ROLLING MILL STRIP BREAKS PROTECTION THROUGH AUTOMATIC SURFACE INSPECTION[1]

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Abstract
Rising production speeds increase the risk of coil breaks in rolling mills due to both visible and hidden material defects. A typical number of seven coil breaks per months is recorded in coupled pickling and tandem lines as well as in non-coupled tandem lines. Approximately half of these breaks are due to visible material defects on the surface. Apart from material losses, coil breaks may cause loss of production of over one hour. This essay presents the results and advantages of a defect warning system to prevent coil breaks in tandem lines. The prerequisite for this is an inspection system installed in the upstream pickling line. The basis for this are detection, classification as well as access to information "relevant" for quality decisions, which is enabled by innovative filter stages. This information may be used for an anticipatory analysis of potential production failures. It leads to a re-definition of the inspection performance as the number of correct quality decisions based on data quality. Methods on which inspection systems are based in order to meet such requirements are introduced.
Keywords: Strip breaks; Automatic surface inspection; Material loss; Tandem line; Rolling mill.

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1 GENERAL APPLICATION OF INSPECTION SYSTEM IN ROLLING MILLS

More stringent customer requirements and aggravated competition in modern steel production require maximum production efficiency and optimum quality of rolled products at the same time. Automated processes in coil production can only be optimized securely if useful information on production defects is available at an early stage. Material defects may result in strip breaks leading to significant damage.
The installation of automated inspection systems is an essential prerequisite for steel manufacturers as regards efficient production. This also shows in the rising number of automated inspection systems installed over the past 20 years, which may practically be integrated in any process environment at any stage of production. They have become accepted tools for detecting material defects, they rapidly deliver inspection results(1) and useful information on material defects. As a consequence, coil breaks due to surface defects in cold rolling may be avoided by installing an inspection system in a pickling line upstream of a cold rolling stand. In addition, other checks, e.g. to detect and prevent periodical defects due to system failures are possible by installing a system at the exit of the cold rolling line. The particularity: Despite rolling oil residues on the line and high line speeds, an appropriately designed inspection system will reliably identify relevant defects. Rolls may consequently be replaced timely and before customers complain. Scrap is hence avoided. Regular (early) replacement based on typical lifetimes may be substituted by replacement upon detection of the first signs of wear.

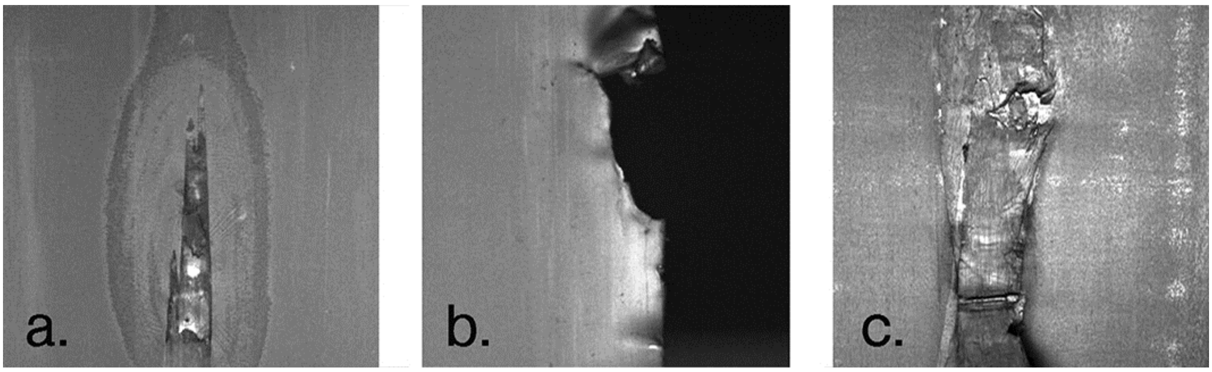


Figure 1. Typical critical and severe defects on a pickling tandem line: shell; b. edge crack; c. rolled in.

