Integration of an automatic hot rod testing system in a three-strand wire rolling mill

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Due to advances in further processing techniques, the quality requirements for wire rod surface are becoming ever more stringent and have led to precisely defined demands on the part of the end customers. The hot rod wire testing system is designed to help minimize waste and assure a high quality level through the early detection of defects.

An eddy current testing system has been integrated into the three-strand rod mill of Ispat Walzdraht Hochfeld GmbH to continuously inspect the surface of the hot rod. The system is characterized by a fully automatic mode of testing, enhanced features for the detection of process-caused defects, an online visual display and user-friendly archiving of the test results. The improvement in efficiency and quality achieved through use of the system is illustrated by means of practical examples.

Ispat Walzdraht Hochfeld GmbH (IWHG), located in Duisburg-Hochfeld, is a subsidiary of Ispat International Rotterdam which is a member of the Indian „LNM Group“ and is one of the leading wire rod manufacturers world-wide.

The IWHG wire rod mill in Duisburg-Hochfeld is a three-strand rod mill that produces steel wire in the size range 5.0 to 21.0 mm from 2-ton billets. The greatest proportion of the quality produced lies in the higher grades and is made up predominantly of steel cord for the tire industry as well as automatic steels, cold heading steels and spring steels.

Fig. 1. Laying head in the rod mill of IWHG

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The production plant of the wire rod mill consists of the following sections: starting with blanks and furnace area, reforming using a 3-strand rod mill and continuous processing, quality-dependent cooling by a water and air cooling bed, coil formation using coil forming stations, removal by means of a transport system in the form of a monorail hook conveyor followed by storage and shipment to the end customer (Fig. 1).

After rolling, cooling and coil formation but before tying, the wire coils are transported via a monorail hook conveyor.

Continuous hot rod surface testers installed in the rolling line could not be used due to a lack of automation facilities.

In 1996, the company decided to invest in a system geared to the future in order to meet the increasing requirements for improved quality. A team made up of specialists from the production, quality assurance and maintenance departments specified the following system requirements:

- Automated surface testing during the production process.
- Online visual display of surface quality.
- Archiving of the test results for subsequent quality-related evaluation.
- Testing according to specified quality requirements and dimensions with the use of process data from computers within the Ispat-WHG network.
- Coil-related allocation of test results.

Planning and realization. The individual requirements of the various departments of the company were added to the list of specifications generated by the team mentioned above. None of the systems available on the market today was able to meet all of these requirements. This meant that a specific concept had to be developed for the visual display and archiving and that testing had to be resolved using standard testers.

When drawing up the specification, the interfaces between the testing computers and host computer were specified in close collaboration between the suppliers and IWHG. The design of the system user interface was specified by IWHG and was adapted for this system by the suppliers of the host computer. The testing PCs and all the necessary components were installed during production. A scheduled system standstill was used for the mechanical installation of the coil holders in the individual strands. Installation was performed exclusively by in-house personnel in close collaboration with the suppliers.

As previously for the testing computers, the host computer was also installed and commissioned during production and, thus, IWHG suffered absolutely no loss of production as a result of the introduction of the system.

Eddy current testing

The hot rod testing system operates together with standard eddy current testers that are already in use in a wide range of applications for the *non destructive testing of material* in the production of semi-finished metal products (tube, bar, wire). As opposed to other procedures, eddy current testing has the following advantages:

- it is does not have any contact with the material,
- the operation of the testing sensors is simple,
- it can be used at very high testing speeds.

In selecting the system, particular emphasis was placed on the protection of the sensors (testing coils) against the rugged industrial conditions within the rolling mill and that the system should require a minimum amount of maintenance.

The testing system for each strand consists of the water-cooled testing coil system, the eddy current electronics and the testing computer with digital signal processing.

Testing coil system. The coil holder is installed between the finishing block and cooling bed and is used as the receptacle for the water-cooled testing coil (Fig. 2). The water-cooled guide sleeves that damp the vibrations of the rolled material are mounted in front of and behind the testing coil and protect the testing coil against contact. A nozzle on the inlet side of the coil holder removes loose scale from the surface of the rolled material to prevent dirt particles from contaminating the holder.

