Integration of Automated Roll-Defect Detection Systems in the Operation of Roll Shops for Heavy Plate and Hot Strip Mills

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Abstract. The surface of work rolls and back up rolls is worn out during hot rolling of heavy plates and strip steel because of micro structural changes and induced crack propagation. After the operation of the rolls in the mills, the surface will be regenerated by the following grinding process in the roll shops. This provides sufficient surface conditions for the next set in service. The roll shops of ThyssenKrupp Stahl will be gradually equipped with modern eddy current and ultrasonic techniques. The procedure for the implementation of these NDE techniques into the roll shop of a heavy plate mill will be described exemplarily. In the first step after bringing the installations into operational use, the former practice skills should be considered within the calibration of the systems. For this, the workmanship is documented by a statistical analysis of the signals obtained by these two non-destructive testing devices. Accordingly, the sensitivity of the operating systems is determined by comparing signals obtained from artificial notches with signals obtained from roll damages. These results are confirmed by taking micrographic examinations of the roll surface. After accurate confirmation of the relationship between the obtained signals and the condition of the rolls, the systems are fully set in service and integrated into the operation of the roll shop. This methodical approach contributes to a considerable benefit during the operation of the rolls since their service life is prolonged significantly.

1. Introduction

During the hot rolling of heavy plate and wide hot-strip material, the surface of the employed rolls wears out because of its high loads in the roll gap. High surface pressure combined with cyclic thermal stress leads to micro structural changes within the material. Furthermore, relative motions in the roll gap between the plate or strip material and the roll surface causes abrasion /1/. As a result of theses loads, the profile of the roll body is lost during the use and crack propagation occurs in the material of the roll surface. A worn surface of a roll has a major impact on the surface quality of rolled plates and strips in terms of dimensional tolerance, shape and flatness. Therefore, the rolling process is interrupted at regular intervals to grind and to recondition the roll surfaces so that the rolls can then be reused in the rolling process.

Presently, roll grinders in roll shops are gradually being revamped and equipped with test facilities to automatically detect damage to roll surfaces using the eddy current method, sometimes in combination with the ultrasonic method. To facilitate the integration of testing and detection operations in the work flow of roll shops, a clear relationship between the signal magnitudes of the testing equipment and the properties of the roll surface needs to be established to obtain adequate surface properties of the rolls so that they can be reused again in the rolling process.

2. Objectives of integrating roll-crack detection in the roll-rotating scheme

After the use of the roll in the stand, the upper material layer of the roll has to be removed by grinding the roll surface in order to yield the correct surface contour required for the next rolling process. The material should be sufficiently machined to grind off any cracks and micro structural damage, and thus prevent the propagation of cracks. If rolls are machined without employing NDE testing techniques, the removed layer thickness usually depends on fixed values specified without considering the real condition of the roll. If testing techniques and detection routines are integrated into this process, the surface condition in terms of cracking and micro structural changes can be quantitatively determined and the volume removed by grinding can thus be controlled. Therefore, the integration of testing techniques in the roll rotation system aims at reducing the amount of roll grind-down and prolonging the service life of the rolls, as shown in Figure 1.

