OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

DISCLAIMER

This document has been produced without formal United Nations editing. The designations employed and the presentation of the material in this document do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Industrial Development Organization (UNIDO) concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries, or its economic system or degree of development. Designations such as "developed", "industrialized" and "developing" are intended for statistical convenience and do not necessarily express a judgment about the stage reached by a particular country or area in the development process. Mention of firm names or commercial products does not constitute an endorsement by UNIDO.

FAIR USE POLICY

Any part of this publication may be quoted and referenced for educational and research purposes without additional permission from UNIDO. However, those who make use of quoting and referencing this publication are requested to follow the Fair Use Policy of giving due credit to UNIDO.

CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

30152

Distr.
LIMITED

ID/WG.74/6
21 September 1970

ORIGINAL: ENGLISH

United Nations Industrial Development Organization

Seminar on Copper Production and
Group Study Tour of Copper Plants
in the USSR

Tashkent, USSR, 1 - 15 October 1970

[illegible]
([illegible]) 1/

by

S. Temple
Technical Manager
Copper Division
Imperial Metal Industries (Kynoch) Ltd.,
United Kingdom

1/ The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the secretariat of UNIDO. This document has been reproduced without formal editing.

id.70-4389

NEW DEVELOPMENTS IN COPPER TRANSFORMATION

(Rolling, Extrusion, Drawing etc.)

by S. C. Temple, M.B.E., M.Sc., A.C.T., F.I.M.

1. **INTRODUCTION** Most of the papers being considered by this Seminar relate to extraction or refining techniques, but this review is concerned with the subsequent fabrication of the refined copper or copper alloy shape into one or other of the forms used in engineering. While the emphasis of the whole seminar is directed towards pure copper or only lightly alloyed coppers, it is inevitable in a paper of this type that techniques developed for harder materials, including copper alloys such as bronze, will be mentioned since most copper works which produce wrought copper products use essentially the same equipment for fabrication.

2. The greatest proportion of the tonnage of copper is initially processed from a casting made by melting refined copper in ingot or cathode form and pouring into a suitably shaped mould. Until the last decade or so the product as cast was invariably fabricated by the use of complex and expensive mechanical equipment by hot and cold working procedures, but now alternative and shorter production routes have been developed. This paper attempts to survey developments in the traditional and more recent fields.

3. **WIRE ROD PRODUCTION** Typical of the above is the developments in production of copper wire - by far the largest proportion of high grade copper used in wrought condition. Wire bars are cast from melted electrolytic copper ingots or cathode to a square section of say 100 sq. cms. and this is reheated and rolled in a hot rolling mill or set of mills to round rod 6 - 10 mm diameter, coiled, quenched in water and pickled in acid. Alternatively and not so frequently employed is a process whereby a cylindrical billet, 150 - 250 mm in diameter is cast, reheated and extruded to a similar rod diameter. Both these processes are followed by cold drawings with suitable annealings and picklings.

It will be appreciated that these processes require capital expenditure of a very high order, occupy large areas of land, are wasteful of energy and have high labour requirements, not to mention effluent disposal problems of great magnitude. Furthermore, demand for more stringent surface and metallurgical quality has caused additional processes, such as 100% inspection for ferrous inclusions or shaving of the surface to remove imperfections prior to final drawing. All these processes increase complexity. Understandably, therefore, considerable research work has gone into alternative methods of producing wire rod, with the dual aim of reducing costs and improving quality and these could be of great significance to developing countries where demands are smaller and less standardised and heavy capital equipment is either not available or would need to be amortised before further expenditure can be justified.

4. Several such processes may be of value in this context viz

5. (a) <u>Continuous Casting</u> The principles of continuous casting are simple enough - basically molten metal is poured into the top of an open ended cooled mould and withdrawn continuously from the bottom. The translation of this into viable processes presents the problem because at temperatures near the melting point, metals are mechanically very weak and friction between die and solidified metal gives rise to hot tearing. Techniques to overcome these hazards have been developed initially for lower melting point metals like zinc and aluminium and only very recently have they been applied to copper. Of these, the most useful would seem to be the Properzi process or its modification developed by South Wire in Georgia, U.S.A. Fig. 1 gives a schematic drawing showing the basic principles. The mould cavity is formed from a continuous steel band which passes round half the periphery of a grooved wheel, externally water cooled by sprays. Then the band supports the product until it is cooled sufficiently to have adequate strength to be handled. In the modifications which have been made since, this unit is now integrated with a hot rod rolling mill with up to seventeen sets of rolls (to produce 6 mm diam. rod). The advantage of such a process is that of its small capital cost for a large output and a coiled length only limited by the melting facilities essentially.

6. Alternative designs of continuous casting machines use a graphite die often as an integral part of the melting unit or a holding furnace. Such equipment is more suitable for use where small tonnages are required because output rates are lower per strand and problems of die life due to friction, oxidation and condensation of volatile constituents, etc. may occur. However,

such units may have advantages for the more specialised types of copper, e.g. oxygen-free grades or alloys. A recent description of such plant at Pori in Finland (Journal of the Institute of Metals, June 1970, vol. 98, p.161) is typical of a development of this type.