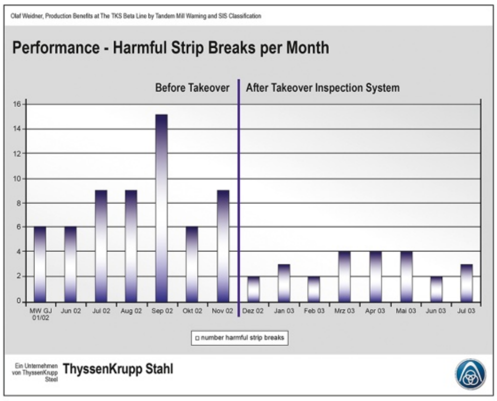
Advanced technologies based on proven solutions and engineering continuously improve the performance of these systems and significantly contribute to higher efficiency. The key essentials for the effectiveness of inspection systems are factors such as real-time capability as well as substance in defect detection and reliability in classification. The inspection systems measure, analyze and classify all surface defects automatically.(2) The common standard for inspection systems is the recording of defects occurred as well as documentation by defect statistics, coil maps and defect images. This already allows for achieving secure, reproducible and excellent inspection results.
New features, however, are the performance definition by data quality and the resulting, correct quality decisions. This allows for the correct assessment of an inspection system's benefits. The following applies:

- *Definition 1:* Inspection performance = percentage of correct quality decisions in proportion to the total number of decisions

The report shows how inspection systems operating according to this principles work and contribute to production optimization.

2 SAVINGS POTENTIAL BY INSPECTION IN THE PICKLING LINE

Using the examples of typical rolling mills below, the level of savings by installing an inspection system such in combined pickling/tandem lines is illustrated. The basis for this are results from cold rolling mills of ThyssenKrupp Steel Europe, Corus (now Tata) as well as USS Posco. Their analyses (Figure 2) show: an average of seven coil breaks per month were recorded before introducing the inspection systems in the rolling mills. Every single break entails over 60 min loss of production. Four of these breaks can directly be traced back to defective material, which means they are avoidable by early identification by an automated inspection system.



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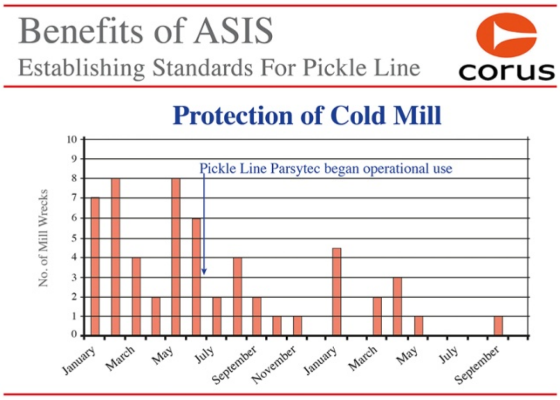

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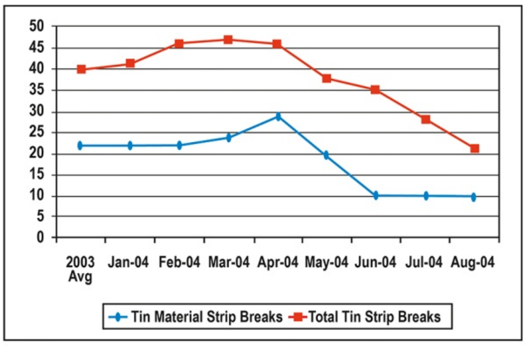

c.

Figure 2. Effect of automated surface inspection system inspection on strip breaks before/after installation: a. ThyssenKrupp steel; b.Tata (Corus) pickling line; c. USS Posco.

From the economical perspective, the costs per break due to loss of production and repair work amounts to approx. $ 25,000. If these four failures per month were prevented, $ 1,200,000 incurred by coil breaks in the tandem line per year could be saved. Additional costs resulting from a lack in information on quality, an estimated amount of $ 390,000, have to be added. In detail, the savings result from reduced recoiling, fewer complaints and less quality downgrading of coils produced. In total, the savings potential by avoiding damage and consequential costs amounts to approx. $ 1,590,000. This can be achieved by using automated inspection along the process chain.