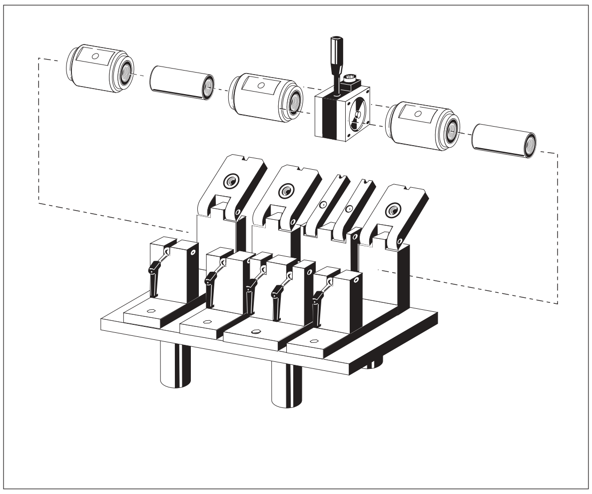


Fig 2. Coil holder

The cooling of the coil holder is monitored by a flow detector. The testing coil, guide sleeves and nozzle insert are changed when the diameter is changed and are each easily accessed by loosening 2 nuts and undoing the clamping devices. This process only takes 5 minutes.

For testing wire with dimensions smaller than 7.5 mm, the testing coil is equipped with a high strength *ceramic insert* that can withstand the contact of the annular head that is unavoidable in this dimension range. The ceramic inserts are replaced *after approx. 6000 coils.*

The testing coil itself is also easily dismantled and can be repaired by replacing the internal components.

Eddy current testing electronics. The testing electronics installed near the coil holder consist of a standard tester that has a modular construction and an integrated computer interface.

To avoid interference with the test signals from the multitude of noise sources within the rolling mill, a *fiber optic cable* is used for the 150 m long distance between the testing electronics and the testing computer.

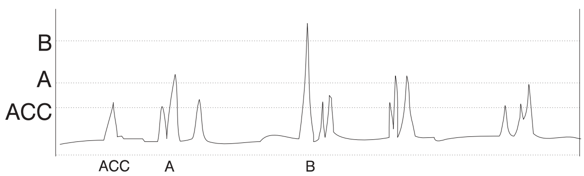


Fig 3. Stochastic defect evaluation

The serial signals for the remote control of the testing electronics and the status signal for the control of the testing software are also transmitted via this cable.

Testing computer. The test results are evaluated in an industrial PC with integrated *digital signal processing* that is installed on the central control platform. Simultaneously, the signals of the testing electronics are also evaluated for randomly distributed stochastic rolling defects (cracks, laps, holes, scales) and periodically recurring rolling defects (impressions resulting from roll pass damage, damage from worn rollers).

Stochastic defect analysis. The amplitude of the testing signal is evaluated using 3 adjustable thresholds (A, B and ACC) and provides a yardstick of the depth and extent of the defect (Fig. 3).

For documenting the defects, the rolled material is divided into approx. 50 *sections* whose length (10 - 300 m) is determined automatically by the evaluation program based on the length of the entire coil. The number of defects of the categories A, B and ACC that occur per section are counted with a resolution of approx. 10 cm and are compared with specified maximum values.

A *quality number* for the section is calculated from the result based on a variable truth table (Fig. 4).

Alternatively, defects of the ACC category can be also be subjected to a defect density calculation. In this evaluation, an event is only evaluated as an ACC defect if the defect achieves a specified length. The objective of this technique is the recognition of rolling defects that only lead to a relatively low signal display but generally extend over longer distances (e.g. laps).

A quality number for the coil is formed by averaging the quality numbers of all the sections.