7. (b) Dip Forming Another novel principle somewhat akin to continuous casting is Dip Forming. A solid rod is continuously drawn up through a bath of molten metal, a layer of copper freezes on to the surface and thus a larger diameter rod emerges than that which enters and at a suitable temperature for drawing to the initial starting size. The excess weight passes out of the loop as a product while the rest is recycled. Figure 2 shows a schematic diagram. Theoretically the heating of 1 kilo of copper from room temperature to the melting point requires the same heat as 2 kilos of copper from liquid to solid at the melting temperature and so under ideal conditions double the quantity should be solidified on to the surface and pass out of the system as product. In practice efficiencies of 93% or more are claimed. This development was originally sponsored by General Electric Co. of Schenectady, New York and oxygen-free copper melted under a protective atmosphere is the chief product. Furthermore, they have developed a shaving process immediately prior to entering the molten metal chamber and so a perfectly clean surface is presented for further deposition. A plant producing this rod at a rate of 5 tons per hour is operating in [illegible] in Sweden (reported in Metal Bulletin, February 13th 1970, P. 26).

8. A similar process is ascribed to Stepanov in the Soviet Union, reported by Mr. G. L. Bailey in the Australasian Engineer, May 1966, but detailed description in English does not appear to have been published.

9. (c) Electrodeposition Since more and more copper is produced by electrolytic refining, a logical development is the direct deposition of a shape which can be directly drawn into wire instead of producing a cathode which has to be remelted. So far, however, only a feasibility study of a production machine has been undertaken, but it is reported that reasonable quantities of wire have been made. A [illegible] square rod is deposited in a spiral form on a stainless steel cathode plate with grooves containing a nonconducting resin to enable enough separation to occur. A smooth deposit is obtained by the use of additional agents and special current density control, but so far no commercial plant has been built to the writer's knowledge.

10 However, of all the processes so far described, this one appears to be the one of greatest cost reduction potential and merits careful consideration by the Seminar.

11. DEVELOPMENT IN ROLLING The production of strip and sheet products exemplifies a rather different approach. The copper industry has followed the practice of steel and aluminium in the trend to large piece weights which help to reduce mill handling costs and facilitate better plant utilisation and industrial controls. Furthermore, customer demands for long length products are increasing for similar reasons. However, such plant means high initial capital expenditure and so while the mass production plants install heavy wide equipment of increased speeds of rolling and automated to a great degree, a number of processes of lower capital cost have been developed which can conveniently be stated as:-

12. (a) Casting thinner sections to reduce or eliminate hot working
As with the Properzi process, developments in zinc and aluminium technology have been adapted for copper and its alloys. Inevitably this has needed the solution of problems concerning the higher operating temperatures, the better conductivity for heat of copper and oxidation characteristics, some of which still remain in part, but the most successful so far appears to be the Hazelett process, where two water cooled steel belts act as the mould moving with the strip being cast. Very high output speeds are possible at the wide widths (1 metre or more) usually made and problems relating to feeding the machine with molten metal often preclude its use. Speeds up to 3 metres/min are quoted for this type of unit which at 25 mm thick and 1 metre wide is equal to 40 tonnes per hour or more. So far no detailed description of operation on copper has been published, but one plant operating successfully is known to the writer.

13. Akin to this method is the possibility of adapting the method of casting strip developed for aluminium by the Hunter Engineering Co. Metal is fed upwards through water cooled rolls. Maybe the fact that the small time of contact precludes removal of heat to the same extent as in Hazelett's method is a restriction, since this would mean very thin sections being cast at slow speeds.

14. However, as an alternative to a moving die or mould, static dies of graphite are in use, similar to the machines reported under wire rod (see p. 8) and these would again appear to have the greatest potential for countries where smaller tonnages are required. Quite a number of commercial machines are on the

equipment and processes based on casting up to 350 mm wide and as thin as 10 mm are well developed. Speed is slow so that outputs tend to be of the order of 1/2 tonne per hour, which while quite significant from a simple relatively inexpensive piece of equipment is not such a problem to provide with molten metal.

15. The technique of centrifugal casting to produce a hollow cylinder which is subsequently sawn and flattened to produce a suitable strip for cold rolling should also be noted. One brass plant in Holland uses this process to avoid hot rolling and manufactures strip 20 mm thick and about 350 mm wide thereby.

16. (b) Large reductions carried out at slower speeds. The trend of the mass production units to roll at high speeds but with traditional pass sequences has been matched by the development of several novel mills which are based on the concept of a few large reductions at moderate speed. These introduce techniques of incremental working akin to forging and have undergone considerable development in this last decade.

17. The Planetary mill developed by Sendzimir is used on steel to reduce 25 – 30 mm thick strip by up to 98% in a single pass at speeds (ingoing) of 3 metres or more per minute. To my knowledge, none are operating on copper or its alloys but the possibilities of even more startling reductions are undoubtedly there. This is a hot working operation when applied to steel and need preheating facilities but greater advantages would accrue by the use of cold working techniques.