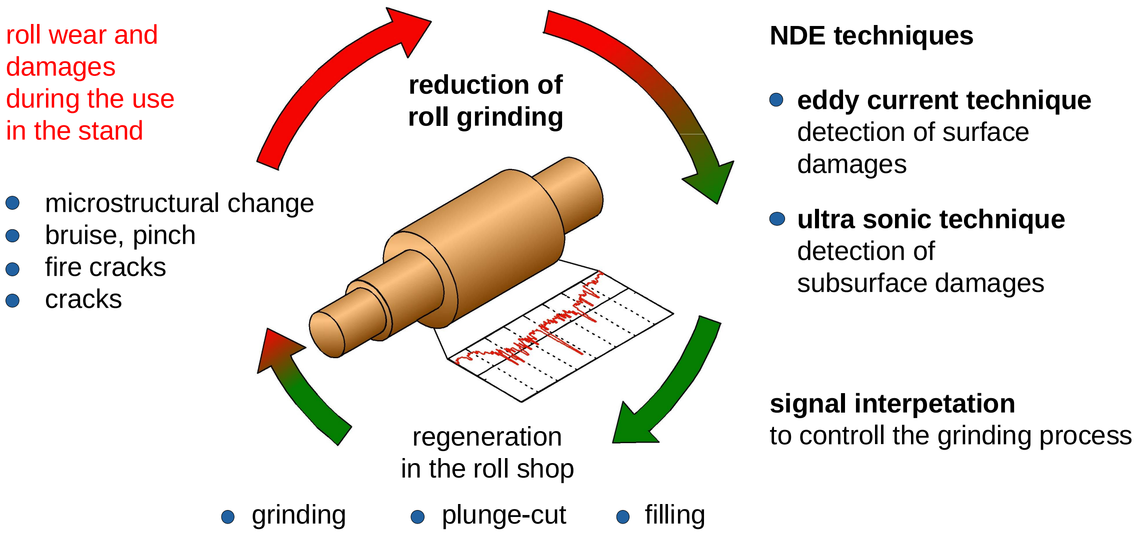


Figure 1: Objectives with respect to the use of automated roll crack-detection systems

3. Equipment and use of a testing system in the Heavy Plate Profit Centre PCG

At the beginning of the business year 2002/2003, a crack-detection system for testing work and backup rolls was installed in the roll-grinding shop of the Heavy Plate Profit Centre of ThyssenKrupp Stahl AG. The length of the chromium steel composite cast work rolls is 3,900 mm with an initial diameter of 1,000 mm.

The detection system comprises eddy current and ultrasonic testing equipment. The eddy current testing method is used to detect propagating cracks and micro structural damage on the roll surface. Crack damage and micro structural damage are indicated by different signals generated by band pass filtering of the eddy current signals. Signal changes of higher dynamics are indexed as crack signals, whereas signal changes of lower signal dynamics are indexed as micro structural changes. Moreover, the system is equipped with a two-channel ultrasonic test unit. The focal position of the two ultrasonic test probes is designed to detect incipient cracks between 2.5 mm and 25 mm below the surface as well as sleeve/core disbonding between 20 mm and 125 mm below the surface. Figure 2 contains a general view of the detection system during its operation.

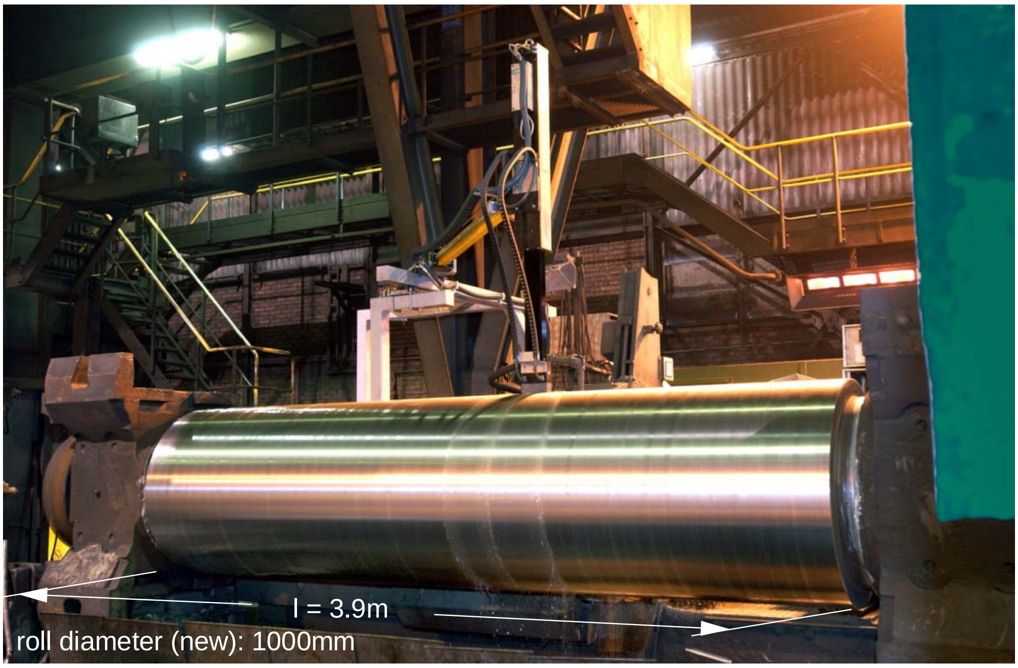


Figure 2: General view of the testing system in the mill shop of the heavy plate profit centre (PCG) of ThyssenKrupp Steel AG

The Evaluation of the eddy current signals is of major importance to reduce the layer volume removed in grinding as these signals indicate incipient cracks on the roll surface, and hence reveal damage at an early stage. Therefore, major attention was paid to the methodology of evaluating eddy current signals when this system was implemented.

