Making Use of the Eddy Currents Effect in the Examination of the Tribological Characteristics of Strip Rolling Mill Rolls

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Abstract: The key element in the proper performance of a rolling mill is the careful planning of the rolls operational conditions, since this factor constitutes the restricting element in the manufacturing process. In the article, a collection of operation and research steel strips hot-rolling mill information was presented, which was processed based on the advanced computer programmes for rolls grinders. The research outcomes were produced, presenting the application of eddy currents to detect materials flaws in metallurgical mill rolls.

Key words: Eddy currents, hot-rolling mill, tear and wear of metallurgical rolls, strip.

1. Introduction

In the process of steel strips and steel sheets manufacturing, the tools which are the most responsible for the quality of the final product are work rolls and backing rolls. They are the most expensive tools used in the process of rolling. Taking into consideration the desired quality of the strips being rolled, the fundamental responsibility rests on the condition of the rolls of the finishing units, since they affect both the quality of the surface and the dimensional accuracy of the strip being rolled. In the process of steel strip manufacturing, the key problem is the high level of tear and wear, especially of work rolls, resulting in the need for their frequent replacements. In case of the work rolls of the finishing unit, the exchange takes place every 8-10 hours, while backing rolls need to be replaced every 2-3 weeks, depending on both the amount and the type of the strip being rolled. Smelting plant rolls work in exceptionally difficult operating conditions. While working, they are exposed not only to both high bending stresses and compressive stresses caused by the pressure of the rolls

on the material being rolled, but also to torsional stresses resulting from the transmission of the turning moment from the driving mechanism onto the rolls. Added to these are temperature stresses being the effect of the temperature changes affecting the rolls while hot rolling, and also significant wearing down of the working surface of the rolls. The influence of these factors results in the loss of the dimensions of the material being rolled, and the transmission of the working roll texture onto the strip. All the time new research methods are being searched for, which aim at more accurate determination of the tear and wear level of the rolls so that strips of higher surface quality and more accurate geometric dimensions could be manufactured. In the analyzed rolling mill, to determine the materials defects, i.e., to diagnose the condition of the materials, the eddy current method is used, which constitutes an innovative solution in NDT (non-destructive testing) of materials. Eddy current method makes it possible to detect cracks in materials, machines parts, joints and tools.

2. Eddy Current Principle Used in NDT of Materials

NDT of materials, making use of eddy current effect,

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depends on the detection, in a variable magnetic field of local physical differences in materials of the elements being tested, which result in the changes in the amperage of eddy current [1].

In practice, the examined element of given dimensions, and made of the given electrical conductivity and magnetic permeability material, is placed in a variable magnetic field and the reaction of the material is collected by the scanning probe and the eddy current flaw detector. The analysis of the electromagnetic field parameters, the amplitude and the phase shift of the voltage and the amperage, enables a very accurate and precise assessment of the condition of the element undergoing examination and the existing non-homogeneity which appear, for example, in the form of cracks, erosion or corrosion flaws with the immediate estimation of their sizes and depths.

The applied research method making use of eddy current effect—serves, in the first place, the determination of the structural non-homogeneity and inconsistency of the rolls material, such as cracks, delamination, pits and cavities in the surface, and also the intrusion of foreign bodies. It also enables the inspection of the product features, when the product is a mixture of either materials or different stages of heat processing. The most often used criteria then are: alloy composition, hardness of the surface, the depth of tempering, strength and microstructural features [2].

The non-destructive eddy wire method does not require a physical contact with the material being examined. The effectiveness of the examination is up to a few meters per second, accompanied by full recording of the collected data, a precise localization and marking while the testing process, all of which constitute the advantages of the method, and guarantee a very high, expected by customers, quality of the final product.

3. Modelling of Rolls Tear and Wear in a Hot-Rolling Mill

The analyses concerning tear and wear of rolls made

of various types of materials, were conducted based on the results obtained through the use of the “management system for the rolls grinding workshop” computer software, being applied at the workshop. The software itself was worked out as a tool for the simulation of the processes which lead to the determination of the level of tear and wear of rolls, with the use of the spatial deformation model. The application of the software enables the determination of the level of tear and wear of tools, and makes it possible to localize the areas on the working surface of the rolls, which are the most exposed to damages. In the process of cracks identification, the working surface of the roll (Fig. 1) is scanned, without a physical contact, by one or more eddy wire probes [3].

In order to make an assessment, the roll being examined is rotated with the help of an additional mechanism, and during the rotation, it is scanned by a stationary probe, following which, the collected data are processed and used by specialized steering systems. They enable the determination of both the location and the character of the flaw, and also make a quick and effective analysis of the faulty elements.