18. Of these, the Pendulum mill developed by my own company in Britain is an interesting example. The principle of this unit is shown in Fig. 3. The ingoing material is forced by feed rolls into a gap formed by the converging paths of two work rolls which move backwards and forwards rapidly with deformation of the strip taking place during both strokes of the cycle. A 230 mm wide unit is in full production now reducing a temper hardening brass alloy by 90% in thickness in one pass and on pure copper much heavier reductions (over 95%) are possible.

19. Several similar designs have been noted such as the Krupp-Platzer mill described in Iron & Steel, February 1969, p.33-34, but both this and the Sendzimir Planetary mill are designed for hot rolling rather than cold rolling.

20. From the point of view of this Seminar, the great advantage of these developments, especially those which can be operated without reheating, are the savings which accrue from reduced annealings and passes on conventional mills. Thus on the temper hardening brass quoted above, the substantial saving was of 5 heat treatments and 15 passes on a conventional mill.

21. (c) Integration of casting and rolling The cost of handling, coiling and other auxiliary operations has focussed attention on possibilities of combining casting with rolling and the developments in (a) and (b) above have revived interest since the speeds of operation of continuous casting are similar to those of these novel incremental rolling procedures. Such developments are already well known in zinc fabrication where several plants operate a Hazelett machine in conjuntion with a traditional mill in widths 1 metre or more, but the greatest advantage to the copper industry would perhaps arise from narrower width units, say 400 mm wide. The concept of a graphite die machine followed by a Pendulum mill, for example, is obviously possible and again would have advantages to a developing country where traditional rolling mills do not exist.

22. (d) Powder and Spray techniques Processes which avoid casting and perhaps utilise products which can be produced from the ore directly should not be overlooked. Because of the high cost of producing powders together with the slow method currently available for compacting by rolling or spraying on to say a moving belt, no production plant appears to have ever operated on copper or its alloys. However, such procedures are perfectly feasible and lessons can be learnt from development work proceeding on steel in several countries.

23. The other aspect of rolling flat products which has been the subject of development is in connection with improving the accuracy of dimensions and the efficiency of the final rolling stages. The 1930's and 1940's saw increasing sophistication of mill design whereby the two high mill was improved by the use of backing rolls, improved tensioning devices and improved lubrication, so that developmentslike the Sendzimir (20 high) and the Rohn (12 high) mills became popular. They were, however, very expensive in capital cost and in the need for continual skilled maintenance and in the last decade several designs of less complicated mills have been put forward. The essence of all these designs has been to increase the rigidity of the mill by eliminating or controlling the elastic distortion of the housing and roll and roll neck bending by either hydraulically loading or pre-stressing the mill housing , and so controlling the roll gap at will, or by bending the roll by supporting it over the major part of its length by hydrostatically loaded pads. A typical

example of the former which has become very popular is that developed by Loewy who claim not only improved gauge accuracy but also faster response to corrections of ingoing gauge variation (see The Engineer, 2nd July 1970, p.29).

24. An alternative method of correcting strip "shape" and flatness is by auxiliary operations after rolling on conventional plant by stretching or roller levelling by an integrated device whereby strip is pulled over a series of rollers which impart a "stretch" of a few percent. A recent device described in Sheet Metal Industries, Nov. 1969, p.978, is in use in U.S.A.

25. The C.B.S. (Contact, Bend, Stretch) Mill devised by G.E. Research Laboratory, U.S.A. - Fig. 4 is a further extension of this principle whereby strip looped through the gap of two driven rollers rotating in the same direction passes over a small idling roll. This was developed for rolling hard alloys, with 60 - 80% reduction in thickness possible in one pass, but its value in the present context is obvious.

26. DEVELOPMENTS IN EXTRUSIONS For copper and its alloys, the extrusion process is extensively employed for materials unsuitable for rolling because of the awkward shapes produced or because of their hot shortness. Copper itself is extruded occasionally for wire rod but more often for special shapes such as commutator sections.

27. The greatest problems encountered in connection with extrusions are:

28. (i) those presented by the tools, because of the high pressures and temperatures involved.

29. (ii) the low productivity of the process, because of the long time between extrusion cycles, in comparison with, say, rolling.

30. (iii) the fact that the whole of the billet cannot be utilised because of "extrusion defect" in the back end.

31. The mechanical aspects have been the subject of developments since the second world war with impressive results.

32. While alloy steel tools are in use, sintered carbides, Nimonic alloys, ceramics and other composites have been introduced and often find favour because of their longer "life" in service.

33. The pumping equipment using either air-loaded or dead weight accumulators & a water fluid medium has been superseded by direct pumping from an installation

mounted over the main cylinder using oil fluid medium. This, together with automatic sequencing of press movement controlled by limit switches, has enabled reduction of the "dead cycle" time to only a few seconds from 4 - 5 minutes. Further improvements with the aid of punch card or computer systems give the potential of continuous automatic operation although it is apparently more usual to take the press through only a single cycle under automatic control.

