

## IMPROVEMENT OF SURFACE QUALITY OF ROLLED SECTION STEEL FOR SPRINGS MANUFACTURING

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### ABSTRACT

*The quality of springs depends on the rod surface. Requirements to the surface quality and depth of decarbonized layer of hot rolled coils are becoming stricter. Allowable depth of partial/complete decarbonization layer is 0,14/0,03 mm. The most common methods for preventing growth of decarbonized layer is controlled steel heating and metal forming control. Using controlled heating we can not always ensure that the depth of the decarbonization layer is not exceeded. The aim of the study is to control the uniformity of deformation to reduce the thickness of the decarbonized layer. This article focuses on roll pass design optimization (the width, height and angle of fillet) for intermediate stands and for finishing high-speed stands block (Danieli "BGV"). During experimental rolling in the new way of deformation in a volume of more than 50 tons, there was no sticking of metal in the stands, and final sizes of rolled round product with 14 mm diameter were within the existing tolerances for products ( $\pm 0.3$  mm). The result of using a new roll pass design configuration was the production of rolled products with high surface quality; and in the future, we have a possibility to produce automotive coil springs meeting high performance requirements.*

*Keywords:* spring steel, decarbonized layer, unevenness of metal deformation, roll pass design, section ovality, surface quality.

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### INTRODUCTION

It is a fact that spring steel is a low-alloy steel, medium-carbon steel or high-carbon steel with elevated yield limit. This makes it possible for the products made of string-type steel to return to their original shape regardless of significant bending and twisting. Under working conditions, coil springs and leaf springs are subject to multiple alternate stresses, and upon their removal, shall be able to completely restore their original dimensions. Due to such work environment, the metal

employed in manufacturing coil- and leaf springs shall possess - apart from the necessary strength under influence of static, dynamic or cyclic loads - sufficiently good plasticity, high elastic strength and durability, as well as high relaxation resistance, while during operation in aggressive media (steam atmosphere, sea water, etc.) shall also be corrosion-resistant.

The coil- and leaf-type springs' quality is also dependent upon the surface quality of finished rolled bars, wire and strips. Surface defects (like cracks, backfins, shells, hairlines, voids, embedded scales, etc.) as well as

decarbonized layer worsen the elastic and cyclic properties of metal. That is why, previously in the springs manufacturing process, the outer defects on the surface of rolled bars and strips were removed by grinding or polishing, while the depth of the decarbonized layer was regulated by national standard for the leaf-and-coil type steels. Presently, the more attractive from the point of view of production costs' reduction are the technologies, which incorporate minimum number of operations, as well as those which ensure resource saving. With this in mind, the up-to-date trend in the springs production is the use of finished rolled products, without extra machining of their surface. Due to such approach, the requirements towards the surface quality and the depth of the decarbonized layer of the rolled products are becoming more and more stringent.

The metal surface decarbonization phenomenon is in the fact that the gases present in furnace and containing oxidizing agents enter into a combination with carbon, which is a part of steel composition. The result of such reaction is gaseous compounds, which are emitted into the atmosphere, while the surface layer of the metal is becoming saturated with carbon. In the flow of time, and at repeated heating, the decarbonized layer on the metal becomes thicker; moreover, sometimes this layer consists even of pure iron. Due to the decarbonization process, the mechanical properties of the metal surface layer significantly drop, and they may only be detected during dedicated investigation.

All types of steel (to one extent or another) are subject to decarbonization, and that is why it should be kept in mind that such a process may impair quality of parts made of steel of any grade. Virtually, one may presume that when in steels with the carbon content being 0.20 - 0.25 % the presence of the decarbonized layer may be hazardous in individual, special cases only, then in steels with the carbon content of 0.40 - 0.45 % it shall be acknowledged as a dangerous shortcoming, which shall always be taken into consideration when taking a decision regarding fabrication technology of any particular part. Surface decarbonization, which practically is incipient during hot mechanical processing of a slab, is regarded as one of the most serious flaws in modern steel production processes, which greatly impair the

steels' strength under variable loads.