DEFECT TOTAL	>	User-defined limit	Limit exceeded? (Yes/No)								Defect type
A	>	a	N	Y	N	Y	N	Y	N	Y	short defects
B	>	b	N	N	Y	Y	N	N	Y	Y	short defects
ACC	>	acc	N	N	N	N	Y	Y	Y	Y	longitudinal defects
Q-numbers			0	1	2	3	4	5	6	7	
Quality			very good ► very poor								

Fig 4. Establishment of the quality number

Periodic defect analysis. In periodic defect analysis, periodically recurring signals are recognized in a frequency range determined by the rolling speed. The cyclical frequency of the signal is determined and the possible cause of the defect (defective roller stand or roller box) is sought in a *calibration table* that contains the mechanical data of the rolling line. The determined frequency is output for each section. The most frequently occurring frequency or defective element is output for the entire coil where an adjustable minimum number of sections must show this defect.

After testing is complete, all the test results of a coil are available in the form of an ASCII file in *CSV format* (character separated values). This enables simple archiving and individual evaluations of the data.

The process data required for the test settings (billet weight, rolling speed, type of steel, etc.), the setup parameters of the testing electronics and the evaluation and the test results are exchanged with the *host computer* by means of files via the IWHG network during the pause between two coils.

Host computer

The host computer ensures that testing is fully automatic without any intervention by the operator. In order to fulfill this requirement, the host computer must provide the testing computers with the data required for surface testing from production planning (PPL) and from the control system of the wire rod mill prior to testing. After testing, the host computer must provide a visual display of the results, it must archive them and transmit them to subsequently connected systems for further material tracking.

The solution of these tasks was achieved by the following means:

– Integrating the surface testing in the network of IWHG together with the appropriate connection of the testing computers and the host computer (Fig. 5).

– The use of a powerful relational database for archiving

– The use of a user-friendly *visual display*.

Material and data flow. After the billet of a rolling batch has been placed in the pusher-type furnace, the production planning system (PPL) sends a telegram containing the data that are the same for all the billets of the rolling batch via the coil transport computer (CTC) to the host computer. These data mainly describe the material characteristics and also contain information on the *testing category* used to parameterize the hot rod testing. A dataset is created in the database on the host computer for each rolling batch. The process control system of the wire rod mill - controlled by a light barrier signal on the start of the new wire rod - sends a timely telegram via the CTC to the host computer. This telegram contains data that

