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A review of contemporary solutions for cold rolling that allow quality improvement

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ABSTRACT

Purpose: of this paper is a literature review on cold rolling of products with tight dimensional tolerances.
Design/methodology/approach: In this paper a review on methods of quality improvement of cold rolled products was performed. Main groups of analysed factors, influencing high quality of rolled products are: rolling equipment, rolling technology, used tools.
Findings: As a result of literature review it is concluded that the most important element involved in the manufacturing process and having an influence on the obtained dimensional tolerances is the roll.
Research limitations/implications:
Practical implications:
Originality/value: As a result of carried out review it seems that control of the roll deflection is the simplest and most effective way to improve the shape and thus quality of cold rolled products.
Keywords: Plastic Forming; Cold rolling; Roll contour; Roll gap control

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1. Introduction

Increasing quality requirements and competition in the market forces the producers to take steps aimed at rolling wider strips, using heavier coils, with maximum yield. Also the producers are trying to reduce the number of necessary technological operations and minimize technological waste. These activities are aimed at improving the economic efficiency of the manufacturing process.

Increasing competitiveness of their products besides the economic aspects of the production process is closely linked with the quality of the offered product which along with the price is a key to the possibility of finding customers. Efforts to reduce costs and improve quality are to some extent the initiating and steering factor in modernization activities [1,2,3].

2. Directions of efforts aimed at improving the quality of cold rolled strip

In the area of quality of manufactured products directions of these modernization efforts are focused on: minimizing the thickness deviations of cold rolled strip, elimination of shape defects, improvement of the surface quality.

Among many methods of improving the quality of cold rolled products three main directions of actions can be identified. Those efforts are aimed at removing or limiting the formation of defects, achieving closer dimensional tolerances and obtaining uniform distribution of internal stress.

Those actions are being taken in three main directions:
- in the area of rolling mill equipment:
  - stand rigidity,
  - bearing type and drive transfer to work roll,
  - multi-roll rolling systems (4, 12, 24 rolls),
- in the field of selection and implementation of technological process:
  - process parameters selection,
  - the way process is realized,
  - pull, backpull,
  - multizone cooling,
- in the field of equipment - rolls:
  - roll material,
  - roll profile,
  - way of roll cooling.

The above mentioned directions (groups) of actions have quantitatively different effects on the quality of the final product. The first two groups of factors (device and the technology of material rolling) have the biggest impact, on minimizing rolling defects associated with variable thickness on the length of the strip. Disadvantages associated with the change in thickness across the width of the band can be reduced with the use of groups of factors related to the way of the process realization and used equipment (the last two groups of factors).

2.1. Solutions of rolling equipment used at present

Rolling device according to the way forces are transmitted (arising from the implementation of the rolling process) is one of the elements affecting the formation of dimensional inaccuracies. In brief, the roll force through the roll neck is being transferred to the bearing system, and then through rolls positioning it is finally being transferred to the roll stand.

Despite a very massive construction of roll stand, its total elastic strain causes significant change of the gap in the roll bite region.

This strain has a linear characteristic in the range of nominal loads. In the range of 10-15% of nominal load the roll stand structure shows greater sensitivity to applied load (due to play deletion and matching the mating surfaces).

The following elements have an impact on total deflection of rolling stand:
- mill housing deflection,
- roll positioning mechanism deflection,
- bearing deflection,
- roll deflection.

The desire to minimize the dimensional deviations is thus reduced mainly to improve the stiffness of all above mentioned elements. So it boils down to increase the stiffness of the structure of the roll stand and all its cooperating components.

Value of an impact of rolling stand elements on its total deflection are shown in Figure 1.

Rolling with the minimum thickness tolerances requires that the mill works with 70-80% of its nominal load (final part of the stiffness graph shown in Figure 2).

