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Moscow, USSR, 19 September - 9 October 1968

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MODERN EQUIPMENT FOR THE ROLLING OF STEEL[1]

by

M.G. Sendzimir,
United States of America

[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. The document is presented as submitted by the author, without re-editing.

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SUMMARY

This paper will concern itself with modern equipment for the rolling of flat steel products and will include both hot and cold rolling phases.

Before we examine the equipment which has been developed for cold working of steel, we should look at the types of product produced by the steel industry and their ultimate application.

In a more sophisticated economy the steel industry has to produce goods in volume and this has led to the development of tandem mills for producing low carbon steel cold rolled products. The objectives are to obtain a low unit cost. Economically speaking, the initial cost of equipment was of secondary importance in comparison to the production costs.

From the technical point of view higher rolling speeds are needed in order to increase the production. The only other way to get higher output from the rolling mills is to kill down-time. Mechanical and electrical improvements have been developed for achieving a better product with closer dimensional tolerances.

* This is a summary of a paper issued under the same title as ID/WG.14/36.

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In countries where economies do not permit big volume application, rolling mill equipment must be flexible and must permit rolling a wide variety of products. Therefore, it is important to look at the reversing type of mills.

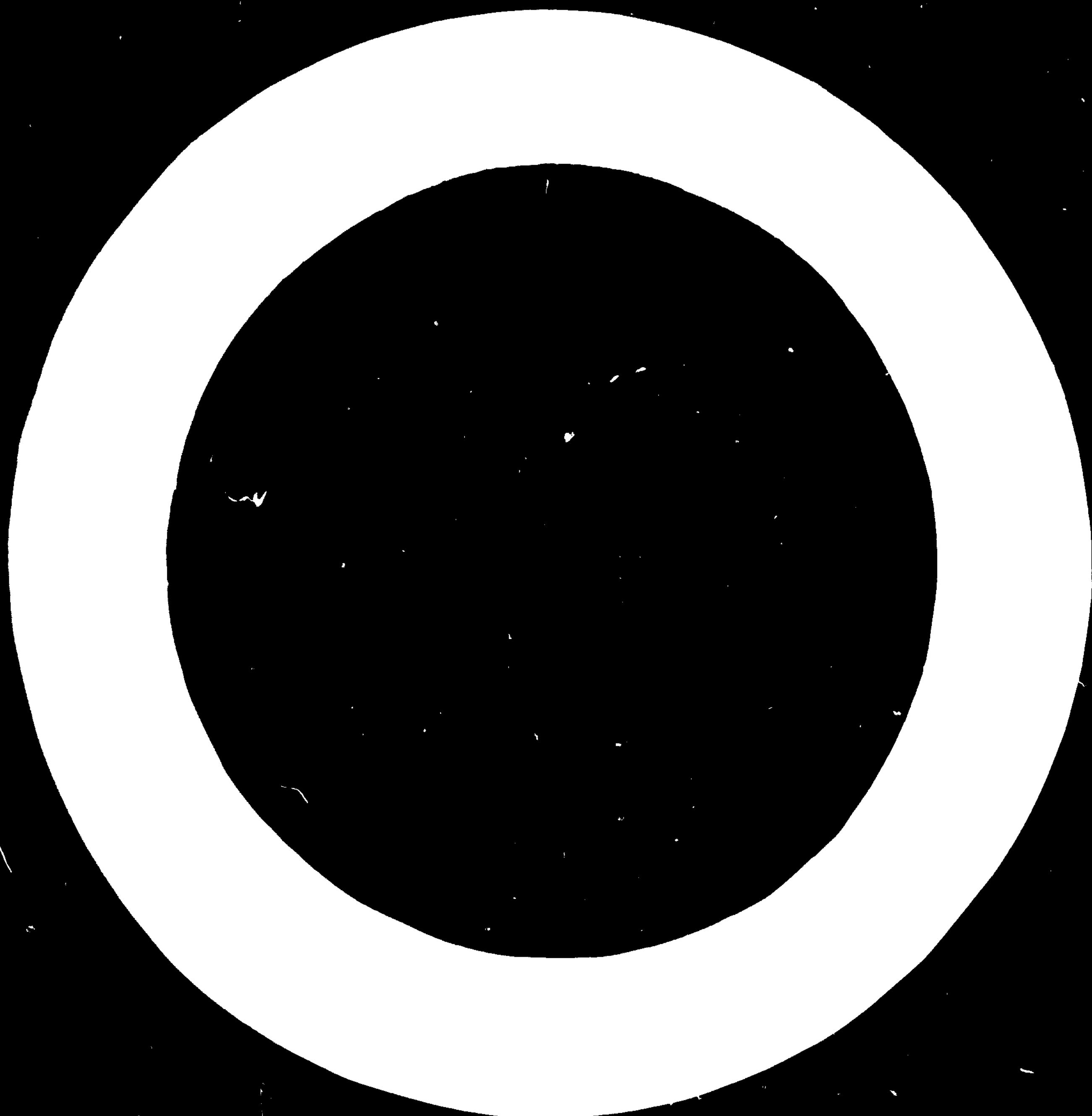
Utilization of the 4-hi mill has been limited mostly to the low carbon and silicon field, but the cluster mills have been doing extremely well when installed for such type of production and have monopolized the field where the metal work hardens rapidly. Detailed description of the cluster mill is given in the paper.