4. Start-up procedure and data collection

To gradually put this detection system into operation, the previously applied roll-reconditioning procedure was documented by recording a comprehensive set of test values upon the completion of the grinding process. Subsequently, the magnitudes of the eddy current signals were evaluated in terms of minor crack growth with reference to the remaining signal magnitudes. Thus, limit values for signals were defined that served as default values under the specific rolling conditions of the rolling mill. Rules were developed for machining roll surfaces on the basis of these signal evaluation results. In addition, changes in the eddy current signals were recorded during the grinding process. As a result of this procedure, the thickness of the layer to be removed from the used roll after the rolling process will be determined precisely with the eddy current an ultrasonic technique. Correspondingly, the signal levels correlate to the actual wear of the rolls.

5. Development of a signal evaluation process

After the installation of the detection system, the eddy current signals of the test data collected were systematically analysed in an initial step. Statistical routines were developed to evaluate the signal magnitudes of individual measurements.

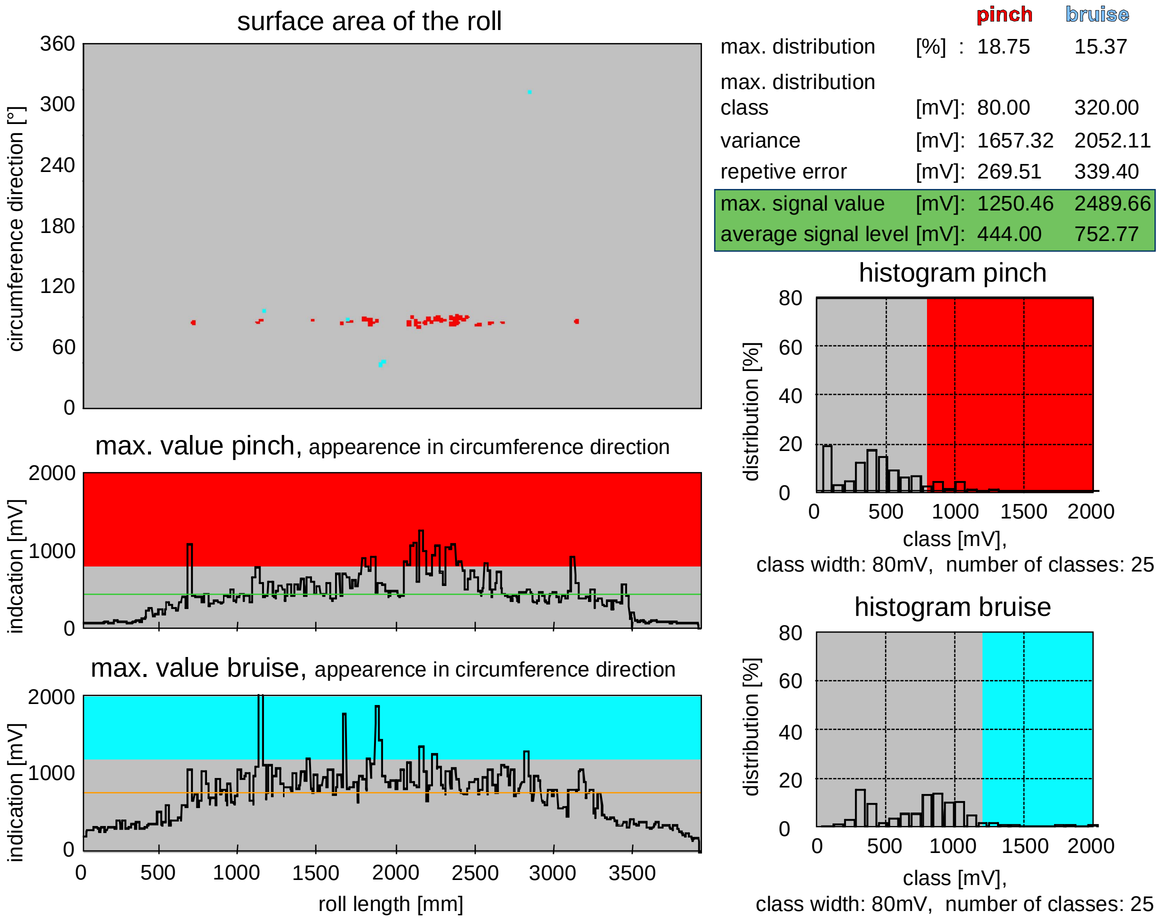


Figure 3: Definition of characteristic parameters for individual measurements