34. Developments of this type have lead to the conception of the "package" extrusion press - a standardised design which up to about 1250 tons capacity can be delivered completely assembled - hence the name. This could be of value for the present discussion.

35. In aluminium technology more sophisticated equipment has been installed to control speeds accurately (and if necessary vary it during the extrusion cycle) but with copper and its alloys, a fixed pre set speed is usually adequate since the controlling factor is the speed at which it is possible to quench the emerging product.

36. Preheating for extrusion has also undergone a change to facilitate more uniform and more easily available products by the development of rapid billet heating furnaces, both gas fired and induction heated, which permit of automation or control by the extrusion press operator. A very recent development is the combination furnace whereby fuel firing followed by electric heating is used, enabling great flexibility in output because the preheating can be very rapid in the fuel fired portion and "cooking" and holding at a controlled safe temperature with atmosphere protection is then easily performed in the section of the furnace electrically heated.

37. In extruded tube shell production the major change has been to make a thin walled shell with closed ends under a protective atmosphere and so avoid internal oxidation. Such a shell needs no cleaning and so can immediately pass to draw benches. Such an arrangement would be of value to a developing country with a relatively small requirement for any domestic copper tubing.

38. Hydrostatic extrusion has been described as the great enigma among the working processes, because it has been the subject of much consideration during the last few years but no industrial applications are known, mainly because of difficulties associated with the pressures required. Theoretically, however, the process would appear to be very elegant and perhaps suitable to use for producing complex shapes such as commutator bars or transformer strips in a single operation

39. Although a hydrostatic extrusion press looks much like a conventional hot extrusion press with ram, bolster, container and die, the operation is carried out in the cold by surrounding the billet with a pressurised fluid, e.g. castor oil, which supports it and so eliminates billet/container friction and enables billets of complex cross section to beextruded by this method. An attractive use would be for the direct extrusion of wire from the wire bar but Lengyel states that a pressure of 190 kgf per sq. mm. would be necessary to reduce 20 mm. diam. copper wire to 2 mm. (Metals & Materials, January 1968, p.9) and competition from established methods of production would at the moment appear to render such a process uneconomic.

40. An article in Contemporary Physics, 1968, vol.9, No.5, p.447, review this process and prototype presses have been installed by U.K.A.E.A. Springfield and more recently by the British Non Ferrous Metals Research Association for work on copper and aluminium.

41. The apparatus, shown diagrammatically in Fig. 5, used for the extrusion of solid rod consists of a die located on a shoulder in the base of a high pressure container. The billet nosed to fit the conical die and provided with a guide ring at the back rests in the die. The container is then filled with liquid which is then subject to high pressure and extrusion occurs. Tubes or hollow sections can also be made by minor changes of the apparatus.

42. An ingenious method of overcoming some of the disadvantages of the hydrostatic extrusion process as outlined above has been put forward, whereby a wire or rod is extruded [illegible]continuously. The initial concept is illustrated in Fig.6. The end of the wire is reduced in diameter, then inserted into the extrusion die and initial load is applied to seal the die exit. A suitable length of wire is fed into the container and bent into a convenient shape - the aim being to accommodate as much material as possible in the container which is filled with fluid. The fluid pressure extrudes the wire through the die and it is wound on to a wire spool. The ram is stopped and the pressure removed before the wire becomes straight inside the container so as to prevent the wire from fracturing. Simultaneously with the withdrawal of the ram into its initial position, a new length of wire is fed into the container and the escaped fluid is replaced by a replenishing system through a non-return valve. The process is then repeated. A further development tension is applied to the emerging product both to reduce the pressure required and to control the rate of extrusion.

43. <u>TUBE PRODUCTION DEVELOPMENT</u> Apart from the improvements in extrusion techniques mentioned above, a similar effort has been mounted on alternative methods of tube making in this last decade or so. Some of the processes already mentioned for the production of wire rod and strip or sheet have been adopted at the same time for tube shell manufacture.

44. Continuous and semicontinuous processes for hollow sections have been used for years to manufacture bronze sections for bearings and the same techniques applied to P.D.O. copper is now in use to a limited extent. There would appear to be scope for such a product being fed to a Pilger tube reducing mill for cold rolling. Recently this latter has been reduced so that three or four passes of extruded tube shells 75 - 100 mm. in diameter are broken down cold to 20 - 50 mm. diameter with 80/90% reduction in wall thickness in the operation. The Aetna mill is such a development, differing from the earlier tube reducer in that the rolls are clear of the tube during the return stroke facilitating the forward feed and rotation of the tube. The working rolls are smaller and backed up so that 5 or 6 draws on an ordinary drawbench are carried out in one operation.

45. Electroforming a tube shell is another possibility for copper and similar remarks apply regarding the deposits as for wire rod production.

46. Powder and spray techniques have also been postulated but have never been developed outside the laboratory, although their advantages for making a tube near to the final dimensions would appear to be good.

47. Finally a process which could be valuable to developing countries is the manufacture of tube from rolled strip by forming and welding. Initially used for steel many years ago, its application to copper awaited the development of H.F. resistance welding. Its full exploitation in highly industrialised countries has probably been delayed by their excellent existing tube making facilities, but the process is fully established and should become increasingly popular.