The economic objective of starting steel production in under-developed countries, should be considered within the scope of their own economies and not thinking about exports - there is too much excess steelmaking capacity in the world. However, co-ordination between different under-developed countries can be of mutual benefit to them.

New techniques can permit under-developed countries to produce their own steel and use recent developments in continuous casting to produce slabs which could be fed into moderate investment hot strip mills.

A desoription of the Planetary hot strip mills is given and the advantages of the continuous set-up in tandem with continuous casting are outlined.

In summary, the under-developed countries could profit by the technology developed by the more sophisticated economies and leapfrog in their development much faster than the original growth of the steel industry and within the framework of their own necessity and capability.



This paper will concern itself with modern equipment for the rolling of flat steel products and will include both hot and cold rolling phases.

Before we examine the equipment which has been developed for cold working of steel we should look at the types of product produced by the steel industry and their ultimate application. These products can be divided into three broad classes: The first one will cover coated steels such as tinplate, galvanized and aluminized material, terncoat and a more special product such as lead-coated material. The second group would cover uncoated steel sheets which can be utilized for subsequent drawing operations and cover such items as car bodies, home appliances, architectural applications, railroad car usage, etc. The third group could cover harder metals of low, medium and high alloy group steels, silicon and stainless steels and even some of the more exotic metals.

In a more sophisticated economy where the steel industry has grown not only in volume, but also laterally in the number of its applications, the production of cold rolled material is measured in millions of tons and in order to produce a given line of product a separate installation specifically designed for a given purpose can be studied and built to supply only a given segment of the market.

This has led to a development of separate 5- and more recently, 6-stand tandem tinplate mills and has led to very high rolling speeds as well as very big coil sizes. The objectives are to obtain as low as possible unit cost, the highest possible quality and the uniformity of the product.

Separate rolling installations have been made for rolling deep drawn stock and here 3-stand tandem mills have been used to a great extent in order to obtain the required gauge and to offer sufficient versatility to the user of the equipment. More recently even 5-stand tandem mills have been built for autobody quality steel sheets. The chief objective of such an installation was to permit such a tandem mill to work without strain and be able to keep the production constantly flowing. With the development of the thin tinplate around 0.1 mm special 2-stand and 3-stand tandem mills have been designed and installed. However, tnese are justified only for enormous production of the material. On the other hand, a flexible reversing 4-hi or a Sendzimir can very well do this job with a relatively smaller output. In America, markets are even being developed for strip as thin as 0.025mm.

Economically speaking, the basic cost of equipment for such large volume of operation was of a secondary nature in comparison to the production costs and, more specifically, to a unit cost of the finished product. The only factor which went into the consideration of the cost of the capital equipment was its depreciation charge in a given unit cost. This is assuming that sufficient resources were available in order to put up an installation in the first instance.

For countries which are beginning to develop their steel industry, it is most important to be flexible. They cannot afford to install a 5-stand tandem which is only capable of producing tinplate. On the same principle, they cannot install a hot strip mill, even if it be semi-continuous, two meters wide. Their production of tinplate and two meter wide hot strip will be only a very small percentage of the total output.

This is where a reversing cold mill or a planetary hot mill has a great role to play. They can take over the marginal productions and thus reducing the capital cost and increasing the flexibility of production.