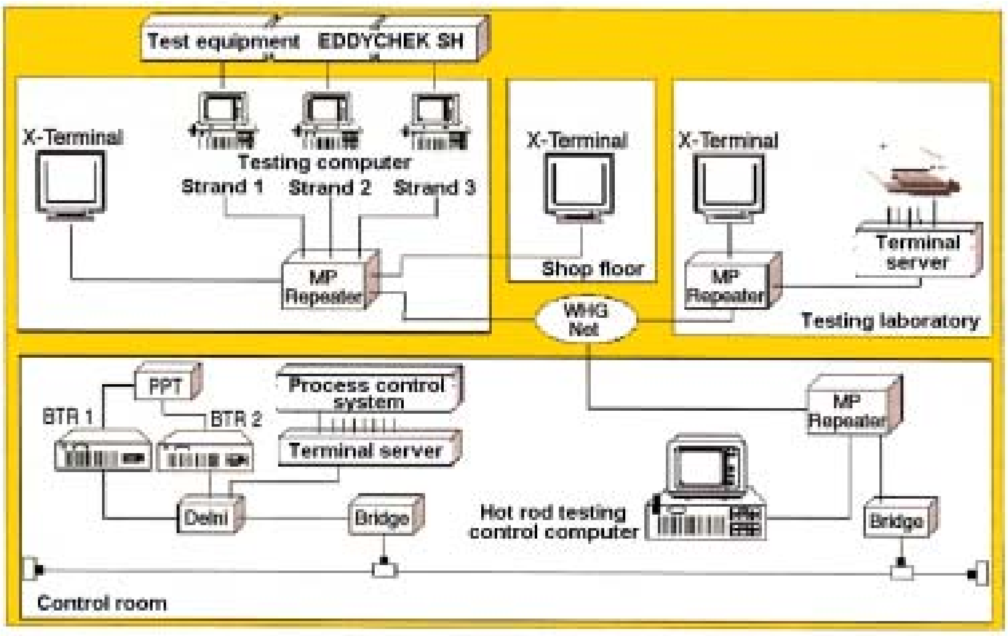
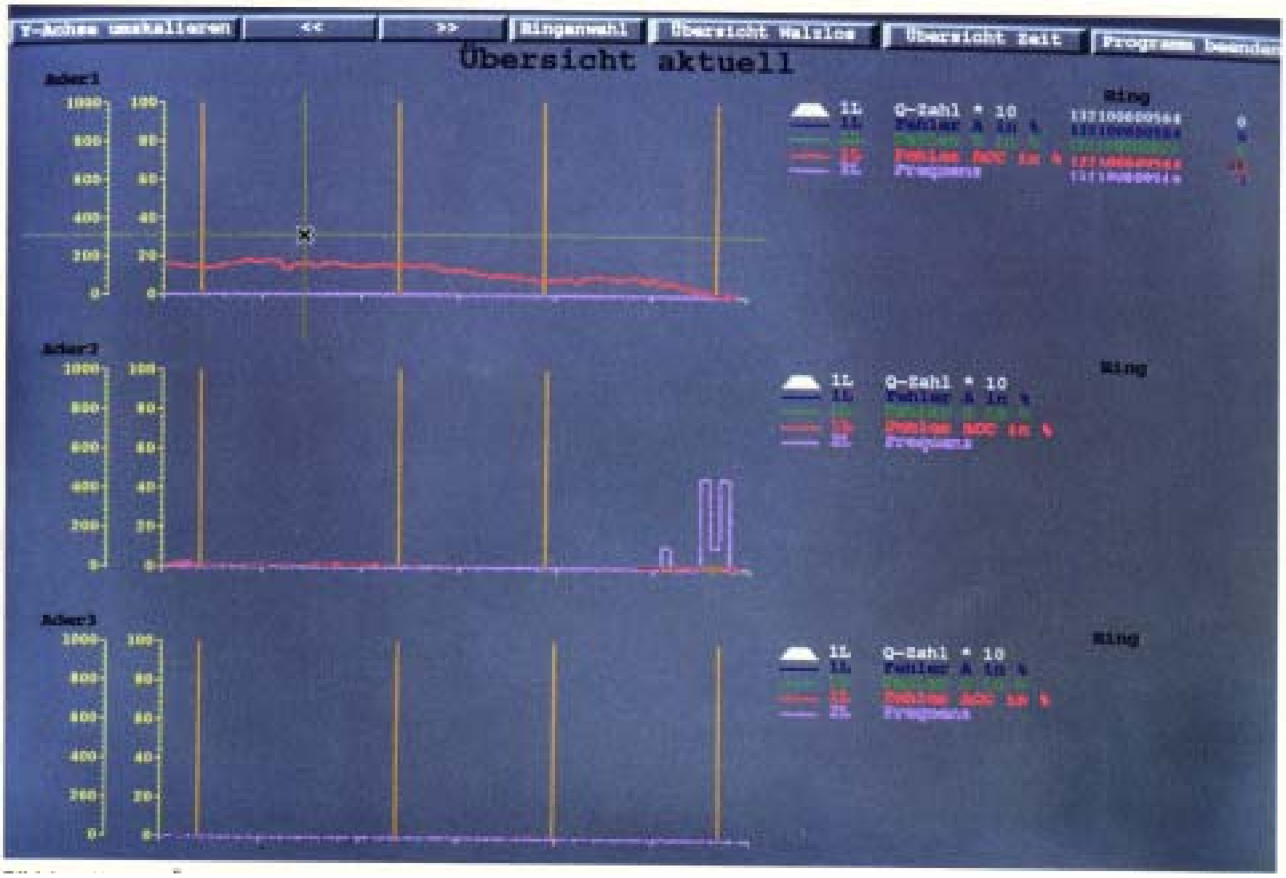


