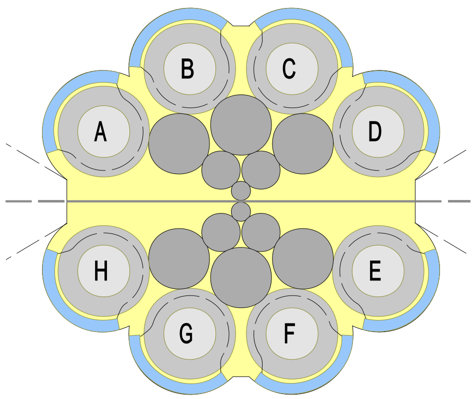
Shape Control in Cluster Mills

Michael Sendzimir, 1993



Cluster mills first came into existence in the 1930s. They are characterized by small-diameter work rolls that are supported by a cluster of rolls as shown in figure 1 (which shows the location of eight backing assembly shafts: "A" through "H" containing eccentric saddles and bearings).

More than 600 cluster mills are now operating around the world. Of these, approximately 400 are of the Sendzimir type, in which, with few exceptions, the housing is monoblock with very short columns and a rigid “die-like” construction, resulting in a high mill modulus (stiffness).

Today, cluster mills are used to roll stainless and alloy steels, silicon and carbon steels, and nonferrous metals and aluminum alloys. In stainless steels, it is possible to make a further subdivision into two groups. The first group is that of wider mills, whose width extends to 1600 mm and which take hot-rolled bands up to 8 mm thick. Many of these mills are 1300 mm wide; some are 1 meter. They produce finished product, which is usually cut into sheets or slit into narrower widths and, sometimes after appropriate heat treatment and pickling, finish rolled on narrower mills.

The second group of stainless mills could be classified as true strip mills. They usually start with strip previously cold rolled on a mill of the first group and 1 meter or less in width and roll to thin gauges that, in some cases, are as thin as 0.02 mm. The end product is very often bright annealed, may be further slit into narrower widths, and is shipped usually in smaller-weight coils. The field of application for stainless steel of this second group is quite broad but can include automotive and appliance applications as well as for architectural uses and the transportation industry, such as high-speed trains. It is interesting to note that every new fast food facility, of which there are over 10,000 each year, utilizes on the average 18 tons of stainless.

Silicon steels are usually rolled in widths of 1 meter or less; however, some installations are 1250 mm wide. We can classify silicon steels into two groups, the one containing the low-silicon non-oriented grades used for electric motors, and the second including more sophisticated grades, with grain orientation in a single or a double sense. In the second group, some of the newer applications require thicknesses in the range of 0.125 mm or thinner.

Mills rolling carbon steels can be classified in two groups. One group rolls high-carbon steel in narrow widths for saw blades and measuring tapes. The other group includes medium-carbon steels in the range of 40 to 50 points carbon, and low-carbon steels that are either used as black sheet or are coated, as for instance tinplate or galvanized. This latter field is a big one, and cluster mills have been used when stringent requirements for thinner gauges, gauge accuracy, and surface finish dictate their use because of their superior performance. Today, about 70 cluster mills worldwide are used on low carbon.

In the nonferrous field, most cluster mills are in the narrow range of 400 mm or thereabouts, with several in the 600-800 mm range. Cluster mills are preferred here for their ability to roll thin gauges and maintain gauge accuracy, as well as achieve a high surface finish. Here, we are talking of very thin gauges – for example, for new radiator stock, which is presently rolled down to 0.03 mm and less. Material for printed circuits, lead frames for integrated circuits, and television shadow masks have also been rolled primarily on cluster mills.

The above classifications reveal several technical requirements for cluster mills: gauge accuracy, good shape, proper surface, good productivity, minimum installation downtime, and low maintenance costs. These benefits must offset the capital cost of the equipment.

During the late 1980s, a great deal of attention was focused on the production of high-accuracy product. This led to the development of high-accuracy gauging equipment (mostly of the noncontact type) and automatic gauge control (AGC) systems which, when combined with advanced servo-valves and fast-response electronics, kept gauge variations on thinner products within plus or minus 1 micron.

At the same time, in order to increase production, mill speeds were increased. In order to keep reductions per pass high, the horsepower on the mill, as well as on the winders, was increased. Some of the biggest installations have 30,000-horsepower motors which, during acceleration, can frequently be pushed to double that value.