From the technical point of view, the design of the high volume rolling mills has required higher and higher rolling speeds in order to increase production , and this has been limited basically by two factors: The possibility of keeping the oil film in the roll bite and also the possibility of extracting heat from the equipment and the metal in order that the shape of the finished product would be satisfactory. Better lubricants have been developed with extreme pressure additives, which permit through better surface tension to keep an effective oil film between the rolls and the metal which is being rolled at higher speeds and heavier drafts. In order to cool the mill, bigger diameter work rolls have been installed. This permits more effective cooling of these rolls through application of external sprays. The distribution of these sprays and their control is becoming more and more of a science rather than an art, as it has been in the past.

In order to control shape, different types of apparatus have been used in order to permit bending of the work roll during the operation of the mill, as well as, more recently, sophisticated apparatus for bending the backing roll itself has been developed. This latter method not only can influence the shape, but, at the same time, permits minute corrections of the roll gap. More recent investigation in this field pertain to the replacement of the conventional screw and electric motor type of roll closing by a hydraulic cylinder screwdown (or screw-up) with oil film being controlled by extremely fast response electro-hydraulic valving system. There are several different methods employed in different countries, but the most sophisticated ones permit to adjust the mill to correct for different gauge of the incoming strip and also for the eccentricity of the back-up roll even at the highest rolling speeds.

Description of improvements in this field would not be complete without reference to the electric and electronic work which has been done in the last few years; to development of measuring gauges for obtaining the exact thickness of the end product and to sophisticated controls which permit to adjust the different rolling stands in order to compensate for variations in the hot strip thickness; to regulate the intra-stand tension and to automize the operation of the mill so that accelerating and deceleration values would be at optimum performance of the electrical equipment. Computers are playing an increasing role both in the technical control of the mill as well as forward planning and organising. The most modern hot strip mills as well as tandem mills are programmed to work and correct themselves automatically, whilst there are Sendzimir reversing cold mills, which are programmed for six or seven passes. Once the pass schedule is chosen, the mill choses its own speeds, tensions, etc., thus taking maximum effort out of the mill on each pass.

PERT (Programming Evaluation Review Technique) is becoming an everyday word in the steel industry, and it has been found that time as well as money have been saved by utilising these new methods of "Management by Computer".

On the electrical side, slender and long armatures have been developed in order to give low rotating inertia values for the entire mill drive system. Frequently, those armatures have been divided into a number of units for each roll stand and big advances have been made in improving commutation on the motors and the generators feeding this equipment. Mercury Arc and, more recently, Thyristor type current convertors have been developed and used successfully on tandem installations. Whereas, transistorized controls have speeded up the response time.

It must be mentioned here also that in recent years the twin drive has been adapted quite successfully to the multi-stand tandem mill application, and some installations have been utilising pinion stands with multiple output shafts.

But if we speak of such large volume production and entire installations being built for a given product, what happens to flexibility? Indeed, it is very difficult to operate such large complexes and obtain equipment which can be used for several purposes at the same time. Countries where economies do not permit big volume application have relied upon other types of equipment which was more flexible and permitted rolling a variety of products to satisfy different market demands. These mills are mostly of the reversing type and have been of different designs depending upon the product which they had to produce. In some cases people have tried to use one single mill for reduction rolling and skin passing or even for rolling low carbon steel and aluminium, but this is going a bit too far, and although it certainly can be done, the results are neither ecoromical nor practical.

The 4-hi mill with its different improvements in shape control by bending work rolls and/or backing rolls has been used in a number of cases to roll aluminium and low carbon steels; whereas, with certain modifications when utilising back-up roll drive, small diameter rolls could be employed for reducir harder metals. In a reversing mill the installed cost of the electrical equipment is normally higher because an expensive drive is required for the winders but an efficiently-operated mill can produce a surprisingly large volume of finished rolled steel, yet it can make any number of passes that the operator desires and consequently can have an almost indefinitely wide range of finished products. Autobody sheets and tinplate can be made on one and the same mill by simply changing the rolls to cater for strip width and the type of finish desired. Nevertheless, the limits of speed and reducing power are similar to those which have been experienced on the tandem applications. Because of the high cost of the electrical equipment the maximum speeds of such mills have in general been held to one half the highest speed of the tandem mills.