The degree of decarbonization and the depth of the decarbonized layer may be determined by a few methods, the most widespread of which are the following: measurement of a specimen's surface hardness prior to and after preheating in a given atmosphere (hardness depends on the carbon content) and analysis of micro structure revealing the nature of the transformations, which had taken place in the steel. Chemical analyses of sequentially cut-away layers of metal, as well as determination of change in its mass are also possible [1].

The most common methods of prevention the growth of the decarbonized layer are the following: controlled heating of steel and specific features of the process, making steel with a pre-defined chemical composition (alloying), control of steel processing by means of applying pressure, thermal treatment of finished hot-rolled steel [1] and physical ways of decarbonized layer removal. In our particular case, the controlled heating made it possible to obtain (Fig. 1) a 0.20/0.06 mm depth of the partial/complete decarbonization layer (the values required by relevant standards are 0.14/0.03 mm).

All the methods listed above have different effectiveness and are studied not in the same extent due to their dissimilar complexity. The least number of invention patents and useful model patents, as well as relevant publications, may be found for steel processing control by means of applying pressure, aiming at reduction of thickness of decarbonized layer of spring-type steels [2].

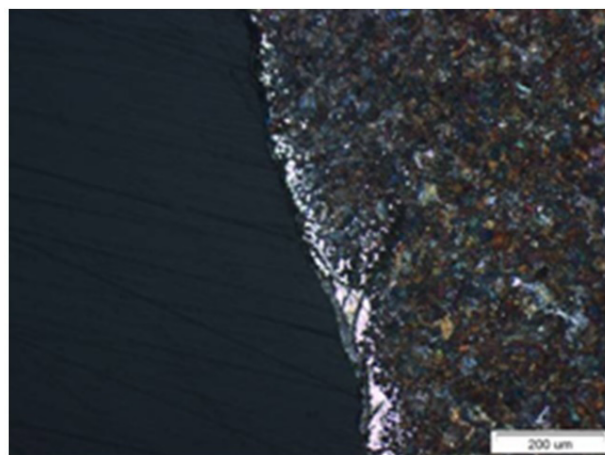


Fig. 1. The result of rolling after controlled heating without change of roll pass design.

Due to what has been previously mentioned, a particular attention, as a separate point, is worth paying to the study of plastic deformation margins during rolling in calibrating devices. The objective of the study is to ensure the maximally possible uniformity of deformation and hence, the reduction in thickness of the decarbonized layer.

## EXPERIMENTAL

In relation to the Rolling Mill 170, the following options of the calibration process optimization were considered with regard to non-uniformity of deformation [3 - 5] during rolling of round bar profile 14 mm in diameter:

- wire block calibration optimization during increase of semi-finished rolled products' cross section and increased number of passes in the block from 2 up to 4;
- optimization of the calibration process of breakdown stands' group, with obtaining of square cross-section at intermediate rolling table;
- optimization of calibration process of roughing stands' group of the Mill (stands No 2 - 8) using diamond-square sequence;
- modelling of rolling of work piece with elevated cross-section (152 x 170 mm) in combination with rolls' calibration options described above.

Among the options considered to solve the task in question, the most promising ones in terms of decar-

bonized layer thickness reduction are those associated with the increase in the workpiece size and, as a result, with increase of the total elongation ratio. At this, in terms of cost minimization with regard to change in production technology and experimental rolling execution, the most preferred one is option 1, which is connected with optimization of rolls calibration of the wire block. The experimental/test rolling in accordance with this calibration option may be executed with minimal expenditures for production preparation. The rolling results with utilization of the new calibration approach are presented in (Fig. 2a). The depth of the partial/complete decarbonization layer of 0.12/0.02 (0.7 mm long) mm and with regard to defect (Fig. 2b) 0.22/0.03 (0.65 mm long) mm (the value required in relevant standards is 0.14/0.03 mm). Here, the positive effect of corrected calibration is observed, which made it possible to ensure the more uniform metal deformation with regard to its cross-section. Inadmissibly high values of reference parameters are observed in the areas of surface defects localization (Fig. 2b). Therefore, the subsequent arrangements with regard to breakdown workpiece quality improvement shall be directed towards employing of the mill's rolls with enhanced surface condition.