Fig 5. Networking of the testing system



are specific for the wire rod just produced. A dataset on each wire rod is created in the database of the host computer. From the rolling batch and wire rod data now available, the host computer forms a data package and transmits it to the testing computer responsible for the selected strand that uses these *setup data* for setting the testing parameters. With this timely transmission, the procedures between the host and testing computer are synchronized and the testing computer is initialized. After completing the surface testing of a wire rod, the testing computer transmits the *results* that are then taken into the database by the host computer and grouped according to the rolling batch, wire rod and sections.

The visual display on the X terminal is updated. For further material tracking, the CTC takes one of the quality numbers formed from the test results from the host computer. This quality number is allocated the unique rolling ID that is unique within the CTC and stored with the other data describing the coil.

Data storage. All the *setup* parameters and test results are held on the host computer in a central relational database. Data that have reached a specified age are automatically transferred to a *long-term archive.* In addition to its function as a visual display and archiving system, the host computer is also used as the central data source for the parameter files of the hot rod testing. The parameter files contain allowed test variables that depend both on the diameter and the material used. As a result, it is unnecessary to maintain individual parameter files for each of the three testing computers since the files are held on the host computer. The parameter files can be maintained from any PC using a standard editor. Changes can be made during operation and applied to all three testing systems. 100 testing classes can be defined for each diameter. This ensures the highest degree of flexibility.

System components, network connection. The host computer system is based on the following hardware and standard software components: IBM RS/6000 43P server, NEC 21" X terminal, 3COM multiport repeater, Oracle database, visual display with LVis. In order to be able to couple the systems that are involved in the data flow and, at the same time, to keep costs as low as possible, already existing protocols and transmission procedures were used wherever possible. Through the connection of the entire system, X terminals for the visual display can be coupled at any position with a network con-

