, if necessary, to avoid coiler jamming.

The Secor casting process offers seven principal advantages. The automatic level control system ensures consistent high-quality cast bar as well as labour savings and improved operator safety. Increased operator safety and labour savings are achieved also by the automated cropped bar cooling and removal system. Mill stands are driven separately to ensure reliable production of a wide range of rod diameters.

The RER grooveless non-twist rolling process permits improved interchangeability of rolls, reduced operating costs and capital cost, and increased productivity. The life of the tungsten carbide rolls is prolonged by 50 % by use of the organic solution cleaning process. Fine wire production down to 71 microns can be achieved without rod shaving. Finally, the low height of the caster reduces building installation costs.

E) <u>CONTIROD (KRUPP-HAZELETT)</u>

In the 1960s Belgium's Metallurgie Hoboken Overpelt (MHO) and Usine á Cuivre et a Zinc de Liege were involved in the joint development of a copper rod casting process. The companies planned to install a rod casting plant at the Olen refinery of MHO. Development work was undertaken on a Hazelett twin-belt casting plant at Olen. In 1970 it was decided to build a continuous casting and rolling plant next to the Olen electrolytic copper refinery. Production of copper rod using the MHO-Usine á Cuivre et a Zinc process began in 1973. The plant included Krupp-Hazelett casting and rolling equipment and was designed for a capacity of 100,000 tpy.
The trademark "Contirod" was patented by MHO for the cast copper rod products.

In this process, cathodes are melted in a shaft furnace and the molten copper is passed to an induction-heated holding furnace. From this furnace, copper is charged into a twin-belt casting unit. Rectangular bars are produced by the caster. A pair of pinch rolls guides the cast bar to a scalping unit which trims the edges of the bar by means of rotating tools. The pinch rolls act as a speed-sensing device for casting and rolling. A pendulum shear is located near the scalping unit to crop bar during start-up and casting breakdowns.

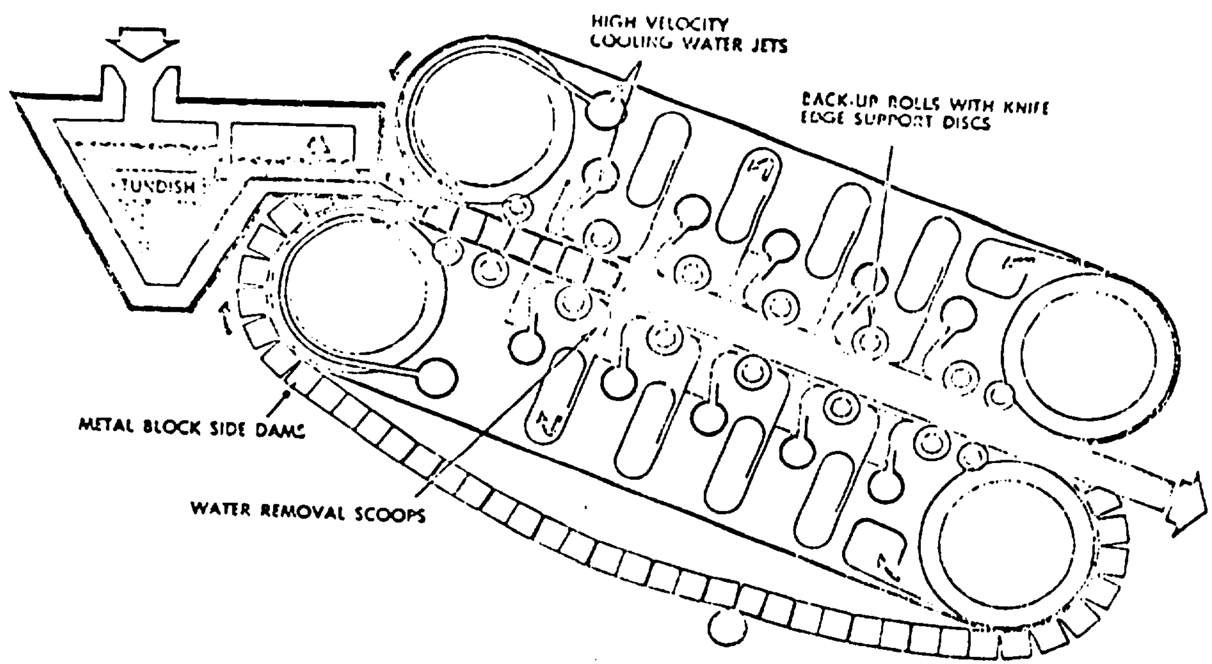


Figure 4. HAZELETT twin belt casting machine

Following scalping, the bar passes to a mill train consisting of 15 horizontal and vertical passes. The mill train is divided into four groups: roughing mill; intermediate mill; finishing mill with rotary shear; loop control unit and emergency shear.
The loop controls are designed to eliminate tension between passes to ensure production of high-quality rod.
After pickling in sulphuric acid solution, washing and soaping, rod is coiled to produce 5-tonne coils. Currently rod ranging from 6.35 to 22.5 mm is being produced on Krupp-Hazelett casting units with capacities ranging from 12 to 50 tph.

F) GENERAL ELECTRIC DIP-FORMING

In this process a cold, clean copper "seed" rod with a diameter of about 9.6mm is pushed upward through a graphite container filled with molten copper. The rod moves at 100 metres/minute and the copper depth is about 500 cm.
On emerging the rod is some 2.75 times its initial weight, with a diameter of about 16mm. When molten copper and seed rod are fed in continuously, a unit of this size will have an output of some 10 tph of hot rod, and by scaling up the diameter of the rod and the depth of copper, higher output rates are achieved.

The hot rod is cooled to 850 ^{0}C and hot rolled in a protective atmosphere then cooled to room temperature while still in protective atmosphere, and coiled.
Dip formed copper rod has a low oxygen content, clean dense surface, uniform single-phase internal structure and mechanical properties suitable for such applications as fine wire drawing.

At the same time, it has to be mentioned that this rod on the one hand is free from hydrogen embrittlement pheno-

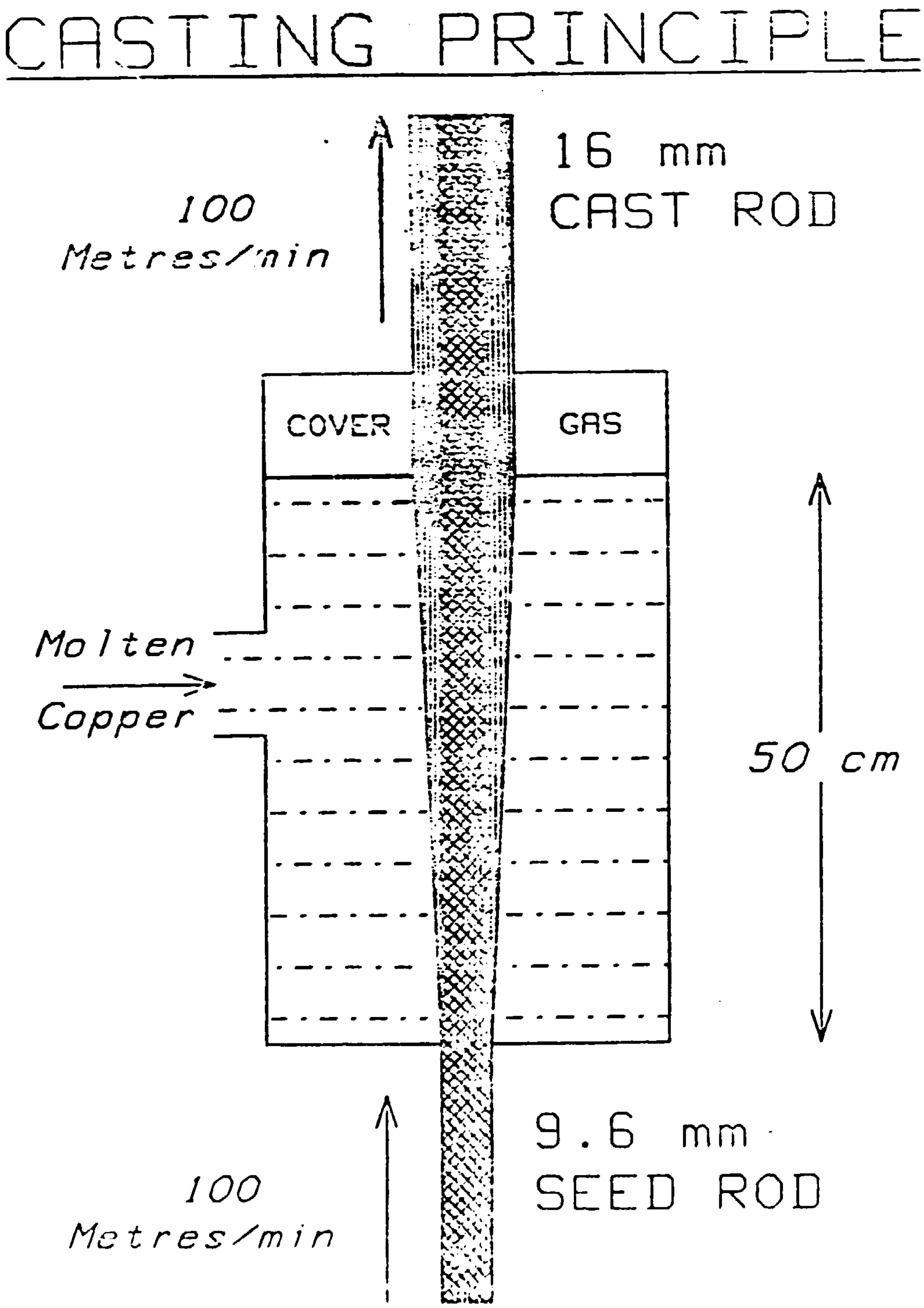


Figure 5. GENERAL ELECTRIC dip-forming process

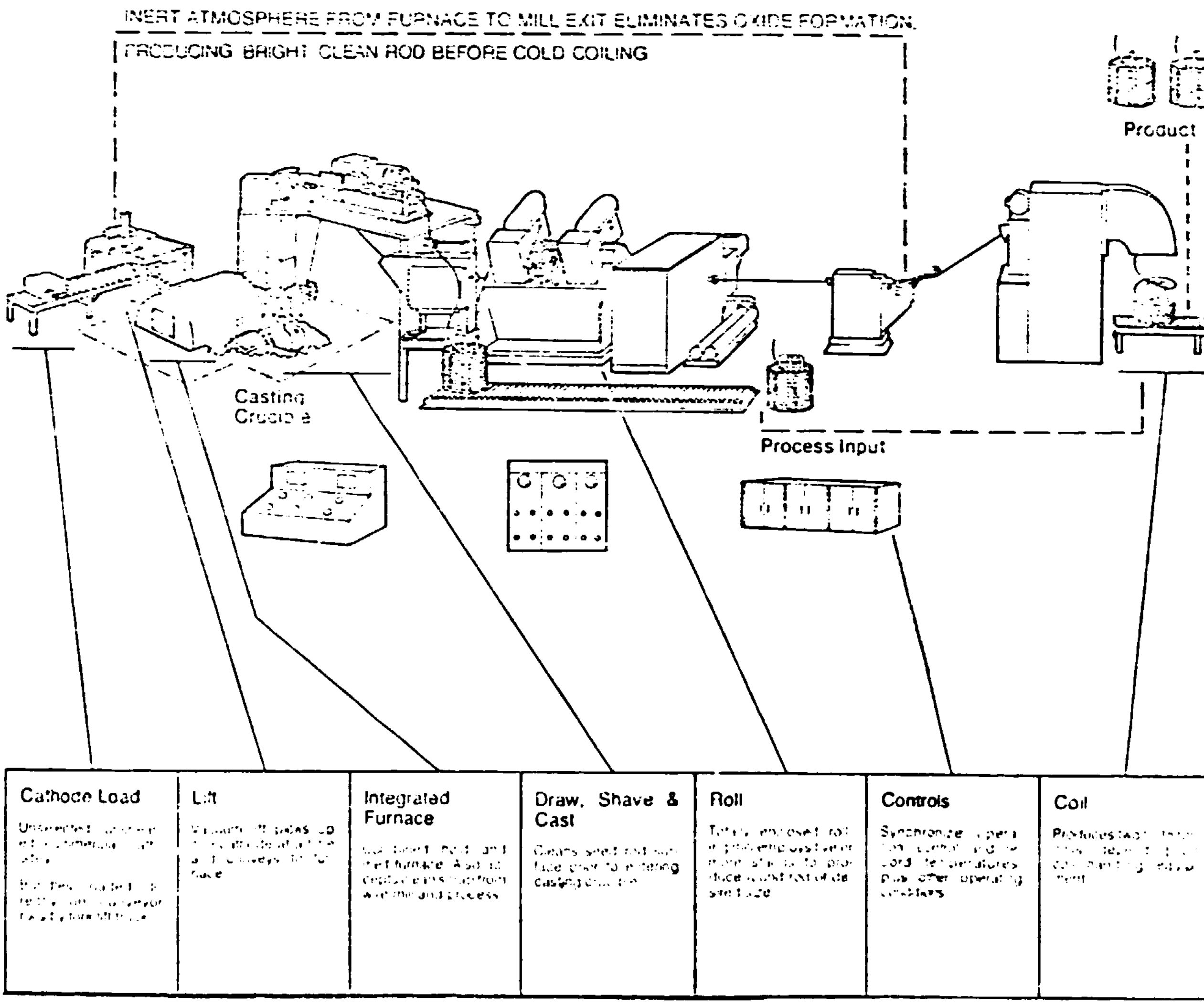


Figure 6 GENERAL ELECTRIC dip-forming process

menon, but on the other hand it has somewhat higher recrystallization temperature, which is always inherent to the oxygen-free copper. The dip formed rod is very much suitable even for special applications, where requirements are high.

G) GENERAL ELECTRIC LEVITATION CASTING (GELEC) PROCESS

The General Electric Levitation Casting (GELEC) process is basically a synergistic combination of an electromagnetic levitation field and a highly effective heat exchanger used in an upward casting mode. The result is a simple, low cost continuous casting process that overcomes problems of friction and adhesion at the mold-metal interface often found using other casting techniques. Among the advantages are high casting speeds, smooth continuous withdrawal of the cast product; excellent homogenity, grain structure and dimensional uniformity of the cast product; absence of imperfections or inclusions in the cast surface and extended operating life of parts in contact with molten metal.
It is particularly well suited for near or net shape casting of small diameter rods and other products from a variety of pure metals and alloys. For most applications, the fine equi-axed grain structure of the "as-cast" product is suitable for immediate drawing or forming operations without the need for hot rolling, annealing, or other processing after casting.

H) CONCLUDING REMARKS

It follows from the above that hitherto traditional wire bar route for the manufacture of re-draw copper rod will, increasingly in the future, only be retained in exceptional circumstances. Thus, for rod outputs in the range of 6-40 tonnes/hr, the Properzi, Southwire and Contirod continuous melting, casting and rolling processes are now firmly established.