Figure 3 depicts characteristic data established for a single measurement. Moreover, the data chronologically obtained during the service life of the roll can be combined for the results of all tests. Figure 4 shows the derivation of maximum values for 15 work rolls as a function of the decreasing roll diameter caused by grinding. Each individual measuring point represents a maximum value attributed to a crack indication after completing the grinding operation and prior to reusing the roll in the rolling stand. The variation in the range of signal readings without integration of the detection system in the roll reconditioning process covers almost the entire scaling range selected. However, the determination of threshold values for the roll reconditioning process is not possible on the basis of these single values only.

In order to be able to classify the signal parameters, selected rolls were tested before and immediately after use. In some cases, a comparison of the C diagrams indicates crack growth of remained indications at the rolls after their use in the stand. Often, these indications are caused from hot cracks. Moreover, a reduction of indications could also be proved by comparing the test results from before and after the rolls were used. Both phenomena provide an initial basis for establishing maximum values to determine limits. Figure 5 shows an example of crack growth and an example of decreasing indications.

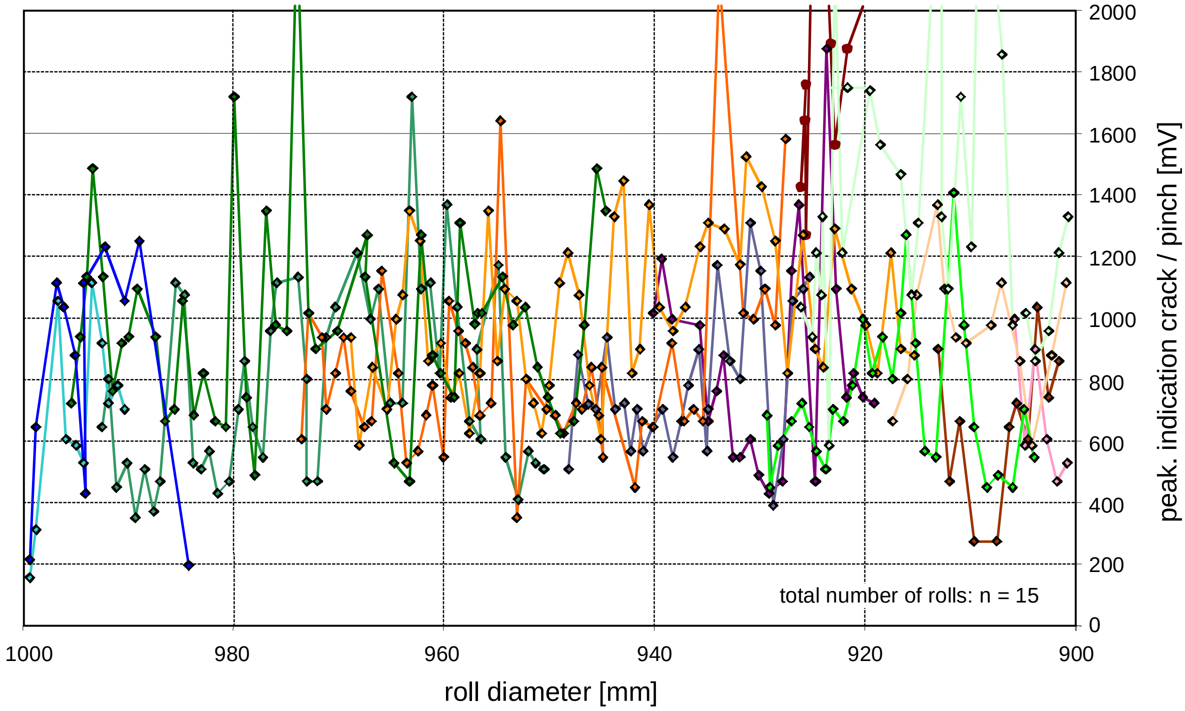


Figure 4: Formation of peaks for indications "crack / pinch" prior consideration of the test results