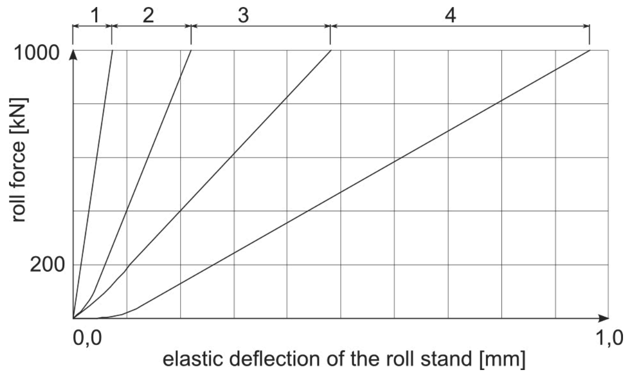

Fig. 1. Value of an impact of rolling stand elements deflection on its total deflection. 1- mill housing, 2 - roll positioning mechanism, 3 - roll, 4 - bearing with its housing [4]

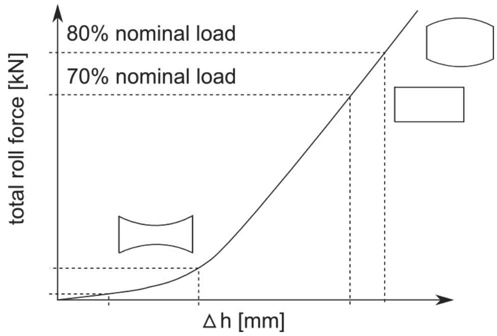

Fig. 2. The impact of running the process outside the 70-80% of nominal load boundary on cross-sectional shape of roll bite

Such approach guarantees that total roll force variations will impact the increase of roll gap insignificantly.

In addition to improving the stiffness of all rolling stand elements, reduction of the value of total roll force is another method of reducing the change in the shape of roll gap.

Because the plastic properties of metals are defined by a manufactured product so reducing the roll force may only occur by reducing the area of interaction of rolls on rolled metal reducing the size of the roll bite region. Such approach requires use of work rolls with smaller diameters but reducing roll diameter is limited by its stiffness.

The improvement in the roll stiffness is realized by the use of multi-roll systems, which guarantee reduction in the total roll force together with an increase in stiffness.

In those systems work roll has much smaller diameters and roll force is transferred by back-up rolls. An increase in number of rolls in roll stand (4-h, 6-h, etc.) allows while increasing the stiffness of the roll stand to get the work roll bending reduced [5].

Sample multi-roll systems altogether with roll length and allowed strip thickness are shown in Figure 3.

Increase in number of rolls not always allows to achieve an appropriate strip quality. Some causes of defects formation in rolled products (such as inhomogeneity of charge dimensions or its properties), even when rolling with the most rigid mills, will not allow to acquire product with desired quality.

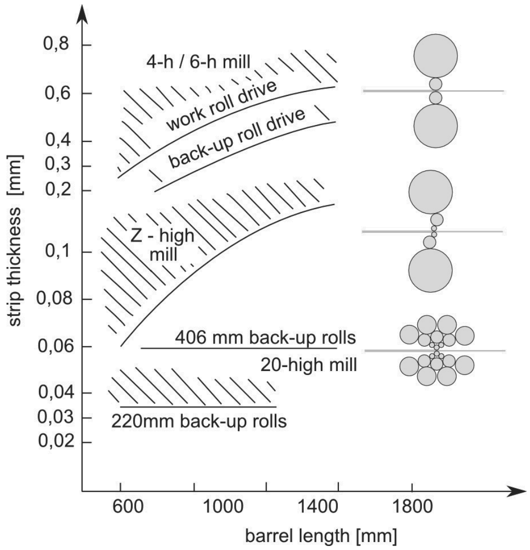

Fig. 3. Sample multi-roll systems altogether with roll length and allowed strip thickness [2]

So the modern multi-roll mills are equipped with additional measurement and control systems and technical solutions. This conglomerate allows to produce only the highest quality products.

Among these solutions are both additional solutions based on a combination of measurements of material thickness, roll force with compensation systems of roll gap, roll bending, as well as technical solutions interfering the shape of the roll bite.

2.2. Methods of roll gap control

Due to the fact that the hardest to remove are shape defects associated with an irregular deformation of strip, a lot of methods of improving the quality of rolled products are focused on monitoring and controlling the shape of the gap between the rolls.