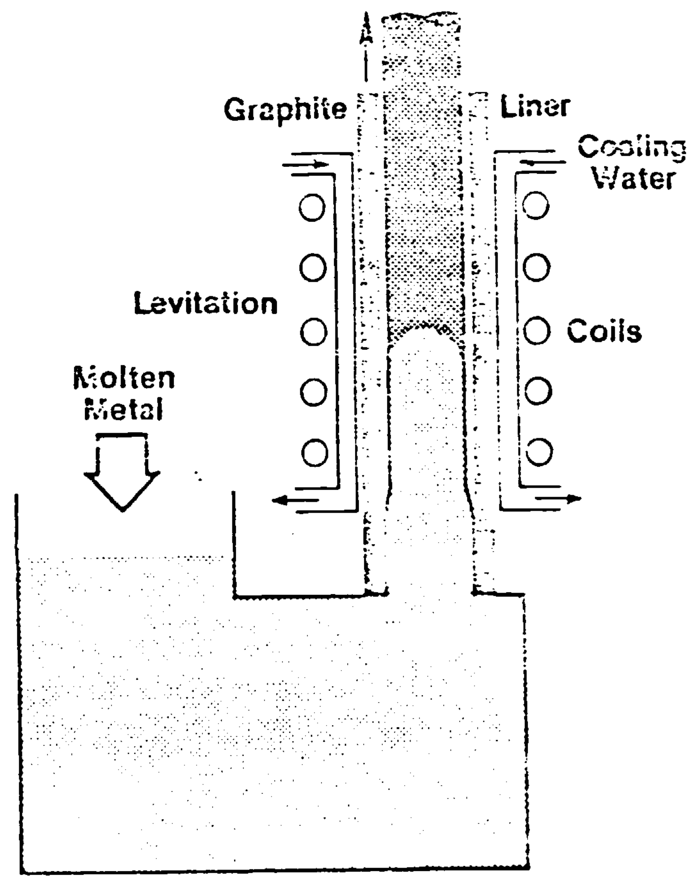


Figure 7. Schematic representation of GE Levitation Casting (GELEC) apparatus

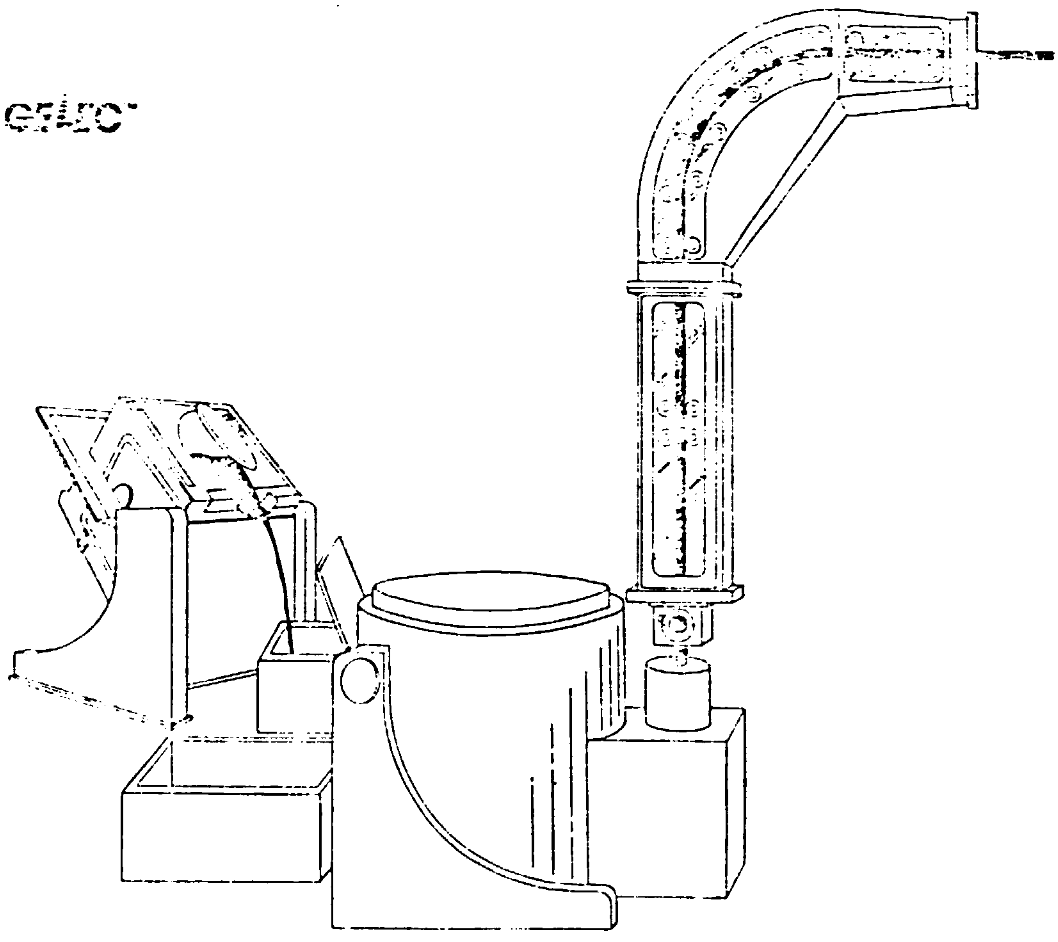


Figure 8. Simplified illustration of GELEC system
in casting mode

A similar situation exists for the GE dip-forming process for outputs in the range of 3.0-11.0 tonnes/hr. Adoption of these processes has been mainly on economic considerations, including those arising from the use of a less expensive in-feed, namely cathode, and the omission of a bar reheating stage. For example, with the Southwire SCR system, the overall saving in energy consumption is estimated as about 1340 MJ/tonne, with an output of about 40 tonnes/hr. The continuous processes also give important advantages in "downstream" operations, among which are the absence of a pickling stage and the greatly reduced frequency of butt welding between coils. The latter allows the use of higher drawing speeds for the rod. Additionally, with appropriate operational techniques, the technical properties of continuously processed rod have proved at least as good and, frequently, markedly superior to those of rod made from wire bar.

However, it should be recognised that the equipment involved in the continuous processes is relatively complicated and its performance depends on the efficiency of a range of control and automatic devices not previously employed in the industry. This part of the technology is therefore still evolving, as is also that dealing with the material design and use of various components for which long-term durability is necessary under the arduous conditions associated with the process. For the user, the equipment represents a major capital investment and its utilisation factor is therefore important. On this point, claims have been made that certain processes are better than the others, but they are difficult to relate in terms of a given product quality.

For lower outputs than those of the processes with a tandemised hot rolling stage, continuous casting methods exists (Outokumpu), or are being developed (GELEC), which produce rod suitable for separate cold rolling to re-draw sizes. They provide increased flexibility with respect to the range of section shape and materials that can be cast as well as to consistency of product quality from the continuous nature of the operation. As far as can be judged, all these casting processes use a submerged graphite die technique. The macro-structure of the as-cast rod usually consists of large columnar grains. While this does not appear to cause any problems with rod ultimately reduced to wire sizes, concern has been expressed about the risk of fire cracking with rod subjected to more modest amounts of deformation before annealing.

(NOTE :

1) The table shown on the following 3 pages are copied from Metal Bulletin Monthly, August 1983., accordingly its figures are based on the situation of that time.
2) Under the processes referred to as General Electric in this table the GE dip-forming process is to be understood, as GE Levitation Casting method was developed at a later date.)

Continuous copper rod casters

Country & company	*Works*	*Process*	*Rod dia.*	*Capacity*	*Date of construction*
ARGENTINA					
Pirelli SA	Buenos Aires	Continuus-Properzi	—	—	1982
Quilmes	Buenos Aires	Continuus-Properzi	—	8	1983
AUSTRALIA					
Copper Refineries	Townsville	Secor	—	25	1977
Metal Manufactures	Port Kembla	Southwire	0.3125-0.625	27.5*	1974
BELGIUM					
Metallurgie Hoboken Overpelt	Olen	Krupp/Hazelett	8mm	32	1972
Lamitref	Hemiksem	Continuus-Properzi	—	—	1969
Lamitref	Hemiksem	Continuus-Properzi	—	—	1972
BRAZIL					
Caraiba Metals	Salvador	Krupp/Hazelett	8-20mm	32	1973
BULGARIA					
FTE Technika	Sofia	Southwire	6.35-14.28mm	13	1978
CANADA					
Cable Tech Wire	Toronto	Outokumpu	—	9,000 tpy	1980
Canada Wire & Cable	Montreal	Krupp/Hazelett	8mm	33	1980
CHINA					
CNTIC	Harbin	General Electric	—	6.0	1983
FINLAND					
Outokumpu Oy	Pori	Outokumpu	—	10 000 tpy	1972
FRANCE					
Laminoirs Trefileries Cableries de Lens	Lens	Southwire	0.25-0.625in	25*	1970
Thomson Brandt, Branche Trefileries et Cableries	Chauny	Krupp/Hazelett	8mm	32	1976
WEST GERMANY					
Deutsche Giessdraht	Emmerich	Southwire	8-15mm	36.4	1976
Lacroix & Kress	Bramsche	General Electric	—	5.4	—
Norddeutsche Affinerie	Hamburg	Southwire	8-9.4mm	30*	1972
	Hamburg	Southwire	8-16mm	45	1980
(To be announced)	—	Continuus-Properzi	—	—	—
GREECE					
A. Chandris Cables	Volos	Outokumpu	—	12,000 tpy	1974
Fulgor Greek	Sussaky	Continuus-Properzi	—	—	1977
HUNGARY					
Csepel Metalworks	Budapest	General Electric	—	6.0	—
INDONESIA					
Furukawa Electric (Japan)/ Supreme Cable Mfg	Djakarta	Southwire	8mm	5.9	1979
IRAN					
National Iranian Copper Industries	Sar Cheshmeh	Krupp/Hazelett	8mm	32	1977
ITALY					
Colata Continua Italiana (a)	Belgioso	Southwire	8-16mm	25	1977
Elcos	Salerno	Continuus-Properzi	-	-	1975
Fulgor Cavi	Latina	Continuus-Properzi		25	Temporarily off stream
Italrame	Avellino	Krupp/Hazelett	6.35-20mm	32	1976
JAPAN					
Fujikura	Sakura	General Electric	—	10.9	—
Furukawa Electric	Chiba	Southwire	0.3125-0.625in	25*	1971
Furukawa Electric	Mie	Southwire	0.3125-0.625	34*	1975

Country & company	*Works*	*Process*	*Rod dia.*	*Capacity*	*Date of construction*
Hitachi Wire Rod	Ibaraki-ken	Southwire	0.3125-0.625in	30*	1971
Mitsubishi Metal Mining	Osaka	Southwire	0.3125-0.625in	25*	1971
Mitsubishi Metal Mining	Osaka	General Electric	—	10.9	—
Numazu Copper Refining & Rolling	Yodo	Southwire	0.3125-0.875in	50*	1981
Showa Electric Wire & Cable	Mie	General Electric	—	9.1	—
Showa Electric Wire & Cable	Kawasaki	General Electric	—	5.4	—
Sumitomo Electric Industries	Osaka	Krupp/Hazelett	7.8-22.5mm	40	1979
Tatsuta Electric Wire & Cable	Kawachi	General Electric	—	5.0	—
Yazaki Wire & Cable	Gotemba	General Electric	—	5.0	—
Yazaki Wire & Cable	Numazu	General Electric	—	5.0	—
S. KOREA					
Gold Star Cable	Seoul	Southwire	8mm	18	1980
Taihan Electric Wire	Seoul	Southwire	8-16mm	27.2	1980
Poongsan Metal Mfg	Onsan	Outokumpu	—	16,000 tpy	1979
MALAYSIA					
Metrod (Malaysia)	Kuala Lumpur	Outokumpu	—	18,000 tpy	1982
MEXICO					
Cia. Minera Kappa	Mexico City	General Electric	—	5.4	1980
Cobre de Irapuato	Irapuato	Outokumpu	—	6,000 tpy	1973
Conticon SA de CV	Celaya	Krupp/Hazelett	8-16mm	33	1981
Industrial y Comercial Tor	Mexico City	Outokumpu	—	6,000 tpy	1973
PHILIPPINES					
Phelps Dodge Philippines	Manila	Outokumpu	—	6,000 tpy	1982
POLAND					
KGHM	Lubin	Krupp/Hazelett	6.35-12mm	32	1975
PORTUGAL					
CPC	Porto	General Electric	—	6.0	1982
RUMANIA					
ICEE — Intreprinderea de Conductori Electrici Emailati	Zalau	Krupp/Hazelett	8,10,12,14 and 16 mm	12	1977
SOUTH AFRICA					
Transvaal Copper Rod Co (b)	Palabora	Southwire	0.25-0.625in	17.6*	1968
SPAIN					
Ibercobre	Cordoba	Krupp/Hazelett	8-18mm	25	1982
SIA Santa Barbara	Lugones	Secor		10.5	1982
SWEDEN					
Elektrokoppar	Helsingborg	Continuous Properzi	—	—	1973
TAIWAN					
Hua Eng Copper & Iron Ind.	Kaohsiung	General Electric	—	3.2	—
Shing Fong Electric Cable & Wire	Taipei	Outokumpu	—	10,000 tpy	1982
Tatung Cable	Taipei	General Electric		6.0	1983
Walsin Lihwa Electric Wire & Cable Corp	Taipei	Southwire	8,9.5,12 and 14mm	8	1977
Walsin Lihwa Electric Wire & Cable Corp	Taipei	Southwire	8-10mm	18.1	1981
THAILAND					
Bangkok Electric Wire & Cable	Samut Prakarn	Outokumpu	—	7,000 tpy	1981
Thai-Yazaki Electric Wire	Bangkok	Outokumpu	—	[illegible] tpy	1974
Thai Yazaki Electric Wire	Bangkok	Outokumpu	—	4,000 tpy	1980
PD Siam Rod	Bangkok	Outokumpu	—	7,000 tpy	(start up) 198[illegible]

Country & company	*Works*	*Process*	*Rod dia.*	*Capacity*	*Date of construction*
TURKEY					
Bakirsan	Hendek	Outokumpu	–	16,000 tpy	1980
Botel Bobin Teli Kablo Sanayi ve Ticaret SA	Istanbul	Outokumpu	–	6,000 tpy	1982
ER Erbakir	Izmir	Continuus-Properzi	–	–	1981
Hens Hacilar Elektrik Sanayii ve Ticaret SA	Kayseri	Outokumpu	–	3,000 tpy	1982
Rabak Elektrolitik Bakir ve Mamulleri	Istanbul	Southwire	8-10mm	8	1979
Sarkuysan Elektrolitik Bakir Sanayii ve Ticaret	Istanbul	Outokumpu	–	12,000 tpy	1974
Sarkuysan Elektrolitik Bakir Sanayii ve Ticaret	Istanbul	Outokumpu	–	16,000 tpy	1977
UK					
BICC	Prescot, Merseyside	Southwire	0.3125-0.625in	34	1975
Enfield Rolling Mills	Brimsdown	Southwire	0.25-0.625in	27.6*	1974
Rodco	Skelmersdale	Krupp/Hazelett	6.35mm, 8mm	25	1980
USA					
Asarco	Amarillo, TX	Krupp/Hazelett	8mm	32	1974
Capital Wire & Cable	Plano, TX	Southwire	0.3125-0.375in	10	1969
Cerro Wire & Cable	Hartselle, AL	Outokumpu	–	12,000 tpy	1981
General Electric	Bridgeport, CT	General Electric	–	5.4	–
Inspiration Consolidated Copper	Inspiration, AZ	Southwire	0.3125-0.625in	22.1 (increased from 16.1)	1968
Kennecott Refining (c)	Baltimore, MD	Southwire	0.3125-0.675in	35.3 (increased from 30)	1973
Magma Copper	San Manuel, AZ	Southwire	0.3125-0.625in	38.6 (increased from 30)	1972
Nassau Smelting & Refining	Staten Island	Continuus-Properzi (modified by Southwire)	0.3125-0.5in	9	1963
Packard Electric	Warren, OH	General Electric	–	6.3	–
Phelps Dodge Copper Products	Norwich	Krupp/Hazelett	8mm	40	1979
Phelps Dodge Copper Products	El Paso, TX	Krupp/Hazelett	8mm	50	1980
Rome Cable Corp	Rome, New York	Outokumpu	–	30,000 tpy	(start up) 1983
Southwire	Carrollton, GA	Southwire (pilot plant)	0.3125-0.625in	37	1965
Southwire	Carrollton, GA (Caster has replaced pilot plant)	Southwire	8-22.2mm	55	1981
Western Electric	Hawthorne, IL	Southwire	0.3125-0.625in	27.6	1974
Western Electric Nassau Recycle	Gaston, IN	Krupp/Hazelett	8mm	40	1976
Westinghouse	Abingdon, VA	Southwire	0.25-0.625in	16.5 (increased from 15)	1965
USSR					
Metallurgimport	Tashkent	Continuus-Properzi	–	–	1964
Metallurgimport	Tashkent	Continuus-Properzi	–	–	–
YUGOSLAVIA					
Bor	Bor	General Electric	–	5.4	–
Bor	Bor	General Electric	–	6.8	1981
ZAMBIA					
Metal Fabricators of Zambia	Luanshya	Outokumpu	–	6,000 tpy	1982

(a) A vertical roughing stand was added to the Morgan mill and started up in September [illegible]
(b) An in-line rod cleaning system and other equipment started up in 1982. [illegible]
(c) A vertical roughing stand was added to the Morgan mill in December 1981. Stand has a capacity of 50 short tons per hour and can process [illegible] rod. It started up in December 1982.
**Short tons*

III. MANUFACTURE OF COPPER AND COPPER ALLOY SHEET AND STRIP

A) CASTING

The manufacture of sheet and strip in the modern copper and brass mill begins with one of two basic casting operations. In the casting plant the metal is melted and either cast in the form of slabs which are subsequently heated and hot-rolled to coils of heavy gauge strip, or directly cast in strip form and coiled. The coils, in either case, will have their surfaces milled to remove any defects from casting or hot rolling. The next set of operations through which they are brought will provide the desired final gauge and temper by a series of cold rolling, annealing, and cleaning operations. Finally, they may be slit into narrower widths, leveled, edge rolled or otherwise treated, and packeged for shipment.

Raw materials from which the melt is prepared consist primarily of virgin copper, either electrolytic or fire-refined, selected clean scrap of known origin, carefully checked for composition, and special alloy elements such as virgin zinc, lead, tin or nickel. After the charge has been formulated, the raw materials are assembled in charge buckets and carefully weighed. These materials are discharged into hoppers which feed electric-induction melting furnaces. As melting of the charge proceeds, samples are taken from the furnace and sent to the spectographic laboratory for analysis. The composition is calculated by computer and returned to the printer on the melt shop floor within minutes. If necessary, the melter can then make additions to bring the melt exactly within the specified composition range.