We should also acknowledge other developments that permitted the cold roller to increase efficiency: First, the incoming material has been greatly improved. Coil sizes are bigger and weld-free. They have better gauge accuracy, better shape, and reduced edge drop. The edges are free of breaks, tears, or slivers, and the surface of the material is cleaner, extending the life of rolls in the cold mill and avoiding skidding or other rolling accidents.

Improvements have also been made in the cooling system, in which a plurality of cooling ramps allows the pressure and volume of the coolant to penetrate through the boundary layer of the strip and more effectively removing heat.

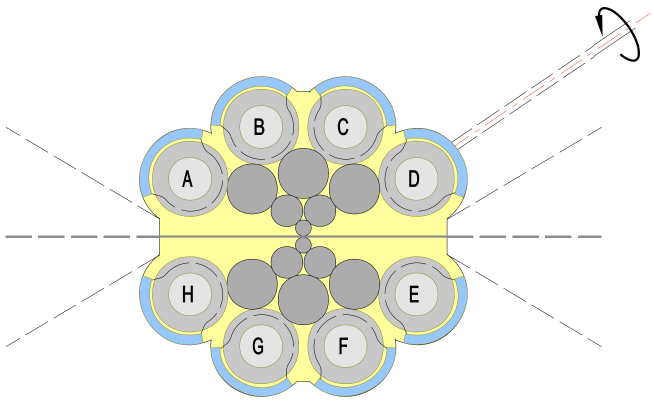
In many cases, direct rolling of hot-rolled materials to final gauge is now done. This process eliminates intermediate annealing and pickling and avoids extra material handling, which can injure the surface or the edges. Savings are realized from fewer rejects, lower energy costs, and a smaller inventory.

As we entered the 1990s, two new requirements were imposed on the cold roller: shape control and mill efficiency. To understand the impact of these demands, it is important to understand their nature.

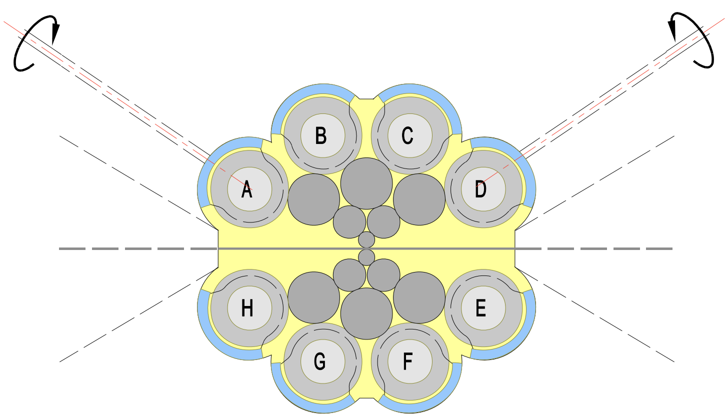
Shape is the flatness of the strip as it is laid out without tension on a flat surface. One can measure deviation from flatness at any point by the vertical distance of the bottom strip surface from the flat bed. Theoretically, perfect flatness is achievable, but only at a prohibitive cost. Achieving good flatness requires either that one operate the mill very carefully, taking small reductions at low speeds and using special camber on the rolls, or that one use expensive equipment that runs the mill automatically. Where is the happy medium? In my opinion, the strip shape should have sufficient flatness to permit the next operation in the process to be conducted at the optimum capacity of the downstream equipment. One must also compare the cost of producing that shape to the value of the final product.

Shape control options on the Sendzimir Cluster Type Mill.

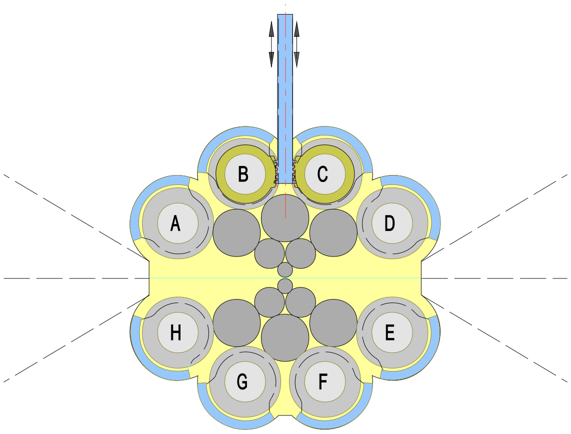
Figure 2 shows the upper cluster of a typical Sendzimir cluster mill. The backing shafts are labeled clockwise: A, B, C, and D.