During the last thirty-odd years the cluster mill has been accepted as a conventional mill and is utilised in practically all countries of the world. The Sendzimir mill is a cluster mill where the work rollsare nested between supporting rolls and permit the roll separating force to be transmitted directly to the rigid monoblock housing.

There are several arrangements of the Sendzimir mill which have been developed previously and included 1-2, 1-2-4 and 1-2-3 types, but that predominant today is the 1-2-3-4 section, which is made in order to get the smallest possible diameter work roll for any given backing bearing diameter.

In the 1-2-3-4 Sendzimir mill (Fig. 1)

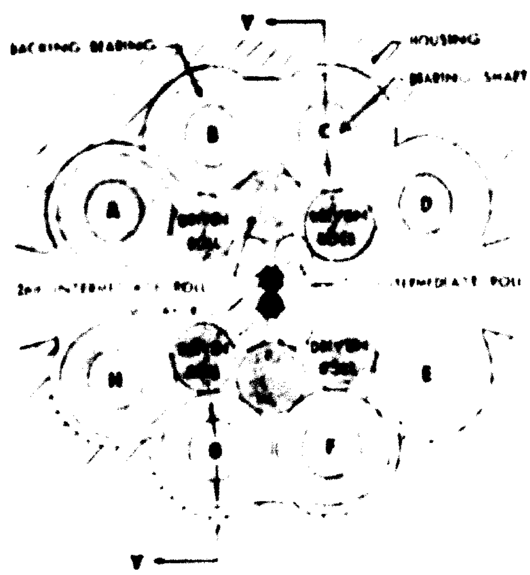


Fig. 1 –Roll arrangement in 1-2-3-4 Sendzimir mill.

there are eight backing shafts, numbered "A-H" in the clockwise direction. Shafts "B" and "C" are the main screwdown shafts which are equipped with large hydraulic cylinders on the top of the mill. These shafts have roller bearings in the saddle rings and can be easily rotated under the heavy screwdown pressure. All other shafts have plain bearings in the saddle rings and can be rotated only under no-load condition. The other shafts are also self-locking, i.e., in order to open or close the mill the shafts have to be positively moved. Shafts "A" and "H" are moved by an electric motor located in the back of the mill, and shafts "D" and "E" are moved by a similar motor. These shafts are brought closer together or further apart, depending on the size of the rolls in the mill.

Shafts "F" and "G", the two bottom shafts, are moved by a hydraulic cylinder located in the front of the mill. These shafts are opened or closed in order to change the work rolls in the mill. the movement of these shafts serves two purposes. First, it brings the bottom work roll to the pass line of the mill and, therefore, provides an even bearing of the work roll end surfaces against the thrust bearings located in the front and back door of the mill. Second, the closing of the bottom rolls takes out all the slack between the rolls and enables the full travel of the top screwdown of the mill. This permits the operator to reduce thick strip of hot rolled gauge down to thinnest gauges without changing the work rolls.

Shaft "D" is equipped with a crown control. Each individual saddle on shaft "D" can be made to change its height with respect to the housing. This adjustment enables the operator to give any shape to the strip he desires. Some recent applications of the Sendzimir mill utilise crown adjustment, motorised through small hydraulic motors which can be controlled by the operator from the operating pulpit during rolling. This adjustment is provided on shafts "B" and "C", acting simultaneously through a secondary very small eccentric gear train. The adjustment can be made under loan and, therefore, the operator can change the shape of the strip while the mill is rolling.

The first intermediate rolls on the Sendzimir mill can be axially adjusted from the front of the mill and on bigger mills this adjustment is motorised necessitating only pushbutton control. This mechanism shifts the rolls to the front or the back of the mill. This feature is very important for the operation of the mill; since these rolls are ground with a taper. The top rolls have a taper from the front side and the bottom rolls from the rear side. In this way, with an independent movement of the top and the bottom rolls; it is possible to control the shape of the edges of the strip to an extremely fine degree. The combination of the crown control and axial shift of the intermediate rolls gives an experienced mill operator a means of controlling the shape and producing flat strip that is without parallel and has to be actually experienced to be appreciated. Consider the 4-hi mill operator, who has virtually no control of his shape once rolls have been ground. He cannot even choose the pass reduction schedule because the roll crown has been made for just one reduction, i.e., one RSF.