The metal is protected from atmospheric oxidation by a cover of carbon or bone ash. When the composition and temperature have been determined to meet the requirements of the alloy being melted, the molten metal is transferred to a holding furnace.

For many years in copper and brass mill casting practice the molten metal was poured from the melting furnace into a pouring box which distributed it into long, rectangular molds. This method had some important disadvantages. The maximum weight of a casting, and therefore the length of finished coil was limited. Molten metal dropping from a pouring box to the base of the mold was subject to oxide scumming and entrapment. Metal splash caused the bottom end of the bar to be spongy. The casting varied from bottom to top in temperature and solidification rate with potential problems from shrink cavities, gas entrapment, surface laps, and mold coating defects.

During the 1960-1975 period, semicontinuous and continuous casting processes began to supplant the book molds. In each of these new methods, molten metal flows into a short, rectangular, water-cooled mold, which initially is closed at one end by a plug on a movable ram or a starter bar. The metal freezes to the plug and forms a shell against the mold surface. The ram is then steadily withdrawn, pulling the shell with it. As the shell exits from the bottom of the mold, cold water is sprayed on it, cooling it rapidly and causing the contained molten metal to freeze. In this manner a continuously cast slab of the desired length is produced.

Gases and non-metallic materials float to the surface of the shallow pool and remains there to collect at the top of the semicontinuous cast slab. This end has to be sawed off before hot rolling. The continuous cast slabs are free from this type of disadvantages.

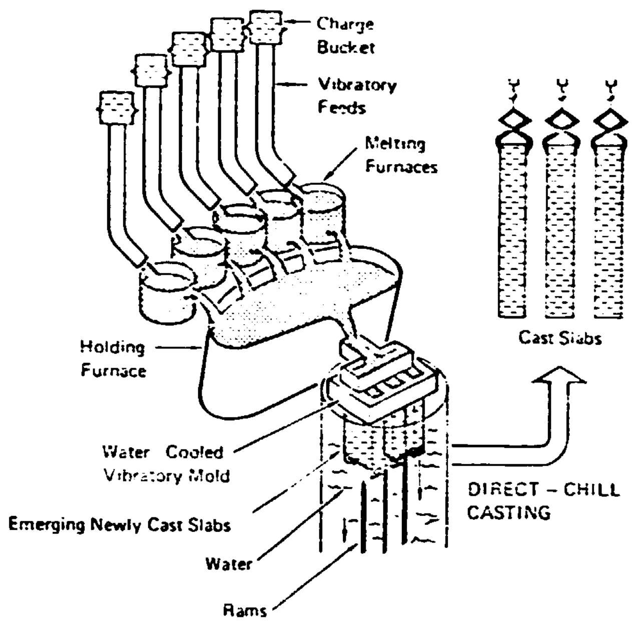


Figure 9/a. Schematic sketch of vertical direct chill (DC) casting of slabs

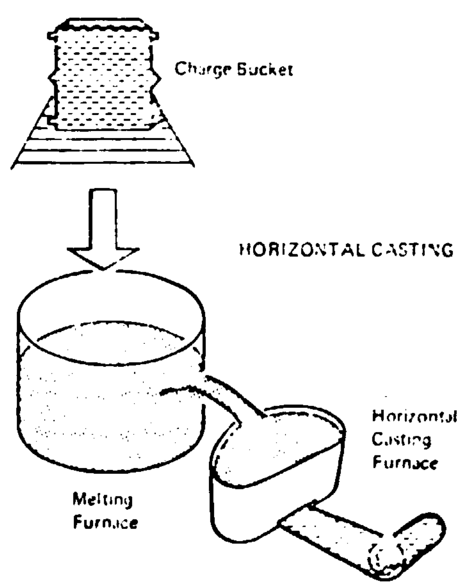


Figure 9/b Schematic sketch of horizontal continuous casting and coiling of strip

The direct chill (DC) casting processes described above are done in vertical molds and are used to produce slabs of large cross section which are subsequently reheated, hot-rolled into heavy gauge strip, and coiled. Such large coils are the most economical to handle through the subsequent rolling and annealing processes at the mill and later by the user who is fabricating finished parts.

Some alloys contain elements which produce phases, or structures, which are difficult or even impossible to hot-roll. Such alloys must be cold-rolled, and the amount of reduction in thickness that can be achieved, before annealing becomes necessary, is small when compared to hot-rolling reductions.

The problem with alloys that are hard to hot-work is overcome with the horizontal continuous-casting method. It offers a means of producing relatively thin cast strips in long lengths which can be coiled in the cast state and later reduced by cold rolling. Tedious, costly cold breakdown rolling and the attendant annealing are avoided.

The horizontal continuous casting process provides a product of excellent quality. Typically, one low-frequency electric-induction furnace is used as a melter. As a charge of selected scrap and refined metal additions are melted and brought to the pouring temperature, samples for chemical analysis are taken. When the proper analysis is established and the pouring temperature attained, part of the metal is poured into a second, smaller electric-induction holding furnace. This furnace is constantly monitored to maintain the metal at the desired casting temperature. The casting mold is attached to the lower front of this furnace. It is graphite mold contained in a copper, water-cooled jacket.

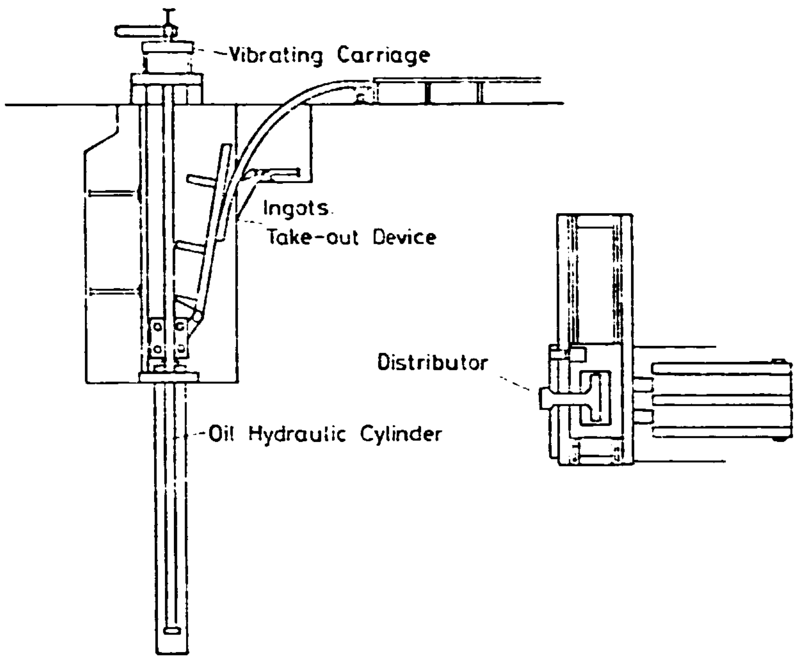


Figure 10/a. Semi-continuous casting machine

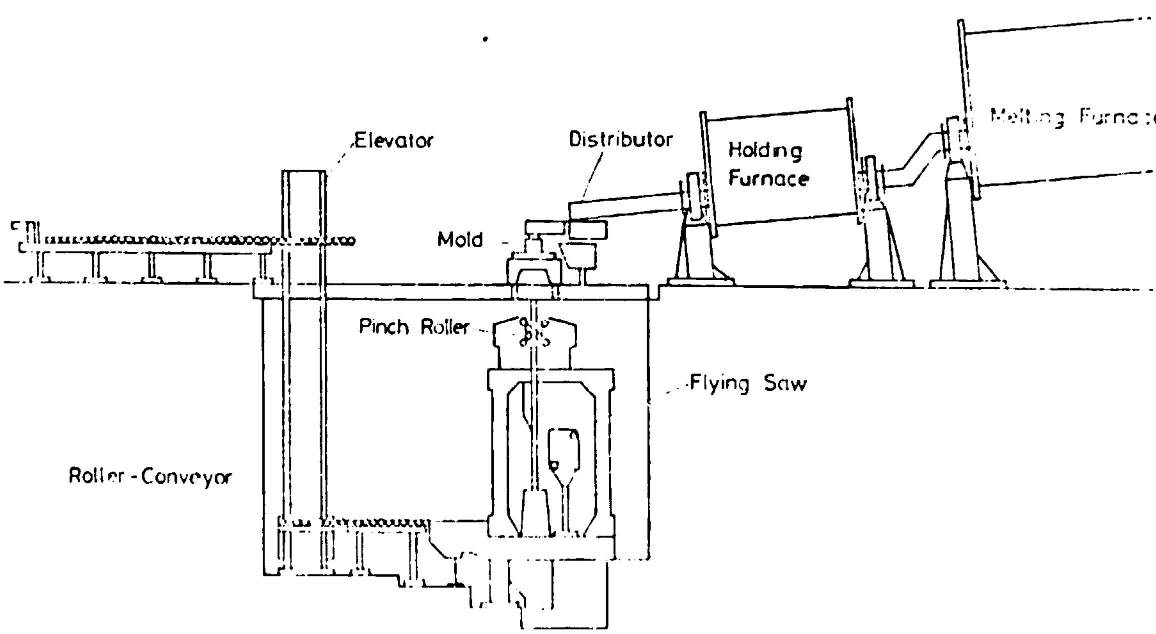


Figure 10/b. Continuous Casting Machine

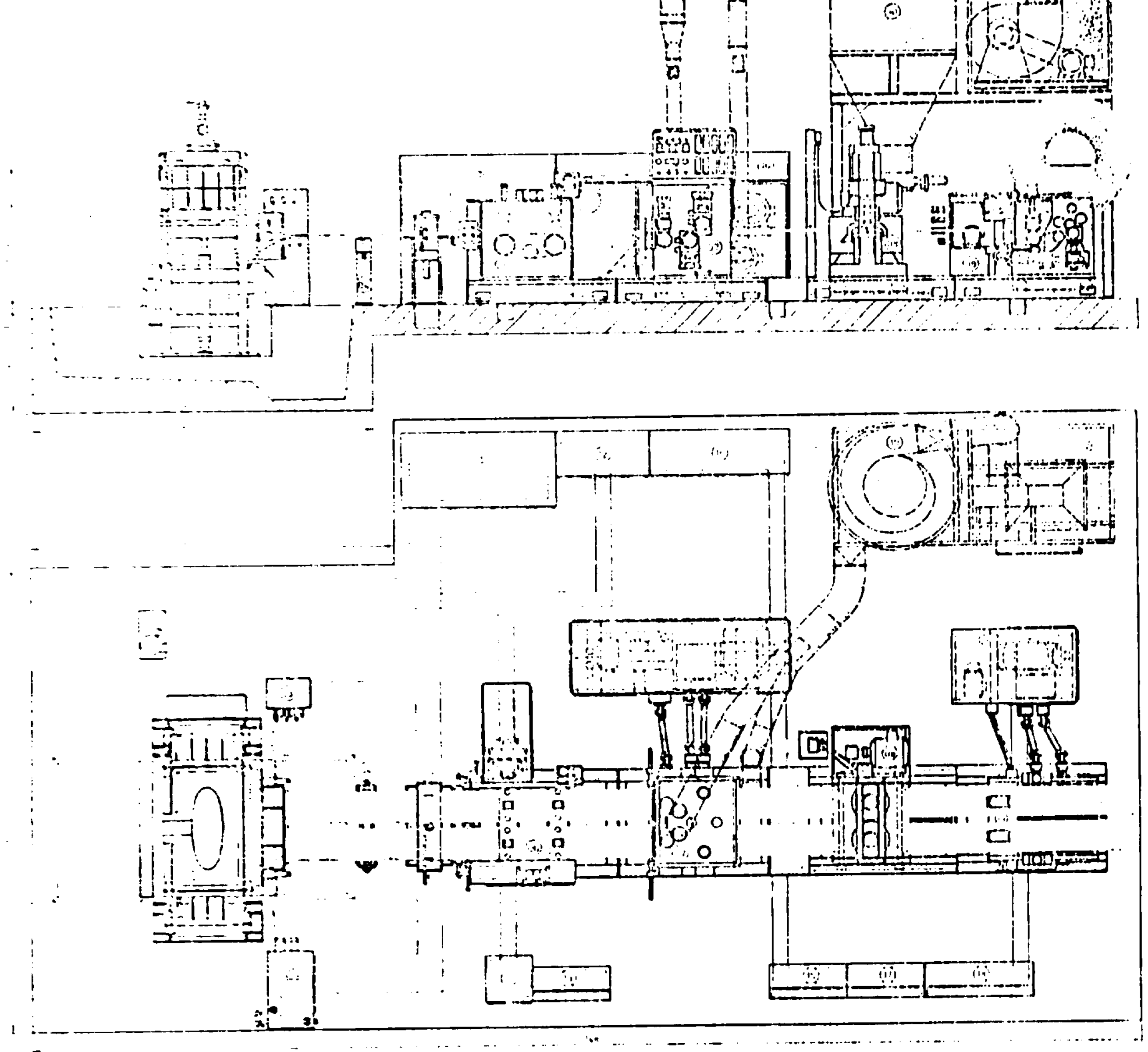
A silicon carbide plate in the front of the furnace contains a slot which opens into the mold. At the beginning of a cast, a starter bar is inserted into the mold and the metal freezes to it. The mold is only a few inches long.

Two stands of withdrawal rolls slowly withdraw the starter bar as the metal freezes in the mold cavity. The cast bar, frozen to the starter bar, is continuously withdrawn as the metal freezes in the mold. Although it is simple process, its practice requires that narrow tolerances on mold dimensions be held, and exceptional melt cleanness be maintained. Any dross or foreign materials that enter the graphite mold will quickly destroy it. Mold sizes range from 200 to over 660 mm in width and from about 12 to 20 mm in thickness. A saw in the withdrawal line cuts the bars off at the desired length, and they are coiled in preparation for subsequent processing. A sample for chemical analysis is cut from each bar end, so the composition at each end of each coiled bar is determined. This process lends itself to in-line coil milling and to maximum coil lengths, dependent only on handling equipment capacity and practical processing of the material itself.

The rapid chilling of the small amount of metal in the horizontal mold produces a fine, equiaxed cast grain structure. The metal drawn from the furnace as it solidifies always has a pool of molten liquid above it where gases and nonmetallic impurities tend to collect. The cast bar is free of porosity and of defects caused by solid inclusions.

The good quality of the horizontal casting shows up in the finished strip in terms of excellent formability. Phosphor bronzes cast this way develop high strength for which they are specified, coupled with the good formability needed in most of their applications.

Figure 11.
Double Strip Caster for Non-Ferrous Metals



01 Holding furnace with inductor
02 [illegible]
03 Cooling water distribution
04 Roller support
05 Secondary cooling
06 Withdrawal device
07 Milling machine
08 Strip shear
09 Strip coiler
10 Chip removal for milling machine
11 Control cabinet for withdrawal device
12 Power cabinet for withdrawal device
13 Control desk for inductor
14 Power cabinet for inductor
15 Control desk for milling machine
16 Power cabinet for milling machine
17 Control desk for strip shear
18 Control desk for strip coiler

Leaded bearing-bronze, also cast by this process, offers improved quality for bushings, bearings, and thrust washers which must carry heavy loads under dynamic stresses without failure. Some smaller mills depend almost entirely on horizontal casting, regardless of alloy, because the process is readily adaptable to the casting of small quantities of several alloys.

CONCLUDING REMARKS

1) The mold casting method is not used in up-to-date mills any more in view of the small weight of the finished coils, inferior surface quality, shrinkage cavities, porosity, etc.

2) Semicontinuous cast slabs have excellent quality, but one end of the slabs has to be sawed off.

3) Vertical continuous casting process is free from the above mentioned disadvantages, it has a very high production capacity, but requires the highest capital investments of all the reviewed technologies.

4) Horizontal continuous casting characterized with low investment cost equipment, good quality, flexible capacity range by using several smaller capacity machines, which also enable casting of different alloys at the same time.
   It offers the possibility to eliminate hot rolling and to reduce costs of cold rolling of some "difficult" alloys, so this method requires the smallest capital expenditure for the mill as a whole.
   Cuts the energy, material and transport costs, requires few but well-trained personnel.
   This process, however, is not suitable for the production of very wide strips.

8) ROLLING

To ready the direct chill cast slab for hot rolling, the top or gate end is trimmed by sawing, and then it is conveyed into a furnace for heating. Slabs or bars of the same alloy are grouped together in a lot and processed through the furnace and the hot mill.

The roll stand used for hot rolling is a very sturdy mill having two rolls (two-high) whose direction of rotation can be rapidly reversed so the strip can be passed back and forth between them. The large horizontal rolls which reduce the thickness are supplemented by a pair of vertical edging rolls.
After the final rolling pass the metal is spray cooled and coiled.

