# PRESENT STATUS AND LATEST DEVELOPMENTS FOR LIGHT GAUGE ROLLING OF HIGH PRECISION STRIPS [1]

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**Abstract**
The steadily increasing demands on higher plant performance and the increasing expectations of customers regarding. High-quality products, maximum productivity and flexibility, high plant availability and last but not least also environmental considerations, require the constant improvement of machinery and automation concepts. With regard to cold rolling mills, the quality of the finished material becomes more and more important in terms of geometrical dimensions, surface quality and closest thickness- and flatness tolerances. Especially the final gauge of material tends to get thinner and thinner. Modern concepts have been developed by Danieli-Fröhling for mechanical and electrical/automation components of the lines, to not only fulfill today's market requirements, but to produce according to even stronger criteria.
**Key words:** Cold rolling mills; Light gauge cold reversing mill; Mill type.

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## 1 INTRODUCTION TO ROLLING MILL CLASSIFICATION AND SELECTION OF MILL TYPE

The first step to design a suitable mill for given geometrical dimensions of in-going and final material, is the selection of a proper mill type. Coming from the history of flat products, Danieli-Fröhling started in the 1950-ies with 4-hi rolling mills, but very soon realized, that other concepts were needed for light gauge applications.
For the selection of a rolling mill type it is necessary to consider some major factors, especially the minimum strip gauge achievable in rolling. According to rolling theory, the minimum gauge is mainly depending on the work roll diameter, material yield strength, strip tension and also several other factors like friction coefficients etc.. Analyzing these parameters, it becomes obvious that the material characteristics are predetermined by customer's application, and that strip tension can easily be optimized by varying the torque of the coiler station. Remaining with the work roll diameter as major design parameter, the following correlation can generally be considered:
The smaller the final gauge - the smaller the work roll diameter, and also: the harder the material - the smaller the work roll diameter.
With decreasing work roll diameters the limits of standard 4-hi rolling mills are reached. When the ratio between the roll's barrel length and its diameter exceeds a certain limit, the increased deflection of the work roll, due to rolling force, leads to configurations with a higher number of rolls to support the work roll and prevent it from deflection. Mill configurations like 6-hi, 12-hi, or 20-hi were designed.

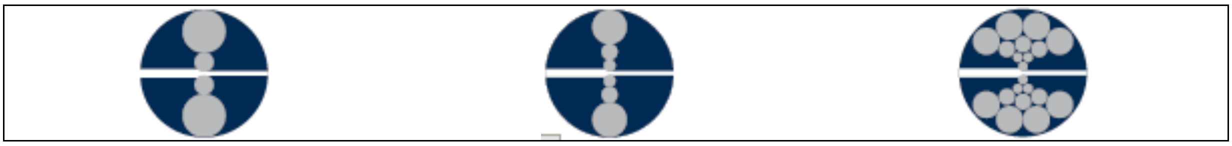

**Figure 1:** Rolling mill classification 4-hi / 6-hi / 20-hi

In order to respond to the steadily increasing demands on the flatness of the final product, several actuators to influence the roll gap profile, have been introduced to these types of mills in order to minimize effects of uneven incoming strip profile, roll deflection and roll thermal crown, which are due to nowadays increased mill speeds.
The following paragraphs show the latest developments of Danieli-Fröhling's portfolio in light gauge cold reversing mill technology.

## 2 4-HI COLD REVERSING MILL TECHNOLOGY

4-hi mills may be used both for intermediate rolling and for finish rolling. Smaller rolls reduce the thickness of the metal being rolled more easily and with far less pressure than the larger rolls. This decreased pressure reduces roll bending and separating forces and permits the rolling of wider and thinner materials with a more uniform gauge. 4-hi mills are a cost-effective solution for the industry to produce a wide range of sheet products with in-house control of finished product quality. These 4-hi reversing mills offer considerable cost advantages compared to multiple-roll mills, such as lower investment-, installation-, operating- and maintenance costs as well as reduced roll and coil stock inventory, but can only be used for rolling down to certain gauge limit.

The mills are equipped with:

- High response hydraulic screw down system
- Work roll bending (positive and negative)
- Quick roll changing systems
- Direct measurement of strip entry- and exit tension for improved strip tension and gauge control
- High tension pyramid type mandrels
- AGC & AFC (Automatic gauge and flatness control)
- Special design concepts to reduce friction between mill stand and roll chocks

High rolling speeds also necessitate special measures to reduce the running noise of the rolls. Roll skewing leads to non-uniform load distribution in the roll gap and may cause undefined natural vibrations of the work roll. Such vibrations are minimized after the roll change by means positioning the back-up roll chock assembly to the exit side of the housing window.