The actual quality is identified and evaluated by such inspection on basis of comparison with the requested target quality. In coupled tandem pickling lines (PLTCM), the main focus of surface inspection is on the identification of defects which may result in coil breaks. As mentioned above, these particularly cause significant economical loss. By using up-to-date surface inspection systems on basis of the latest philosophy, it is possible to reliably identify the causal defects and consequently to respond to defective material in due time. The high efficiency of these inspection systems ensures that all defects are detected and alarmed.

3 CORRECT QUALITY DECISIONS ON BASIS OF SEVERAL CLASSIFICATION STAGES

Not every defect will cause a coil break. The relevant ones, for instance, are shells (non-metallic inclusions, e.g. casting powder), edge breaks, rolled in as well as holes near the coil edge. These defects must be identified reliably, since they result in coil breaks and may damage the cold roll stand. The avoidance of false alarms is of particular significance. The reason: excessive incorrect information will considerably reduce acceptance of the inspection system by system operators. The target is therefore 100% correct quality information.

Reliable defect detection and classification ensure high quality requirements. The requirements of classification of surface defects in metals are complex and have been described in various publications.(1-6) There are different approaches for implementation. These are based on learning processes on the one hand and various classifier approaches(7-10) e.g. network-based Bayes classifiers, on the other hand. Important for the user: the ease of use as well as the rapid achievement of a high classification quality. In short, enormous safety in application. In this respect, a so-called multi-stage classifier is apt. The main classifier already ensures high quality in defect classification(3) and uses up to over 800 characteristics in order to allocate the recorded defect images to the appropriate defect classes. In addition to defect types, the degree of severity may also be defined for preparing reliable quality decisions.

For an even higher classification rate it is possible to use special classifiers for certain defect types, so-called class specialists. These in particular allow for distinguishing between tandem-critical and uncritical defects. As a consequence, a higher quality of the classification level than with standard classifiers is achieved. Apart from this, classification quality is enhanced by simultaneously running classifiers enabling optimum defect classification in a voting process. Using a multi-stage classifier results in a significantly improved differentiation of classification than would be possible with individual classifiers - a significant prerequisite for data quality.

Image information alone is sometimes insufficient for reliable classification. Considering the defect environment, so-called "Context Evaluation" (Figure 3), offers additional security against incorrect decisions. It verifies and corrects classification results on basis of context information. In this regard, it is checked whether the classified defect matches the current overall appearance - i.e. the context - and/or whether it can indeed be a defect. Consequently, there is an additional plausibility check.

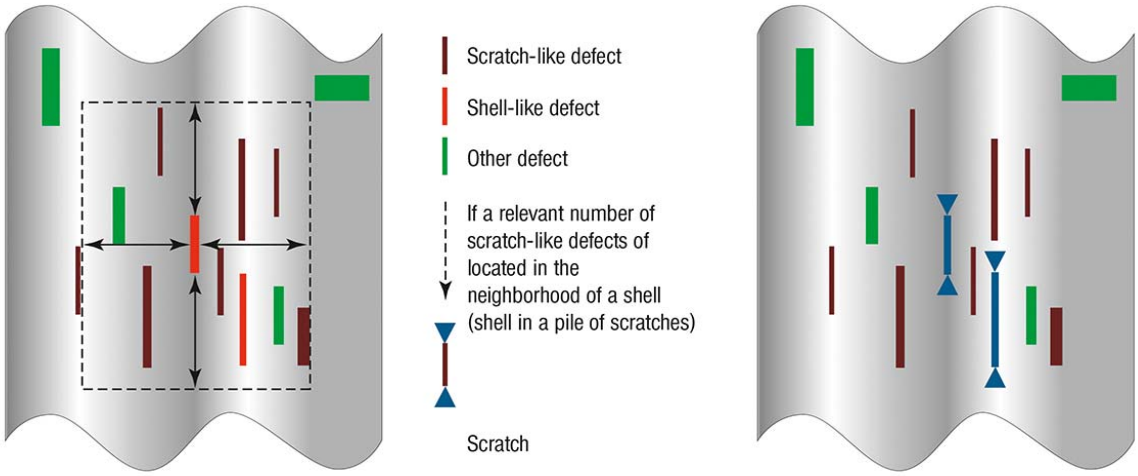

Figure 3. Principle view of “Context Evaluation”.

