Quality Control system for a hot-rolled metal surface

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ABSTRACT. The modern ideas about of quality of products are based on the principle of the absolute satisfaction of requirements of recommendations of the buyer. A presence of surface defects of steel-smelting and rolling origin is peculiar to the production of hot-rolling mill. The automatic surface inspection system (ASIS) includes two digital line video cameras for the filming of the upper and lower surfaces of the flat bar, block of illumination of the upper and lower surfaces of the flat bar, computer equipment. A system that secures 100 % control of the surface of rolled metal (of the upper and lower side) detects automatically and classifies the sheet defects in the real time mode was mounted in the domestic practice in the first time in 2003 on hot rolling mill 2000 JSC «Novolipetsk Iron & Steel Corporation» (NISC). The whole assortment of the mill 2000 was divided for the five groups by the outward appearance of the surface. The works on the identification of defects of hot-rolled metal and widening of data base of knowledge of ASIS were continued after the carrying out of guarantee tests. More than 10 thousand images of defects were added to the data base during the year.

KEYWORDS. Hot rolling; Sheet; Quality; Control, Surface.

INTRODUCTION

The modern ideas about of quality of products are based on the principle of the absolute satisfaction of requirements of recommendations of the buyer [1]. It is defined as a totality of product characteristics necessary for the use in accordance with its destination. The mechanical properties and geometrical adjectives of the flat bar are for the first turn such characteristics for the rolling.

The main producers of metal production guarantee and document to the buyer these quality ratings at the today's level of development of rolling-mill production. It is attained by the introduction of automated control systems and by the introduction of control of technological process [2-4].

The state of surface of rolled metal is a separate item of quality. The most mass use of control of surface is accomplished on the final process stages of production of metal production (after of cold rolling, etching, annealing, deposition and so on.). It excludes a delivery of production that does not meet the requirements of the buyer. If the process stage on which

such discrepancies are detected becomes deeper then the losses caused by rejects are deeper and so the introduction of control systems in all process stages has its logic.
A presence of surface defects of steel-smelting and rolling origin is peculiar to the production of hot-rolling mill. That production cloud be a commodity output and pre-rolling. It is not always possible to identify them precisely on the outward signs on the finished commodity. The main methods used for the detection and study of defects of surface of sheet steel, visual – using an external examination without or with the use of special systems [5].
But the speed of the flat bar, its temperature and oxidation of surface complicate the performance of inspection. That is why the rolls are checked for the purpose of presence of defects after a cooling-down as a rule. A volume of insufficient production is increased in that way especially when the defect has a rolling origin (a periodical caused by worker for example).

SYSTEM OF QUALITY CONTROL OF SURFACE OF SHEET PRODUCTS

Today there are only a limited number of creators of such systems (Codnex, EES, Matra, Parsytec, Siemens-VAI, Sipar and the others) in spite of great need of the enterprises of ferrous metallurgy in the systems of automatic inspection and identification of surface defects.
It is explained by the fact that the systems suitable for the rolling are considerably expensive because the surfaces of steels rolled in one company are greatly differ by the outward appearance that leads to the complication of algorithms of detection and classification of surface defects [6-8].
A considerable break-through in the working out and in the introduction of systems of machine check of surface occurred thanks to the creation of highly productive computers and digital video camera of high-resolution that made it possible to obtain and process the image of the moving flat bar in the real time mode.
At that time two detections of systems based on the obtaining of primary image from the line scanning video cameras registering the image of surface with the scanning of line by line and matrix fixing the image of surface area had the development.
A discussion on the advantages of different systems that took place in different publications is not always constructive because of narrowness of consideration. It is connected, for the most part, with the primary image processing obtained from the cameras.
The discussion loses the importance and the criteria for the sake of which these systems are introduced on the metallurgical plants become of current importance on the development and improvement of image processing algorithms, introduction of computers with high data-rate. Namely the accuracy detection and classification of defects, their minimal size and a possibility of use of these results in further technological process stages.

