USE OF EDDY CURRENTS EFFECT IN THE RESEARCH OVER TRIBOLOGICAL PROPERTIES OF STRIP MILL ROLLS

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Abstract

Proper planning of the rolls service level is a crucial element of correct rolling mill operation, since this factor constitutes a limiting element in the production process. Article presents collection of exploitation-research results including hot rolling mill of steel strips, which were drawn up based on advanced grinders programs in determined operation period. Carried out research results with a use of eddy currents effect were presented, in order to detect material defects in the metallurgical rolls.

Keywords: eddy currents, hot - rolling mill, waste of metallurgical rolls, strip

1. INTRODUCTION

In the production process of strips and steel metal sheets with tools the most responsible for their quality are working and beck up rolls. They are the most expensive tools applied in the rolling process. Due to required quality of rolled strips, a primary importance has rolls state of finishing line, because they in a larger degree impact on the surface quality and accuracy of rolled strip measurements. During steel strip productions a major concern is the high degree of wear, especially working rollers and because of that frequent their remodeling. In case of finishing line in the working rolls a replacement is carried out every 8-10 hours; and in the beck up rolls every 2-3 weeks, depending on the amount and assortments of rolled strips. A major concern in the production of steel strip is their high degree of wear out. Metallurgical rolls operate in an extremely difficult exploitation conditions. During operation a great bending and compression arises due to pressure from rollers on rolled material and torsional stress, incurred as a result of torque transfer from the drive mechanism on the roll. Including thermal stresses which results from changes in the roll temperature at hot – rolling as well as a strong abrasive action of the roll face working surface. An effect of these factors impact on working rolls is loss of rolled product dimensions as well as transfer of roll texture on the strip surface. There is incessantly search for new research methods to determine waste level of rolls in order to provide strips about the highest area quality and more precise geometric dimensions. In the analyzed rolling mill for defects detection of rolls material i.e. material state diagnostics, the eddy currents method is used, which constitutes an innovative solution in non-destructive materials research. Eddy currents method enables to detect cracks in materials, elements of machinery part and welds as well as in tools.

2. PRINCIPLE OF USE EDDY CURRENTS EFFECT IN A NON-DESTRUCTIVE MATERIALS RESEARCH

Method, which uses an effect of eddy currents for materials state research in the non-destructive way, consists in local differences detection in the physical properties of examined material elements using changeable magnetic field, causing stresses change of those currents [1]. In practice it is conducted in such a way that examined element, about determined dimensions, made of material about given electrical specific conductance and magnetic penetrability, are subjected to changeable electromagnetic field in studied material as well as receiving material reaction by research probe and eddy current flaw detectors. Analysis of electromagnetic field variations, amplitude and phase shift of tension and stress allows for very accurate state evaluation of studied material, appearing discontinuities in a form e.g. cracks, erosional or corrosion losses, an evaluation of their size and depths.

Applied research technique with eddy currents is used above all to detect structural diversities and roll material discontinuity, such as cracks, delamination, times or cavities on its surface as well as interjections of strange metal. It also enables to control materials properties in case of mixed types or different heat treatment states. Then most often applied criteria are: alloy composition, surface hardness, depth hardens, toughness and microstructure characteristics [2]. Non-destructive method with the eddy currents technique doesn't requires physical contact with studied material. Research speed to a few meters per second, full registration of indications, precise location and marking during examinations constitute advantages of this method and guarantee a very high and expected by recipients the quality of finished products.

3. MODELLING OF ROLLS WEAR OUT IN THE HOT ROLLING MILL

Analyses concerning research of rolls wear, performed from different material types, were carried out based on obtained results using a computer program “Management system of the rolls grinder”, being on the equipment of examined rolling mill. It was drawn up as a tool to simulate the processes for determining rollers size in rolling process of steel kind, using spatial deformation model. This software application enables to determine wear out value of working tools as well as enables to appoint on the working surface of roll face an areas most exposed to damage. Upon cracks detection the surface of studied roll material (Fig.1) is scanned without physical contact with it, by one or more eddy current flaws probes [3].

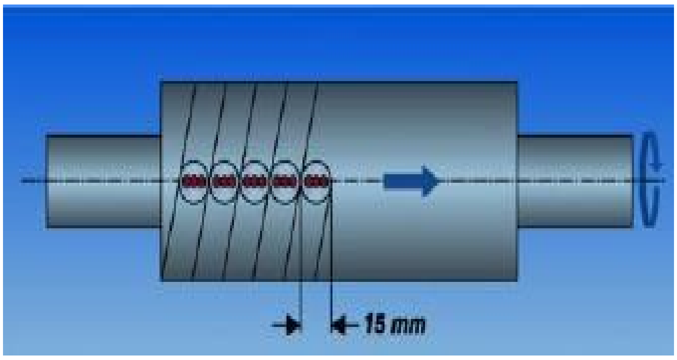

Fig. 1 Scheme of spiral probe scanning the roll surface

In order to carry marking out the studied roller is rotated by an appropriate mechanism, during which its scanning is carried out, and next its data are processes to a special control systems. They enable to determine location and type of occurred defect as well as conduct fast and effective analysis of defective elements.