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At the same time, the classifier must be trainable and adaptable efficiently. The initial classification may be pre-defined for many defects on basis of experience from various applications. For teaching line-specific defects and ongoing adaptation to changing processes, an easy and intuitively to use software interface, the so-called "Classifier Build Environment" (Figure 4) is available. It allows for creating and testing new classifiers within a very short time.

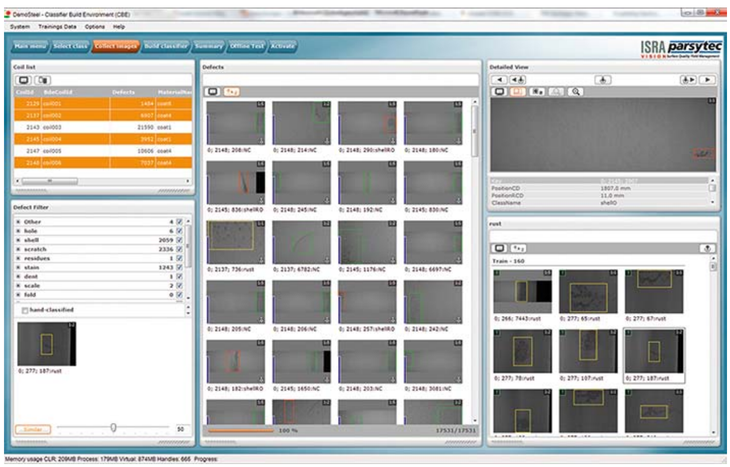

Figure 4. Easy-to-use tool for classifier set-up: “Classifier Build Environment”.

The conclusion: the user reaches objectives rapidly and obtains correctly classified information in the form of immediate alarms, statistical evaluations and analyses. An operator interface clearly presents all results.

4 FOCUS ON RELEVANT DATA

The defects detected are filtered in relation to their tasks and consolidated into valuable information - this is the new philosophy of inspection. Apart from defect detection and classification, the generation of unobjectionable quality data is one of the key tasks of a surface inspection system of the new generation. Only data relevant for the respective task are processed into information. If, for instance, 10,000 defects have been identified, 1,000 of them may be relevant to decide whether the process runs properly. In order to evaluate the quality of a coil, about 100 relevant defects, are required. In order to inform the upstream or downstream process on quality problems, no more than ten defects are usually needed. Useful quality data selected intelligently and automatically support manufacturers in material evaluation and production optimization.

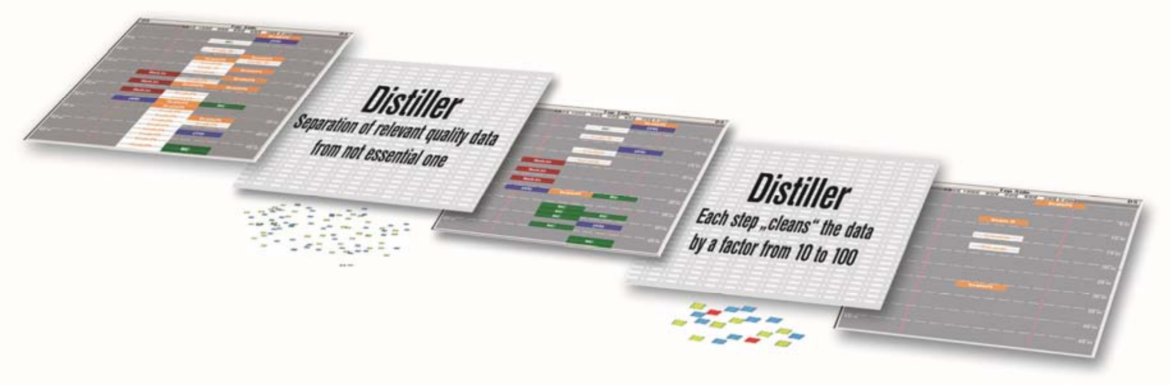

Figure 5. Principle view of filtering and grouping to get the relevant quality data only.