The modern hot mill is operated from an air-conditioned pulpit overlooking the rolling stand and the conveyor run-out table. With the aid of television cameras, placed at strategic points focusing on the rolls, the furnace and the transfer buggy, the alligator shears at each end, and the coiler, the operator can control all these from his vantage point.
A schedule of rolling reduction for each pass through the rolls is established and recorded on a punched card. Operation of the hot mill is sequenced by computerized controls to insure uniform processing through the hot mill.

Following hot rolling the DC cast bars are coil milled, and after careful surface inspection are ready to be applied on orders for processing to final gauge, temper and width. Horizontally continuous-cast bars are milled in-line.

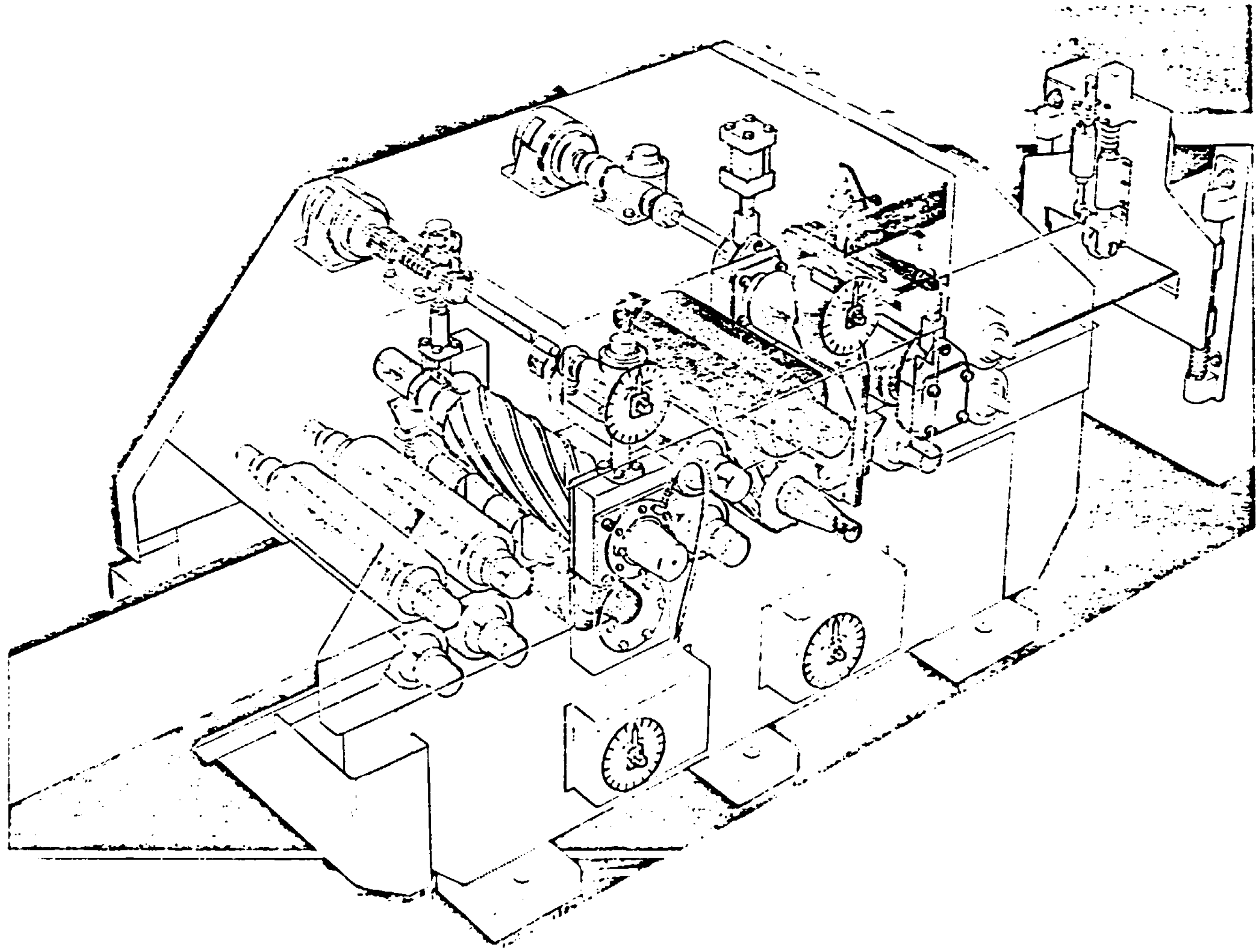


Figure 12. Slab and strip milling machine

Cold rolling of coppers and copper alloys into sheet and strip of excellent quality requires a combination of skillful workmanship, knowledge, and good rolling mills.
To keep cost as low as possible and competitive, the reduction in thickness to final gauge needs to be accomplished in the fewest operations compatible with quality requirements.

Continuous cast strips are usually rolled on reversible two-high breakdown mill with large roll diameter. On the mills heavy reductions are performed in every pass.
From 20mm to 6mm thickness the metal is rolled without tension between two upcoilers. Under 6mm winders and tension are applied.
In some cases combined two-high/four-high mills or a combination of one-way/reversible operation is used for roughing, intermediate and finish rolling; achieving savings in investment costs.

Small diameter work rolls are most desirable for providing maximum utilization of roll force in reducing metal to thinner gauges, but they lack the stiffness required. The wider the metal to be rolled, the longer the rolls, and the greater the tendency for the rolls to bend or spring.
To overcome the tendency four-high and cluster rolling mills are used for cold rolling in the brass mill.

Four-high rolling mills contain a pair of work rolls of relatively small diameter. A second pair of rolls, of large diameter, is placed above and below the work rolls in the stand to back them up and prevent from springing. This arrangement allows the advantage of the small contact area of small work rolls and the transmittal of high force through the large back-up rolls while maintaining the rigidity required for gauge control.

The minimum size of the work rolls is limited by the forces in rolling, which tend to bow them backward or forward during rolling.

For the very high capacity rolling of heavy gauge coils tandem mills consisting of 2-4 four-high mills are operated in some plants.

Cluster rolling mills, for example, Sendzimir 20-high mills were designed to counteract both the vertical and horizontal elements of the rolling forces and thus enable the use of minimum diameter work rolls. In cluster mills the work rolls are backed up by a cluster of rolls placed with respect to the work rolls so they contain the rolling forces and prevent bending or springing of the work rolls.

The traditional 20-high Sendzimir mills are very complicated and expensive, so rolling mill manufacturers started to design and manufacture new type of rigid rolling mills.
One of the most commonly used solutions is to upgrade the existing four-high mills changing the mechanical screwdown system to a hydraulic one. This is a very cheap way of modernization giving optimal results.

Converting existing two or four-high mills into Z-high cold rolling mill with smaller work rolls enables to roll thinner gauges and tougher alloys with extremely tight tolerances. This mill combines the advantages of a four-high and a Sendzimir cluster mill, and can be used as a four-high mill, too.

In new four-high mills hydraulic screwdown system is commonly used and the rigidity is increased by application of prestressed mill housing frames. Good examples for that are the genuine Fröhling mills. To improve cross-sectional shape of strip hydraulic roll bending devices are lately spreading all over the world.

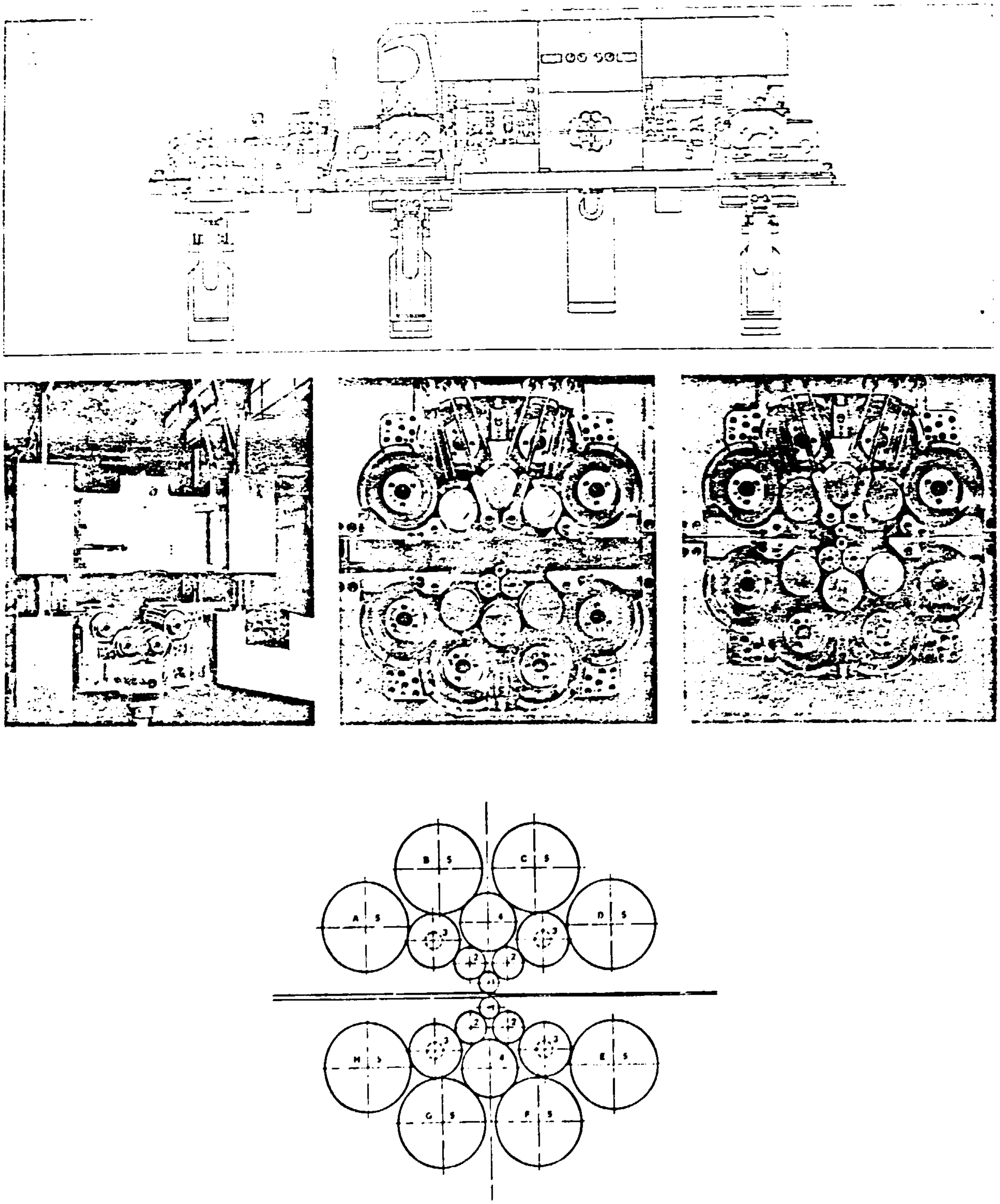


Figure 13. 20-roll cluster mill

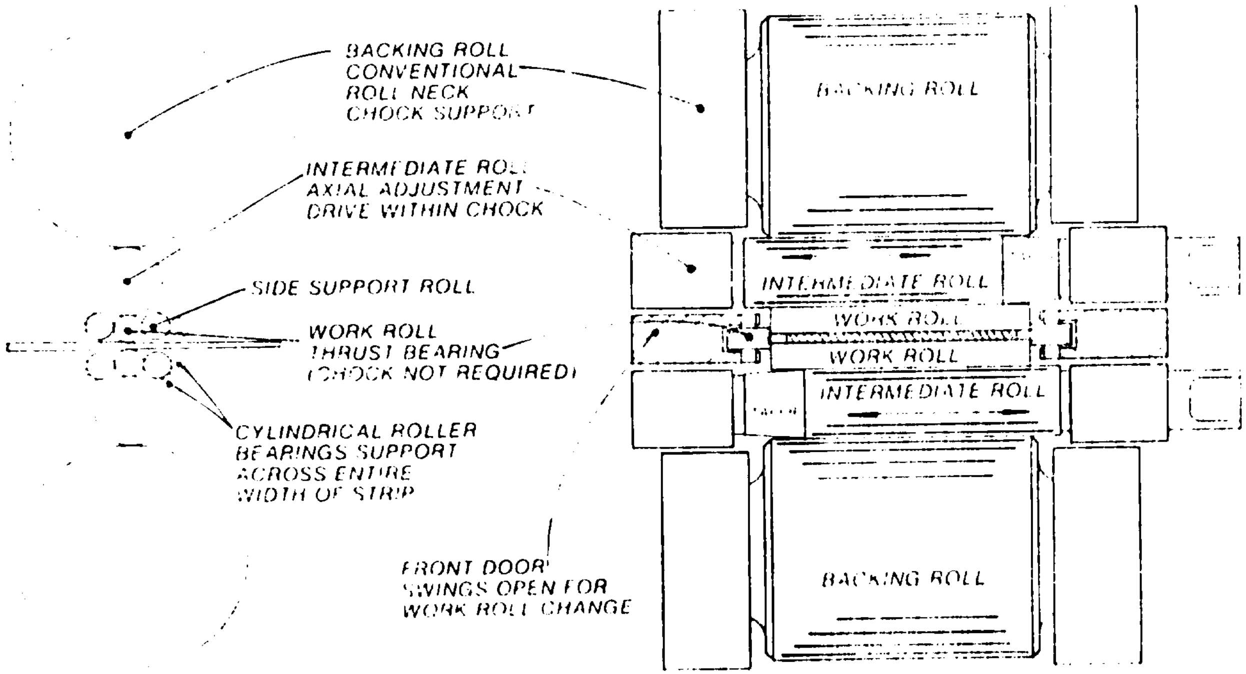


Figure 14.. SENDZIMIR Z-high cold rolling mill

For thickness control during high speed rolling, continuous measurement of this dimension is a necessity. Rolling mills are equipped with X-ray or contact instruments, which continuously gauge the metal and provide a continuous readout of thickness. There are also control devices which actuate the screws in the roll housings and automatically open or close the gap between the work rolls to adjust the thickness being produced as required. These gauges may also adjust back tension and forward tension applied by payoff and recoil arbors to effect changes in the thickness of the rolled metal.

In the last decade the Vollmer contact thickness and roll gap gauges are used most commonly on the non-ferrous cold rolling mills. These gauges are safe for the personnel, cheaper than the X-ray or beta-ray instruments, and require less and more simple maintenance.

C) ANNEALING

During cold rolling, hardening of the metal occurs. One reason for annealing is to soften the metal so it can be further reduced by cold working. In case of finished strip the anneal is designed to produce a specified tensile strength and chosen uniform grain size. There are two methods of annealing operations : coil annealing and strand annealing, both having advantages and disadvantages of their own.

Coil annealing may be carried out in a roller hearth furnace in which the coils are continuously conveyed slowly through the furnace as they are gradually heated to the annealing temperature. This type of furnace usually does not have a prepared atmosphere, but the products of combustion fill the furnace and reduce the metal oxidation rate. More commonly, coil annealing is done in bell furnaces of the type in which a controlled atmosphere can be maintained. The annealing unit consists of a base on which the coils are stacked. Under the base is a fan for circulating the hot gases through the load, to provide more uniform and rapid heating.

After the metal is stacked on the base, the inner hood or retort is placed over the load and sealed. The controlled atmosphere begins to flow through the hood purging the air. The furnace is placed over the hood and heating begun.

The heat input is constantly adjusted to maintain temperature uniformity in the load. This controlled temperature rise also allows roll lubricants to vaporize and be carried off before the metal gets so hot that surfaces can be harmed. After the metal has reached the annealing temperature, it is held there for a short period or soaked to provide maximum uniformity .

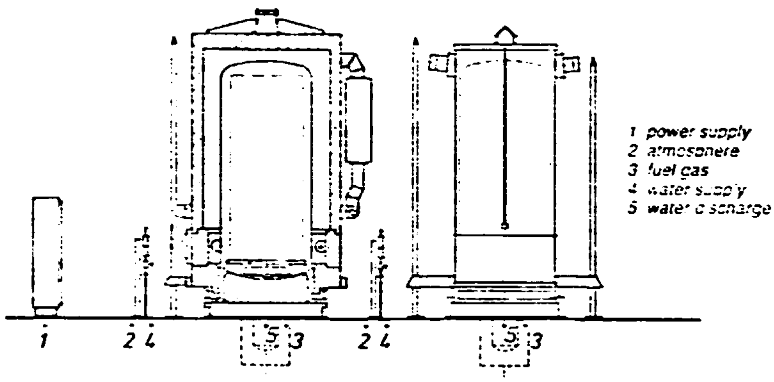


Figure 15/a. High-convection bell annealer : the basic setup

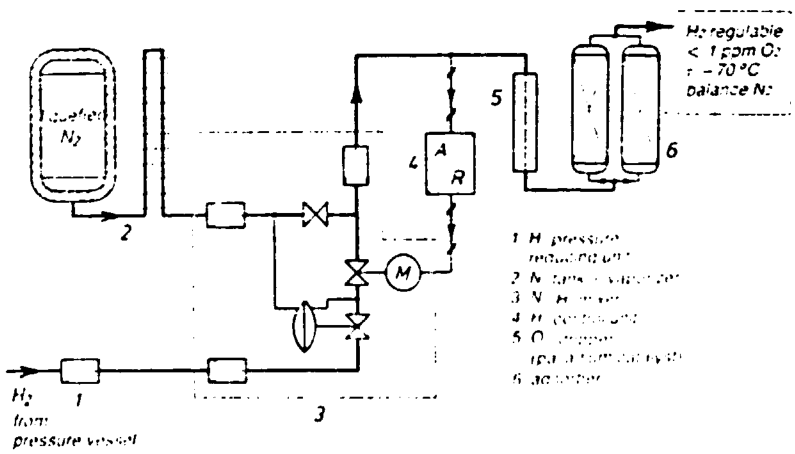


Figure 15/b. Nitrogen/Hydrogen mixer plus absorber

Then the furnace is turned off and removed, and the metal cools in the controlled atmosphere under the inner hood. Cooling may be aided by a cooling cover containing a water spray system. The inner hood is not removed until the metal temperature is low enough that no discolouring or oxidation of the metal takes place.