48. <u>DEVELOPMENTS IN DRAWING</u> The final cold working process for tube, wire and rod is often cold drawing to secure dimensions and the required mechanical properties. As with other mechanical equipment, developments have been in the direction of increasing speeds of overall operation including integration of the drawing process with others such as annealing to secure the advantages of reduced handling, less space requirements, uniformity of product

and minimum stock holding.

49. Speeds of drawing per se have not increased overall from the maximum used pre war of about 40 metres per second but speeds of 30/40 metres per second are now normal practice for the finer copper wires where demand warrants it with proportionally lower speeds for thicker gauges of wire. These are operated in coordination with continuous annealing furnaces, electrically heated by resistance and provided with a protective atmosphere either of steam or of an inert atmosphere of nitrogen produced by burning ammonia or propane, etc.

50. Considerable interest has also been shown in the reduction of working loads and improvement of the wire surface by the application of hydrostatic or hydrodynamic fluid pressure to the material undergoing deformation in the zone of deformation. Christopherson's pressure tube technique with the wire, before entering the die, passing through a tube with only a small radial clearance, into which lubricant is drawn and so hydrodynamic pressure is build up at the die entry is well known and drawing loads are decreased appreciably with improved lubrication of the die. The drawback of this technique however vis the need for different sizes of pressure tube for different diameters of wire has led to attempts to pressurise the lubricant externally at a variable but controlable pressure with interesting results. Recent work, reported by Thomson and Hoggart, Journal of the Institute of Metals 1968, vol 96, p. 325, shows that the die load to draw hard copper wire at 12 metres per second decreased by 20% with lubricant pressure of 0.85 kgf per sq. mm. but how far such results have been applied in practice has not been published.

51. Another development which shows promise of lower costs of drawing, is the possibility of replacing the earlier dies of a machine by a smaller number of roller dies which are capable of giving heavier reductions per pass. The last die is a normal tungsten carbide die and more effective lubrication of the wire in this die is an additional advantage. Although roller dies are considerably more expensive than conventional tungsten carbide dies, wear is much less and lives of the order of 1,000 tonnes of wire are reported. The use of this same technique for tubes has also been suggested.

52. Tube drawing has not altered fundamentally in that the three standard processes - sinking, plug drawing and mandrel drawing - have remained essentially unchanged. However, plug drawing has taken pride of place over mandrel drawing because of the development of the floating plug and its application to coil drawing at speeds up to [illegible] metres per minute. This is another

example where the same trend as in other processes can be seen.

53. Significant reduction in drawing load has been claimed by the application of ultrasonic energy to the drawing of copper and other metals, but problems were encountered due to pick up of metal on the dies and also difficulties with coupling of the die to the ultrasonic transducer. However, a reduction of 24% in the drawing load is reported in U.S.A. from such an application when drawing tinned copper wire 1 mm. diameter, and Watkins, Contemporary Physics, vol 9, 1968, p. 471, reports that "considerable savings" occur in the drawing of tube with a fixed mandrel and that a "production type machine" has been operating for several years in a tube mill. It is claimed that the greatest benefits are obtained from the application of such energy, when wall thickness is small and the outside diameter/wall thickness ratio is 500:1. Information on the whole subject is, however, very sparse.

54. <u>OTHER METAL FORMING PROCESSES</u> To conclude this review, mention needs to be made of a variety of developments aimed at avoiding [illegible] rolling, extruding or drawing a semifinished product and producing a component direct. In the present context, some of these processes could be of value to developing countries since capital expenditure could be considerably less than on providing conventional plant. Unfortunately, none of them as yet appear to have been developed very far.

55. (a) <u>Diecasting</u> The most direct route between molten metal and a finished product is casting and pressure die casting leads to rapid production of an object of high precision. Pressure die casting of copper and its alloys presents considerable problems in respect of die materials. Die steels used for zinc or aluminium soon develop cracks when used on copper and in any case their "life" is very limited. The International Copper Research Association have initiated trials with dies made of molybdenum and tungsten alloys and claim significant savings in cost over die casting made with ordinary die steels. Sintered tungsten appears to be the most promising material for pure copper and successful tests are reported from Italy of copper rotors for small squirrel [illegible] motors so cast.

56. (b) <u>Electroforming</u> Earlier references to the use of this technique to the production of wire rod and tube shells have been made and it is obviously valuable for making a finished component. The process is already applied to making wave-guides and similar products, where stringent precautions have to be taken to obtain a stress free deposit with high thermal and electrical conductivity. If some loss of conductivity can be tolerated, higher mechanical

strengths are possible by the addition of additives to the electrolyte and these could extend its use appreciably.

57. (c) <u>High energy rate forming processes</u> An entirely different conception is the use of high deformation rates achieved by explosive, electrical discharge or pneumatic means. The aim is to deliver energy to the metal by high velocity rather than by high tool mass. Originally they were developed for dealing with components difficult to form by other methods either in difficult materials or in awkward sizes.