This is also applicable to tandem protection (Figure 6). By inspection directly after pickling, particularly critical defects are properly detected and classified automatically. The line operator is warned in due time, gets an overview on basis of the defect image and may initiate quality assurance decisions and action. The operator has time for this up to the looper and a pre-defined synchronization point. This for instance allows for adding comments to the alarm, e.g. "Ignore defect", "Slow down line", "Stop line" or "Open tandem". The alarms from the pickling system are then available at the roll stand and result in the required action.

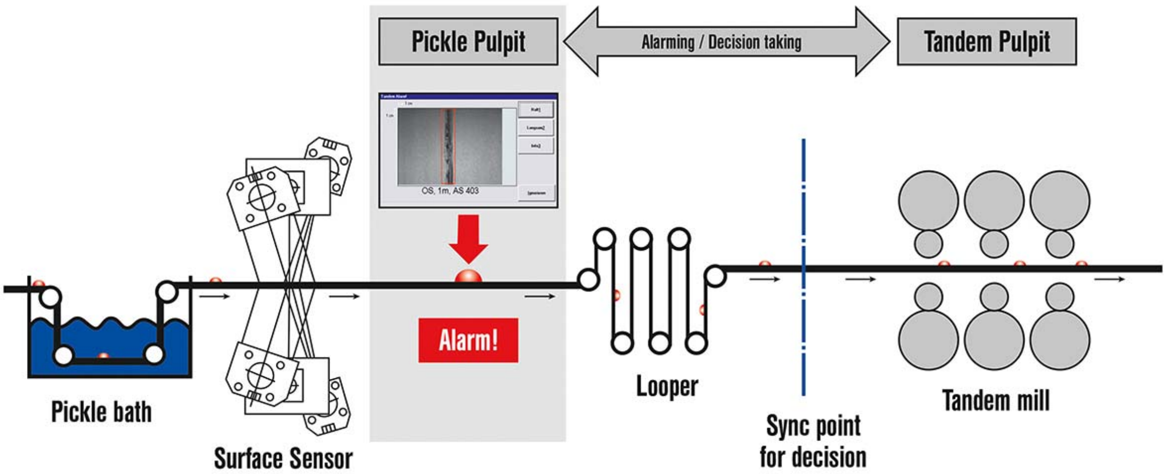

Figure 6. Functional view of automated surface inspection system set-up and interactions within a coupled pickling tandem line.

5 THE BASIS - RELIABLE DETECTION WITH HIGH ADAPTABILITY

Important prerequisites for exact classification and intelligent automatic reduction to significant, relevant information are high-contrast, clear images and secure detection. For this purpose, an inspection system must be adaptable to the different surfaces and their properties such as reflection. The latter is of particular importance for metals.[11,12] If this is successful, even low contrast defects on structured surfaces are securely identified.. In the present application, a low-contrast defect, e.g. is a closed shell caused by non-metallic inclusions. This very frequently results in coil breaks, since this kind of defect is difficult to identify.

There are various parameters for adapting inspection to the surface: modification of camera and optics, as well as controlling the illumination. The camera settings are exposure time (shutter) and gain. These settings, however, are limited, because image noise is increasing with a higher gain and may affect detection. The same applies for changing the optics settings. Enlarging the aperture results in brighter images, but also in a reduced depth of sharpness. Direct, individual illumination control for optimal image brightness is more purposeful. This ensures contrast-rich images and good detection. The conditions are optimum if the illumination control is able to react on changes even within one coil. The overall result: highest system efficiency without any production stop.

This is the case with the inspection system discussed. Illumination is adjusted to the surface and its structure automatically and online. Brightness and contrast are controlled directly and adapted to the metal surface reflection. This active "online" illumination control ensures optimum images and detection conditions.

Optimization of the detection performance is further supported by semi-automatic detection tuning (Figure 7). This is a process using a bulk of relevant reference images. Sensitivity adaptation in consideration of texture allows for an optimum setting of detection with minimization of pseudo defects and reduction of the influence of the surface structure at the same time. This "semi"-automatic process with direct feedback is hidden behind an extremely simple user interface.