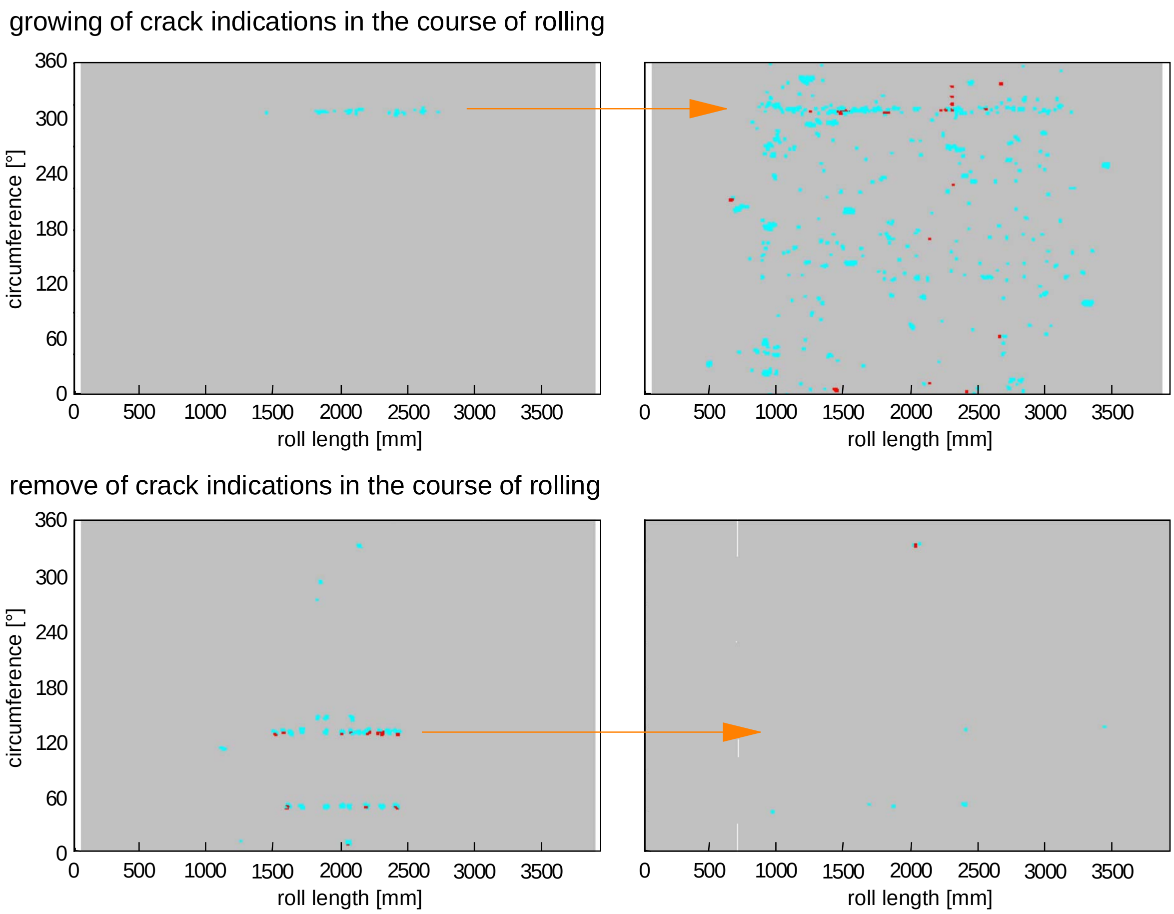
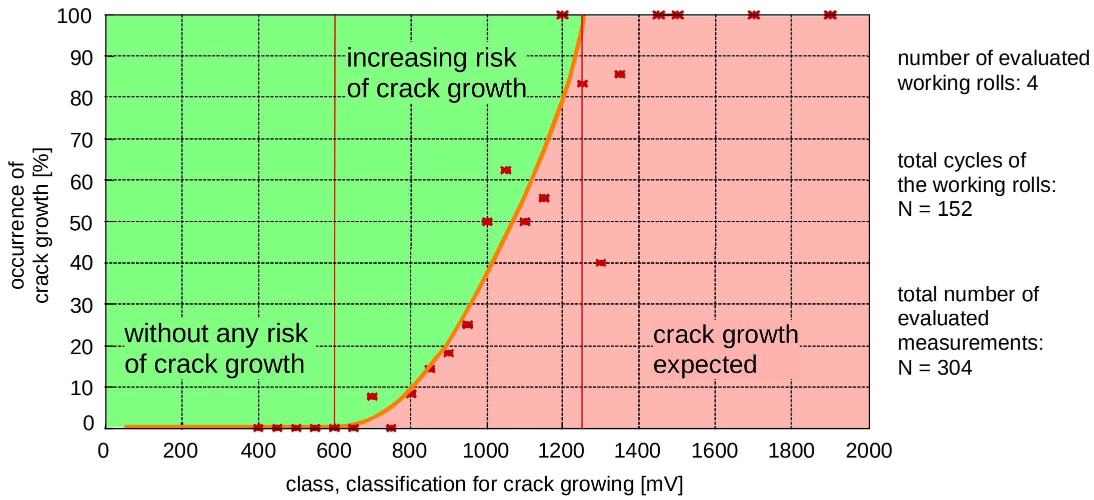