58. Explosive forming is carried out by firing a charge of explosive close to a sheet or plate of the met in order to force it into a die as shown diagrammatically in Fig 8 (a). Water, air or an inert material like clay is used to transmit the shock wave. In the main, the process is best suited to the manufacture of very large or complex shaped articles needed in small quantities, although it has been applied to the expansion of large tubes and to the making of clad (sandwich) metals like the copper-cupronickel combination used for recent U.S.A. coinage. A review by Bahrani and Crossland in Metals and Materials, February and March 1969 lists legal and safety requirements in U.K.

59. Electrohydraulic (Fig 8b) and Electromagnetic forming techniques are somewhat similar in concept with, in the first instance, an electric spark discharge being used to provide the shock wave and, in the second, advantage is taken of the forces of repulsion between two conductors by virtue of the current flowing in them. A typical example would be the expansion of a tube of copper (Fig 8c). The tube is fitted closely round a high-current coil. The coil produces high frequency current from the discharge of a bank of condensers. Eddy currents are created in the work piece and the forces of repulsion expand the tube to fit a surrounding die. Of the three processes probably the latter, where no transfer medium is used, noise level is low and the forming control is precise, is of greatest immediate use. An example is the terminal-to-conductor assembly shown in Fig 7.

60. High energy rate forming has also been undertaken by actuating the press ram by the rapid expansion of a compressed gas or air or by the combustion of air/petrol mixtures. The Petroforge (Fig 9) is one such example developed in Birmingham, U.K., and units capable of providing energies up to 300 kilo Joules at ram speeds up to 10 metres per second are quoted as available in this design.

61. **CONCLUSION** In the foregoing, I have set out recent developments in manufacture of copper semi-manufactured products and from time to time have emphasised where I felt they may have applications in developing countries. The extent to which any of them can be applied in any country will depend on its existing resources, e.g. if they already possess casting and rolling plant, then continuous casting of a thin section would be an appropriate development, whereas with no such plant one of the other processes described might be worth pursuing. This is the reason why mention has been made of some rather unconventional processes and no doubt in the discussion specific aspects of these processes can be enlarged upon if required.

62. **ACKNOWLEDGEMENT** Thanks are expressed to several of my colleagues in Imperial Metal Industries Ltd. for helpful comments on the text of this paper.

The opinions expressed herein, however, are, in accordance with United Nations' practice, my own and not necessarily those of my Company.

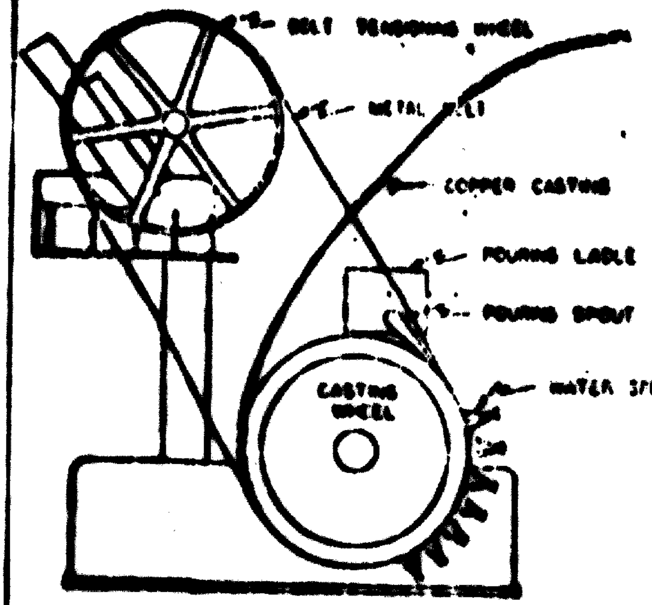

Fig. 1 Schematic drawing showing the basic details and principle of the Properzi casting machine.

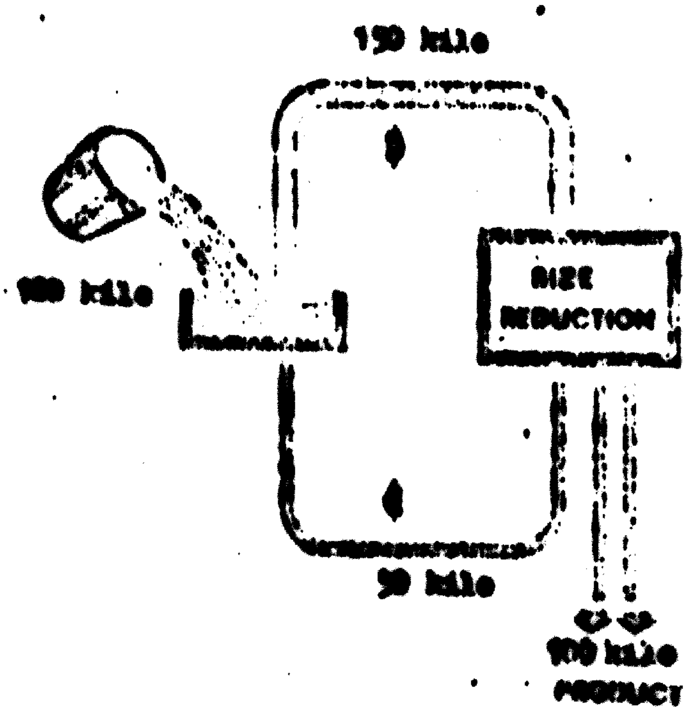

Fig. 2 This diagram illustrates the basic principle of the dip-forming process where a seed rod is continuously withdrawn from a bath of molten metal.