The basic criterion of the calibration correction/adjustment effectiveness was the possibility to "expel" the resulted decarbonized layer due to implementation of the more uniform deformation of metal during the rolling process. With structural/matrix approach, which

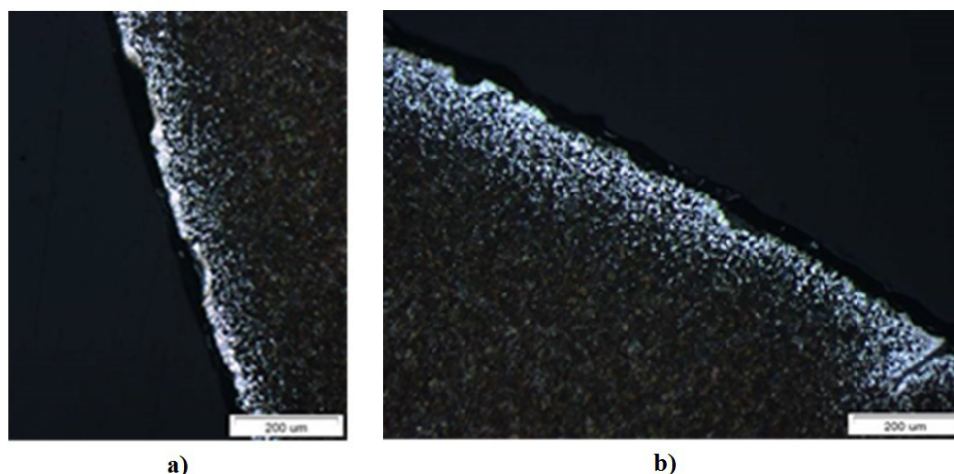


Fig. 2. The result of rolling after controlled heating with change of roll pass design.

already exists and has been regularly used for more than 20 years for description, analysis and design of rolled section products' modes, the uniformity of deformation in calibration devices of various shapes is characterized with non-uniformity factor  $K_{non}$ .

It is specifically worth mentioning that the high deformation non-uniformity contributes, to a great extent, to wear of the mill's rolls, and, as a result, to formation of new areas of increased non-uniformity.

The more uniform deformation may contribute to a better rolling out of the defects, which might occur at the phases of metal and workpiece production, and, what is particularly important, positively influences the uniform distribution of the decarbonized layer both with regard to breakdown workpiece length, and with regard to its cross-section. Consequently, to reduce the number of defects and to improve the surface quality of rolled products, it is essential to ensure the minimum possible level of the deformation non-uniformity. Besides, a decrease in internal residual stresses will enable to more efficiently utilize the rolled products in future re-processing.

Among the reasons causing the deformation non-uniformity, the most relevant one is non-conformity of a processing tool with the shape of the body being deformed. During rolling of sectional products, such the non-conformity is inevitably present.

Imperfection of the mill's rollers calibration schemes leads to reduction of the shape homotheticity rate of the body under deformation and of the process tool [6, 7]. Increase in similarity degree of such shapes will make it possible to reduce the deformation non-uniformity. In most cases of sectional products rolling, the calibrators have to deal with non-homotheticity shapes.

Reduction of deformation non-uniformity will enable:

- to reduce wear of the mill's rollers;
- to decrease energy consumption in the metal rolling process;
- to obtain more uniformly distributed loads during rolling across the workpiece width, by having spread the loads over the mill's rollers;
- to increase process stability with regard to "ac-

curacy" criterion;

- to obtain more accurate geometrical dimensions of the finished products;
- to extend service life of mill stands' mechanisms/gears.

Relying on structural/matrix approach, to assess the deformation non-uniformity during the metal shape change in calibration devices, the non-uniformity factor  $K_{non}$  shall be applied.

The  $K_{non}$  may be calculated both for the shape change process of a deformation within a single location point, as well as for two adjacent points.