The roll gap geometry, respectively the strip flatness, is influenced by the mechanical actuators work roll bending and roll-stack tilting. In addition to the mechanical actuators, also the zone cooling system is used as an actuator to influence strip flatness. The selective single nozzle control covers local flatness defects of the strip via the flatness measuring- and control system. The principle of zone cooling is based on the fact that variations in the local temperature within the work rolls lead to different diameters in these spots. With regard to tension distribution this means, that, in case that a local higher strip tension demands for a smaller roll gap, the rolls in this area are locally “heated” by switching off the respective nozzle of the cooling system. If a local lower strip tension is needed, the rolls are locally cooled by switching on the respective nozzles. The special design of nozzle arrangement, orientation and twist angle optimizes the zone cooling effect.

## 3 6-HI COLD REVERSING MILL TECHNOLOGY

The main advantage over the classical 4-hi mill is its large range of mechanical shape control actuators. The effective roll gap contour is significantly influenced by work roll bending, intermediate roll bending and intermediate roll shifting. In this way a wide range of strip widths and materials can be rolled without fitting the crowns by roll changing. Another advantage is the rather small work roll diameter that reduces the roll force and torque and considerably decreases the edge drop effect. It allows the rolling of harder material and the achievement of thin final strip thickness. The Danieli-Fröhling 6-hi Mill Stand Technology is a high flexibility cold mill that allows for improved performance and product quality, able to fulfill the most demanding applications such as thinner gauges, improved flatness profile conditions and higher strength materials. The mechanical design bases on all well proven features of the 4-hi light gauge rolling mill stand and is fully optimized by 3D-CAD and FEM analysis.

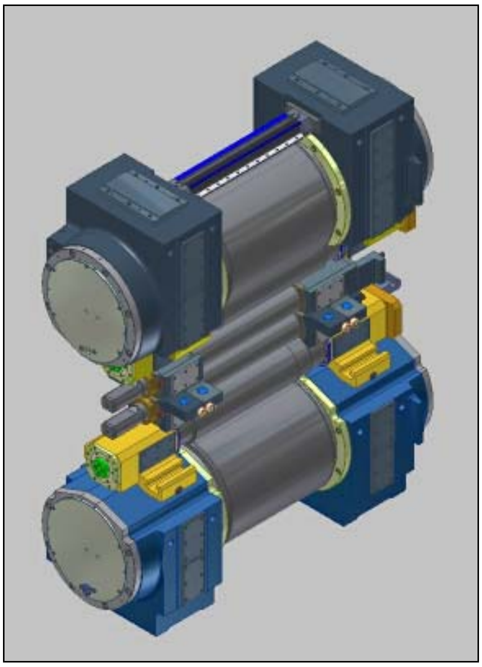

Figure 2: 3D-CAD of 6-hi mill stand

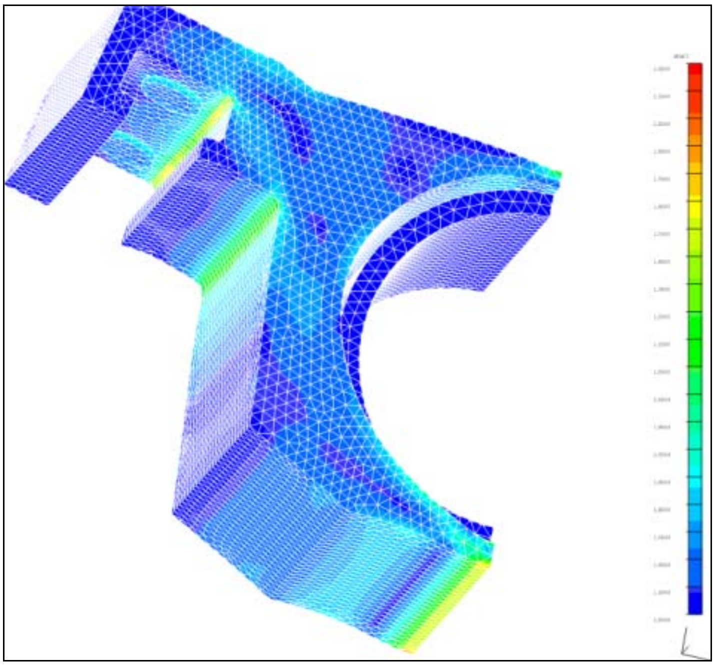

**Figure 3:** FEM analysis of roll chocks

In cold rolling, one of the most dominant aspects is the ability to control the roll gap geometry which affects the strip flatness and cross-sectional strip profile. In the 6-hi mill the standard control elements for strip flatness go beyond the capabilities of work roll bending and sectional cooling thanks to the additional actuators of:

- intermediate roll bending (positive and negative),
- intermediate roll shifting,

The intermediate roll is designed as tapered roll, having the function of the axial shifting to reduce the edge drop of the strip. The positive and negative roll bending leads to a symmetrical changing of the roll gap shape and thereby also modifies the symmetrical distribution of the strip tension between center and edges. In combination with the axial shifting of the intermediate roll, the roll gap geometry can be best adjusted to the strip profile. Furthermore the sectional cooling, already a well known actuator element from the 4-hi mill, is also applied in the 6-hi mill.

The problem of work roll deflection due to a relative small work roll diameter compared to the barrel length is overcome in the 6-hi mill by horizontal shifting of the work roll. The horizontal shifting of the work roll moves the work roll from an unstable position in the centerline of the stand to a stable horizontal offset position, depending on roll forces and strip tensions. A stable position is only assured with the shifting to one side out of the centerline depending on the rolling direction, thus the work roll is moved automatically to the opposite direction for each reversing pass. The horizontal shifting design additionally offers the advantage of higher stability of the whole roll stack and minimizes the tendency to vibration.

Summarizing the major technical advantages of the 6-hi mill stand in comparison to the 4-hi:

- better distribution of roll force over the width for more uniform reduction,
- clearly reduced edge load of strip, causing less trimming scrap,
- better regulation of flatness quality, this means improved flatness and control of a wide range of products without altering the natural roll crown (reduced roll stock),
- no special roll contours,
- Easier adaptation to frequently changing pass schedules and strip profiles.

- Quick response to thermal crown changes of the rolls,
- Increased rolling speed and steeper acceleration/deceleration ramps while maintaining uniform strip flatness,

## 4 20-HI COLD REVERSING MILL TECHNOLOGY

Before 1984 Fröhling has built several 20-hi mills featuring pre-stressed four column design. In 1984 Fröhling introduced as first supplier 20-hi mills with direct hydraulic screw-down. Today's cluster mill design of Danieli-Fröhling is by far superior to the old one and also to other types of 20-hi mill stands for many reasons such as:

- Only two hydraulic cylinders which means less maintenance,
- lower friction hysteresis and in consequence to this better gauge control
- Roll balancing and bending not only for outer intermediate rolls but also for inner intermediate rolls resulting in better range of profile and flatness control.
- Linear roller guides to prevent friction between the cluster housing and mill stand which results furthermore in better thickness control.
- Pre-stressed guiding of above mentioned cluster against mill housing. Therefore no backlash in horizontal direction.
- Split of roll gap adjustment and strip profile adjustment
- Hydraulic cylinder with long stroke, thus large range of work roll diameters, which increases the flexibility of the mill to run a wide range of products.

The design generally differs from the familiar monobloc, tilting or columnar designs. In fact, it is the similar to the housing type of a 4-hi stand, with drive and operator side housings joined together by cross-beams to form one stable unit. Two vertically moveable bearing housings are mounted one above the other. Each bearing-housing accommodates the top or bottom set of rolls and backing shafts with rollers. The independently moveable bearing housings make it possible to widely open the roll gap, which is advantageous for threading the strip head and facilitates access to and observation of the roll gap. In addition to this, the cooling lubricant drains off well and therefore assists cooling. The bottom bearing housing can be moved in order to adjust the height of the pass line. The roll separating force is directly applied to the top bearing housings by means of two hydraulic screw-down cylinders. The cluster is embedded in a pre-stressed guiding against the mill housing to avoid backlash in horizontal direction. Linear roller guides prevent friction between the cluster housing and mill stand

The roll stack consists of eight outer backup roller bearings, six outer intermediate rolls, four inner intermediate rolls and two work rolls. The arrangement of the backup rollers is staggered to avoid any imprints on the rolled strip. This is realized by having alternatively odd / even configuration for the number of backup roller bearings on the eight outer rollers. The bearings themselves are fully closed and sealed with separate lubrication. This in nearly doubling the lifetime compared to open bearings lubricated by rolling oil.