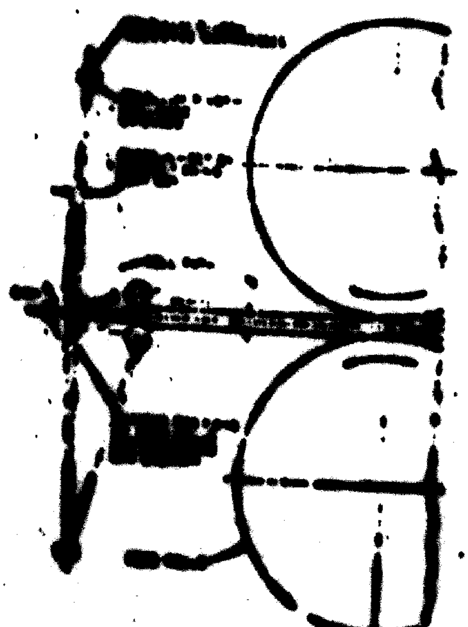

Fig. 3
Principle of the Pendulum Mill.

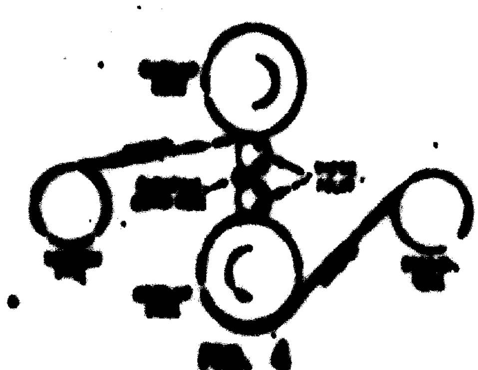

Fig. 4
Principle of [illegible] Mill.

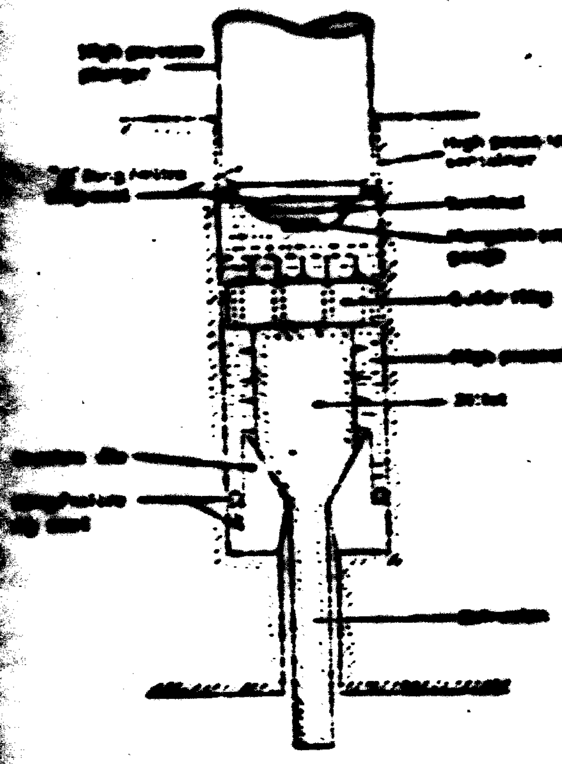

Fig.5. Diagram of hydrostatic extrusion

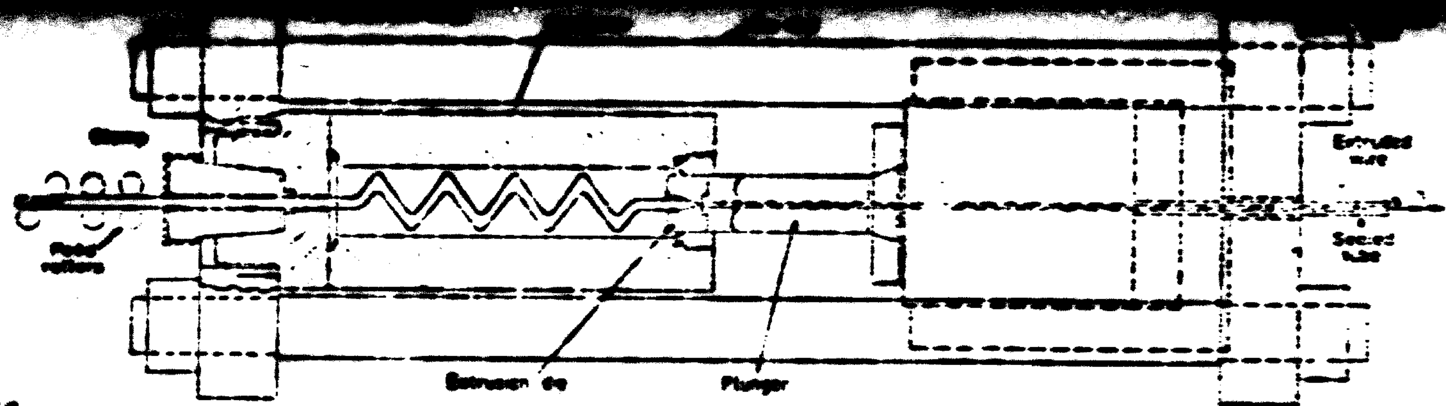

Fig.6. Semi-continuous hydrostatic extrusion: initial concept.