4. RESEARCH PROGRAM

Research carried out in the work [4] included drawn data concerning wear out rolls in years 2012-2013 of individual finishing line cages of the constant rolling mill, marked F1-F6. In the analyzed period a roller made of steel were operated: high-speed steel – HSS, from high-chromic cast iron – Hi-Cr and from modified alloyed cast iron of EICDP and ICDP type. Rolls of mentioned materials worked in total by 51 roll line campaigns and rolled in 2012 yr. of 1840 Gg, and in 2013 yr. of 1320 Gg strips of non-alloyed steels as well as alloyed of general purpose in the following types: S235JR, S355JR, F1, F2, F2B, DD11 and UG.

Data for analysis was collected based on rolls cards, production reports, rolls market reports in the operation from individual months and other documents. Data analysis of every roll enables to state that two years period, for which data was analyzed, wasn't homogeneous in terms of production. At that time periods appeared, in which low-alloy steels were rolled, as well as periods in which they weren't rolled, however rolling conditions applied at that time didn't change significantly. As measure of roll usage rate an indicator Q was adopted, applied in the metallurgy and determined from the following formula [5]:

$$Q = \frac{Z}{U} \tag{1}$$

where:

Z - amount of rolled steel, Mg,

U - loss of roll mass as a result of rolling and calibrating, kg.

Total rolls waste, called natural, is a sum of metal waste of the roll face, expressed in kg, as a result of compulsory rolling within the entire roller operation period, i.e. from first folding to withdraw for scrap. Collected data as well as data analysis about waste rolls provides very valuable information for every rolling mill, thanks to which it is possible to plan rolls reconstruction times. It much improves a production planning process of the entire production line and contributes to a reduction in operating costs.

5. RESEARCH RESULTS AND THEIR ANALYSIS

In order to reduce number of necessary rolls reconstructions as well as an optimal use of their work surface, and thus the rolling mill production costs, a computer simulation was conducted using “Management system of the rolls grinder” program. The simulation aim was to determine defects type using eddy currents research method and a way of their location in the rolls material structure made from cast iron of Hi-Cr type. “Management System of the Rolls Grinder” is connected with the rolls grinder equipped with a computer numerical control (CNC), with rough treatment and after-machining of rolls, in order to give them demanded profile in a narrow tolerance range. It also enables to specify their tribological properties with eddy currents method. After entering all roll parameters into the computer system and compare them with a scope of real tolerance, examined curve of roll work in the rolling process extends beyond a range of established acceptable tolerance for optimum its work, what presents Figure 2.

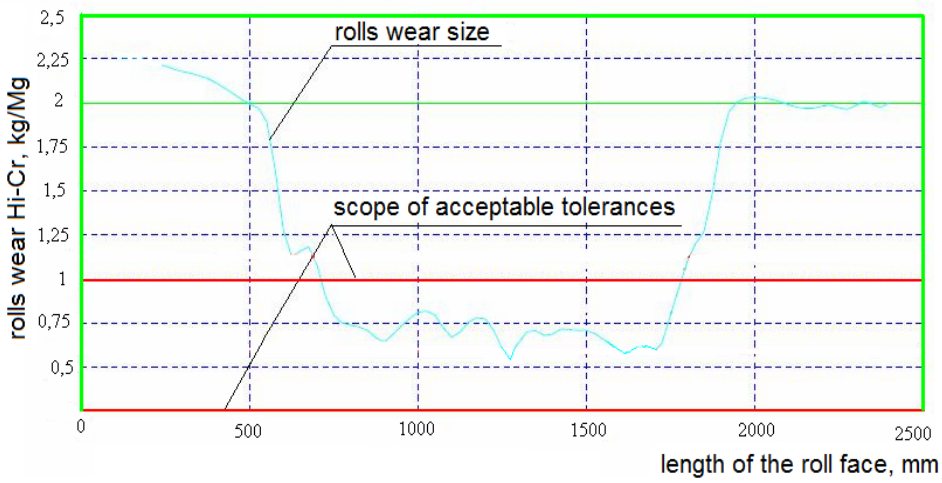

Fig. 2 Value graph of the local wear for high-chromic cast iron Hi-Cr rolls

This means that roll of the cast iron Hi-Cr type after rolling 1 roll line campaign of strips (2000 Mg) has clear defects, which affect its use. It is possible to describe these defects based on faults maps, which implies a program using error graphs generated based on theoretical model compared with the received profile. For thorough analysis the roll surface was conventionally divided into sectors along its beam and stations on its length (Table. 1). A level of determined roll waste is indicated for every separate sector unit as well as definite roll station. Based on faults maps it is possible to determine roll defect types, among others: cracks and whipping, which are caused by friction and affect their wear out.