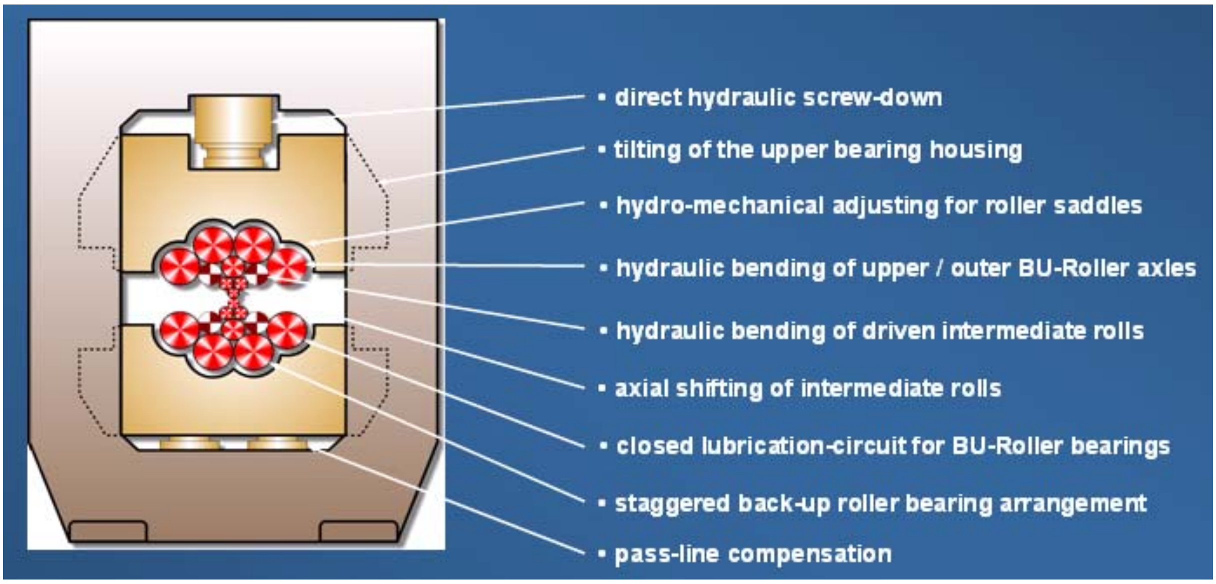


**Figure 4:** Danieli-Fröhling 20-hi mill design

The described stand design allows the use of two hydraulic screw-down cylinders which in each case are positioned under the drive- and operator side crossbeams and introduce the roll separating force directly into the top bearing housings. This type of screw-down has already proved successful in 4-hi stands, its advantages being short reaction times, high-speed screw-down and, in conjunction with a good strip thickness control, the possibility to use it for rolling strips to the closest tolerances. Different adjustment of the two screw-down cylinders enables tilting of the top bearing housings and thereby matching to any wedge-shape of the ingoing strip.
The roll gap contour adjustment is done via:

- crown adjustment of the outer backup rollers
- 2nd intermediate roll bending
- 1st intermediate roll bending
- 1st intermediate roll shifting
- Tilting and adjusting of the upper roll chock

whereof especially the unique and patented “double bending” technology of bending the 1st and 2nd intermediate roll deserves to be mentioned. These bending facilities, not only for outer intermediate rolls but also for inner intermediate rolls, result in more profile and flatness control possibilities and more dynamic flatness control by the hydraulic actuators.
With these roll gap adjustment actuators the gap geometry can be influenced significantly to adapt to the incoming strip profile and to reach the target shape. Comparing these flatness actuators to traditional monobloc 20-hi mills, which are just equipped with crown adjustment and shifting facilities, the superior Danieli-Fröhling cluster mill design offers far more possibilities to control flatness.
FEM analysis and field experience show that the crown adjustment of the back up rolls can be used as a setup pre-adjustment to approach the working point and is only moved if other actuators get close to saturation. Adaptation of the stand to the profile, asymmetric to the strip center, is effected by raising or lowering the top bearing housing by means of the direct hydraulic screw-down (roll tilting). The fine adjustment of profile is done with the bending of the intermediate rolls as primary actuator in a closed loop control. The shifting of the inner intermediate rolls, each of which has one tapered end, has a local effect on the strip outer edges to reduce the edge drop. On account of their qualitatively different character, when combined with

the roll tilting facility, the effects of intermediate roll bending systems on the roll gap contour are ideally suitable for incorporation in a flatness control system.