On the early mills of the 1950s, crown adjustment was provided on shafts "D" by manually rotating adjustment nuts located just above the mill window. These nuts rotated the saddles and changed the effective height of each unit. One could set the saddles for parabolic, concave, or convex shapes, or some other nonuniform configuration. The adjustments had to be done while the mill was stopped and the screwdown load removed. Moreover, the arrangement was only effective if you rolled against the cluster, i.e., from left to right. It had little effect when rolling in the opposite direction. Consequently on some of the mills built in the 1960s such an arrangement was provided also on shaft A (figure 3).

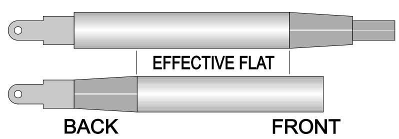


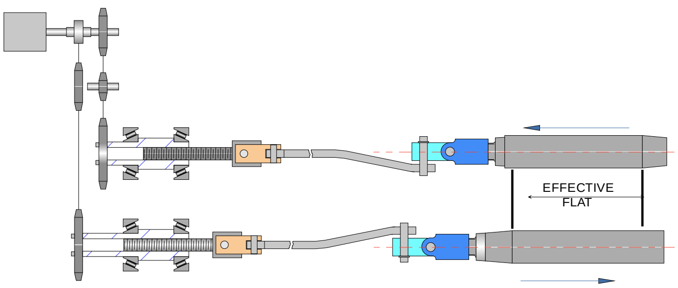
During the 1960s, a more advanced system was developed, providing crown adjustment on shafts B and C and acting through racks located between the two shafts (figure 4). The racks acted on eccentric rings that had small eccentricity and turned on small needle roller bearings. Power was supplied by hydraulic motors located on top of the housing, and a worm gear raised or lowered the rack extension on the top of the housing. This system is known as the "As-U-Roll" or simply the "As-U" system because of its ability to adjust mill crown during rolling.

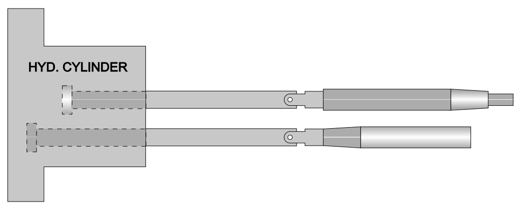


Please note that the direction of the eccentrics is always the same on a Sendzimir mill – if you pull on the rack, you close the eccentrics towards the center. If you push on the rack, you open them. The "As-U-Roll" system lasted for many years and was combined with axial displacement of the first intermediate rolls, which were ground with the taper in the front on the upper rolls and the taper in the back on the lower rolls (figure 5).

Axial adjustment of the intermediate rolls was done manually on small mills and hydraulically on the bigger ones (figure 6). Action of the system was relatively slow and depended upon the roll separating force, the speed of the mill, and the roll finish utilized. But it was effective enough eventually to permit automatic shape control as long as an adequate shapemeter was installed on the deflector rolls to give an accurate indication of strip shape under tension.



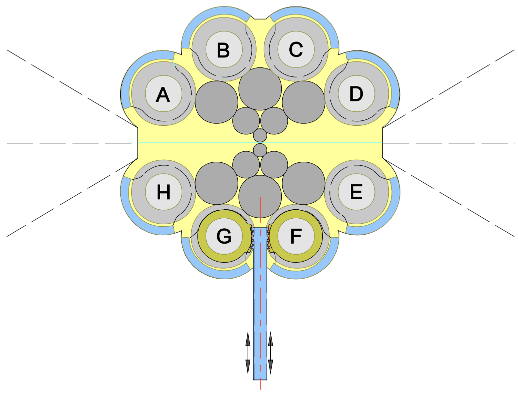




The difficulty of the automatic shape control system was that adjustments were constantly being made and the worm gears of the crown adjustment drive would wear out prematurely. Moreover, the actual adjustment was relatively slow and weak. Consequently, the next development used direct-acting hydraulic cylinders for axial adjustment of the first intermediate rolls (figure 7) and crown adjustment. Electro-hydraulic closed-loop servo positioning was used for all the cylinders, with improved operator displays of crown and intermediate-roll settings.