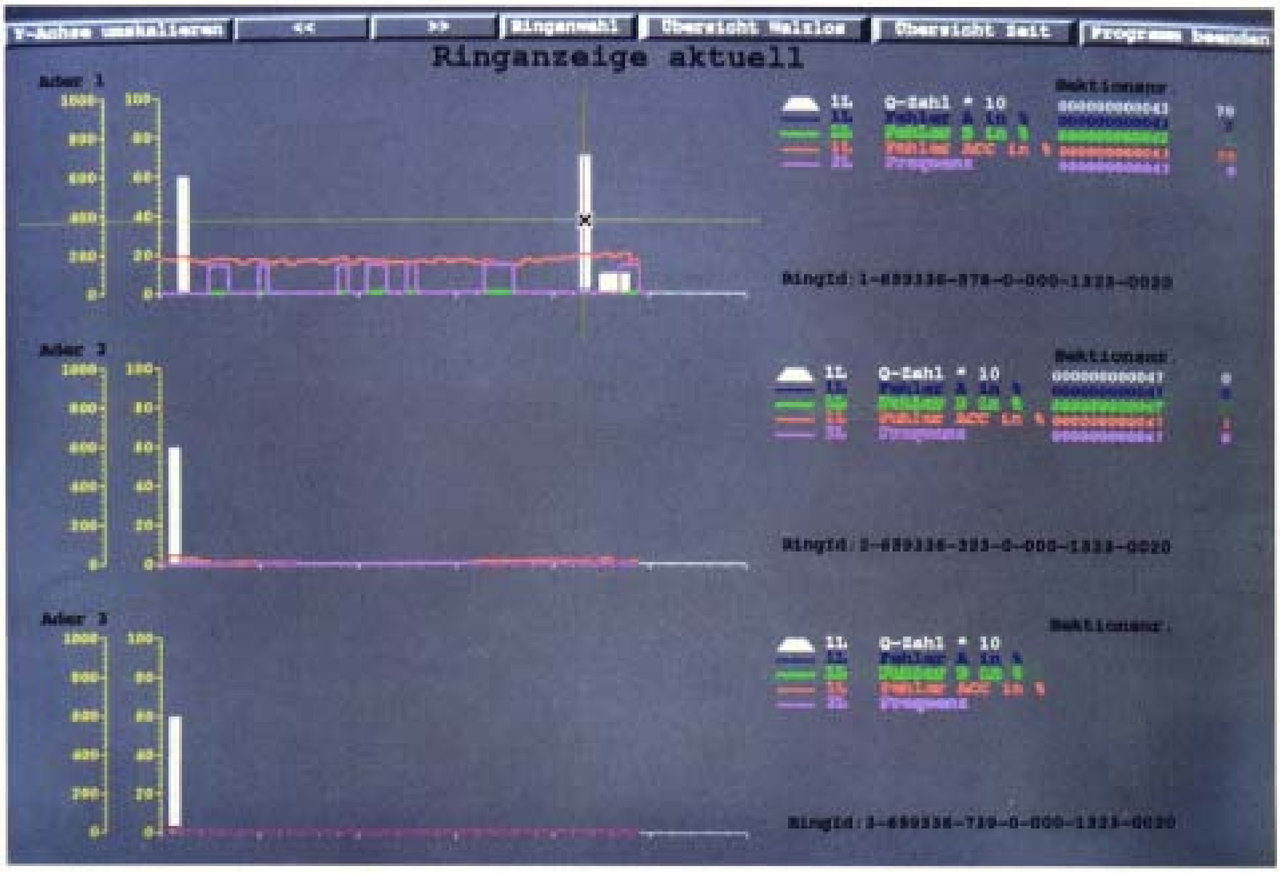


Fig 7. Up-to-date display of coil data

nection. At the moment, X terminals are installed in the testing laboratory, on the platform and on the rolling shop floor.

Visual display. An important objective in the definition of the graphs to be displayed was the simultaneous display of the test results of all three strands on a single screen. Only in this way does the personnel obtain a good idea of the qualitative situation in the rolling mill. *Coil displays* that show section-specific data are available for the more detailed inspection of individual wire rods. The operator can swap between the individual displays as required. Before activation of the historical (archived) data, various filters (rolling batch number, time, ID number of the wire rod) are interrogated. The following displays are available: „Current overview“, „Current coil display“, „Historical overview“ and „ Historical coil display“.

All the displays show the values, Q number (light gray area), A defects in % (blue stepped line curve), B defects in % (green stepped line curve), ACC defects in % (red stepped line curve) and „Frequency (violet stepped line curve) „. Values relevant for the evaluation of the results such as the ID number of the coil, the section number, the number of defects in %, etc. are displayed on the right of the graphs corresponding to the position of the cross wire.

Current overview. Figure 6 shows the values of the last 60 coils tested for all three strands. After each wire rod is tested, the values of the last coil tested are displayed on the left. To make it easier for the personnel to correctly interpret the test results, the changeover between two rolling batches is shown by a vertical line.

Current coil display. Figure 7 shows a display of a detailed view of the last rolled wire rod. At the end of each coil, this figure is automatically updated. The division of the entire wire length into approx. 50 sections enables the precise display of the defect distribution over an individual wire rod.

The display of archived data is basically the same as that of the current data. The data to be displayed can be filtered according to various criteria (time, rolling batch number, coil ID number, etc.).

Operating results

A decisive criterion for the successful operation of hot rod testing is the acceptance of the system by the employees involved in production. This was rapidly achieved as a result of the simple operation of the system, the clear display of the test results and, not least, through the convincing results.

The current quality trend can be tracked on screens installed on the workstations that are a key factor in monitoring the quality trend. In the case of defects caused by the process such as, e.g. roll pass damage, roller wear or damaged armatures, corrective measures can be started immediately.

The current overview of the last 60 coils tested for each strand provides an excellent representation of the trends in defect occurrence. The display of the defect number reflects the quality of the rolled wire surface while the quality number enables the defect occurrence to be monitored using specified maximum values. Through the use of coil-related and section-related displays and comparison of the test results of the individual strands, process-caused defects and defects caused by defective semi-finished material can be differentiated.