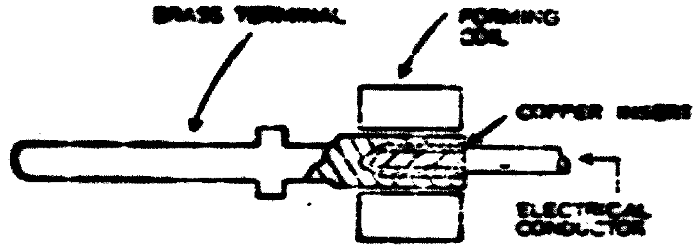

Fig.7. Terminal-to-conductor assembly for electromagnetic joining.

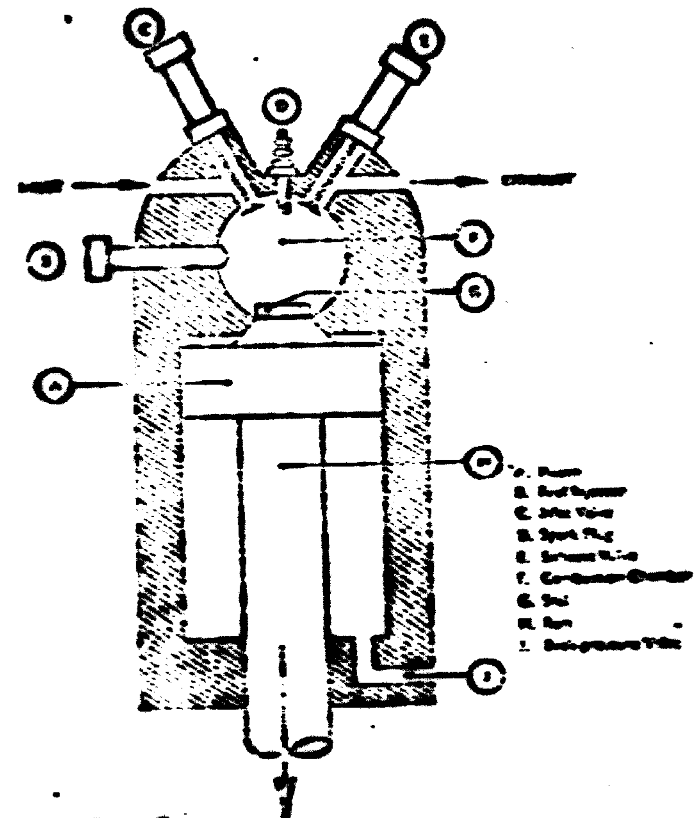

Fig.9. General design of the prototype machine.

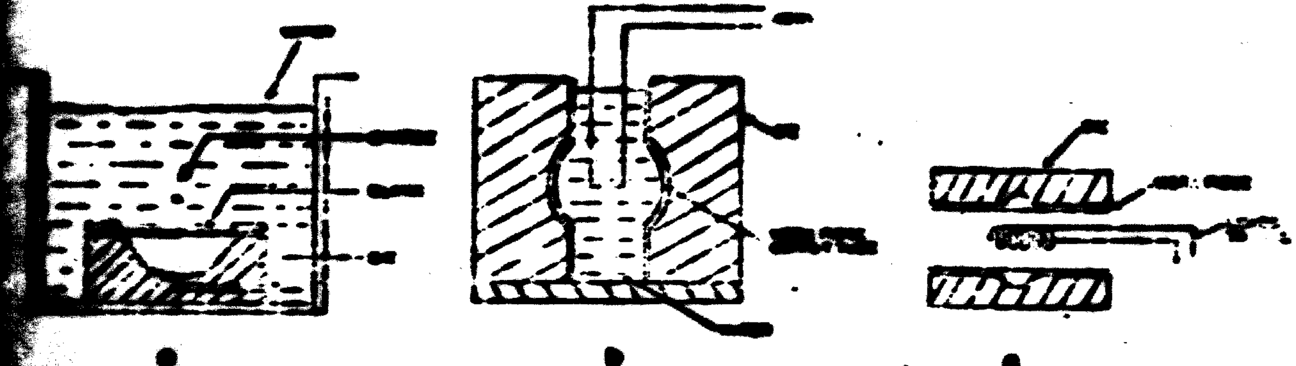

Fig. 8 Tooling arrangements for explosive forming (left), electrohydraulic forming (centre), & ... forming (right).

14