The most popular method of compensating the deflection of the roll is the use of rolls with profiled roll face instead of not profiled cylindrical rolls.

Size of the roll crown is determined by force-energy parameters of the process realization and the rigidity of the roll itself or the stiffness of the work roll - back up rolls system. Due to roll deflection, a required roll gap profile is acquired. Positive crown is mainly used in industrial practice.

A similar effect to the use of profiled roll face, can be achieved with the use of roll bending system, in which a hydraulic cylinder loads the roll necks to obtain the desired crown. This method is more versatile than the previous one, because in combination with pressure measurement system, it allows continuous crown of the roll gap profile.

Another way to obtaining roll crown is a solution used in Pair Cross (PC) rolling mills (Figure 3). In PC mills where the gap between the upper and lower roll takes the shape of a parabola by the means of crossing of cylindrical rolls axes. As a result positive crown of work rolls is obtained [6,7,8,9]. Different configurations of Pair Cross mills are shown in Figure 4.

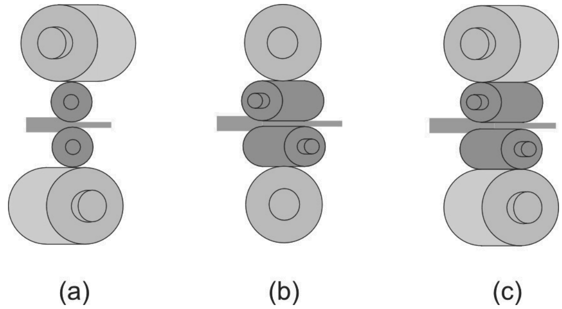

Fig. 4. Various configurations of Pair Cross mills. Crossed back-up rolls (a), work rolls (b), both work and back-up rolls (c) [7]

Another way of roll gap control is Roll Shifting (RS) system. The operation of this system is based on the axial shifting of rolls parallel to the axis of the rolled strip. The main task of this system is to extend the mill campaign and reduce roll wear at the points of contact with the edges of the band.

During normal mill operation, different materials of various widths are rolled. To avoid work rolls wear in one place and defects creation (eg. dents) as a result of this phenomenon there is a need for specially optimized production program in which the sequence of charge for rolling is being chosen appropriately.

Alternatively, using this method, charge could be rolled in almost any order, since the ability to axially move of the work rolls ensures that the distribution of roll wear is uniform [6,7,8].

The above described system, besides its main application is being connected with different types of rolls (profiled rolls), which allows the control of roll gap control. Sample configurations of RS system with CVC rolls, Smart Crown and tapered rolls are shown in Figure 5.

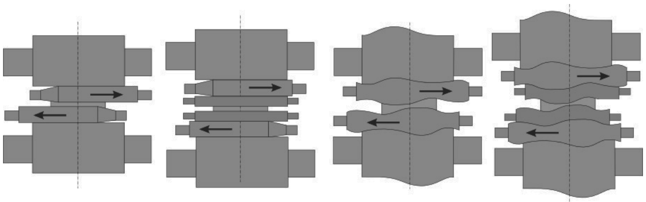

Fig. 5. Various configurations of Roll Shifting system [7]

This system is also being connected with Pair Cross rolls and as a result Roll Crossing and Shifting system is obtained [6].

Combined systems of the RS system with other roll gap control systems allows to control the shape of the roll gap and allows for longer interrepair cycles by reducing roll wear due to axial movement of the work rolls.

2.3. Ways of technological process realization

The realization of technological process has a significant impact on the size of the rolled material dimensional tolerances. Improperly designed rolling technology and errors in the process realization are the cause of most of geometrical defects of cold rolled products.

Proper selection of pull and back pull allows to control over roll force and that affects size of roll flattening and deflection.

Ensuring the stability of the process by controlling parameters affecting the rolled material deformation, results in significant reduction of production waste and obtaining high quality band within dimensional tolerances [4].

The correct realization of technology, by placing rolled strips in order from the broadest to the narrowest allows to reduce the possibility of defects due to work rolls wear.