The controlled atmosphere is produced in gas cracking units, or in N_2/H_2 mixer and absorber.

For oxygen containing copper, the atmosphere must be nearly free from hydrogen and the annealing temperature low enough to avoid hydrogen embrittlement.

In traditional coil annealers, a thin oxide film forms on the surface of zinc containing alloys (brasses). The natural colour of the metal has to be restored by dilute sulphuric acid pickling and brushing following the anneal.

In the early 1970s, the Austrian Ebner Company developed a process for bright annealing of brasses in high-convection bell annealers. Since then about 100 annealers of this type are operating all around the world. In these furnaces a charge temperature of 750 $^{\circ}C$ can be achieved. They all use a vacuum purge in the first stage of the annealing process. Beside safety reasons, this is a very important feature from technological point of view as well, because during this period traces of properly selected rolling lubricants evaporate easily and without discoloration. After the vacuum purge 25% H_2 - 75% N_2 protective atmosphere is introduced under the tightly sealed hood. The high convection system using powerful fan allows to bring the charge in a very short period to the annealing temperature selected somewhat lower than usual and this prevents diffusion of zinc to the surface layer.

Bell annealing is a very productive method requiring relatively small investment expenditures.

A disadvantage of coil annealing is that large coils of some alloys in thinner gauges can be easily damaged : one wrap can become welded to the next because of the high temperature and pressure encountered, usually making the coil unsuitable for further processing. Another disadvantage of coil annealing is that it is time consuming.

In the late 1940s continuous strand or strip annealing lines began to be used in brass mills. From these early beginnings, the high speed vertical strip annealers were developed in the 1960s. Annealing lines of this type are now in use for annealing copper and copper alloy strips. When several such lines are available, a variety of thickness ranges can be rapidly annealed, providing great flexibility in production scheduling and enabling fast delivery of finished strip.

The continuous strip anneal lines include payoff reels, a stitcher for joining the front end of a coil to the trailing end of the one preceding it, a degreaser for removing roll lubricants, looping towers for metal storage, a seven-story high vertical furnace which includes a heating zone, a controlled atmosphere cooling zone, and a water quench tank. This is then followed by acid cleaning tanks, a water rinse, a drying oven, and a reel for recoiling the metal.
Degreasing unit removes roll lubricants from the metal surfaces before the metal enters the furnace, so a clean, uniform surface is presented for annealing. The metal passes over a large roller outside the furnace at the top and does not touch anything inside while it is being heated.

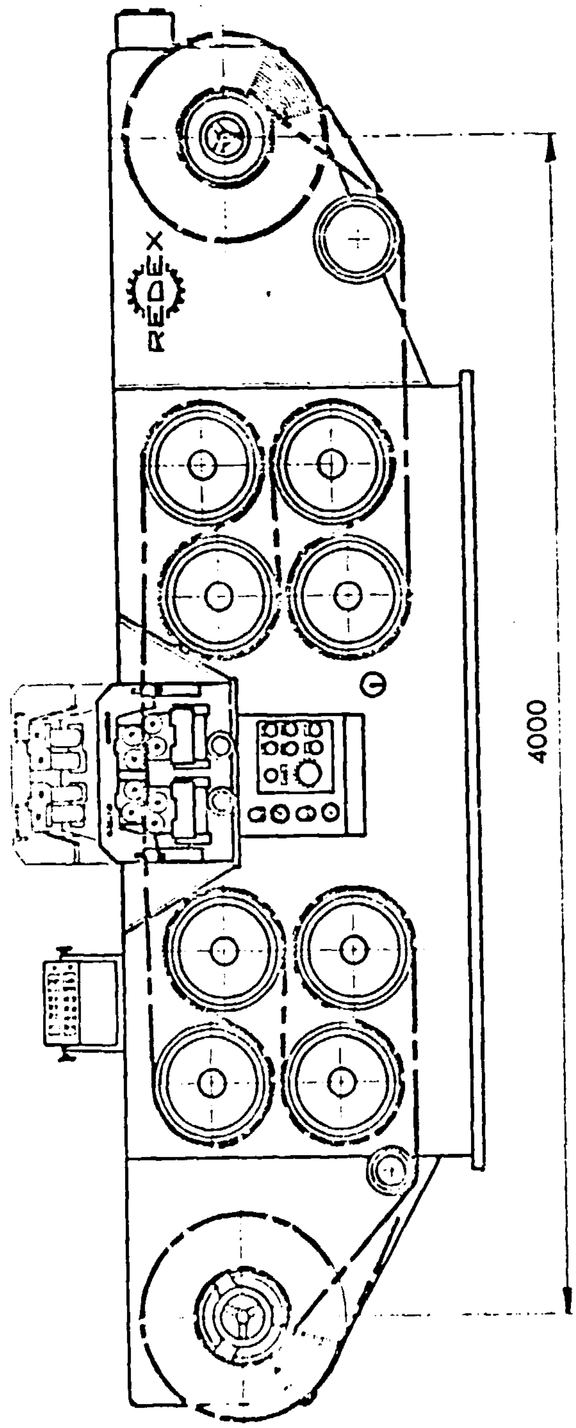


Figure 16.   Strip stretch leveller machine

It then passes under another large roller at the bottom in the cooling water tank. This arrangement avoids any possibility of surface damage to the hot metal, which was common in the earlier horizontal strip anneal furnaces.

After acid cleaning, rinsing and drying, the surface is usually coated with a detergent solution or a light sulfur-free oil to protect it during handling in transit.

Since every foot of a coil is exposed to the same temperature for the same period of time as it passes through the strand annealing furnaces, grain size from end to end is uniform.

D) SLITTING, CUTTING, AND LEVELING

Following the final rolling, the metal is slit to final width.

Slitting is accomplished by opposing rotary discs mounted on rotating arbors. These knife sets mesh together as the metal passes between them and shear it into a multiplicity of width.

Processing operations which follow final slitting are occasionally required. Blanking is one such operation. Blanking of squares or rectangles is generally done by cutting to length. The metal is first flattened and then cut to length on a flying shear. When circular blanks are required, they are die cut on a press.

The circles are used for the manufacture of deep-drawn articles, e.g. kitchenware. Coin blanks, cartridge and bullet-blanks and cups are also produced on similar presses from strips.

Edge rolling is another process which may follow final slitting. Edge rolling can produce rolled square edges, rounded edges, rounded corners, or rolled full rounded edges.

For some applications, extremely strict tolerances on flatness are stipulated. To achieve this aim, continuous stretch-levellers are used. These lines are also very well prepared to eliminate some rolling defects, such as waves and buckles, and even slight camber. For width of max. 300mm a compact machine shown on Fig. 16. can be used. It consists of bridle rolls building up tension and multi-roll leveller. A strip elongation of max. 3% can be maintained which is sufficient for a major improvement of flatness.

IV. MANUFACTURING OF COPPER AND COPPER ALLOY TUBES, RODS AND WIRES

A) CASTING

The technological route of these products in almost every case starts with casting of billets.
Usually vertical DC semicontinuous or continuous casters are applied. The operation of these machines is described in details in the previous chapter.

Casting of wire rods and large size bars and tubes can be carried out on horizontal continuous casting machines, equipped with graphite mold of desired shape. Features of these lines are the same as those with the strip casters.
After horizontal casting, the surface of the products has to be milled. Cast wire rods are cold rolled, annealed and then drawn to different sizes. For the casting of wire rods - as it was mentioned in Chapter 2 - Outokumpu upcasters are widely used.

The horizontal cast rods and tubes are used for manufacturing of bearings, bushings, washers, etc. at the as-cast and milled sizes, and for hot stamping purposes.

The continuous casting of wire rods, bars and tubes drastically simplifies the technological route. It is a very flexible process regarding the alloys and sizes. Machines are relatively cheap, casiliy maintained, require small building. The production can be easily diversified by adding new lines.
It has to be emphasized that any properly equipped machine can cast wire rod, bar or tube using the desired molds and tools. The process is characterized by low material and energy costs. It is very much suitable for small-scale producers and newly established manufacturing facilities.

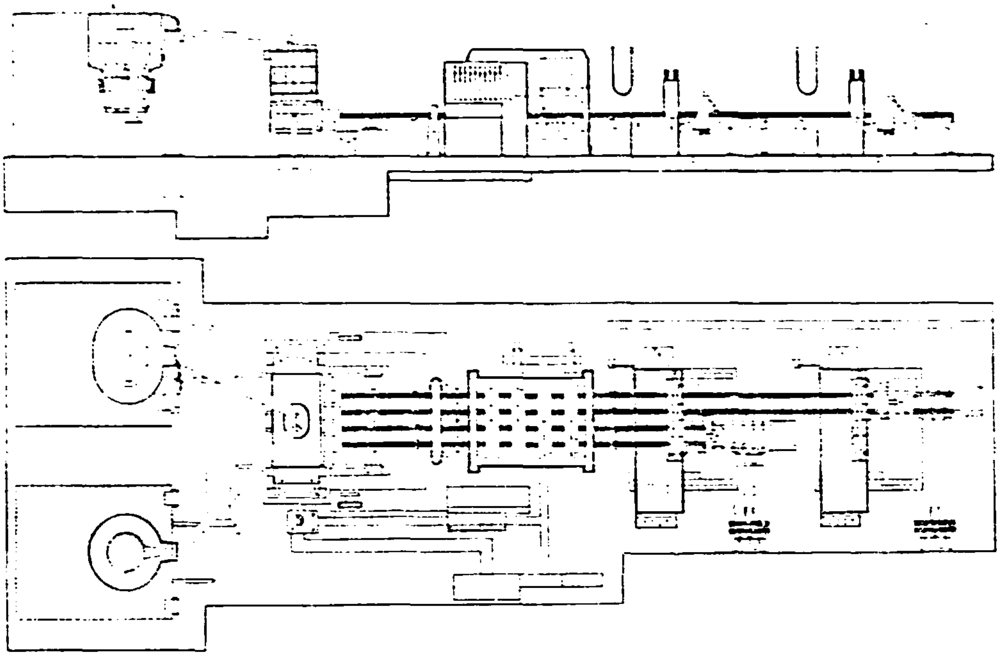


Figure 17/a. Schematic drawing of a horizontal continuous casting line for four strand production equipped with two drives and two walking saws

Figure 17/b. Integral-mould set-up in a Technica Guss plant with a strand dia. of 160 mm and a total output of 8 tons per hour

Figure 18. Horizontal wire-rod casting machine

The only disadvantages are that the cast tubes or bars have a very coarse grain structure and therefore they don't lend themselves to drawing operations; moreover the size range of the products is limited by the casting parameters.

B) EXTRUSION

The end of the mold or semicontinuously cast billets has to be sawed off to achieve good quality end product. The billets are cut to lengths appropriate for the extrusion press.

Before extrusion the metal has to be preheated to the desired temperature depending on the type of alloy. This is a very delicate operation having great influence not only on the pressing force, speed and other parameters of the presses, but even on the quality of the product.
Gas or induction preheaters are both widely applied, but in many cases a combination of the induction and gas systems provides the best results : homogenous temperature of the billets along their whole cross-section, high heating speed allowing large capacity, and formation of only a very thin oxide layer on the surface.

For the extrusion of bars and tube shells usually horizontal oil or water hydraulic presses are applied with a power typically from 1000 up to 3500 tons.
Tubes can be pierced on the extrusion press itself, if it is fitted with an internal piercer. The piercers usually have a force up to 600 tons. Regarding concentricity of the tubes, very good results can be obtained by using predrilled billets. This method is optimal only if the press is not suitable for good quality piercing, having in mind the increased metal consumption and the extra operations of drilling.

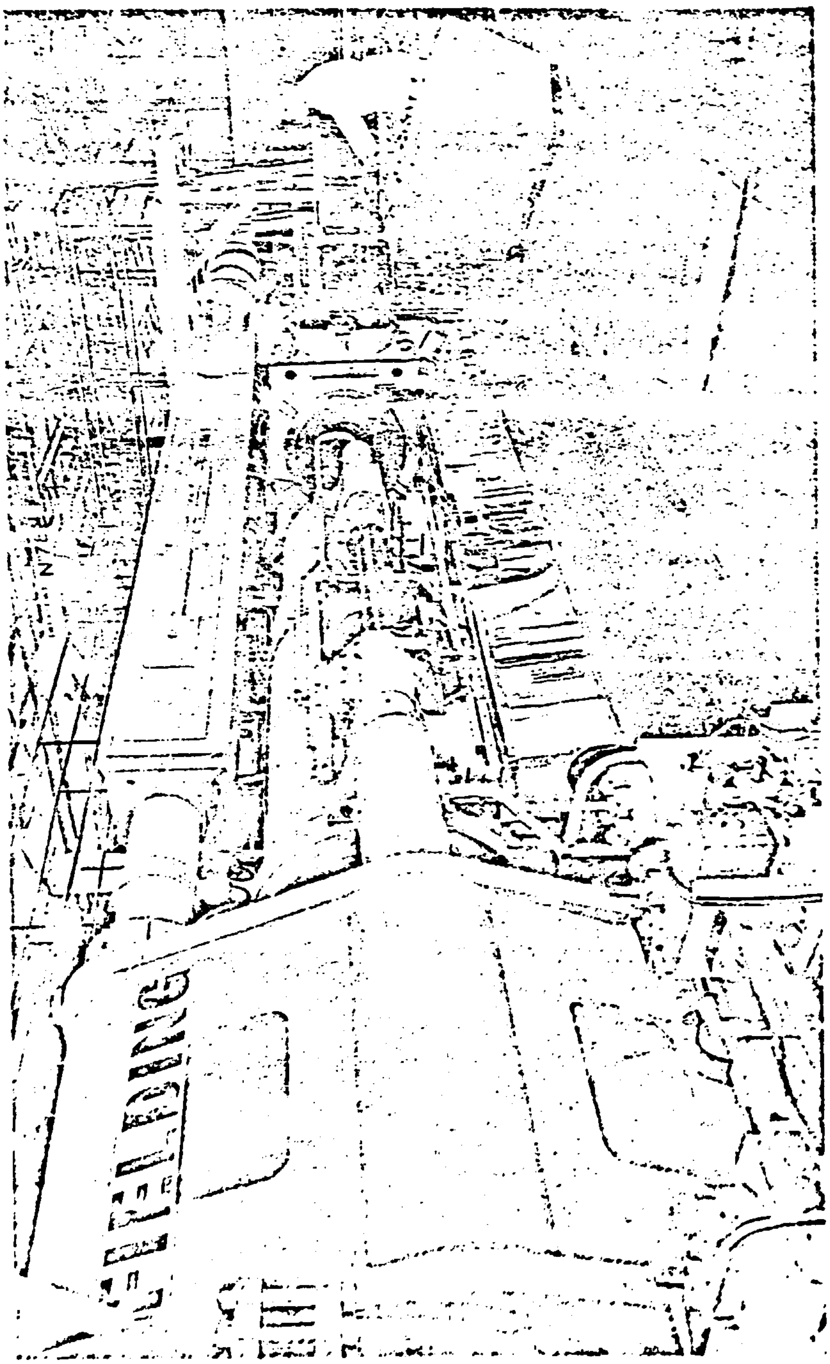


Figure 19. A 3000 ton Horizontal Direct Extrusion Press for copper tube production fitted with a 500 ton internal piercer