CONTROL OF SURFACE OF HOT ROLLED METAL ON THE CONTINUOUS BROAD-STRIP MILL 2000

A system that secures 100 % control of the surface of rolled metal (of the upper and lower side) detects automatically and classifies the defects полосы in the real time mode was mounted in the domestic practice in the first time in 2003 on hot rolling mill 2000 JSC «Novolipetsk Iron & Steel Corporation» (NISC).
The companies SYTCO AG, SIEMENS-VAI and the Lipetsk State Technical University (LSTU) took part in the realization of the project together with NISC.
The automatic surface inspection system (ASIS) includes two digital line video cameras for the filming of the upper and lower surfaces of the flat bar, block of illumination of the upper and lower surfaces of the flat bar, computer equipment (Fig.1).
A resolution of digital video cameras amounts 0,5×1,0 mm. by the width and length of the flat bar correspondingly that defines lower limit size of the fixed surface defect.
A graphic presentation of the upper and lower surfaces of the flat bar is received by video cameras and is transmitted to the computer part of the system.
The image processing of surface defects occurs in four main stages – preliminary correction of image, determination, segmentation and classification.

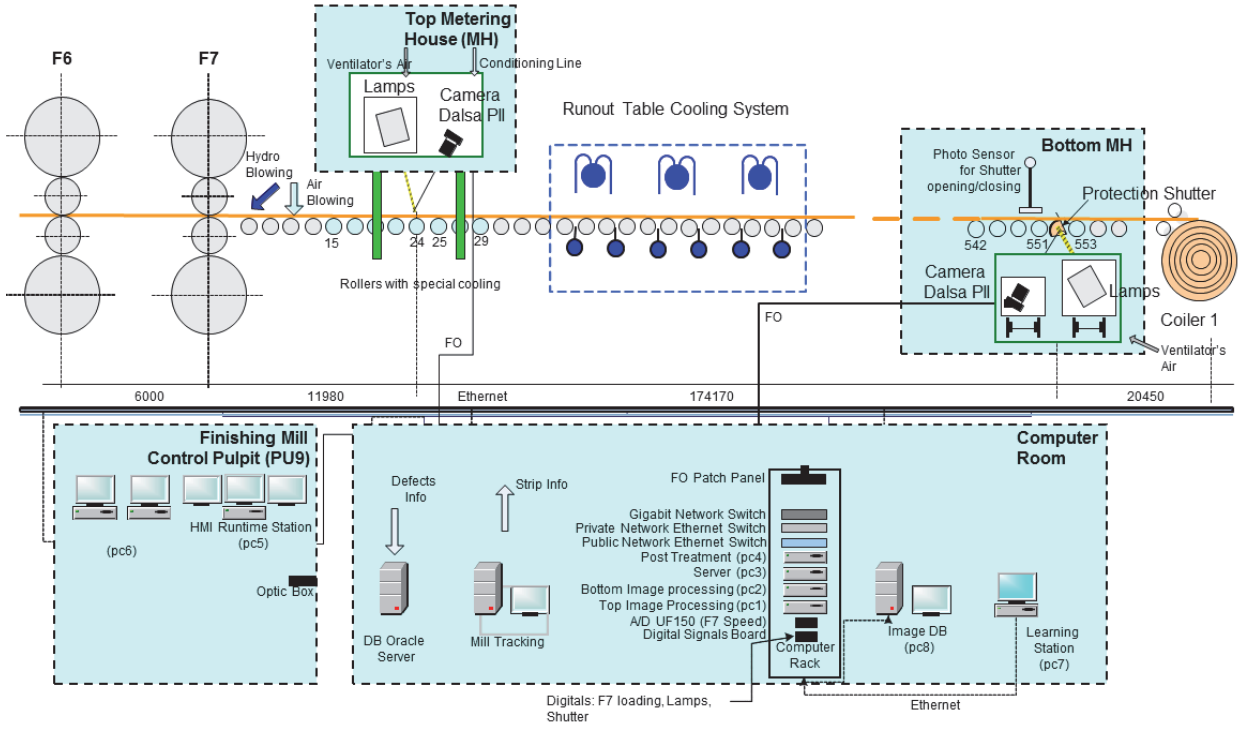

Figure 1: Placement of ASIS equipment

The system that received from the video cameras a primary image of surfaces corrects the general background that always should be constant in time for the correct classification of defects. Several algorithms of detection of defects (for the vertical, horizontal and diagonal contrast, of thin and lengthy, of dark or light defects) are used in parallel to the received. Then a morphological grouping of the obtained signs occurs for the obtaining of the information necessary on the stage of classification.