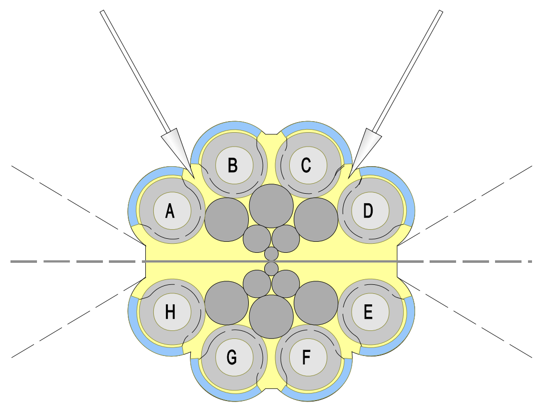
In 1990, it became apparent that the market required thinner strip. Minute changes in roll pressure affected the strip quite considerably. New means had to be provided not only to produce good strip shape but also to maintain good strip shape during rolling so that maximum effective reductions per pass could be achieved with minimum risk of strip breakage.

A number of ideas were produced. The first one came from Europe, where building a second "As-U-Roll" Crown Control System at the bottom of the mill, on shafts "F" and "G" (figure 8),



was considered. Three mills were built with holes at the bottom of the housing to permit this system as a retrofit at a later date. (In the interim, they were used as oil evacuation holes to provide better flow of coolant.)

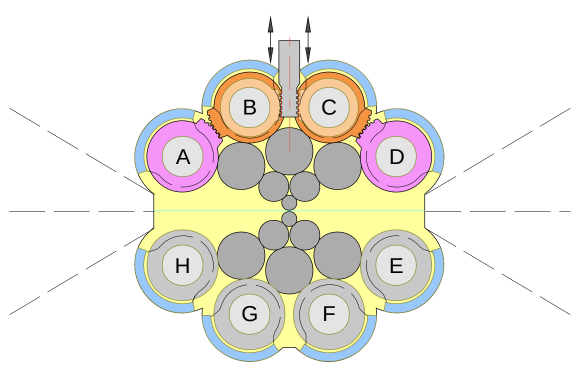
A breakthrough idea was developed in Japan in the form of a double As-U-Roll arrangement. Known as the KZR-type Mill (figure 9), shafts "A" and "B" have one As-U-Roll adjustment, while shafts "C" and "D" have a similar arrangement. These systems could be operated together or separately. In the design of the mill, adequate precautions had to be taken in order to provide for locking of the outer shafts "A" and "D", as they were on roller saddles. In addition, shafts "A" and "D" had to have smaller eccentricity, as the load on those shafts was higher and the racks had to have balanced load to prevent skewing



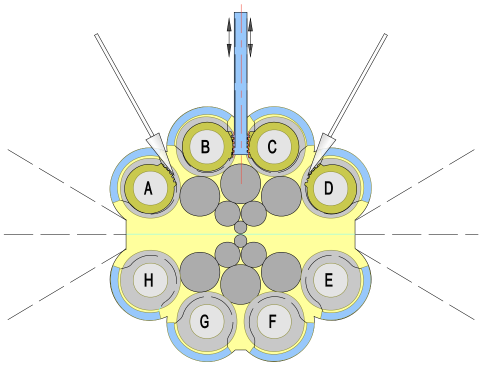
The first mill of this type was built for the Kinuura Works of Nippon Metal Company. It had a ZR 21-AN mill section with a very small diameter work roll (65 mm). The net result was that the mill was able to take reductions of over 20% per pass on austenitic stainless steel and to keep the strip shape sufficiently flat to obtain good rolling.

There are three other ways to add crown control through the upper cluster:

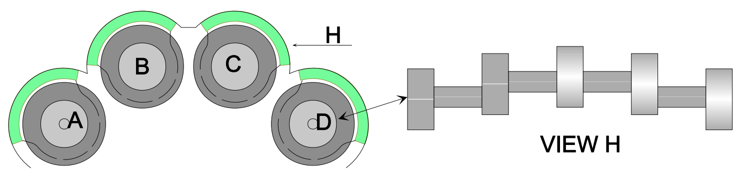
1) For retrofitting mills that already have an “As-U-Roll” system on shafts "B" and "C", we can provide assemblies that have the same gears as those that are between shafts "A" and "B" and "C" and "D". In other words, we connect the "B" and "C" adjustment so that it spreads over four shafts and becomes thus more effective. The advantage of this solution is that additional holes do not have to be drilled in the housing. A new set of saddles for all four shafts, with appropriate connecting gears and roller saddles, must be provided (figure 10).



2) If drilling additional holes in the housing is acceptable, then separate one-sided “As-U” systems can be added: one for shaft "A" and another for shaft "D". This “Triple As-U” makes the upper four shafts adjustable using three separate systems through hydraulic cylinders (figure 11). The "A" and "D" shaft saddles can be either fitted with roller bearings to adjust under load, or can be adjusted when the screwdown is lifted. In the latter case, the saddles will be self-locking.