Figure 5: Comparisons of crack indications before and after rolling

6. Establishing signal thresholds and their integration in the production flow

To establish threshold values, the occurrence of crack growth was statistically evaluated, under consideration of remaining crack indications after the rolls had been reconditioned and crack growth during the subsequent use of the rolls has been observed. To this end, first the maximum values of remaining indications were assigned to value classes with a class range of 50SKT prior the roll is used. After the rolls had been used, they were tested again. The results were evaluated with respect to signs of crack growth. Hence, it was possible to determine for each value class prior to the use of rolls, the frequency at which crack propagation occurred among the remaining crack indications. Figure 6 shows a super proportional increase in the frequency of crack propagation among the remaining crack indications larger than 700SKT.



classification of crack growth [mV]	...	850	900	950	1000	...
range [mV]	...	825 >x≥875	875 >x≥925	925 >x≥975	975 >x≥1025	...
total, without crack growth $N_{without\ crack}$	...	6	9	6	6	...
total, with crack growth $N_{with\ crack}$	...	1	2	2	6	...
occurrence of crack growth [%] $N_{with\ crack} / (N_{without\ crack} + N_{with\ crack}) * 100$	...	**14.3**	**18.2**	**25.0**	**50.0**	...

Figure 6: Statistical evaluation of observed crack growth

Based on these relationships, threshold values were specified for eddy current signals in the roll reconditioning process. After the test results had been sufficiently verified, the detection system was integrated into the roll reconditioning process. Figure 7 shows the maximum values for the remaining crack indications of 7 work rolls after their reconditioning following the implementation of the detection system. The range of variations of the test signals is much lower compared to the signal magnitudes in figure 4, which thus represents the situation prior to the integration of the detection system.