A method, based on the method of classification spheres is realized for the classification of defects in the given system of control of quality of surface. A comparison of found defects of surface with the samples of defects from the existing data base on which the classification is based is in the foundation of method. Not less than 20-40 samples of analogous defects are necessary to have in the data base for the automatic classification of defects.

The results of the processing are transmitted to the control station informing the operator of the mill about the state of the surface of the rolled metal after the classification of image and also are recorded to the data base for the further analysis of the quality of the rolled metal.

The main difficulties arised on the stage of development of ASIS on mill 2000, consisted in the setting of the system for the detection of defects on the current assortment of the mill and also in «training» of the system to classify the detected defects. The training consisted in the accumulation of samples of defects in the data base (base of «knowledge of defects»).

The actions on the setting of the system of control of quality of the surface consisted out of four stages for the obtaining of maximum of detection of surface defects:

- fragmentation of assortment of steels rolled on the mill for the groups by the outward appearance of the surface of the rolled metal;
- decrease of quantity of water on the upper the surface of the rolled metal;
- determination in the system of threshold valuation of contrast of detection of defects for the groups singled out in the assortment of steels;
- creation of class file.

The whole assortment of the mill 2000 was divided for the five groups by the outward appearance of the surface after short-lived operation of the system because the surfaces of steel strip are different by the outward appearance (for example, transformer steel grades have, for the most part a homogeneous grey surface, of dynamo steel grades and carbon steel grades have a dark and heterogeneous):

group 1 – rolled metal 10UA, 20 and transformer steel grade;

group 2 – rolled metal 08U, DC04 and St3sp;

group 3 – rolled metal of dynamo and alloyed steel grade;
group 4 – rolled metal S355J2G3, St5sp, 09G2 and A36;
group 5 – rolled metal with corrugation,
and a threshold valuations of contrast were defined for each group and classification spheres were done [9].
A presence of drops of water on the upper side of rolled metal was one more problem for the detection of surface defects on the upper side of rolled metal and also a presence of water splashes and vapor between the flat bar and upper video. Not less than 50-100 images of water will be classified as «defect» at the presence of 4-5 thousand images of water on one flat bar even at the high rate of classification (98-99 %).
The design of water cooling of the roll-table rollers mounted in the zone of measurement shelters was altered for the elimination of water and another hydraulic blow-off assigned for the water drops moving off from the surface of flat bars with the width of more than 1200 mm., was installed in addition to the regular hydraulic blow-off after the fifth 5 roller and air blow off for the rolled metal with the width of 900-1200 mm. was installed after the seventh roller.
It became possible to go to the next stage – a training of the system for the automatic classification of defects in the result of the setting of ASIS for the detection of the surface defects of rolled metal and the elimination of negative influence of water splashes for the detection. And though the use of data base of knowledge of standard images of defects obtained on different metallurgical plants was possible for this the stage of setting of ASIS for the automatic classification was performed in the manual mode.
This is more laborious method of setting connected with the stoppages of units but effective because precision of classification of unknown defects is increased due to visual inspection. The examination of rolls containing the defects of unknown type was realized on the units of cutting and lines of preparation of hot-rolled rolls. An identification of defects, and their documenting and digital photographing was carried out by the experts of quality. A complex of metallographic examinations was carried out when it was necessary.
A primary training of ASIS for the automatic classification of defects was carried out from the December 2003 up to the May of 2004.
About 120 rolls with defects were examined altogether at that period of time and more than 1000 image of defects were entered into the data base of knowledge.
It became possible to carry out the training of the system without carrying out of laborious visual examination of rolls or resort to it in the exceptional cases after the accumulation of a definite experience of work with the images of defects obtained from the system.
A catalogue of digital images of defects developed by LSTU assisted to it (Fig. 2). Accumulated data base of knowledge ASIS and digital images of defects detected in the result of visual examination and identification of defects of surface of hot-rolled metal became a basis of that catalogue.
The guarantee tests were carried out (June 2004) jointly with the participation of companies SYTCO AG and SIEMENS-VAI when the volume of trained images of defects became sufficient. The rolls with the surface defects detected by the system were selected for it. The selected rolls were examined according to the method analogous to the method used for the training of ASIS to the automatic classification. The deffects were registered manually on the units of preparation of hot-rolled rolls. A coordinate of defect from the trailing end of roll, the dimensions of the defect were fixing and its class and tenseness were defined. Then, a rate of detection P_d and a rate of classification P_c according to the results of manual and automated detection of deffects of surface of hot-rolled metal was calculated:

$$P_d = \frac{N_d}{N_e} \cdot 100\%, \qquad P_c = \frac{N_c}{N_d} \cdot 100\%,$$

where: N_d – the number of deffects of the given class detected simultaneously by the system in automatic mode and by the expert at the visual examination on all the rolls the selected for the test;
N_e – the total number of deffects of the given class detected by the expert at the visual examination on all rolls the selected for the test;
N_c – the number of deffects of the given class detected simultaneously detected by the system in automatic mode and by the expert at the visual examination on all the rolls the selected for the test and classified correctly by the system (as the given class) at that.

Only the defects that are the deffects from the point of view of the expert were taken into consideration at the calculation of the rate of detection of defects but a class of deffect назначенный for them by the system in automatic mode was not taken into consideration. Altogether 16 rolls were examined in the course of guarantee tests.
The analysis of the obtained results showed that the main surface deffects of hot-rolled flat bars are skins (ingot and stitch) and also the bubbles and rolled-in foreign particles . The rate of detection and a classification of these defects amounted 100 % and 94,2 %, 95 % and 95 %, correspondingly. The level of detection of pseudo-deffects (drops of water, «not deffects») amounted 99 % and 98,3 % of the classification. The average rate for the selected lot of detection of deffects is equal to 99,7 % at the classification in 97,3 %. So the guarantee indices were confirmed and the ASIS was put into commercial operation.

USING OF RESULTS OF DETECTION AND CLASSIFICATION OF DEFECTS

The works on the identification of defects of hot-rolled metal and widening of data base of knowledge of ASIS were continued after the carrying out of guarantee tests. More tan 10 thousand images of defects were added to the data base during the year. The images of skins (ingot and stitch), slags, rolled-in foreign particles, cracks (longitudinal and transversal), hairlines, imprints, riffle, edged cracks, water and other defects detected on the surface of hot-rolled metal are among them.
A high rate of detection and a classification of surface defects on the hot-rolled metal, generated volume data base of knowledge and a catalogue of digital images of defects created an objective basis for the realization of tasks connected with the use of results obtained from ASIS. A software executed in the form of separate applications was worked out in LSTU [9-11]:
digital catalogue of images of defects (Fig. 2);

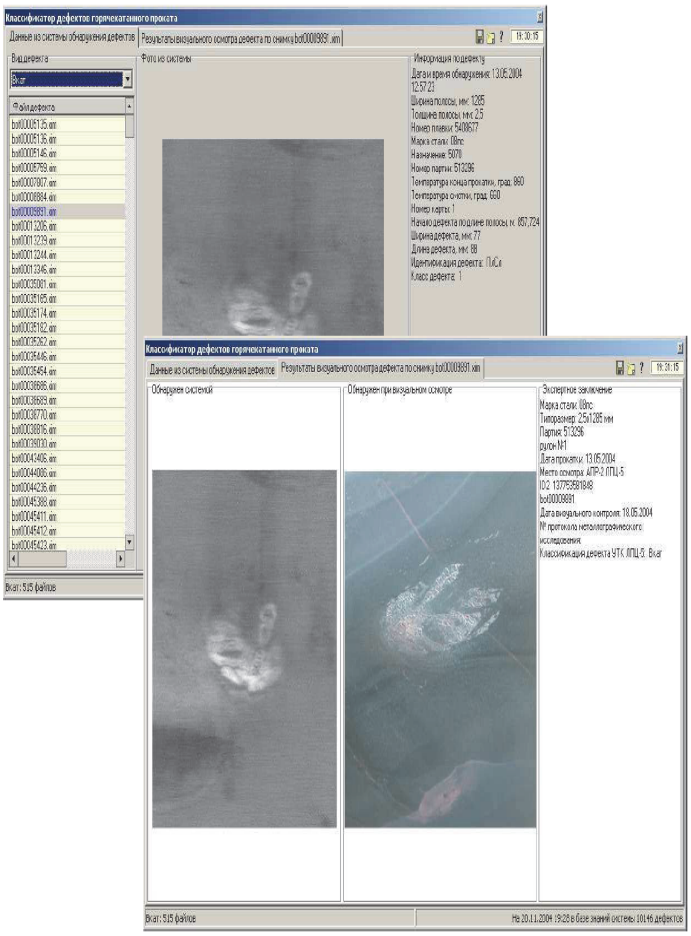

Figure 2: Digital catalogue of defects of surface of hot rolled metal

module of processing of periodical defects (Fig. 3);
module of certification of hot-rolled rolls (Fig. 4);
module of monitoring for the critical defects at the preparation to the cold rolling on the mills 2030 and 1400 (Fig. 5);
module of visualization and analysis of rise of defects of surface (Fig. 6).