During the rolling process a part of the energy needed to realize the process of deformation is dissipated. The resulting heat causes negative effects, one of them is the change of the lubricating properties of the rolling oil or emulsions, which negatively affects the quality of the rolled strip surface.

The heat is partly absorbed by the work rolls. Since the cooling system cools the entire width of the roll and the heat is generated only in the area of contact with the rolled material, the roll has a homogeneous temperature field so it will have a different dimensions resulting from thermal expansion (for D = 350 mm and $\Delta T = 50°C$ - $\Delta D = \sim 0.2$ mm).

To counteract this phenomenon intense heat removal systems should be used. By introducing measuring and control systems to roll cooling systems, roll crown can be adjusted with the use of described phenomenon (Crown Control) [10,11,12,13].

The use of the solutions that improve the shape of the roll gap along with enhanced measurement and control system allows for high quality products. These products will have very small thickness deviations and will be characterized by good flatness. Such solution is known as AGC and is shown in Figure 6 [14,15,16,17].

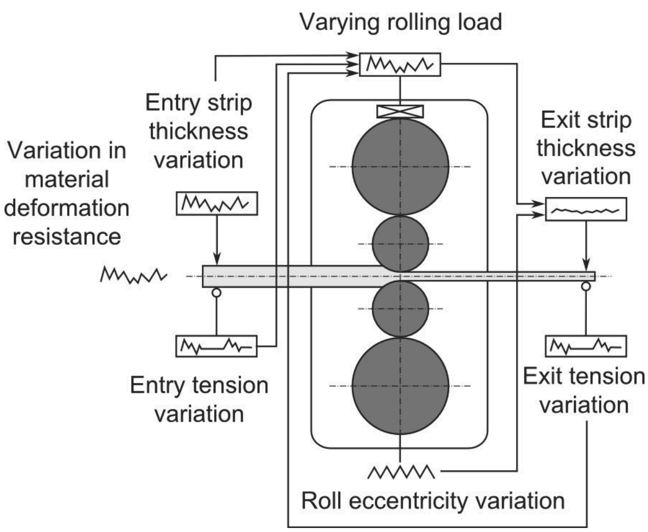

Fig. 6. A cold rolling AGC system [18]

Modern mill systems capable of ensuring high quality products (minimum shape and size deviations) are a hybrid composed of modern stand construction, its equipment, work roll profile systems and integrated measurement and control systems.

Rolling systems described above, despite (in some cases) the guarantee of acquiring high quality bandwidth are not widely used. The cause of low popularity of these systems is their high price.

An overview of North American cold rolling mills [3] clearly shows that companies tend to use low-cost solutions that are simple and effective.

Among the ways of shape control of the product, the most popular, as indicated by nearly half (48%) of the surveyed include roll bending systems, the next most popular (41%) proved to be multi-zone cooling systems, 1/3 of the plants (34%) pointed out the use of both of these methods. A summary of survey results is shown below in Figure 7.

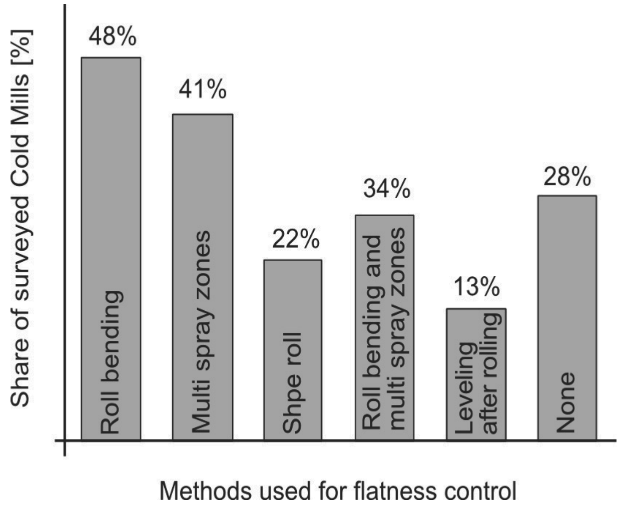

Fig. 7. Most popular shape control methods as indicated in North American cold rolling mills market research [3]

2.4. Contemporary solutions for tool design

Roll is a tool which is directly involved in rolling process. Surface quality of the manufactured product significantly depends on this tool properties and functional characteristics.