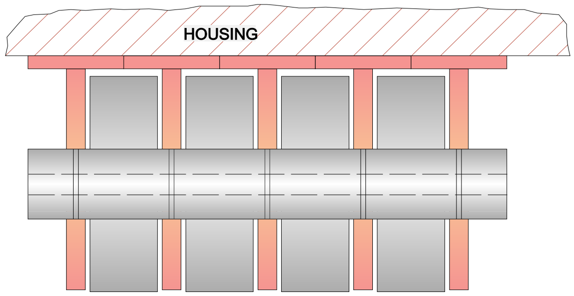
3. A third method is for mills that have a split housing and do not require rotation of shafts "A" and "D" to adjust for roll sizes. In this system, an eccentric can be provided for each saddle on the main shaft in assemblies “A” and “D” (figure 12). The eccentrics are mounted out of phase with each other such that rotation of the main shaft will increase or decrease the crown and give a parabolic form of either convex or concave shape.



Inasmuch as a number of ways, such as the above, can increase the magnitude of the crown that can be set, each of the above systems is limited by the fact that it has to act through a stack of rolls which, in itself, resist bending. This is not so important when a simple crown form is needed, but it is a major limitation (for all types of rolling mills) when correction of a quarter buckle or 4th order flatness defect has to be made. To accomplish this, double reverse curvature of each roll is required in order to transfer the "M" or "W" shape of the adjustment to the roll gap.

Likewise, the shafts on which the bearings and saddles are mounted are strong and robust. This also counteracts the effect that we want to secure through adjustment of the crown.

Bearing this in mind, the first thought is to reduce the stiffness of the shafts in the backing assemblies by making them of smaller diameter, by making them hollow, or by making them of a more elastic material. Eventually, we chose instead to make the shafts more “bendable” by splitting them into sections, as shown on figure 13. Each shaft section functions as an independent "bridge" between two saddles so that the shaft itself does not have to bend and thus provides no resistance to adjustment of the “As-U-Roll” system.



In the roll stack itself, it is the big 2nd intermediate idler rolls that are the most resistant to bending. Here again, the center idler roll can be manufactured in a "digitized or segmented" form, composed of a number of rings mounted on a central, flexible shaft. Each section can then bend to conform to the shape imparted by the “As-U-Roll” system.

To make the most use of the segmented rolls just described, the mill must also have a reliable shapemeter on the deflector rolls. The operator can use information provided by the shapemeter to correct shape by adjusting the controls. However, an increasing number of mills now use a closed loop system to adjust the “As-U-Roll” crown control system and axial displacement of the intermediate rolls so as to hold flatness variation within a narrow band. The use of hydraulic cylinders permits constant operation of all the components without undue fatigue.

Mill efficiency is a very important area that is constantly improving. Stoppages, which greatly decrease mill efficiency, are of two types: indigenous to the installation and exogenous of the operation. The latter cannot be controlled by the mill operator and consist of items like Interruption of power supply, lack of material to be rolled, inability to discharge the finished product (e.g., lack of storage area), and/or lack of demand for the product from the mill.

However, indigenous stoppages can and should be controlled. For example, the consistent and fast feed of incoming coil into the rolling mill is very important. Automation of the entry section should include automatic arrival of coils to the mill all the way through automatic feed of the band through the mill. Second, the rolled coil has to be quickly removed. A shear at the mill window is needed to cut the finished strip and thus permit fast winding of the coil to the exit winder. Automatic binding and stripping of the coil onto the coil carriage, as well as dumping the coil onto the exit conveyor, has to be done by fast-acting hydraulically actuated methods.

It is becoming evident that more carefully prepared coils – ones that have a constant inner diameter, whose edges are straight, and that are wound under uniform strong tension – will eventually eliminate the need for the entire entry section of the mill. Several installations for "finish rolling" after intermediate annealing have been converted to this type of operation. This makes the rolling mill more compact and simpler to operate.

Work roll changing should be fully automatic. The same should be true for the intermediate rolls of the mill.

All maintenance should be simplified. For example, winder mandrels should be greased at one central point instead of through a dozen nipples. Filtering systems should have automatic filter media that indicate, in advance, when maintenance will be required, thus avoiding unnecessary stoppages.

Mills with the new automatic gauge control and shape control systems should permit the operator to use mill management systems in order to optimize pass schedules.

Assuming the above will be universally operational by the end of this millenium, I can see the possibility that by early 21st Century, we will see one operator operating two mills and his function will be mainly reduced to overseeing computer screens and insuring that all the lights are on “GO”.