The root-mean-square deviation of a shape-changing matrix component may quantitatively reflect the shape change non-uniformity both in one calibration device, and in the two adjacent ones. In this case, the integral coefficient of the shape change non-uniformity for metal deformation in the two calibration devices may be written as:

$$K_{non} = \sqrt{\frac{\sum_{i=1}^n \left( \lambda_{ij-1} \lambda_{ij} - \frac{\sum_{i=1}^n \lambda_{ij-1} \lambda_{ij}}{n} \right)^2}{n}} = \sqrt{\frac{\sum_{i=1}^n (\lambda_{ij-1} \lambda_{ij})^2}{n} - \left( \frac{\sum_{i=1}^n \lambda_{ij-1} \lambda_{ij}}{n} \right)^2}$$

where  $K_{non}$  is the deformation's non-uniformity coefficient,  $n$  - the number of vectors that describe the one-fourth of the calibration device cross-section, or of the metal incoming/fed-in cross-section,  $\lambda$  - the ratio of each incoming cross-section's vector to that of the outgoing one (Fig. 3).

As practical experience shows, employing the value of the deformation non-uniformity coefficient for the case of sectional products rolling in various calibration systems shall vary within the range from 0.18 to 0.30 [3, 4].

Different calibration systems, deformation individual features, calibration devices' shape and clearances



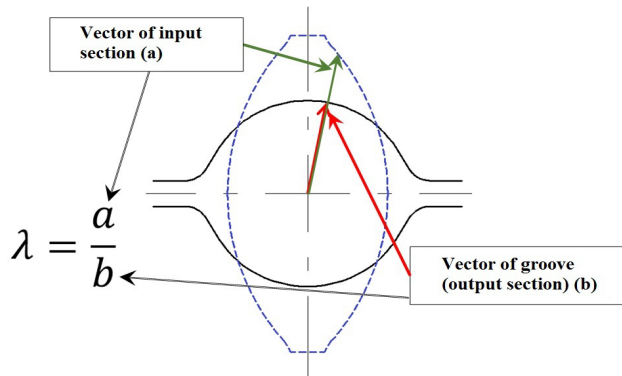


Fig. 3. Explanation to the deformation non-uniformity coefficient  $K_{non}$ .

specified for the rolling process to a great extent influence formation of the numerical value of the deformation non-uniformity coefficient.

To assess the deformation non-uniformity integral coefficient, classic statistical parameters and characteristics shall be considered, namely: standard deviation, the least squares, mean arithmetic value, median estimation, etc.

## RESULTS AND DISCUSSION

Analysis and comparison of the metal deformation non-uniformity during rolling, in accordance with existing and the newly-proposed calibration, have been done on the basis of production technology modes for rolling of round bar 14 mm in diameter.

In order to calculate the deformation non-uniformity coefficient, all the available calibration devices shapes and the breakdown workpiece transitional cross-sections were subject to digitalizing on the structural/matrix approach basis. On the basis of the deformation non-uniformity coefficients, which were calculated for production technology charts (we call them “Regular calibration” and the “New calibration” respectively), the deformation non-uniformity coefficient distribution diagrams have been plotted, which are presented in Figs. 4 and 5.

Additionally, statistical characteristics were calculated for the obtained values of the deformation non-uniformity

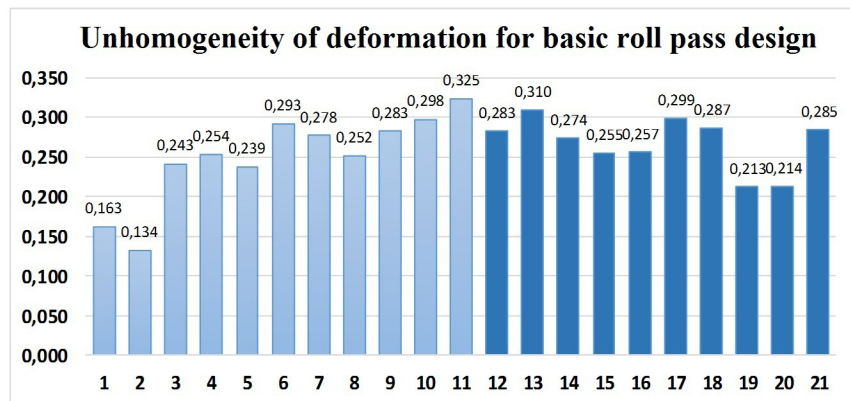


Fig. 4. Distribution of the  $K_{non}$  by passes for regular roll pass design.