4. Research Programme

The research made for the needs of the dissertation [4] comprised the analysis of the data concerning tear and wear of the rolls working in the separate cages of the finishing units of the round-the-clock strip hot-rolling mill, in the years 2012-2013, marked F1-F6. In the analyzed period of time, rolls made of HSS (high-speed steel), of Hi-Cr (high-chromium) cast steel, and of modified cast alloy steel of the EICDP and

Fig. 1 Diagram of a spiral probe scanning the surface of a roll.

ICDP types, were operated on. The rolls made of the above mentioned materials worked for 51 rolling campaigns altogether, and in the year 2012, they rolled 1,840 Gg of low-alloy strips and general purpose alloy strips, of the S235JR, S355JR, F1, F2, F2B, DD11 and UG types, and in the year 2013, the amount of the rolled strips reached 1,320 Gg. The data to be analyzed were collected based on the rolls cards, manufacturing reports, reports on the operation of the rolls in the given months, and other documents. The analysis of the information concerning a single roll showed that the period of two years, for which the analysis was made, was not uniform in terms of production load. There were times, in which low-alloys steels were rolled, and also periods when they were not rolled at all, but the existing rolling conditions did not vary considerably over the time. The Q index, commonly used in the iron and steel industry to determine the effectiveness of a roll usage, can be obtained from the following formula [5, 6]:

$$Q = \frac{Z}{U} \quad (1)$$

where, Z is the amount of the rolled steel, Mg, U is the loss of the mass of the roll resulting from regrinding and calibration, kg.

Total tear and wear of the roll, called normal, is the sum of the wearing down of the metal on the working surface of the roll, expressed in kg, due to the obligatory regrinding in the whole period of its working life, i.e., from its first assembly until it is withdrawn. The collection and the analysis of the data relating to the rolls tear and wear gives every rolling mill valuable information, thanks to which one can plan the times of the rolls rebuilding. It improves considerably the creation of the manufacturing plans for the whole technological line and contributes to the lowering of operating costs.

5. Research Results and Their Analysis

In order to decrease the number of the necessary rebuilding steps towards the rolls, and also to make use

of their working surface in an optimal way, thus, to lower the operating costs of the rolling mill, a computer simulation was made with the help of the “management system for the rolls grinding workshop” computer software. The aim of the simulation was the determination of the flaw types and their locations in the structure of the rolls made of the cast of the Hi-Cr type, based on the eddy current method. The “management system for the rolls grinding workshop” computer software is connected with the rolls grinder, equipped with the numerical control (CNC) module and coarse and fine rolls processing units so that the rolls can receive the desired profile within a small range of tolerance. It also makes it possible to determine their tribological characteristics with the help of eddy current method. After feeding the programme with all the roll parameters and then comparing them with the range of the actual tolerances, the curve picturing the roll performance in the process of rolling goes beyond the acceptable level, defined for its optimal performance, which is shown in Fig. 2.

It means that a Hi-Cr type cast roll, having worked for the period of one rolling campaign (2,000 Mg) possesses evident faults, which contribute to the process of its tear and wear. These faults might be determined based on the map of faults created by the programme, which is making use of the faults generated by the differences of the theoretical model with the one that had been received in the examination of the roll. To make a more accurate analysis, the surface of the roll was symbolically divided into sectors alongside its radius, and into stations alongside its length (Table 1). The level of the determined tear and wear of the roll is presented individually for every single cell of the sector and the station of the given roll. Based on the maps of faults, one can define the types of rolls damage, for example, cracks and running-out, which result from the friction and contribute to its tear and wear.

The darker fields with the digits in bold in Table 1 show the location of the material flaws.

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Fig. 2 Diagram of high-chromium cast rolls local tear and wear levels.

Table 1 Map of faults in the high-chromium Hi-Cr cast roll, mm.

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

The detection of the material inconsistency is obtained in the sequence shown in Fig. 3.

If a probe is moved, at a constant speed and distance from the surface of the tested object, then all the changes in the consistency or the thickness of the tested material influence the flow of the current, thus the magnetic field, the voltage and the voltage phase in the coil [9]. This method enables the detection of the most dangerous inconsistencies appearing on the surface or lying close to it, the inconsistencies under the coating layer, and also inconsistencies which can be found in separate layers of multi-layered objects. Cracks of the depths bigger than 0.1 mm, widths bigger than 0.0005 mm and lengths bigger than 0.4 mm can be detected. In this way, one can detect and localize a material fault existing in a given roll. Fig. 4 shows a damage in the form of a crack, which was revealed in a Hi-Cr roll, being in operation for sometime in the F5 and F6

finishing units. Making use of the simulation programme, the location of the fault, i.e., the sector and the station, was determined.

The diagram shown in Fig. 5 indicates that the biggest tear and wear appears in the medial part of the roll, which suggests that the roll of this type does not undergo the process of tear and wear evenly on its whole surface over the time.