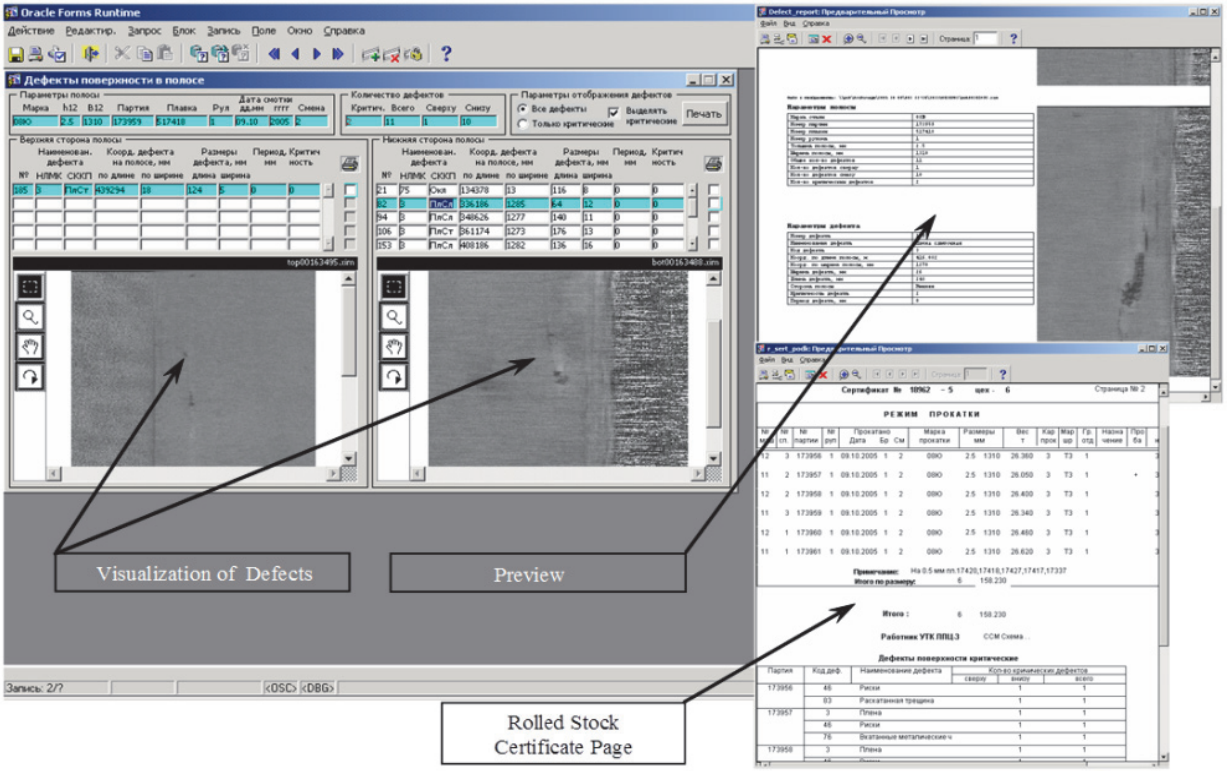

Figure 3: Visualization of application for the certification of hot rolled rolls

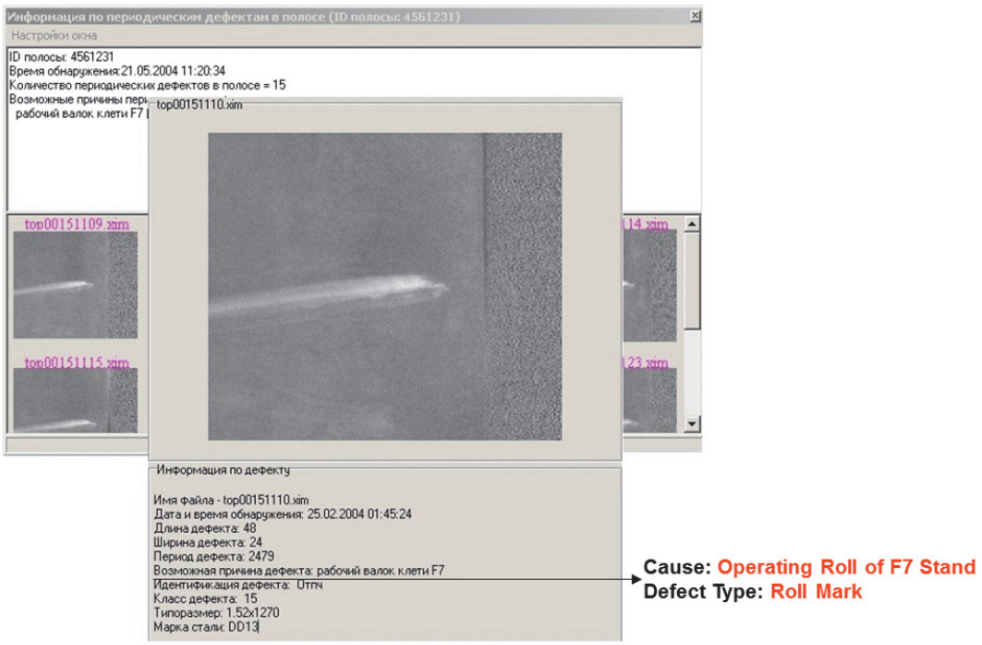

Figure 4: Visualization of application of processing of periodical defects

The functioning of modules is based on the notion of a «criticality» of defect. The criticality is defined for the cold-rolling mill by the probability of emergency shutdown of the mill due to the breach of flat bar caused by the surface defect.
An algorithm of conferment of code of criticality (from 0 up to 7) against of the steel grade, of the type of defect, its location (edge, center of pre-rolling) and of linear sizes is worked out on the basis of experimental data on the breakness of flat bars obtained on the mills 2030 and 1400.
A decision is made on the further processing of roll (the change of status «critical/ uncritical», cutting out of defect, decrease of speed of rolling on the problem sectors and the others) or its destination is altered at the processing of rolls on the units of preparation (in front of the mill of cold rolling) according to the information about the defects presenting on the flat bar and their codes of criticality.
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A module of visualization of defects of surface of hot-rolled flat bars with the reference to the identifier of roll is intended for the analysis of rise of defects depending on the fusion, lot, metal grade, mode of its rolling and so on (Fig. 6). The algorithm materialized in the module makes it possible to carry out the analysis of formation of surface defects on-line mode for the flat bars rolled on the mill 2000, and in the mode off-line on the archive data of rolled flat bars. It makes possible to reveal in time the regularity of distribution of defects, to find the causes of rise, to propose the actions for their elimination and to decrease the losses from rejects and insufficient production thereby. These are some results of introduction of ASIS:
the use of system of control of surface condition with additional applications led to the decrease of stoppages of the mill 2030 for 14,4 % in 2004, for 31,2 % in 2005 as compared with 2003;
in April – August 2009 the control with the use of ASIS of hot-rolled steel of the grade St24 supplied to the europium client made it possible to the experts of quality to take from the shipping and move it into the insufficient production of 112 rolls at the certification of the production that amounted 3,0% from shipped.
The considered user's applications are installed on the working stations of production engineers of different services included into information net of the industrial complex. The engineering center, oxygen-converter plants, sheet-rolling production sectors, subdivisions of market department and other subdivisions are among them.

CONCLUSIONS

The diagnosis of surface defects в rolling production is a complicated and multiple-factor process. The experience of introduction of the system of control of quality of surface on the uninterrupted wide strip mill of hot-rolling and also its further use showed that automatic detection and classification of surface defects in the end-to-end technology of production of sheet products make it possible:
to secure a provision of the requirements of consumers on the quality of the surface of the rolled metal with the submission of electronic passport;
to provide 100 % control of surface of all flat bars rolled on the mill for the detection of defects of pouring and hot rolling;
to provide automated systems of subsequent process stages by the information about the defects of surface of hot-rolled metal;
to carry out monitoring of quality of surface in the adjacent process stages;
to carry out an audit of the existing technologies of rolled metal production and develop the actions on their improvement.
The management of technology of process stages adjacent with hot rolling with the use of results obtained by the system of control of quality of surface opens good prospects on the decrease of insufficient production and to the increase of productive efficiency.