Table 1 Map of defects in the high-chromic cast iron Hi-Cr roller

Roll sectors	Roll stations of the high-chromic cast iron Hi-Cr, mm						
	14	13	12	11	10	9	8
8	0,29	0,14	0,18	0,17	0,25	0,19	0,15
7	0,60	0,13	0,21	0,22	0,27	0,16	0,14
6	0,22	0,11	0,16	0,27	0,23	0,22	0,13
5	0,18	0,21	0,11	0,18	0,20	0,17	0,12
4	0,14	0,14	0,12	0,15	0,16	0,21	0,15
3	0,13	0,14	0,13	0,18	0,28	0,19	0,14
2	0,40	0,19	0,12	0,18	0,22	0,20	0,13
1	0,24	0,13	0,17	0,17	0,22	0,19	0,14
Roll sectors	Roll stations of the high-chromic cast iron Hi-Cr, mm						
	21	20	19	18	17	16	15
8	0,11	0,17	0,22	0,20	0,16	0,43	0,13
7	0,09	0,19	0,25	0,25	0,14	0,27	0,23
6	0,13	0,17	0,23	0,17	0,16	0,16	0,48
5	0,13	0,19	0,20	0,14	0,15	0,14	0,11
4	0,16	0,18	0,21	0,17	0,16	0,15	0,13
3	0,13	0,16	0,21	0,16	0,12	0,16	0,29
2	0,13	0,21	0,23	0,19	0,16	0,21	0,52
1	0,11	0,24	0,21	0,18	0,18	0,16	0,14

Darker fields with bold numbers in Table 1 indicate the position of material defects. Detection of discontinuities in the material is carried out according to phenomena order shown in Figure 3.

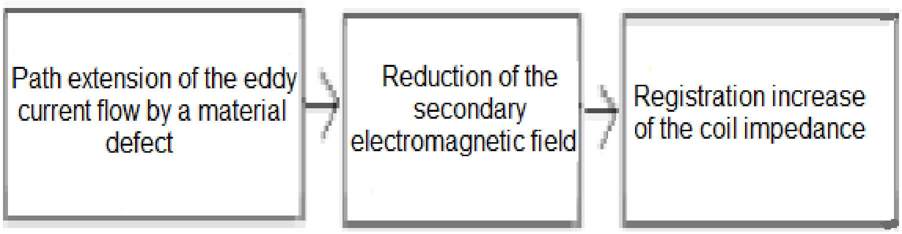

Fig. 3 Phenomena order at detecting discontinuity in the material

If the coil is moved at a constant speed in fixed distance from the object surface, then all changes in a cohesion or thickness of studied material have impact on the current flow, and as a result on the magnetic field, size and phase of tension in the coil. This method enables to detect the most dangerous discontinuities outgoing on the surface or lying close to it and discontinuity beneath layer as well as discontinuities in individual layers of multilayered objects. Cracks are detected about depths of 0.1 mm, about widths of 0.0005 mm and about length of 0.4 mm. In this way it is possible to detect and locate the material defect appearing in the given roll.

In Figure 4 a roll crack defect of Hi-Cr type was presented, which was operated by a determined period in F5 and F6 cages of the finishing line. Using simulation program the location was located, i.e. a sector and stations of its defect.

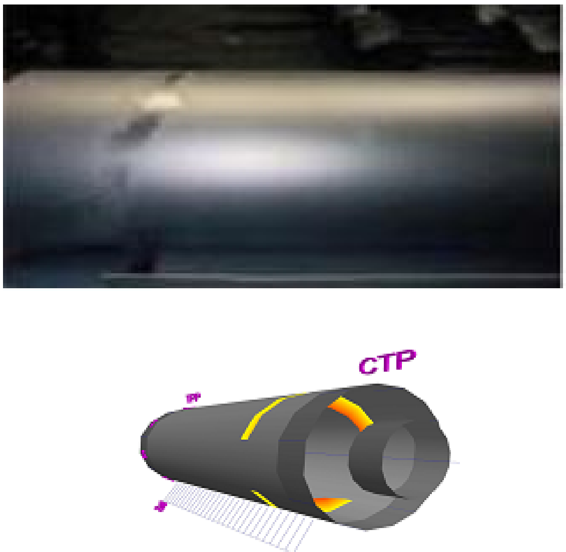

Fig. 4 Typical roll defect, damaged during operation

Presented diagram in Figure 5 indicates that the greatest occurs in a central part of roll, what provides the fact that this type of roller doesn't wear out evenly on the entire its surface.