Roll, in the process of rolling gets worn, which causes degradation of its working surface. As a result of roll wear a small texture forms on the surface and during the process of plastic forming is being transferred to the surface of the rolled strip.

Apart from wear it is important how the roll behaves under the influence of cyclic loads deriving from the rolling process. The total roll force and associated bending and twisting moments (drive transmission) affects roll gap deformation and therefore the resulting distribution of thickness of the rolled strip.

The desire to counteract this deformation caused the search for new solutions in the field of work roll cross section profile and its construction. The most commonly used profile is positive roll crown with the value reaching level of 0.001 roll diameter.

A different approach to acquiring a convex roll crown is to implement rolls with a variable profile geometry. Roll profile, instead of a parabolic shape has the outline of an inverse trigonometric function. This profile can be superimposed on the outline of the work rolls or back-up rolls. Such shaped roll with an additional mutual axial shifting (RS) allow to form the shape of roll gap in any way. An example of this solution are Smart Crown and CVC rolls.

CVC and Smart Crown are rolling systems where roll has a profile on the entire length of the barrel with a shape similar to the letter "s". This systems allows the adjustment of the roll gap by moving rolls in opposite directions (this applies to work rolls, intermediate and back-up rolls). One set of smart crown or CVC rolls allows to acquire any shape of the roll gap that can be achieved by the use of several sets of profiled rolls with various conventional barrel shapes (positive, neutral or negative crown) [6,19]. The way of achieving roll gap shape in CVC with roll shift system compared to conventional technology is shown in Figure 8.

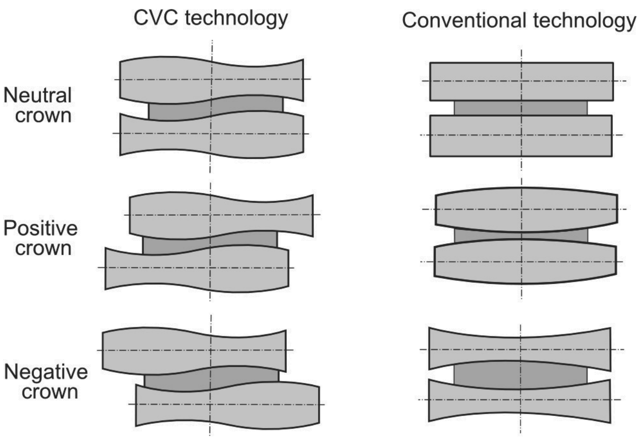

Fig. 8. The way of positive, negative and neutral crown with CVC and conventional technology

Both of these systems provide high controllability of roll crown and are characterized by great versatility. The differences between the CVC and Smart Crown system lie in different roll and roll gap contour. The main differences between these systems are presented below in Table 1.

Table 1.
Differences in roll contour and roll gap contour in Smart Crown and CVC [19]

	Smart Crown	CVC
Roll contour	sinusoidal	3-order
Roll gap contour	cosine-Shaped	paraboilic

In addition to the rigid shape of the roll barrel profiles resulting from the profile imposed during machining of a roll, there are some solutions in which the final shape of a roll is variable and controllable. The variability of the profile is obtained by various methods.

One of those methods is Variable Crown Roll (VC Roll). In this roll there is an oil chamber under a metal sleeve that contacts with the rolled material. Changes in pressure in oil chamber affect the shape of the roll.

VC Roll can be installed in any roll stand, and its application does not require major modifications, also installation of this roll does not require more downtime than when installing a conventional roll. One of the advantages of the system is the reaction time. When coupled with measuring and control system the VC Roll system makes it possible to continuously adjust the parameters of the roll gap in a follow-up manner [20,21]. The VC Roll is shown in Figure 9.