The defect distribution over the coil length can be seen on a section-related display of the last coils tested in each strand. This also enables systematic correlation between the defect location on the coil and the location of where the defect was produced. In the past, the causes of systematic defects were found mainly in either the furnace brick lining, the extraction roller after the pusher-type furnace or the diverter before the 1st rolling stand. As a result, the construction of the extraction roller and the diverter were changed.

Periodic defect analysis enables groove damage on the rollers or roller boxes to be recognized very rapidly.

The employees in the testing laboratory visually check the rolled wire surface when the testing system locates defects. If surface defects are identified on the rolled wire, the affected coils are removed temporarily. These coils are stored in a holding storage area. The defects on the rolled coil are localized with the aid of the section-related display. Afterwards, a decision is made on the further testing or use of the rolled wire.

Some of the results are described below.

Roll pass damage. Figure 8 shows the typical defect formation of roll pass damage. This concerns roll pass damage in the 23rd roller stand out of a total of 26 stands. The rolled wire had a diameter of 6.5mm. The diagram shows the percentage of defect types ACC, A and B and the Q number over the consecutive coil numbers. This makes clear that the period of time between the occurrence of the defect (coil no. 342) and the removal of its cause is considerably shortened and, thus, only a few coils are affected.

Roller wear. Figure 9 shows a constant increase in the number of defects. After a specified maximum value of 12% (ACC defects) is exceeded, the quality number is increased to 1. After the roller boxes in the last mill stands of the finishing block were replaced, a normal level reappeared. Inspection of the roller boxes revealed increased wear of the rollers.

Rolled wire defects due to starting material. Figure 10 shows the display of scale-type defects caused by defective starting material.

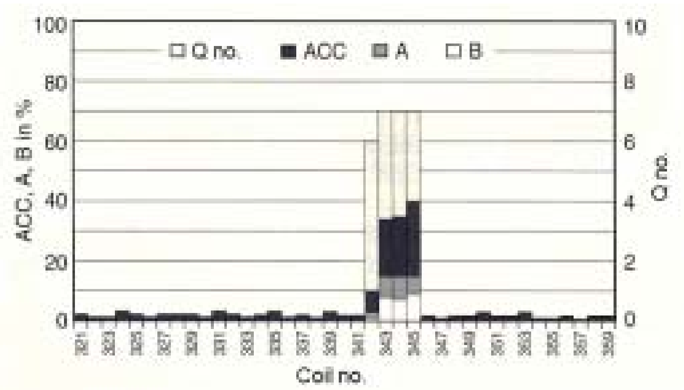


Fig 8. Development of roll pass damage

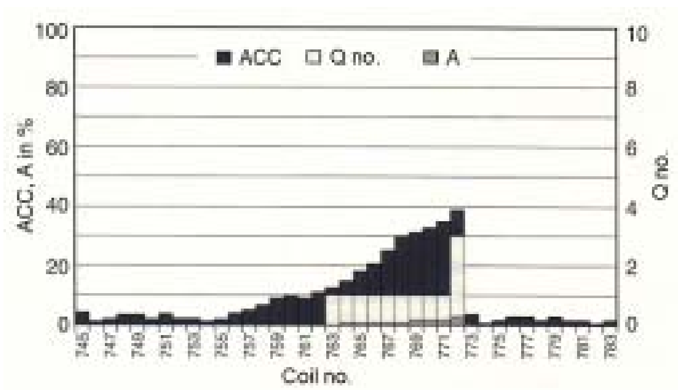


Fig 9. Increase in defects due to roll wear

Systematic defects. Figure 11 shows the test results of 3 consecutive rolled wires. The surface defects occur in the 9th section of each rolled wire. This clearly indicates a systematic correlation between the defect location on the rolled wire and the location where it was produced. As confirmed later, the cause was a worn furnace brick lining at the front of the pusher-type furnace.