The roll separating force on the 1-2-3-4 Sendzimir mill is distributed from the work rolls to the intermediate rolls and then to the backing up shafts in such a fashion that the outer shaft takes a heavier force component, i.e., absorbs more load than the centre shafts. The driven rolls on the mill are the outer second intermediate rolls. The choice of driving these rolls enables the designers to incorporate larger size pinions and, therefore, the mill can transmit more torque. Fig. 2 shows a Sendzimir mill and Fig. 3 a backing roll from such a mill.

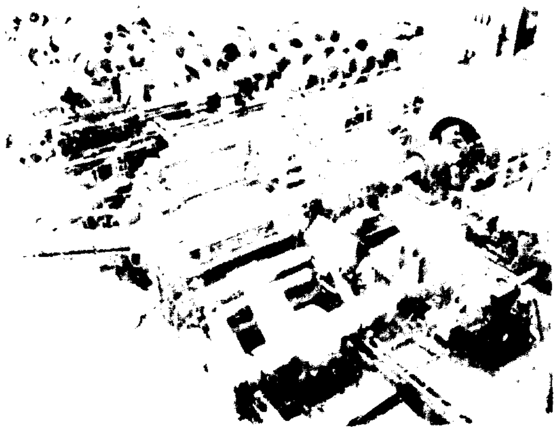


Fig. 2 –General view Sendzimir cold-strip mill.

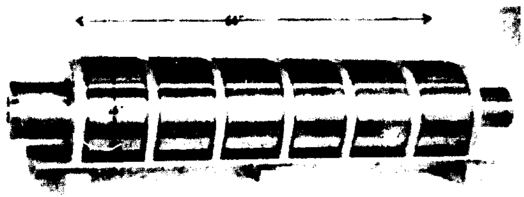


Fig. 3 Backing roll from a Sendzimir cold-strip mill.

The objective of this symposium is to examine how the under-developed countries can best develop their economies and produce steel products at the most reasonable cost. Certainly they need flexibility; they need simplicity and they need equipment which will produce the material required by their finishing industries. There are over half a billion tons of steel produced every year in the world. There is nearly 100 million tons per year of excess capacity. Consequently, any equipment for production of steel in the under-developed countries must be focused on their own requirements and not blithely contemplated for nebulous export possibilities. The adaptability of the most modern equipment will permit the under-developed countries to quickly bridge the technological gap and obtain high quality and production with relatively small investment. It must be remembered that steel is always sold for cost, quality and delivery. When the production is small and the delivery relatively unimportant, quality becomes the primary factor assuming normal costs. This is unfortunately contrary to the experiences in the developing countries who, hungry for the product, tend to forget quality.

In my opinion, proper planning for integrating steel production in under-developed countries has to be done early and before the first spade of dirt is turned over. I consider that there are two approaches by which under-developed countries should start integrating their steel economy:

For the countries which do not have basic raw materials to produce steel, they should start from the finishing end by installing cold rolling equipment of a flexible type to furnish a variety of products for their consumer industry.

whatsoever in the slab length. The longer the better! This system of operation has also the following advantages:

1. Unlimited size of hot rolled coil.
2. Exactness of width and accuracy of the finished gauge in every meter of the product.
3. The same metallurgical quality in every piece of strip.
4. Possibility of rolling different grades of steel.
5. Possibility to vary the gauge or change the width for a given product, virtually without losing any production time.

Furthermore, the planetary mill has unique advantages as a breakdown mill in a continuous hot strip mill. As the coil sizes increase, it becomes necessary to utilise longer and longer slabs. This means that the distance between the roughing stands becomes prohibitive both from the space as well as from the metallurgical point of view. The front end of the slabs is no longer of the same temperature as the back end. The planetary mill solves this problem by taking a very long reduction in one bite.

The description of the planetary mill follows:

I would like to show now a section view of the planetary mill which will enable us to see the geometry of the mill proper (Fig. 4).