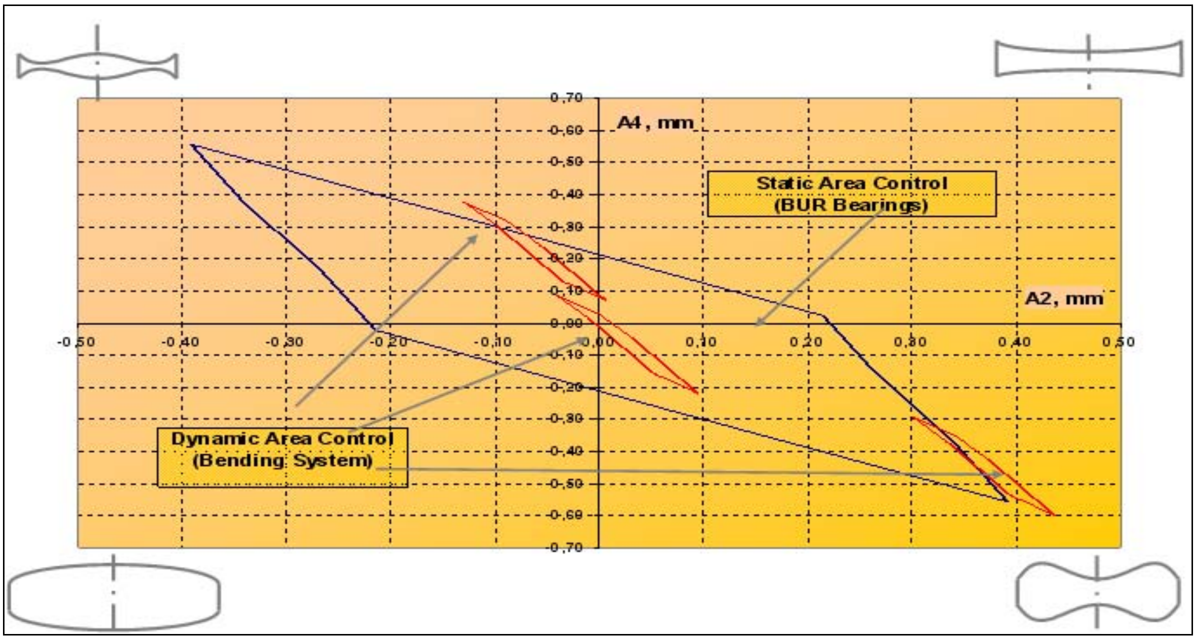


**Figure 5:** Flatness control area of 20-hi mill

The bending of the 1st and 2nd intermediate rolls is the actuator with the highest dynamics in the 20-hi mill. It is controlled by direct hydraulic setup, changes of the bending reference value can be initiated immediately without restrictions to surface damages on strip or rolls. Whereas the intermediate roll shifting is restricted regarding speed adjustment due to the risk of surface damages on rolls and strip when shifting too fast. Thus the intermediate roll bending allows a quick reaction to flatness defects and reduces the strip length which is out of tolerance because of unstable rolling conditions.

## 5. HIGHLIGHTS OF THE AUTOMATION CONCEPTS

Danieli Automation's integrated system allows to utilize modern equipment to its highest possible degree, providing intelligent solutions for Level 1 and Level 2 applications for all types of rolling mills. The most significant feature is the implemented technology, based on the concepts of:

- hardware and software technology based on market standards,
- totally open architecture with guaranteed expandability,
- flexibility and scalability,
- modular process models and application software,
- open connection and communication capacity,
- high dynamic performance,
- technological controls,
- user-friendly operation and easy setup,
- easy maintenance and minimum downtimes,

A set of different Level-1 control and compensation functions ensures highest quality products in respect of very tight thickness tolerances over the complete strip length. Integrated control algorithms are beneath the standard thickness control modes the mass flow control based on Smith Predictor technology, and several sophisticated

algorithms like roll Friction Compensation, Bending Force Compensation, model based Roll Eccentricity Compensation and Vibration measurement and analysis.
Special highlight of the automation system is the integrated Level-2 system ranging from technological line control aspects up to statistical process analysis. Its setup is based on mathematical models. In terms of mill operation the models:

- facilitate operators work, due to automatic pass schedule calculation
- enable repeatable setup

In terms of quality they:

- bring the line faster on target tolerance due to optimum mill setup
- thus minimize the scrap
- are adaptive to the process and materials
- log the coils and process history for constant improvement

the models which are mainly divided into two categories, one dedicated to the calculation of force related effects and the second related to shape/profile- and temperature effects. The models are auto-adaptive, utilizing process data gathered by the mill sensors and stored in several databases, which hold material data, mill equipment and roll data, coil order and coil result data and rolling practice data. Soft sensoring is one of the main features of the observer and offers new possibilities to analyze the rolling process.
The first category of models contains roll force and mill torques prediction, as well as general roll and strip temperature models. The second category cares about all effects on strip flatness, using a roll crown model based on thermal profile, ground profile and roll history. This is superimposed by a roll stack deflection model basing on various effects like roll deflection, roll flattening, strip to work roll and work roll to backup roll load distribution, roll bending and if applicable the loss of forces during closed gap rolling.