And the polar diagram, shown in Fig. 6, provides with essential information concerning the hidden faults, which appear under the working surface of the roll, and also faults in the form of non-roundness, indicated for various angle positions.

Fig. 3 The sequence of phenomena while detecting non-consistency in a material.

Fig. 4 A typical flaw of a roll damaged in the course of its operation.

Fig. 5 Diagram of faults level generated based on the map of faults for the high-chromium Hi-Cr cast roll.

Fig. 6 Diagram of non-roundness and run-out of Hi-Cr cast rolls.

When the heights of the top and the bottom peaks get measured in relation to level “zero”, one can obtain the key information on the technical condition of the roll, expressed in the form of its non-roundness $N(\alpha)$:

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

where, $N(\alpha)$ is the roundness of the roll, $E(\alpha)$ is the height of the top peak of the roll, and $Q(\alpha)$ is the height of the bottom peak of the roll.

If the sum of the peak heights calculated based on the above mentioned formula gives a circle, it means that the roll is perfectly round and free from the running-out defect influencing its faster tribological

tear and wear. If, however, the calculated sum of the peak heights gives an ellipse, it means that the roll is not round and possesses a fault in the form of running-out, which results in the spreading of cracks, leading consequently to the roll faster tear and wear. Having analysed the diagram produced for the roll made of the modified Hi-Cr cast alloy, as shown in Fig. 6, and making use of the superposition of effects principle, in which both the non-roundness defects produced by the roll neck and roll centre were taken into consideration, the final conclusion was that, in fact, the roll has an elliptic shape, thus, the running-out effect has a significant influence, going beyond the acceptable tolerance level, which can be observed

mainly in the F5 and F6 finishing units. These rolls need to be frequently replaced for the new ones, which increases the manufacturing costs and also disorganises the whole planning activities in the rolling mill.

6. Conclusions

Taking into consideration the user-friendliness of the integration of the systems in the production line, low maintenance costs, quick and accurate measurements, the eddy current method is widely applied in the metallurgical industry [10]. It serves both the needs of semi-products examinations on separate stages of the production cycle and the quality control of finished goods and tools. The examinations made with this method prove that the applied examination programme is very effective and useful in the quick assessment of the hidden material faults which appear during the operation of the object. The presented research outcomes prove that the suggested models, working as tools aiding the metallurgical plant management processes, were correct, both on the designing stage and in the operation of the existing production systems.

References

- [1] Smetana, M., and Strapacova, T. 2013. "Detection Capabilities Evaluation of the Advanced Sensor Types in Eddy Current Testing." *Przegląd Elektrotechniczny* 89 (3a): 247-9.
- [2] Antczak, M., and Idziak, P. 2012. "The Influence of the Sheet Punching on the Magnetic Field Distribution in a DC Machine." *Przegląd Elektrotechniczny* 88 (4a): 6-9.
- [3] Borek, R., and Stelc, W. 2004. "Accuracy of the Method and the Uncertainty of the Measurement Results Conductivity Metal Layers Using Eddy Currents." *Elektrotechnika* 27: 25-32.
- [4] Niekurzak, M. 2012. "The Application of Simulation Methods for the Shortening of Steel Strips Rolling Cycles with the Use of Roll Tear and Wear Model." Ph.D. thesis, AGH University of Science and Technology.
- [5] Zasadzień, M., Mazurkiewicz, J., and Szala, J. 2004. "Operational Activities versus Rolls Tear and Wear." *Hutnik—Wiadomości Hutnicze* 12: 608-9.
- [6] Kubiński, W., Kaleta, E. K., and Niekurzak, M. 2010. "The Modern Hot Rolling Mill and Directions Development of Processes Their Production." *Hutnik—Wiadomości Hutnicze* 7: 333-8.
- [7] Gotom, Y., Matsuoka, A., and Takahashi, N. 2007. "Measurement of Thickness of Nickel-Layer on Steel Using Electromagnetic Method." *IEEE Transactions on Magnetics* 43 (6): 2752-4.
- [8] Shin, Y., Lee, J., and Song, M. 2004. "Preparation of eddy Current Impedance Plane Diagram by Finite Element Modeling." *Key Engineering Materials* 270-273: 579-84.
- [9] Rao, B. P. C., and Nakagawa, N. 2006. "Recommended NDT Practice and Its Model-Based Investigation for Eddy Current Inspection of Aerospace Structures." *Journal of Nondestructive Evaluation* 25 (4): 183-94.
- [10] Romicka, A. L. 2005. "The Measurements of Coating Thickness, Surface Layers, Tapes and Films by Eddy Currents." *Online Magazine Industrial Radiography* 2: 45-56.