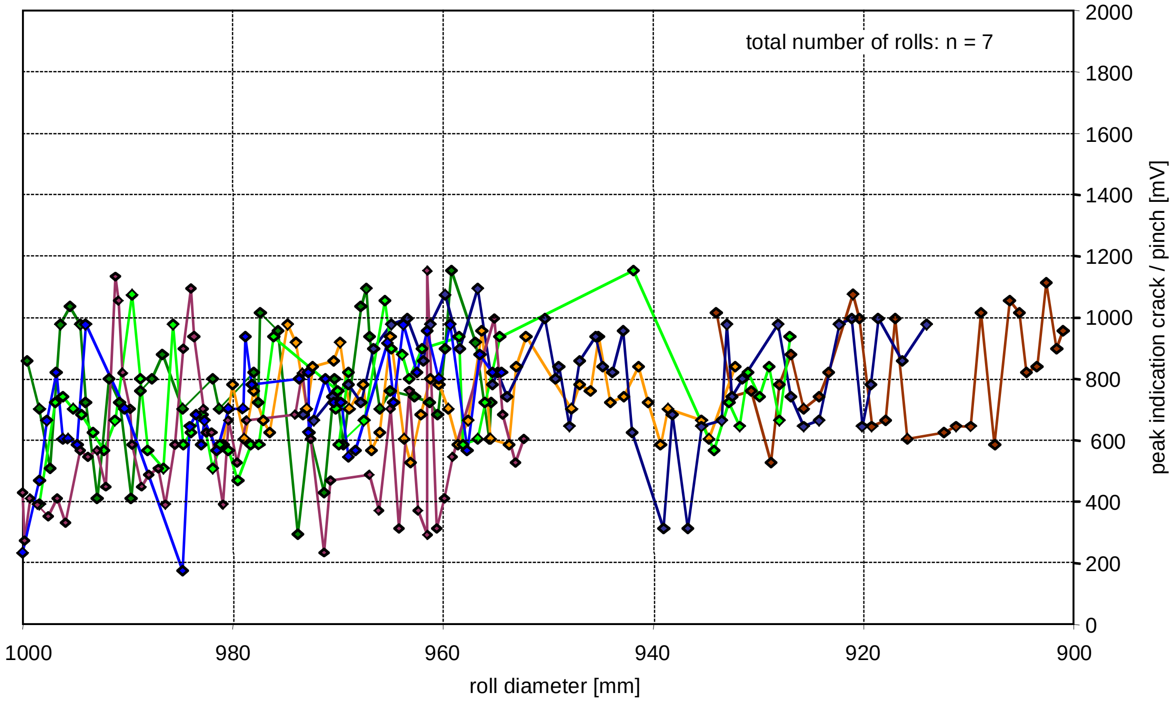


Figure 7: Formation of peaks after integration of the detection system in the roll-grinding shop

7. Verification of the test results and the procedure

To verify the capabilities of the detection system and to confirm its sufficient sensibility for the use in the roll shops some indications were analysed very carefully. To this end, significant indications in the C diagrams were localised on the roll surfaces and subjected to a metallurgical analysis. The crack properties on the roll surfaces were determined by means of the dye penetration method and the magnetic particle test. Moreover, the relationship between the signal magnitudes of the detection system and the signals from manual eddy current measurements was determined with the aim to adapt qualified artificial test geometry. These test geometry enables comparisons of the different properties of the installed detection systems in the roll shops of the ThyssenKrupp Steel AG.

Small eddy current indications, which could not be confirmed by means of the dye penetration method, were thoroughly investigated by means of metallographic examinations of the roll surface. Figure 8 shows the use of an incidental light microscope for performing a detailed examination of the roll surface in a hot-strip mill. A CCD camera was used to transfer the findings to a computer where they are then recorded. Figure 9 depicts an example of the overall length of a crack zone by lining up the individual images.

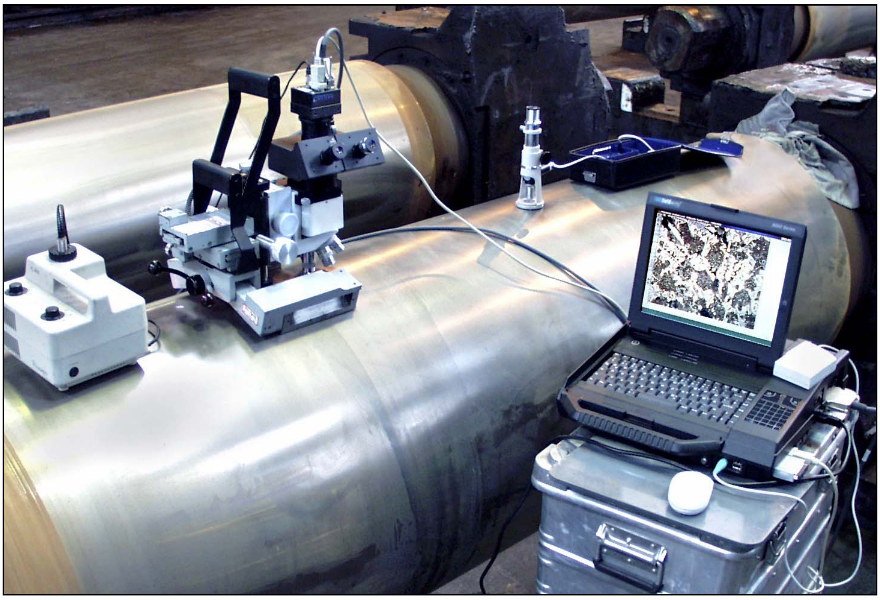


Figure 8: Verification of indications by means of metallographic examinations in the roll shop of a hot rolling mill