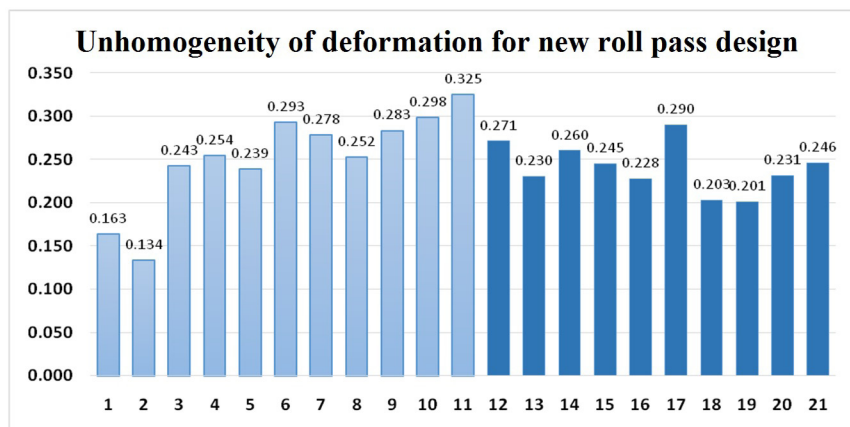


Fig. 5. Distribution of the  $K_{non}$  by passes for new roll pass design.

Table 1. Statistical characteristics for deformation non-uniformity assessment.

Characteristic	Basic roll pass design		New roll pass design	
	Passes 1 to 21	Passes 12 to 21	Passes 1 to 21	Passes 12 to 21
Standard deviation	0.04707	0.03273	0.04508	0.02939
Sum of squares	1.45353	0.55050	1.31201	0.45910
Variation	0.18171	0.12562	0.18320	0.12352
Mean arithmetic	0.25905	0.26053	0.24605	0.23797
Median	0.27411	0.25680	0.24600	0.23812
Maximum	0.32484	0.29948	0.32484	0.29013
Minimum	0.13357	0.21311	0.13357	0.20124
Span	0.19126	0.08648	0.19126	0.08943

coefficients, which are presented in Table 1, as well as the necessary values for the task-oriented adjustment of inter-rollers clearances that ensure prevention of the breakdown workpiece defects with regard to geometrical indicators [8, 9].

Having analysed the data obtained, one may come to the following conclusions:

- standard deviation and mean arithmetic value for the new calibration is less, consequently - the deformation non-uniformity has also become less and more stable, which is supported by variation;
- the lesser median value for the new calibration is a clear evidence of the total drop of numerical values in the selection of deformation non-uniformity coefficients;
- the sum of squares for values from 12 up to 21 passes has dropped by 16.6%, which also indicates a decrease in the extent of the value understudy;
- the minimum and maximum values for passes from 12 to 21 have reduced, which indicates a decrease in peak values and fluctuation of the non-uniformity in the new calibration;

Based on the information presented it may be concluded that the proposed calibration is the most efficient one from the deformation non-uniformity index standpoint.

The reduction of the deformation non-uniformity and its more uniform distribution by passes made it possible to obtain the rolled products with more uniformly distributed decarbonized layer, and as a consequence, the more uniformly distributed mechanical properties of the surface, which is crucial for operation conditions of the spring-type steel.

During selection of likely deformation modes, the main goal was to minimally “interfere” into the existing calibration process. Such an approach makes it possible to cut costs for implementation of the results obtained, and to reduce effect of mismatch factor of the existing production technology with the new integrated solutions. The resulting proposed option of the deformation sequence modification has contributed to enhancement of versatility of the rollers’ stock utilization through creation of feasibility conditions to manufacture the round bar section 14 mm in diameter, by being frequently implemented in the Mill, the round bar procedure of rolling 6.5 mm diameter bars, in addition to the existing sequence, which is twice as less used however, in rolling of the round bar 5.5 mm in diameter. This advantage contributes to the increase in production efficiency, to reduction of production downtime during the transfer from one production order to another, as well as to simplify the optimization task solution, with regard to stock of rollers available [10, 11].