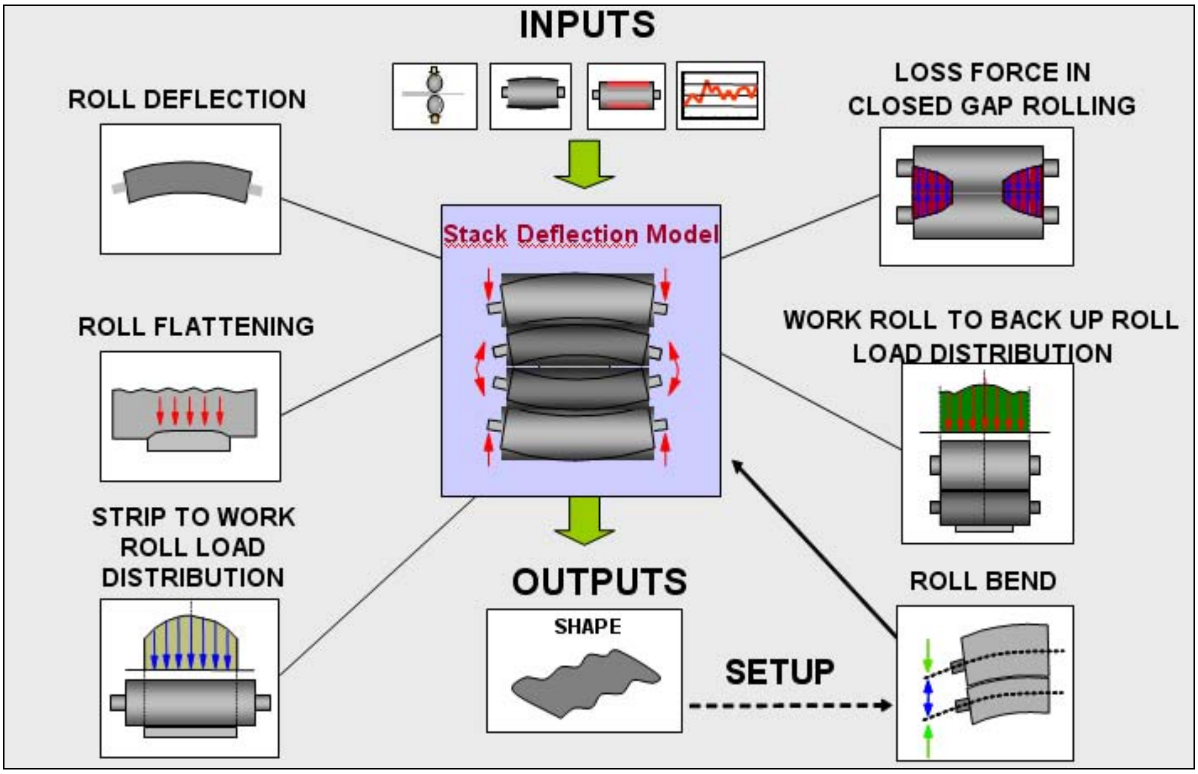


**Figure 6:** Roll stack deflection model for 4-hi and 6-hi mills

## 6 RESULTS

Both, the equipment manufacturer and the end-user of the equipment, strive to be market leaders. The market wants cost-efficient solutions with high reliability, best possible product features as well as economic production.
Close cooperation between plant supplier and end-user, starting in the project phase and lasting up to the daily operation ensures best planning, optimized plant layout and performance, good after-sales service and finally optimization of the production process. Therefore, the initial needs of the line operators have to be respected, and the applications and use of the final strip in subsequent industries (food, electronics, automotive, decoration, etc.) has to be taken into account.
As a result, the line composition has to be considered very carefully. Even though investment costs shall be optimized in the beginning, the life-cycle costs of the machines and the marketability of finished material must be the key factor for investment decisions. Danieli-Fröhling's solutions can help the end-users of its technologies to open new market segments both domestically and abroad in a competitive way.