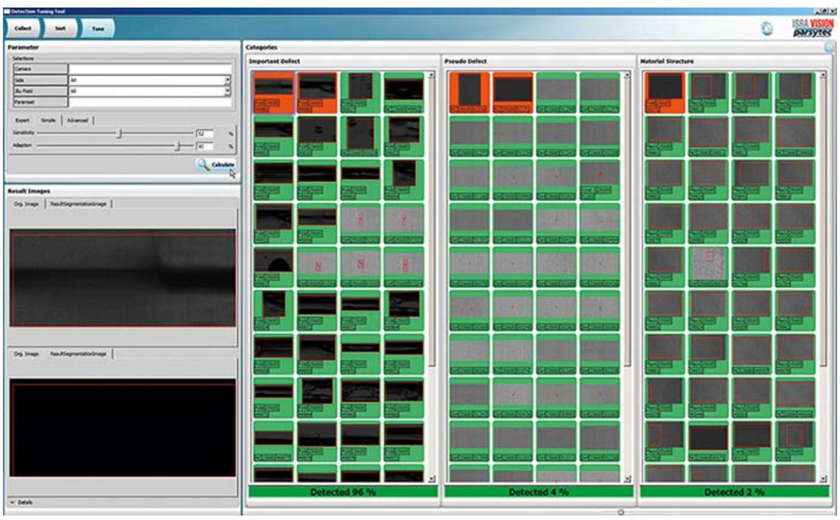

Figure 7. Graphical user-interface for “semi”-automatic detection tuning.

Other significant factors for the sensitivity of an inspection system are the sensor resolution and the real-time computational power available for detection and classification. Standard systems operate with a resolution of approx. 320 µm. With this value and an assumed standard computational power, information on low-contrast defects is available approx. every 200 m. By increasing both factors, significant improvements up to an exact, highly-sensitive complete line coverage may be achieved. Of course this is a great advantage for making 100% correct quality decisions.Apart from sensitivity, complex and sophisticated algorithms requiring an appropriate computational power for real-time computation are needed for reliable classification.(4) Their correct execution essentially decides whether a defect on the frequently dark surface in this area is indeed a serious defect or "only" a "scratch". The same applies to the secure detection and measurement of edge breaks, which is - apart from holes near the edge - the most critical defect for cold rolling.

6 PRACTICABLE OVERALL CONCEPTION - PREREQUISITE FOR SAFE OPERATION

An important requirement for the operation and use of automatic inspection systems is their practicability and reliability. The latter is also reflected in the performance criterion "Number of correct quality decisions". For PLTCM applications this means in particular avoiding coil breaks.

Significant features have already been addressed in the previous sections. But also factors as sensors, calibration, commissioning and maintainability are significant. Sensor technology must be adapted individually for the relevant area of application. As regards cameras, both line scan or matrix cameras, or combinations of both, may generally be used. Matrix cameras have proven to be especially safe and insusceptible to failures for use in coupled tandem pickling lines. Appropriately designed and adapted sensor technology for inspecting the strip top and bottom side has a compact design and can also be integrated in restricted space. For illumination, controllable IR illumination which is suitable for short-pulse flash operation is used for example [Figure 8]. The advantage of this concept as against sensor technology with line scan camera: a very low susceptibility to pass line deviations. By using the selected spectral range for illumination, potential liquid residues on the surface have nearly no affect on defect detection after pickling. The application of precisely calibrated sensor technology for meeting high demands is a matter of course.

Figure 8. Compact surface inspection sensor for top and bottom strip inspection.

For ensuring high availability and good maintainability at the same time, redundant configurations should be used. The inspection systems should be composed of proven, high-quality standard components which may be replaced within a very short time as required. Reducing the number of various components increases reliability and simultaneously decreases maintenance expense. Due to this design, systems like these may be customized to a high degree and expanded easily. The simple expandability finally also reduces the financial risk for the user, since the inspection may "grow" with its tasks.

An inspection system may only be of benefit when it is used. For this reason, the time to operation, i.e. the commissioning period, should be as short as possible. Appropriate pre-settings and tools for simple, rapid set-up should enable a high detection rate and high inspection performance in a very short time.