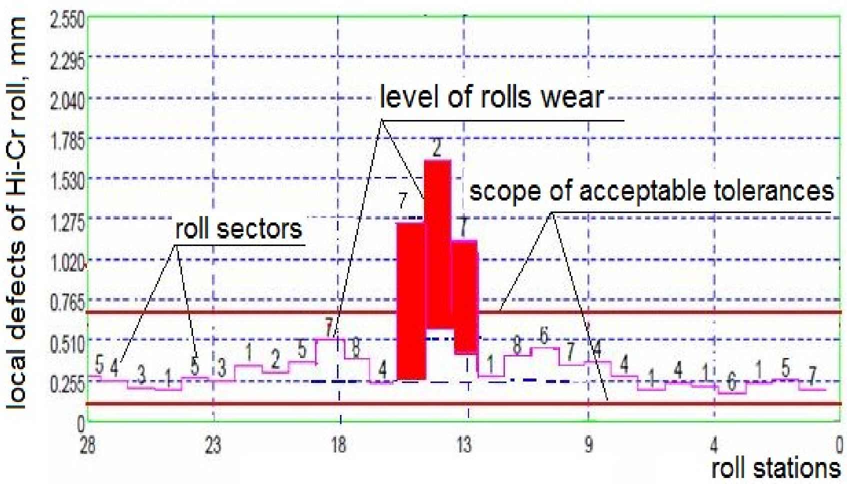

Fig. 5 Defects level graph generated based on defects map for the high-chromic cast iron Hi-Cr roll

In turn, a polar graph shown in Figure 6 provides necessary information associated with concealed defects, appearing under working surface of the roll face and defects in the non-circular form, presented for different angle positions.

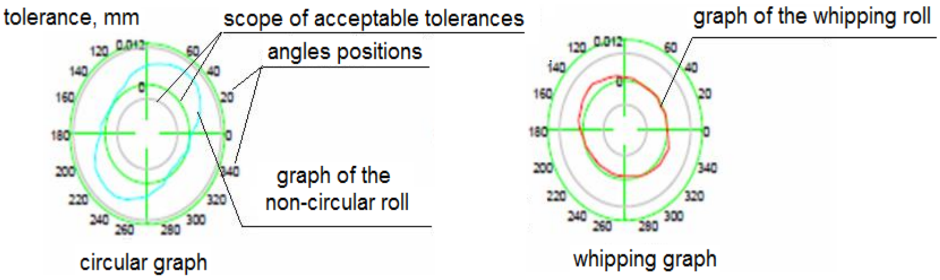

Fig. 6 Graph of the non-circular and whipping rolls from cast iron Hi-Cr

If a height of upper and bottom vertexes will be measured on the roll surface with reference to zero position, a crucial information about the technical state of studied roll will be received, determined by its non-circular $N(\alpha)$:

$$N(\alpha) = \frac{E(\alpha) + Q(\alpha)}{2} \tag{2}$$

where:

N (α) - circular roll,
E (α) - height of the upper roll vertex,
Q (α) - height of the bottom roll vertex.

If the sum of vertexes height calculated based on the model gives a circle it means that the roll is perfectly circular and doesn't cause whipping, affecting its accelerated tribological wear. However, if the calculated sum of vertexes height gives an ellipse it means that the roll isn't circular and has a defect in whipping form, which results in cracks spread, in consequence leads to its untimely wear out.

During graph analyze for the roll of modified alloyed cast iron Hi-Cr presented in Figure 6 and using principle of superposition effects, in which took into account both the circular errors caused by roll necks and fangs, it was determined that in fact there is an elliptical shape, therefore the roll has distinct whipping which extends beyond the margin of established tolerance, noticeable mainly in F5 and F6 cages of the finishing line. It is often necessary to restructure these rolls, replace on a new ones, what increases production costs as well as disrupts the entire planning system of rolling mill function department.

CONCLUSIONS

Due to easiness of systems integration in the production line, low operating costs, measurement speed and sensitivity, the eddy currents method is universally applied in a metallurgical industry. It is used both to control semi-finished products at each production cycle stages as well as to control finished products and metallurgical tools.

Research carried out using this methodology shows that applied research program is very effective and useful for quick evaluation of the concealed defects, which arise during the operation.

Presented research results provide about the correctness of proposed models as a tool which support decision-making processes on the business management level of metallurgical industry, both on the design stage as well as operation of existing production systems.

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