Here, it is noteworthy that the defects on the rolled wire only extend over approx. 10 wire windings. This corresponds to a wire length of approx. 30 m. A wire diameter of 5.5 mm yields a section length of approx. 240 m and, thus, a relatively low percentage of defects occur in the affected section. In this example, the sections show a maximum of 6% ACC, 0.9% A and 0.7% B defects. The operators monitoring the quality on site are able to discern even the smallest defective wire sections as a result of the conditions specified in the test category used in forming the quality number.

Maintenance

Remote diagnosis of the computer system is included within the scope of the order to the software suppliers and enables instant access to the supplied programs via ISDN connection if any faults occur in the software.

The robustness and the user-friendly maintenance of the components in the test system is convincing. All the parts subject to wear can be serviced and repaired by in-house personnel in the workshops within the vicinity so that the necessary operating costs can be kept to a very low level.

Changing the coils to accomodate different wire diameters is simplified to an extent that it can be integrated in the changeover phases of production and, consequently, the operating time of the mill is not affected by it.

Prospects

By evaluating the defect patterns, including the macroscopic view as well as the microscopic view, further optimizations of the setup parameters are planned. These are dependent not only on the type of steel but also on the respective density factor, i.e. on the ratio of the eddy current test coil diameter to the rolled wire diameter. The results will be used to extend the defect catalog which forms the basis for the adaptation of the parameter files according to quality groups.

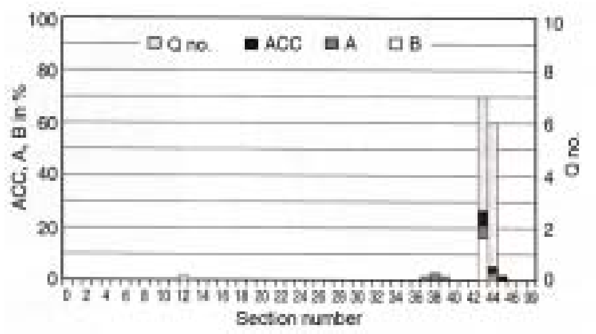


Fig 10. Coil-end defects stemming from the semi-finished material

The coil-related archiving of test results forms the basis for statistical evaluations. For example, conclusions can be drawn on the types of steel used and the surface quality of the semi-finished material from these evaluations. Thus, an optimization of the rolled wire surface can already take place on the semi-finished material. Furthermore, it is possible to recognize and prevent systematic defects that have their origin in the rolling mill. In addition, the construction of a long-term archive and the use of a special evaluation software is planned.

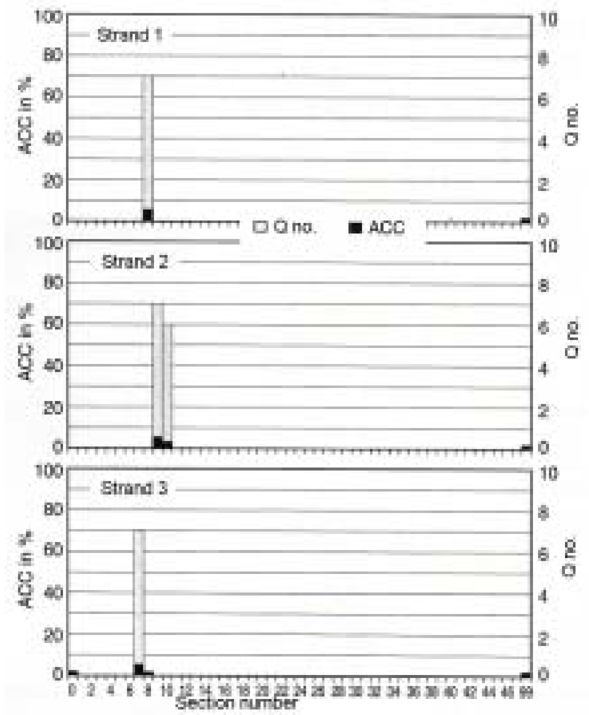


Fig 11. Display of a systematic defect