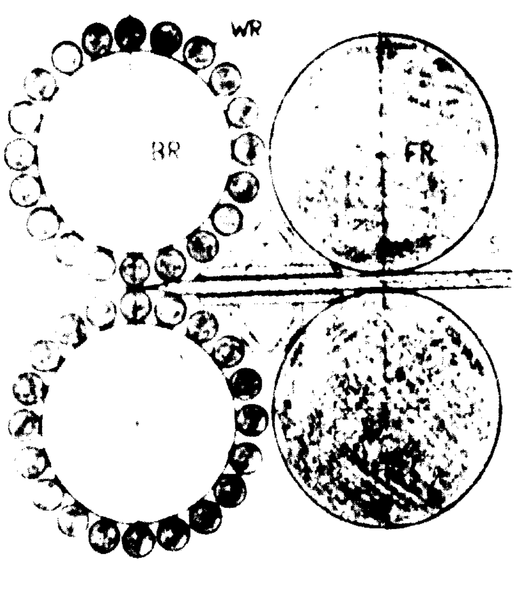


Fig. 4 –Sectional view of planetary mill.
WR work-rolls.
BR back-up rolls.
FR feed roll.
S sheet.

For the countries which have iron ore, coal; limestone, sufficient electric energy and adequate capital they should start from the smelting end and using the newest techniques available, produce cast shapes for finish rolling.

It would be to a mutual advantage if the chosen countries could be geographically located next to each other so that one could start at the finishing end and the other one at the smelting end and complement each other's operation. Eventually, with a blueprint for the entire growth having been planned from the beginning, each one would have its own steel industry fully integrated vertically and horizontally.

The question then arises as to how can an under-developed country start a small steel producing operation with a low investment. It is not easy but can be done. Today simple techniques are available for smelting small quantities of iron ore and the direct reduction has been successfully developed and is utilised in Canada, Mexico, and a plant is being put up at the moment in New Zealand. Continuous casting has made tremendous strides in the last decade and shapes of all sorts can be produced today by this method. Rounds, squares and slabs can be cast in all types of steels and sizes. Finishing equipment to fit continuous casting has also been developed.

Inasmuch as in high volume countries big continuous hot strip mills have been installed; semi-continuous, reversing; or planetary mills have been installed when a heterogenious product has to be rolled and when higher flexibility is desired.

Of all the hot strip mills mentioned the planetary mill needs a special mention in the role which it could play when coupled with continuous casting. In that particular hot strip mill there is no limit

The planetary mill consists of two feed rolls which take a light reduction on the slab and push it through a guide into the planetary rolls where the main reduction takes place. As it will be seen from the picture the reducing instrumentality consists of two back-up rolls surrounded by a number of small work rolls which are held in cages at their extremities. These cages are synchronized by outside means so that each pair of work rolls will pass through the vertical centre line of the mill at precisely the same time. These rolls are also synchronized so that their axes are always parallel to the axes of the back-up rolls.

The angular velocity of the cage is somewhat less than half the angular velocity of the back-up roll. The direction of rotation of the upper back-up roll is clockwise, when the slab is fed from right to left. The cages holding the upper set of work rolls will also turn in the clockwise direction. However, these work rolls turn in a counter-clockwise direction.

Obviously planetary assemblies can be built with varying ratios between the back-up roll and the work roll diameter. Also the number of work rolls per assembly can vary. In actual preactice mills have been built with 18, 20, 24 and 26 work rolls per back-up roll. The exact choice of roll diameter and the number of work rolls is one of the problems of the designer of the mill.

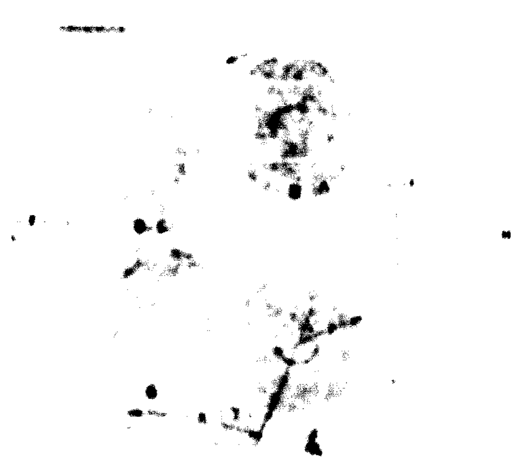


Fig. 5 Sectional view of actual roll-bite zone in planetary mill

Fig. 5 schematically represents the roll-bite zone of a planetary mill; showing the actual reduction of the slab to strip. Two pairs of work rolls are shown, the first of which is close to the point where the material is reduced to almost its finished gauge, whereas the second pair has just touched the slab at its initial thickness "H" and has penetrated deep enough to establish a full width of the deformation zone "BA". It will be seen that the work rolls establish this condition at an angle "a" from the vertical. The radius of the backing rolls is "R_1", the radius of the work rolls is "r" and the circumscribed radius of the whole planetary assembly is "R".