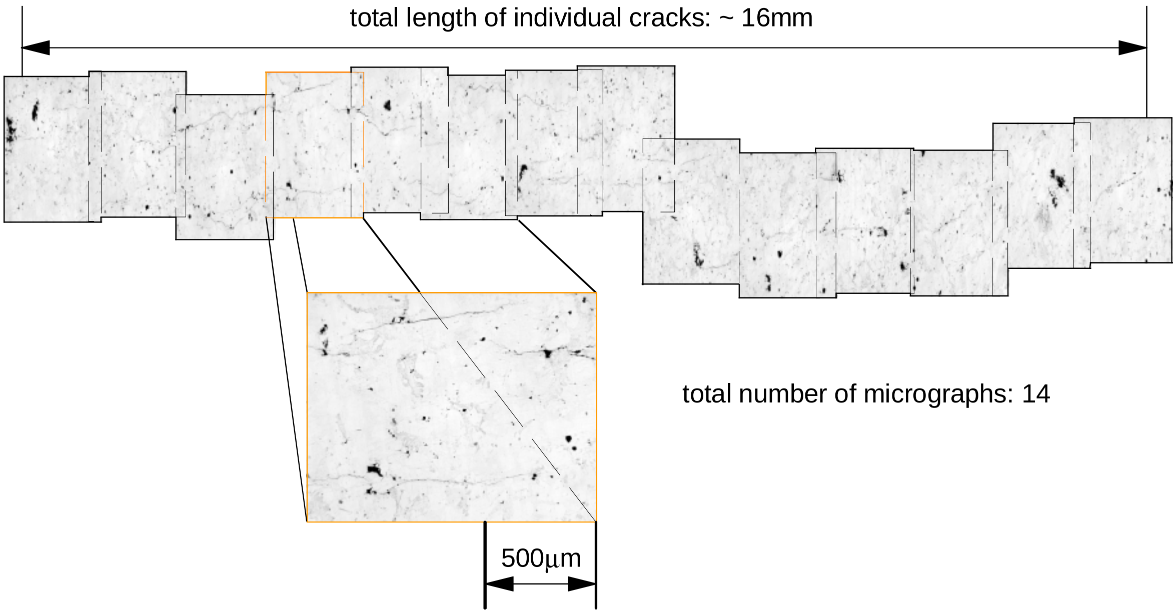


Figure 9: Verification of crack indications by means of micrographs on the roll surface

To prove the economic efficiency of the implemented crack detection system, changes of the specific roll performance before and after the implementation and start-up phase were observed. The specific roll performance is the ratio of the quantity of rolled steel to the volume grind off during the use of the rolls. Thus, this parameter describes the roll consumption. After the start-up of the test facility had been completed, the roll performance could be increased by 30%. However, it should be pointed out that the roll performance essentially depends on the steel products to be rolled. Therefore, it varies from order to order in a rolling mill. Thus, this high increase of 30% cannot be fully attributed to the use of the detection system for controlling the roll grind off. On the other hand, this increase cannot be obtained without controlling the roll grind off by integrating a detection system into the flow of operations in a roll-grinding shop.

8. Summary

The surface of work rolls and backup rolls is subjected to the wear out due to loads on the rolls during rolling in the roll stand. The roll surface of worn out rolls are reconditioned by grinding in roll shops. To this end, the outermost surface layer of the roll is removed to regain the roll contour needed for the next deployment of the roll. Moreover, the removal of a sufficient quantity of the outermost layer also removes incipient cracks and microstructural damage. Increasing numbers of shops use roll crack-detection systems to evaluate the condition of the rolls. The detection systems and test procedures are based on the eddy current method and the ultrasonic method. The use of eddy current technology is particularly important for the sensitive detection of incipient cracks on the roll surface. The integration of these test methods aims at improving the detection of incipient damage to prevent roll breakouts in the sleeve area and reduce the volume removed by grinding. The relationship between the signal magnitudes and the required surface properties of the rolls surfaces had been established before the detection system was fully integrated into the flow of operations of the roll-grinding shops – particularly under the operating conditions in rolling mills.

In the Heavy Plate Profit Center PCG of ThyssenKrupp Steel AG, the sensitivity of a roll crack-detection system was methodologically determined during the start-up phase and under operating conditions. This involved the statistical evaluation of comprehensive test results. A procedure for reconditioning rolls was developed on the basis of the test results. After all results had been sufficiently verified and validated, the detection system was integrated fully into the flow of operations of the roll shop. The economic efficiency of the system was proved by means of a marked increase in the specific roll performance.

9. References

/1/ Spuzic, S.; Strafford, K.N.; Subramanian, C.; Savage, G.:

Wear of hot rolling mill rolls: an overview

Wear 176, 1994, S. 261-271