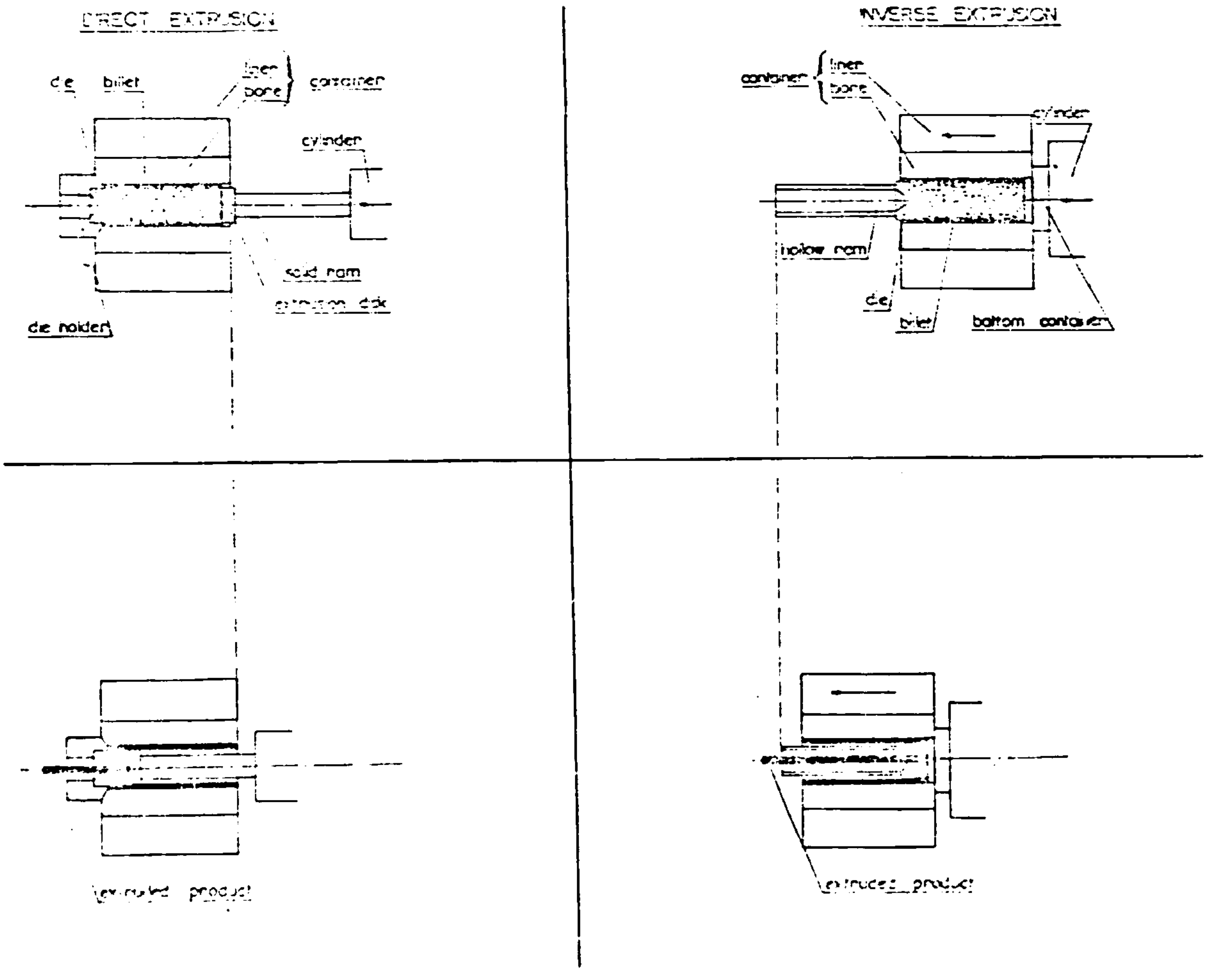


Figure 20. Direct and indirect extrusion methods

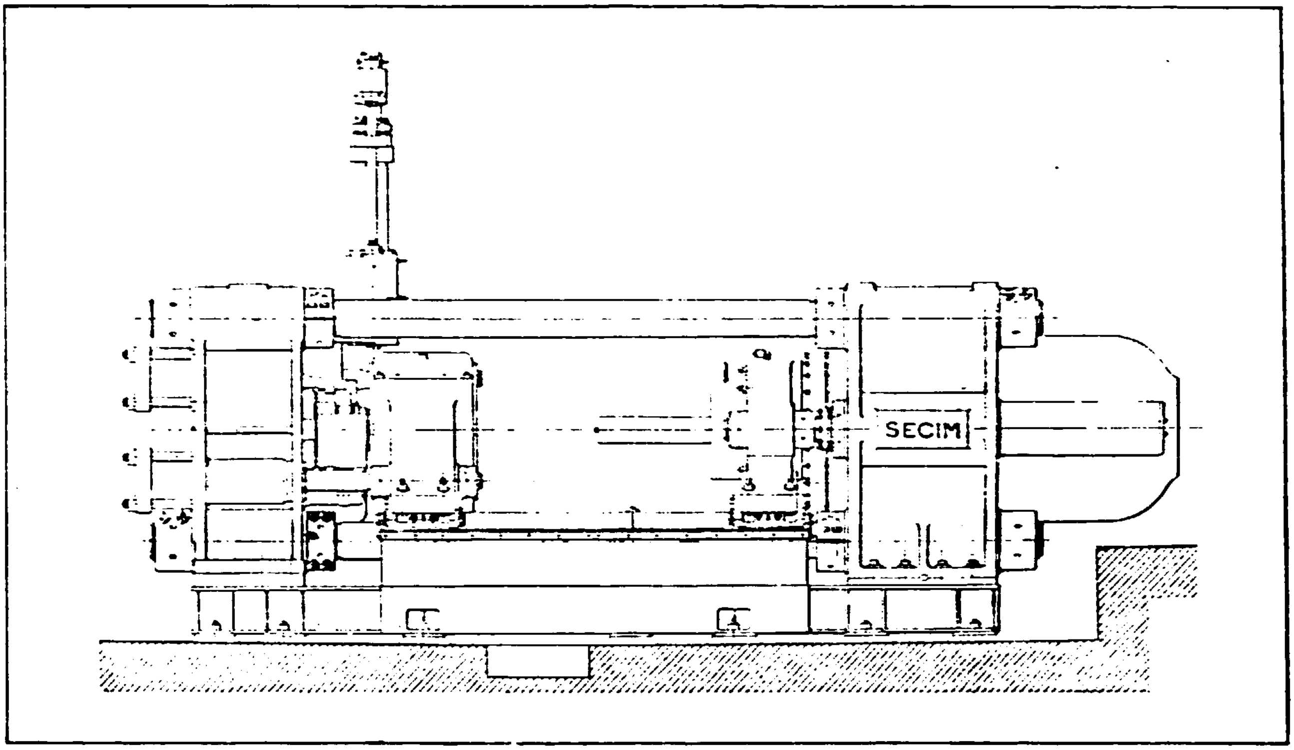


Figure 21/a. Schematic drawing of a direct

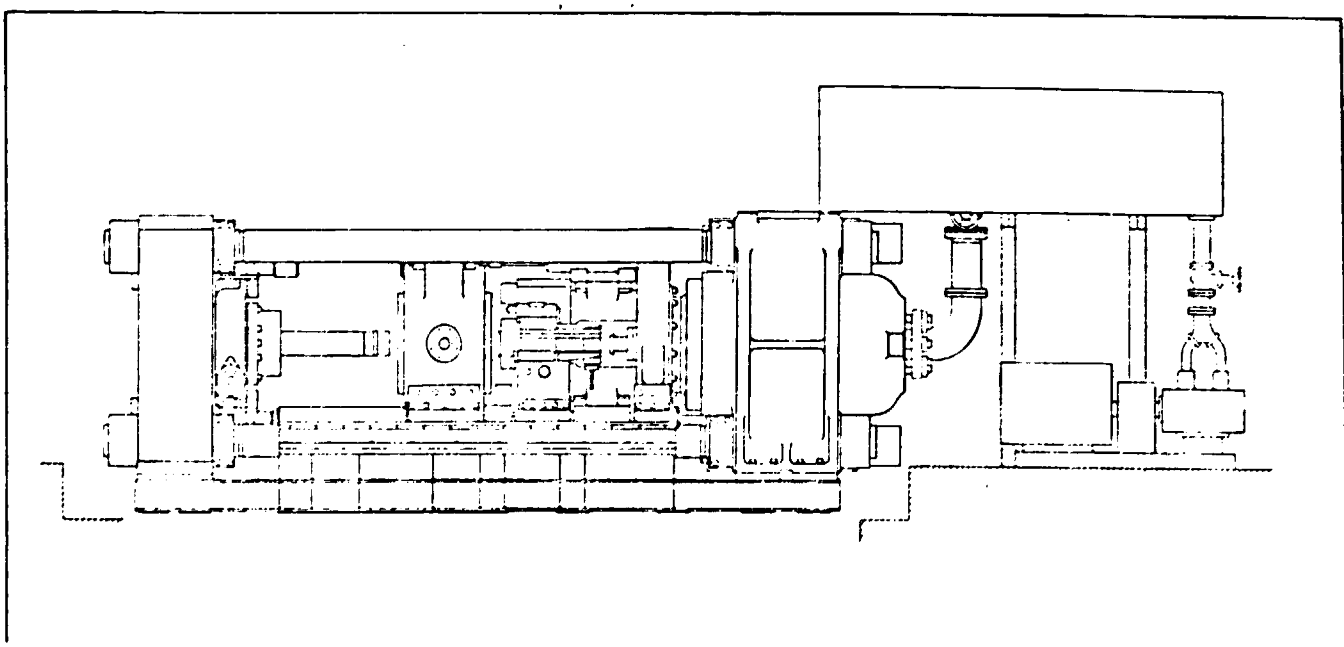


Figure 21/b. Schematic drawing of an indirect extrusion press

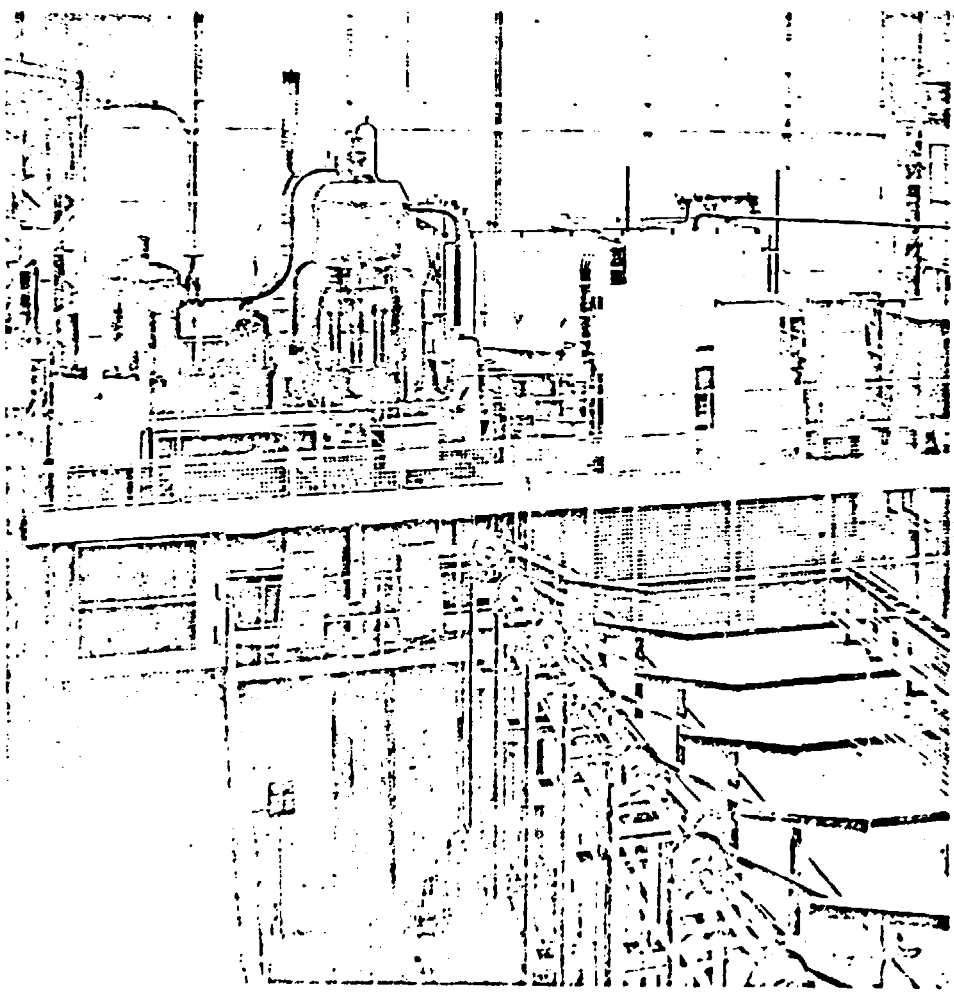


Figure 22. A 1000 ton Vertical Extrusion Press designed to extrude brass and copper tube shells from either pre-drilled or pierced billets by the indirect process or solid sections by the direct process

In the recent years a new, so-called "indirect" pressing method has started to spread over intensively. This new method, shown on Fig.21.b, has several outstanding features. Due to the decreased friction the pressing force (energy) is reduced by 15-20 %, speeds are increased by 7-10 % , metal savings can be achieved and wear of the container and its parts is smaller compared to the traditional direct presses.

Existing direct presses are converted into indirect presses in several plants.
The indirect presses at the present stage of art are less suitable for extrusion of tubes and complicated profiles. To achieve good quality of the product, billets are usually extruded with shell. It is a well known fact that the surface of the billets are rich in impurities. To avoid penetration of these impurities into the extrusions, a thin shell collecting most of these particles is formed during pressing.The shell is discarded after finishing the extrusion.

In some cases for the production of smaller tubes vertical presses are used applying force in the range of 1000 tons and using pierced or solid sections.

After pressing extrusions are pickled in dilute sulphuric acid, end-cut, and in case of ready products they are cut to length, straightened, packed and delivered.

C) DRAWING

Other part of the extrusions are pointed and drawn on different drawing benches. Some alloys, e.g. brasses, require intermediate annealing after each drawing operations.

Annealings are carried out in roller hearth furnaces, or in case of wires and coiled tubes in bell annealers. These equipment are described in the previous chapter in details.