Application-specific detection settings and the so-called "instant classifier" ensure that manufacturers benefit from an inspection system even financially within one month. This is the result of experience from 70 pickling line installations, of which alone 15 were combined pickling and tandem systems. The instant classifier, an intelligent, pre-taught classifier, recognizes 80 % of typical defects already. The settings are based on experience from over 400 installations of surface inspection systems. The approximately remaining 20 % of defect types are line-specific and must be taught. Pre-setting significantly accelerates commissioning.

Figure 9. Efficient optical surface inspection "Surface Master**".**

In order to meet any experiences described and requirements, scalability of inspection systems is advantageous. This was implemented in a new conception of inspection systems, the Surface Master product line. It provides three performance classes: The standard type is the high-quality standard system for surface inspection to cover basic requirements. The advanced type represents a superior grade inspection system with extended capabilities. The main advantage is a higher sensitivity due to better resolution and computational power. It also may be integrated in networks.The premium system allows for high-performance inspection with most comprehensive functionality. The new product line opens up completely new possibilities for metal manufacturers with regard to monitoring the surface quality, improving the quality produced, optimizing processes and maximizing throughput at even higher quality. The system offers best performance as measured by the number of correct quality decisions.

7 CONCLUSION

Surface defects make surface inspection indispensable for steel manufacturers. In pickling/tandem lines, surface inspection systems allow for the identification of surface defects causing coil breaks during cold rolling. In this regard, defects identified are filtered and hence converted into high-quality information so that the line operator is only warned of defects relevant for coil breaks and may make a secure decision. False alarms are excluded. As a consequence, all coil breaks attributable to surface defects can be excluded by inspection systems. The total number of coil breaks is halved as is shown by practical examples. This results in relevant cost savings. The inspection systems in the pickling line are amortized within a short time after commissioning, among others due to increased throughput with reduced standstill time.

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REFERENCES

1 WU, W. Y.; Hou C. C. Automates Metal Surfaces Inspection Through Machine Vision. Imaging Science Journal, V. 5, 2003
2 PIIRONEN, T.; SILVEN, O.; STRÖMMER, E. et. al Automated Visual Inspection of Rolled Metal Surfaces. Machine Vision and Applications, Springer Verlag New York Inc. Volume 3,Issue 4, .p 247-254, Fall 1990
3 DON, H.-S.; FU, K.-S. ; LIU, C.R. ; LIN, W.-C. Metal surface inspection using image processing techniques. Systems, Man and Cybernetics, IEEE Transactions on (Volume:SMC-14 , Issue: 1), p. 139-146, 1984
4 ZHENG, H.; KONG, L.X.; NAHAVANDI S. Automatic inspection of metallic surface defects using genetic algorithms. Journal of Materials Processing Technology, Elsevier, V. 125-126, p. 427-433, September 2002
5 Dupont F., Odet C., Carton M.; Optimization of the recognition of defects in flat steel products with the cost matrices theory, NDT&E Int 30(I): 3-10, 1997
6 Datta BN; Numerical linear algebra and applications. Brooks/Cole Publishing, Belmont, California, 1995
7 Jain AK, Zongker D.; Feature selection: evaluation application, and small sample performance. IEEE Trans Pattern anal Machine Intell 19(2): 153-158, 1995
8 Dash M., Liu H.; Feature selection for classification. Intell Data anal 1(3): 131-156, 1997
9 Singh M., Provan G.M.; Efficient learning of selective Bayesian network classifiers. In: proceedings of the 13th international conference on machine laerning (ICML'96) Bari, Italy, July 1996, pp 453-461
10 Duda R.O., Hart P.E., Stork D.G.; Pattern classification 2nd edn, wiley, New York, 2000
11 Batchelor B-G., Hill D.A., Hodgson D. C.; Automated Visual inspection, Chapter 7: Lighting and viewing techniques, IFS Publications Ltd. And North holland, 1985
12 Nayar S.K., Ikeuchi K., Kanade T., Surface Reflection: Physical and Geometrical Perspectives, IEEE Trans. On Pattern Analysis and Machine Intelligence, Vol 13, no 7, pp 611-634, 1999