The work rolls, of course, remain in rolling contact with the work piece throughout the roll bite. They also remain in rolling contact with their respective backing rolls and there is no slippage anywhere in the mill. Power is supplied by the backing rolls which turn the work rolls as well as propel them forward, by their frictional contact along the common generants such as "G". For each pair of work rolls passing through the bite, the slab is fed by outside means (such as a pair of feed rolls not shown on this figure) by a small distance represented as "f" on this drawing. After reduction, this slab length is transformed into a length "F" of the strip. Fig. 6 shows a typical set of planetary rolls.

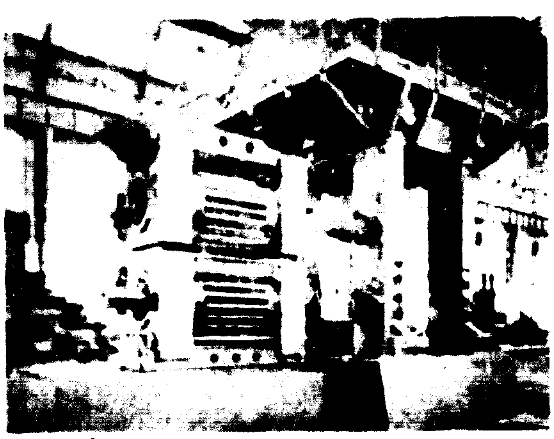


Fig. 6 Set of planetary mills and housing.

The field of application of the planetary mill can best be deduced from the analysis of what happens in the deformation zone. The metal travels through the deformation zone quickly - usually taking from 1½ to 6 seconds.

Generally speaking, the temperature of the strip is higher at the exit from the planetary mill than the temperature of the slab at its entrance. This is in contra-distinction to rolling on continuous, semi-continuous, or reversing hot strip mills.

While in the zone of plastic deformation, the metal is subject to two opposing effects, the relative influence of which, together with their magnitude, should be carefully evaluated. One is the temperature rise of the metal due to the energy of plastic deformation, which averages 40 KWH per ton for steel and should be capable theoretically of increasing the temperature of the metal by several hundred degrees. At the same time, heat is rapidly abstracted from the surface of the metal within this zone by contact with the rapidly passing, and relatively cold, work rolls.

In comparison the reversing hot Steckel mill is limited by the coil size and is not a continuous mill, which is an obvious disadvantage.

The semi-continuous mill has been installed in many countries because it does not have the disadvantages of the reversing mill. It has higher production, limited only by the breakdown facilities and it has been utilised in many instances for production of low, medium and high alloys as well as stainless steels.

Whichever mill we are talking about be it hot or cold, 4-hi or Sendzimir, or other type, these mills have reached today's limit in speed and reduction on account of lubricant and ability of the metal to withstand reduction. How can we therefore obtain higher output from a given unit of production? The obvious answer is: Kill the down-time. Bearing that in mind, the thought occurred to me why can we not exchange the working rolls peripherally instead of axially. It is in this way that the turret mill was born which is similar in outward looks to the planetary mill but where the working rolls are pressed away from the backing roll in all positions except when actually rolling the material. The turret mill can operate like a 4-hi mill and when a new roll is needed, because of surface, camber or diameter, then the screwdown is opened, the new roll is indexed into position, then the screwdown is closed and the rolling is re-commenced. In this way roll changes can be made in 15 to 20 seconds in lieu of 5 minutes minimum on the present newly developed 4-hi technique. In the case of the cluster mill this arrangement can also work and not only the work rolls but also the intermediate rolls can be exchanged at the same time.

The fundamental principals of the design of a rolling mill has not changed much. In fact, it can be said that the only revolutionary ideas which have proved to be successful are those of the cluster mill and on the side of the hot mills those of the planetary mill. Otherwise it can be said that all the development has taken place in the improvement of the original 4-hi mill and not in a new method of rolling.

The above paper presents only but one aspect of what can be done for the under-developed countries. I am sure there are many others. But in a small way I hope it can open the way for quickly bridging the technological gap and avoid the lengthy development process which other countries had to go through. These countries could then benefit from the research and development done by countries with more sophisticated economies and technologies. They can then achieve their ends more rapidly and with smaller effort and with the help which we all would like to give them.

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