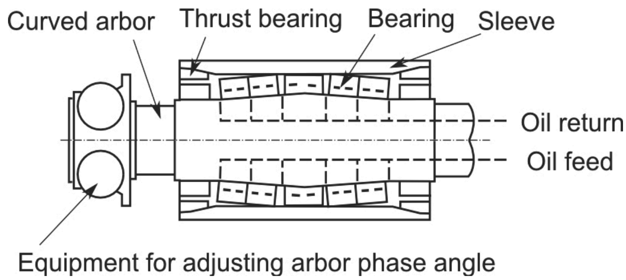

Fig. 9. A schematic representation of the VC Roll [20]

The DSR (Dynamic Shaperoll) roll is based on a similar base. The DSR roll is predestined for use as a back-up roll with driven work rolls. Its design is based, similarly to VCR, on working sleeve. The sleeve rotates on the bearings mounted on a stationary core of the roll. The core is equipped with an actuator segments located along the barrel. By applying the appropriate pressure to separate sections of the actuator, there is a possibility of obtaining any shape of the roll profile. The Dynamic Shaperoll is shown in Figure 10.

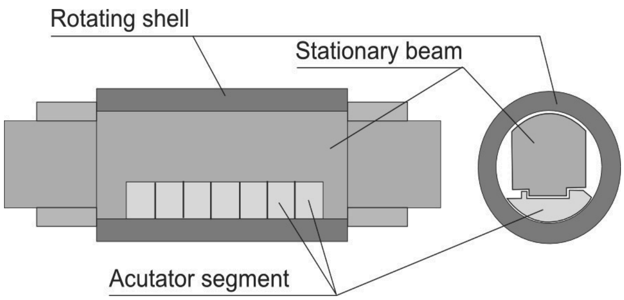

Fig. 10. A schematic representation of a DSR roll

Currently the DSR roll is being used in cold steel and aluminium mills [22,23,24,25].

3. Description of achieved results

Analyzing the quality of cold rolled strips and sheets, it was found that defects originating from the previous processes-metallurgical process defects are likely to disqualify products, and their removal is often impossible.

Defects deriving from the implementation of the rolling process can be eliminated or at least their impact on the final product can be reduced. Such actions will be implemented in the way of improvement of the technology itself (understood as a way to realize the process and parameters used) and appropriate selection of tools and their geometric features.

Defects that are a derivative of a cold plastic forming process are mainly defects resulting from deviations from the geometry of the product "perfectly flat" with a uniform cross section.

All deviations from the hypothetical ideal geometry are derived from several groups of factors. Factors affecting keeping of dimensional tolerances in the process of cold rolling are:

- available rolling equipment solutions,
- the way of technological process realization,
- applied tool (roll) solutions.

Only in the case of designing the new mill, or a significant upgrade of the existing technology it is possible to choose the rolling equipment in a way to improve the quality of the final product in range of shape and dimension tolerance. However, in most cases the process is conducted using the available machinery and it is impossible to alter.

Technological process that is properly carried out, significantly affects the quality of the finished product, however, the process should always be realized "correctly". Thus, properly realized process allows maintaining a certain level of quality arising from the technical possibilities. Wrong way of this process realization may only reduce the achievable quality. However, in the analysis of these factors, it is assumed that the process is always realized in the correct manner.

The most important element involved in the manufacturing process and having an influence on the obtained dimensional tolerances is the roll. Regardless of the rolling mill equipment used and the scale of its complexity, the roll has a significant impact on the quality of the product. Its quality, design and features allow maintaining high dimensional tolerances. Roll and its features are a conglomerate of factors which give the greatest possibilities in the field of narrowing obtained dimensional deviations, and thus improve the quality of cold rolled products. It seems that control the roll deflection is the simplest and most effective way to improve the quality of cold rolled products.

4. Conclusions

In this paper a literature review on cold rolling solutions currently in use has been made and it is concluded that:

- defects originating from the previous processes-metallurgical process defects are likely to disqualify products, and their removal is often impossible,
- defects deriving from the implementation of the rolling process can be eliminated or at least their impact on the final product can be reduced,
- defects that are a derivative of a cold plastic forming process are mainly defects resulting from deviations from the geometry of the product "perfectly flat" with a uniform cross section,
- the most important element involved in the manufacturing process and having an influence on the obtained dimensional tolerances is the roll,
- it seems that control the roll deflection is the simplest and most effective way to improve the quality of cold rolled products.

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