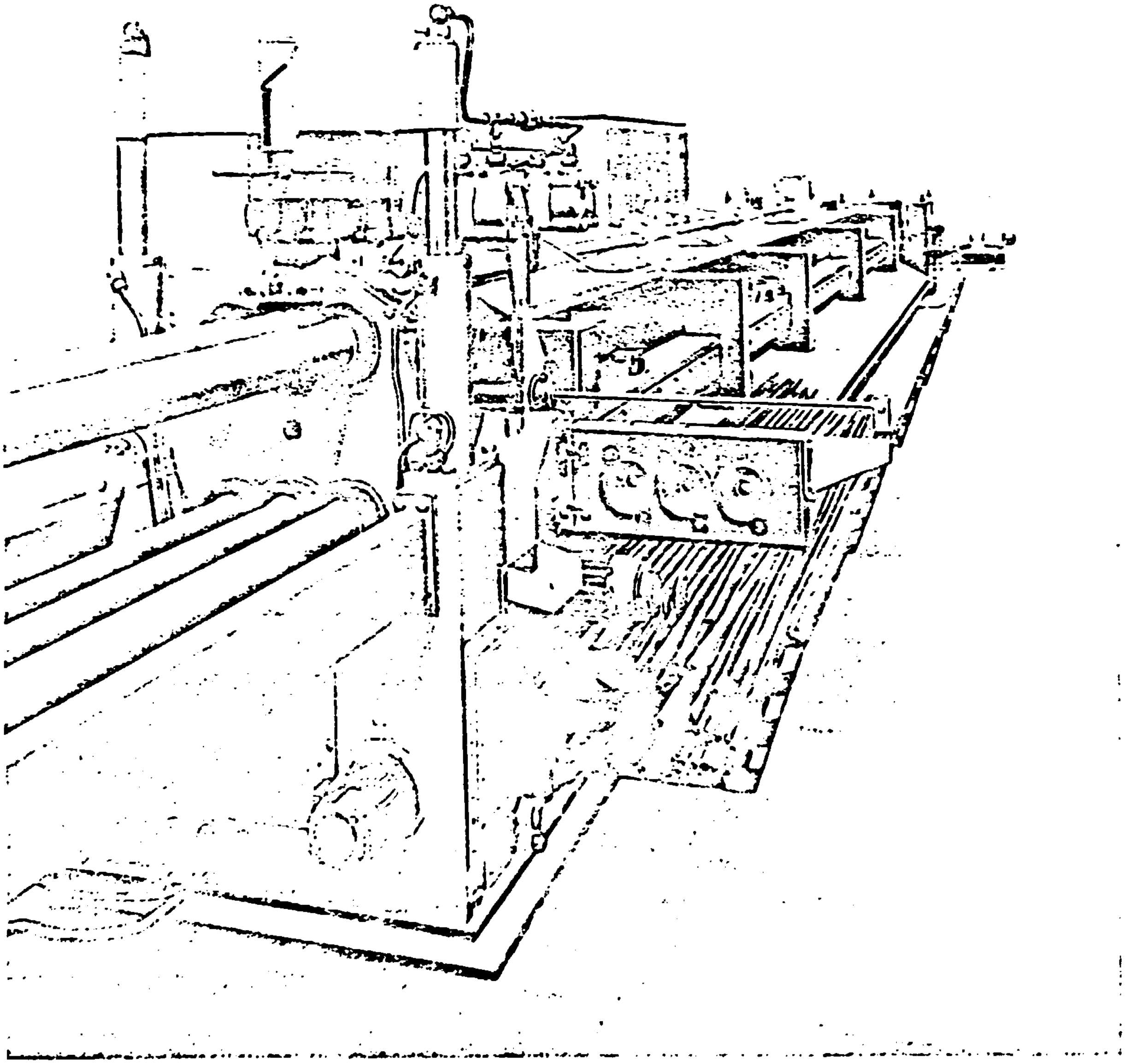


Figure 23. 3-strand tube and rod drawing bench

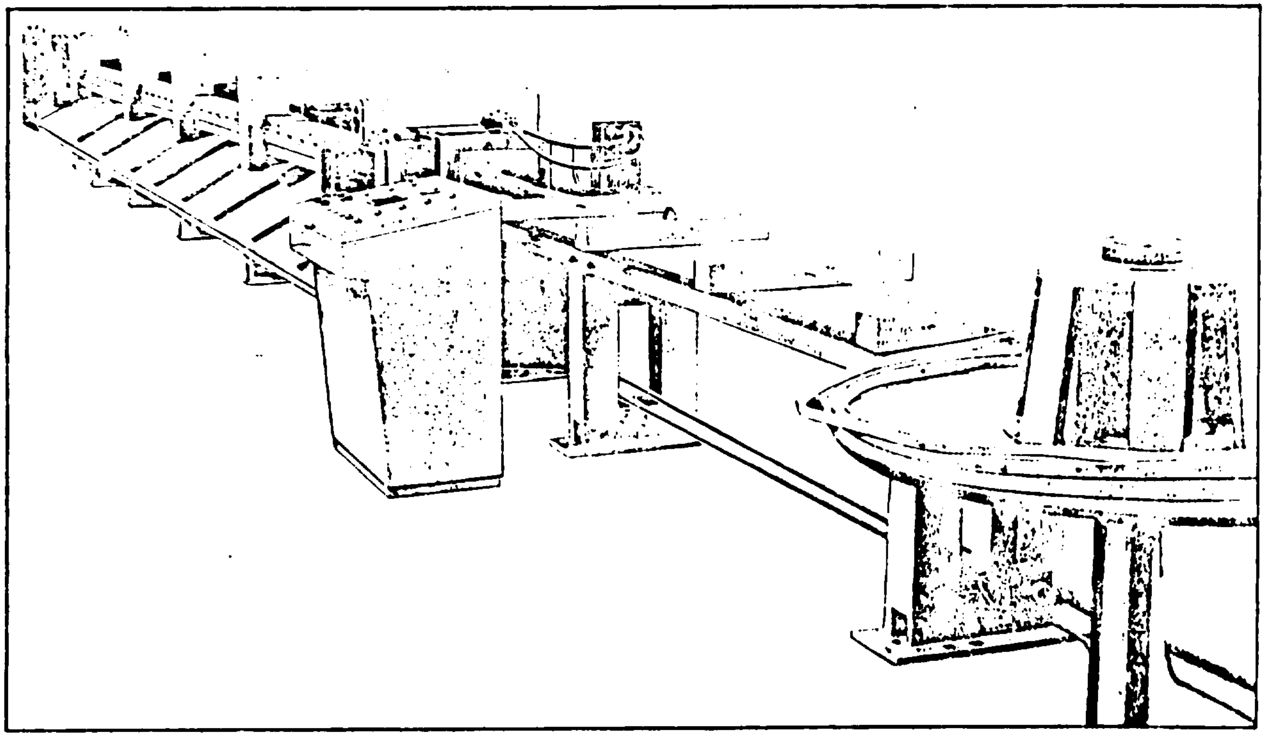


Figure 24. Drawing bench for the production of rods from coils

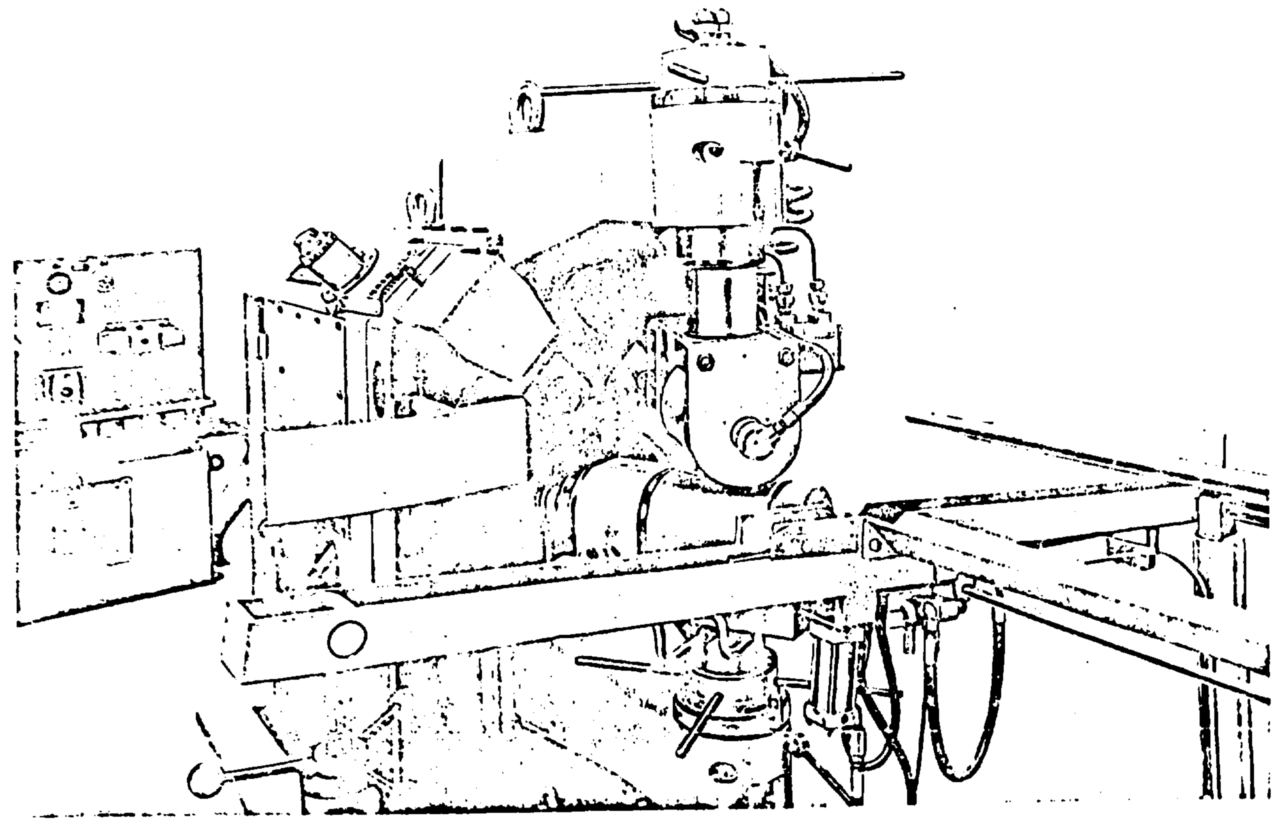


Figure 25. Tube pointing machine

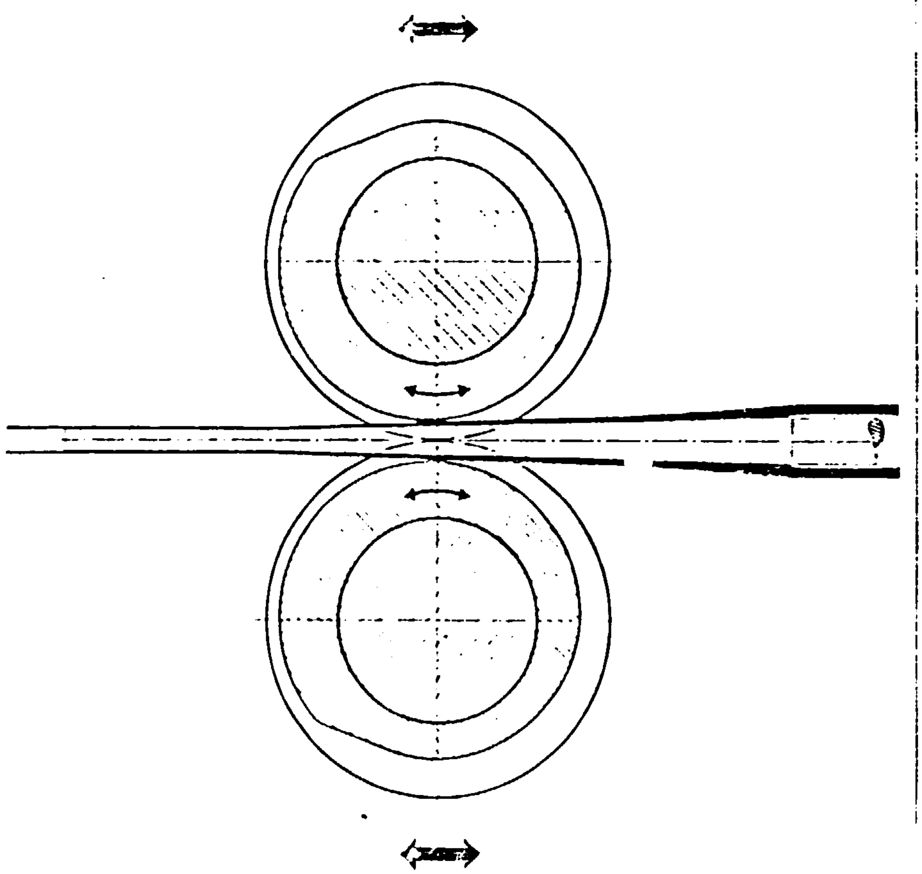


Figure 26. Schematic drawing of a pilger mill

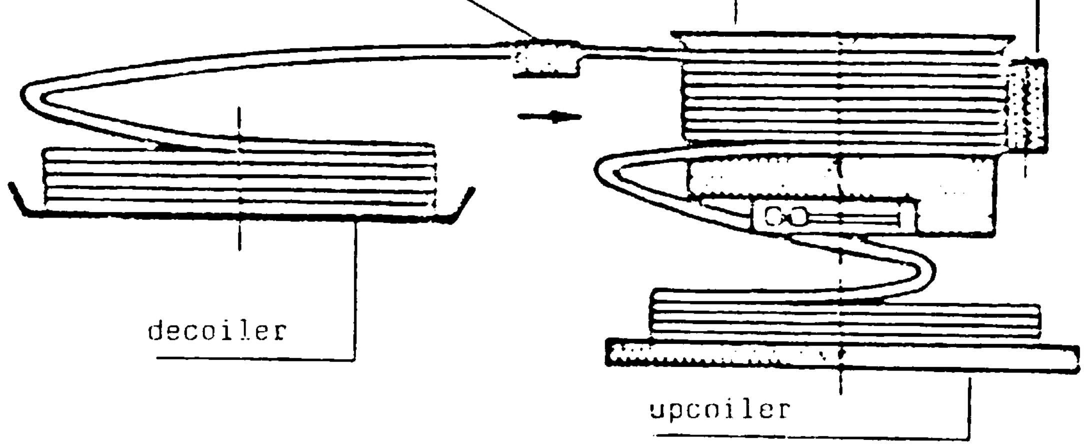


Figure 27. Schematic drawing of a spinner block

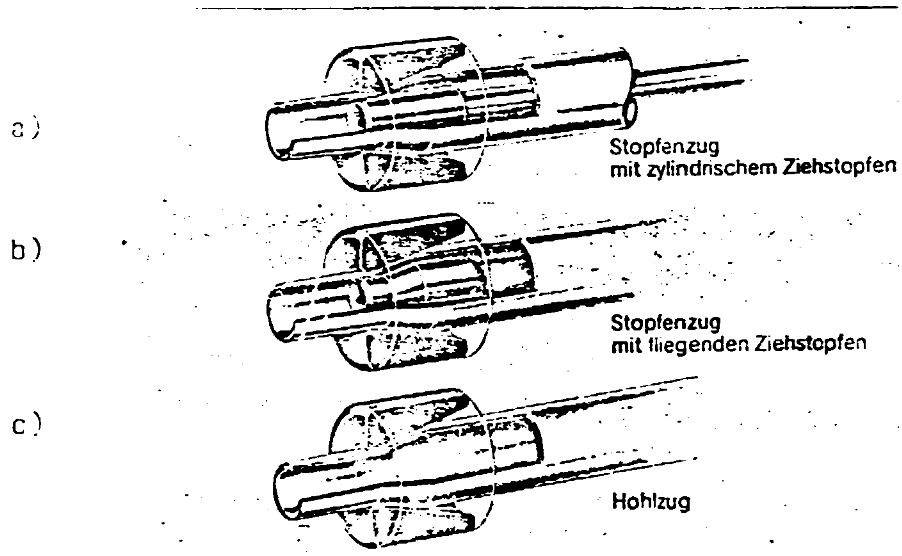


Figure 28. Tube drawing methods

a) tube drawing with cylindric plug

b) tube drawing with floating plug

c) tube drawing without plug

After intermediate or final annealing, the product has to be pickled in dilute sulphuric acid and then washed.

Brass and other copper alloy tubes are usually drawn on traditional drawing benches not in a coil form. Some benches allow drawing of up to three tubes parallel at the same time.

Rods are pressed into larger lengths and coiled after leaving the run-out table of the press. There are several different type of equipment for drawing this type of product, but the most popular among them are the combined Schumag lines allowing continuous drawing, straightening, polishing, sawing, and packing rods of different sizes and cross-sections.

D) COPPER TUBE MANUFACTURING

Copper has much higher ductility than its alloys, therefore the production of copper tubes is different from the previously mentioned technological route.

On the extrusion press heavy gauge tube shell is extruded into water eliminating the oxidation of the surface.
The tube shells are end-cut and directly transported to the pilger mill. The pilger mill is a special rolling mill with alternating rotation of rolls.
It enables to roll long, high-accuracy and good quality copper tubes applying large reductions. The tubes are coiled after pilgering.

Copper tubes weighing up to 250 kgs are drawn in several passes without intermediate annealing on spinner blocks applying "floating plugs". Lubricant and drawing plug are placed inside the tube and a point is made on a push-pointer. The pointed tube is pushed through the die and drawn. Tubes down to 5 mm OD and 0.5 mm wall thickness are drawn.

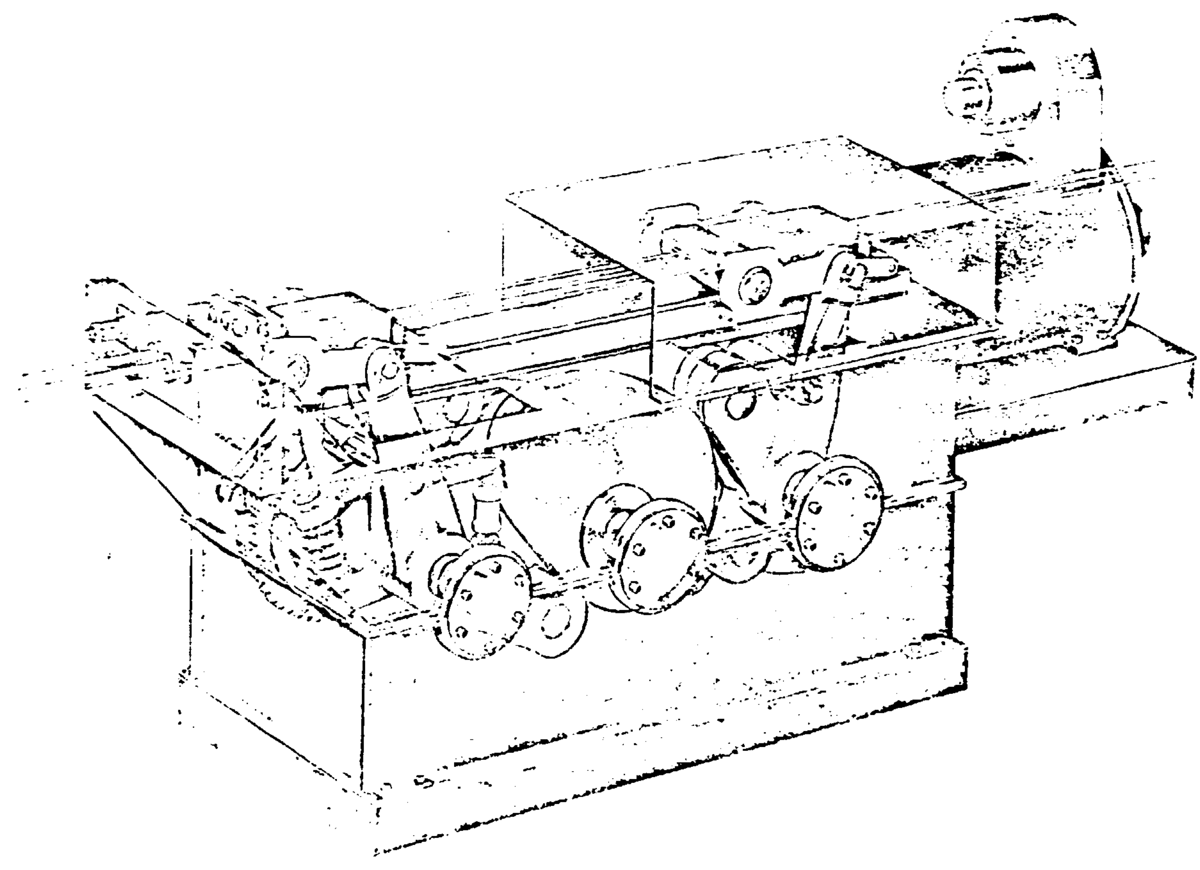


Figure 29. Continuos tube drawing machine

35 % reduction is used in each pass. The total reduction is 99 % without intermediate annealing.
The last drawing operation is made on a combined continuous drawing bench which improves the shape of the tube, cut it to lengths, and in case of refrigerating tubes, forms coils of ordered size. The annealing of the tubes is performed in bright annealing roller hearth or batch furnaces.