Moreover, during transfer to the new calibration procedure, with completion of the finished sectional products at the forth position of the finishing wire block, that is with the use of rollers with reduced diameter, the reduction of the rolling force and momentum applied have taken their place due to the fact that the roller diameter in the block was 1.5 times less, while the extent of the deformation location, and the contact area have been consequently reduced. The result is that even with the increase in rolling speed from 15 to 18 m/s and at operation of the mill stands with reduced rpm, the load to the stands and drive did not exceed the specified values, being within the

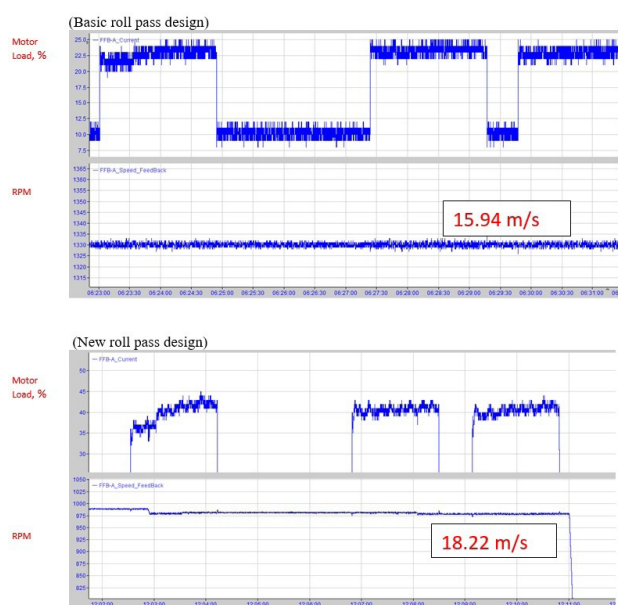


Fig. 6. Comparison of electric motor load of wire block.

range 24 - 85 % (specified load - 100 %). Comparative analysis of the main actuators' electric motors load, by the rolling momentum prior to and after implementation of the new deformation mode for the mill stands of the finishing block is shown in Fig. 6.

Increase in the rolling speed of round bar 14 mm in diameter is associated with obtaining of the finished profile closer to the end (the forth position of finishing ten-stand wire block) of the mill, and the need for proportional speed growth. However, this particular fact does not lead to increased productivity of the Mill.

During rolling in accordance with the new strain pattern no jamming took place, the finished dimensions of the rolled round bar 14 mm in diameter were basically within the existing tolerances for the products ( $\pm 0.3$  mm) (Table 2).

Increase in the finishing calibration device taper of groove introduced earlier in order to get rid of periodical whisker, contributed, to some extent, to growth of

out-of-roundness. Consequently, this solution has only partially compensated the influence of the real cause of breakdown workpiece periodic oscillations. For that reason, as one of the arrangements to reduce out-of-roundness of the finished sectional product, it is feasible to recommend the identification and elimination of mechanical cause of the periodic oscillation of breakdown workpiece, with the frequency being equal to one turn of the roller in the finishing stand, as well as reduction of the finishing calibration device taper of groove from 24 to 22 degrees.

## CONCLUSIONS

The performed transfer to non worn-out calibration devices during the test rolling of round bar 14 mm in diameter in the intermediate group of stands, as well as employing the new reduction of cross-sectional area modes, in combination with developed calibration methods, and implementation of majority of requirements with regard to chemical composition of melted steel and dedicated heating mode of the workpiece, has made it possible to ensure high quality of the rolled products surface, and the required operational characteristics of experimental spring products, which were subject to tests at the premises of "Mubea" company.

With that said, with regard to production of special-purpose sectional rolled products, the scientific/production task solution is a set of arrangements and innovations [12]. One of the core roles is played by the scientific tool of task-oriented calibration of profile, which provides for reduction of the deformation non-uniformity. Employment of the new calibration procedure resulted in the rolled products manufacture with high surface quality, and then in the future - in the spring products for motor vehicles, which will comply with high-level operational requirements.

Table 2. Dimensions of round bar 14 specimen made of steel grade 60C2XA after test rolling.

Parameter		Value	Remark
by height		14.0 mm	
by width (by grade)		13.85 mm	
by diagonals	1.	14.0 mm	result of "table" displacement of incoming gear at 4-th position
	2.	14.2 mm	

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