In the past years the production of copper tube by strip welding has started. By using high-frequency induction welding of cold rolled and slit strips, combined with spinner-block drawing and finishing lines with incorporated intermediate induction annealing, the production can be made in a more continuous way, and tubes up to 5000 kg per coil can be produced.

WIRE DRAWING

The drawing of wires in principal doesn't differ too much from the production of rods. The only difference is that continuous wire drawing machines with incorporated induction bright annealers are usually applied.
Wires for special applications are flattened on small rolling mills.

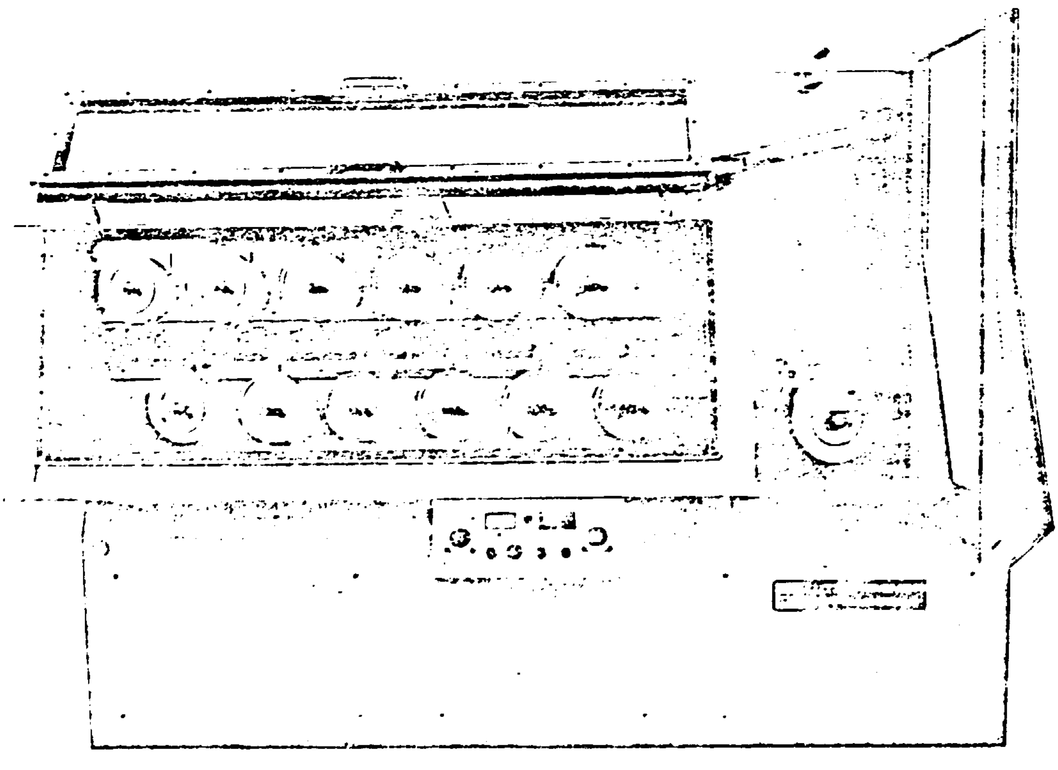


Figure 50. Non-slip thin wire drawing machine

V. OTHER TECHNOLOGIES

Castings and hot stamping of different copper alloys - brasses, bronzes - are widely used in the transport, sanitary, electrical and mechanical engineering.
These items are mostly produced by small specialized companies and rarely in the frame of factories producing non-ferrous semis. The volume of present study doesn't allow to elaborate the various casting and hot stamping technologies in details, so only a few important trends will be mentioned here. At the same time it has to be emphasized that no dramatic changes could be seen in this field during the last decade.

Raw material for these product is mostly scrap mainly collected and purchased outside the factory and partially recycled within the production process. Although the prescriptions for the chemical compositions of the casting alloys are not as strict as the same for the wrought product, it is very important to pay special care and attention for the selection and separate collection, handling and storage of different alloys avoiding their mix-up.

There is a world-wide tendency showing intensification of scrap recycling.
In 1980, the USA, the biggest copper supplier all over the world, gained as much as 46,6 % of his copper production from scraps. In the majority of industrial countries the ratio of production from scraps has also increased between 1970 and 1980; and from the total of 34.8 % in 1970 it grown into 38.8 % in the year of 1980. It is obvious, that the energy consumption has also made an influence on this tendency, which is 13,500 kWh/t for production from ores, while it is as low as 1,700 kWh for production from scraps.

The utilization of scraps and other copper containing waste materials helps to economize with copper ores; at the same time it results in sufficient decrease of environment pollution, for example sulphur emission into the air and diminishes the problem of pollutant storage.

Different casting processes are applied, such as :

- sand casting,
- die casting,
- shell mould casting,
- pressure casting,
- centrifugal casting.

For all these processes copper alloy scrap is melted in oil, gas or electric furnaces of 100-2000 kg capacity. The composition of the melt is controlled by quick laboratory methods, and adjusted if required. After that the metal is cast by the technological route selected depending on the size, shape, quality requirements, size of the series, etc.

In the past decade, more and more producers use horizontal casting instead of centrifugal casting for the manufacture of bearing tubes. The horizontal casting has size and alloy limitations, but it is much more suitable for mass production offering better tolerances, homogenity, lower metal and energy consumption and other advantages.

Hot stamping is a very productive method for mass production of different machine parts and sanitary appliances. As it was previously mentioned, in up-to-date factories these products are made from cut-to-length continuous cast rods of different sizes.

Hot stamping, similarly to die or pressure casting methods, are economically feasible only for parts ordered in large quantities due to the time-consuming and expensive process of die-making. As a result of the relatively high capital investments required - in comparison with sand casting equipment - these production facilities are viable mostly in case of demand over 1000 tpy.

One must note that die-making shop should be an integral part of any well equipped and competitive die casting, pressure casting or hot stamping plant.

VI. MAIN FIELDS OF RESEARCH

Although in the recent years one could see tremendous changes and improvements in almost all fields of copper semi-finished product technologies, there are still vast possibilities for technical developments and research in this sector of industry.
The most important trends are shown below :

A) Copper wire rod manufacturing

New continuous casting methods are being developed or the existing ones are being improved in order to ensure

- casting of smaller gauge product closer to the end use size
- production of new and difficult alloys
- metal and energy saving in the whole technological route
- higher productivity
- increased flexibility of production program, i.e. fast change of alloys and sizes, shut-down and start-up
- elimination of environment pollution.

New materials are being developed for use in critical applications which are responsible for the major part of downtime of the lines, such as casting moulds, shaving dies, refractory materials, etc.
Automation of handling and transport is another aspect of innovations.Reliability of control and regulating system is a very important problem to be solved.

B) Strip and sheet production

Continuous casting is the last achievement in the production of strips and sheets. At the present stage this method however is limited as far as the alloys are concerned.

Research is intensively carried out to improve the material of the moulds in order to enable the manufacture of alloys which are difficult to cast continuously, to increase the lifetime of the moulds and to decrease costs related to the dies.

Grain refining is also an important feature in improving the ductility of the cast product.

In this sector an other main field for research is aimed at applying higher speed rolling mills of improved design or to reconstruct the existing mills and equip them with hydraulic screw down system, electronic drive regulating circuits, automatic thickness and shape control and regulation. New coolants, cooling and filter systems are being introduced. All these efforts are resulting in

- higher productivity
- tighter thickness tolerances, better shape and surface of the product
- rolling of thinner gauge strips
- manufacture of heavy coils
- better yield.

In the field of annealing development efforts are aimed at ensuring uniform properties, clean metallic surface of the products. Energy savings, high productivity and flexibility of heat treating processes are of great importance, too.

The finishing processes should improve the flatness and surface quality, too.

C. Tube and rod production

In the extrusion technology the most outstanding break-through of the last decade is the introduction of indirect presses. Investigations are under way to apply this new technology for the manufacture of tubes and complicated sections. Improved design of run-out tables and finishing machinery is one of the preconditions of better product quality.

In drawing operations continuous drawing and welding processes like spinner blocks, Schumag machines, etc. offer high productivity, good and uniform quality, large length of product, high yield and energy savings.

For the production of complicated sections special rolling operations are being introduced.
Improving material and shape of pressing and drawing instruments and tools, developing high efficiency coolants are essential in achieving higher productivity and better quality during extrusion and drawing operations.

D) Casting and hot stamping

In this field the main trend is aimed at providing more accurate parts, smaller wall thicknesses, and approximate the final shape and dimensions of the ready product in order to decrease the quantity of scrap and finishing operations.
Robots are improving both productivity and quality, so they are obtaining wide use in this sector of industry.

E) New alloys and properties

New fields of applications of copper alloys are thoroughly discussed in the first chapter. These applications require not only better quality semis, but sometimes even new properties.
The main task of research in this respect is to produce new alloys having optimal properties for the specific application.

To achieve this aim it is very important to obtain a better understanding of the influence of forming, heat treating processes and different alloying elements on the properties of alloys.
Sophisticated heat treating and forming procedures may offer special combination of different parameters.Precipitate hardening alloys or amorphous metals produced by superfast cooling are good examples of the achievements in this field.

New alloys like copper-iron or special shape-memory brasses are very much asked for in the electronics.

Microalloying is able to drastically change the structure and through it the properties of some alloys.

Sandwich metals in recent years are produced in the up-to-date plants by means of cold-cladding. These plated semis combine the characteristics of different metals, like the strength of steel and corrosion resistance of copper alloys. Very special combination of different metals and properties can be obtained this way at very reasonable cost. That is why this technology is in the focus of a number of research work.
The same way composite materials are attracting much interest, too.

VII. CONCLUDING REMARKS AND RECOMMENDATIONS

Some developing countries are rich in ore reserves and natural resources of energy. Their non-ferrous ore mining (copper, zinc, tin, aluminium, nickel, etc.) is highly developed, but only the first phase of metallurgy is well established. This way only the low-processed products (concentrate, blister copper, cathode, etc.) are exported. The following statistical data show (Tables 5 and 6) e.g. the ore mining and copper production figures for Africa, together with the more informative data on refined copper production and consumption. The sophisticated labour-intensive non-ferrous semis and the finished products are mainly imported. The high costs of this double transport alone can make out a serious waste in the economy of these countries.

Consequently, at present in this region only the natural conditions required by a rapid industrial development are provided. The establishment of mutually advantageous cooperations between the countries with energy resources and ore reserves, would provide great possibilities for the fast and economic development of copper technologies in order to meet the demands on copper alloy semi products in this area.

By gradual establishment of a chain of an expandable capacity industrial plants, the up-to-date and economic production of copper alloy semi products could be performed. Small plants are built at a faster rate, and the need of the limited investment resources can be spread over a longer period of time.

Analysing the trends of industrial growth it can be pointed out that most copper intensive sectors of industry, i.e. electrical and electronic sector, transport,

Countries	Ore mining 10^3t Cu/year		Blister copper production 10^3t/year	
	1981	1982	1981	1982
Algeria	0,2	-	-	-
Botswana	17,8	18,3	-	-
Congo	0,2	-	-	-
Morocco	7,6	19,0	-	-
Namibia	44,3	49,3	38,7	49,3
South Africa	210,6	207,1	185,4	184,1
Zaire	504,8	494,8	486,2	466,8
Zambia	587,4	529,6	571,6	598,2
Zimbabwe	24,6	24,0	22,9	30,0
Africa altogether :	1397,5	1342,1	1304,8	1328,4

Table 5.

Ore mining and copper production data of Africa

Countries	Refined Copper Production $10^3 t/y$ 1981	1982	Consumption $10^3 t/y$ 1981	1982
Algeria	-	-	2,0	2,4
Egypt	2,0	2,4	11,7	12,0
South Africa	144,8	142,8	89,9	89,4
Zaire	151,3	175,1	1,4	1,6
Zambia	564,0	596,5	2,2	2,8
Zimbabwe	16,5	18,0	6,0	6,0
Other African countries	-	-	0,2	-
Africa altogether	878,6	934,8	113,4	114,2

Table 6.

Refined copper production and consumption of Africa construction and mechanical engineering, are showing up the fastest growth rates all over the world. The very low figures of copper intensity of developed countries call for a change in the near future. So the production of copper and copper alloy semis may be organized in every region, subregion or countryin order to meet the growing demand of the national economies on these materials regardless to the fact whether cheap ore or energy resources are available or not

Good examples for the tendency are some developing countries not too rich in natural resources, but having growing demand of copper semis like Taiwan, South Korea,etc., where the manufacture of these products have been set up already. But the areas and capacities have to be chosen very carefully because they require considerable capital, technology, metal and energy. Availability of these resources and the trends of demand even on regional or inter-regional level have to be studied very thoroughly.

As it is shown in the previous chapters there is an abundance of various technologies in every sector of this industry. The equipment and the necessary know-hows are mostly available.

Upon selection, the following main tendencies have to be considered :

- In every technological route continuous casting processes are recommended to apply, which offer increased yield, low energy consumption and capital investment, decreased environment pollution, flexible production capacity, good productivity, high product quality.
- Selected wire rod production technology should be matched to the local or regional demand. Where the demand is

low and excessive ore resources are not available, flexible or low capacity processes should be selected, like Outokumpu, GE dip-forming or horizontal casters. The best solution is to have a possibility for casting not only different sizes, but even different alloys on the same equipment. The paramount importance of the demand side is related to the fact that the conversion price (added value) of wire rods is relatively low and can't cover long distance transportation costs.

- Cold rolling mills equipped with hydraulic screwdown and automatic thickness regulation are recommended to apply. Combination of two-high/four-high or four-high/Z-mill may considerably cut investment costs.
  Hot mills should be selected only for very high demand or special cases.

- For heat treatments of strips, wires and coiled tubes bright annealing bell furnaces offer the best solution at the lowest capital investment.

- Indirect presses offer a number of advantages, but at present horizontal direct presses are more flexible regarding the product mix. Having a suitable extrusion press a lower demand for wire rod can be temporarily covered too compromising on the size of the coils.

- Highly efficient, very productive manufacturing methods are in operation in several countries for the low-cost production of brass rods using almost 100 % scrap. Considering this fact careful attention has to be paid to the demand side in this sector too. The best technological alternative in this field seems to be the use of extrusion and some Schumag type continuous drawing, finishing, chamfering machines.

- Technological route for copper tube manufacturing should be selected on the basis of several factors. In a plant having free capacity on a cold rolling mill, welding tubes from strip and drawing them on spinner blocks could be an ideal solution.

  In case of a plant having free capacity on the existing extrusion press, reduction on drawing benches is the optimal solution offering a very wide product mix.

  The most efficient way for the production of medium and small size tubes is the continuous casting - pilger rolling - spinner block drawing.

- The most suitable casting method must be chosen on basis of demand, as it is shown in Chapter V.

- When establishing copper and copper alloy semifinished product manufacturing, special emphasis has to be made on recycling production and collected scrap. The better the scrap is separated the higher is its value.
  High economy can be achieved using every scrap for its proper purpose.

- High quality second-hand equipment dismantled for one or another reason can be used very well as it is or reconstructed to meet the demand of some developing countries. This is a source of tremendous economy of investment capital. When purchasing second-hand equipment in most cases it is possible to make agreement for the technology transfer.

- Gradual establishment and development of production considering the viable size of capacities is dominant factor in every sector of industry. The importance of local, subregional, regional and even interregional market and production cooperation possibilities has to be emphasized once more. In the frame of such cooperations production based even on imported metal might be profitable, promoting the overall development of industry in the countries concerned.

- In light of the sophisticated nature of copper and copper alloy semifinished product manufacture and the wide range of research and development works, developing countries may consider the establishment of R + D Institutes and advisory centres for copper industry working in close cooperation with the producers and customers of products concerned.

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