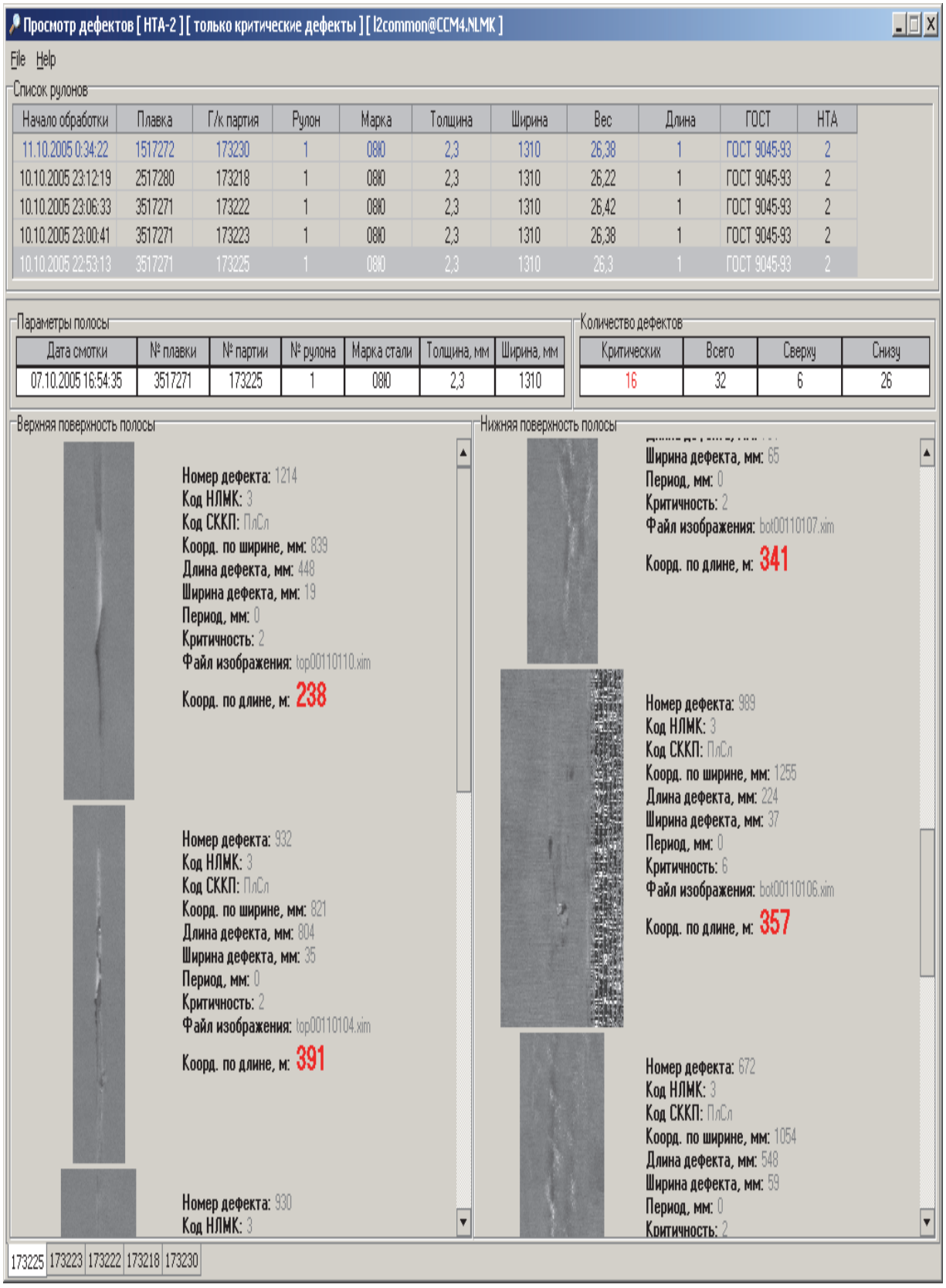

Figure 5: Visualization of application for the monitoring for the critical defects on the mill 2030.

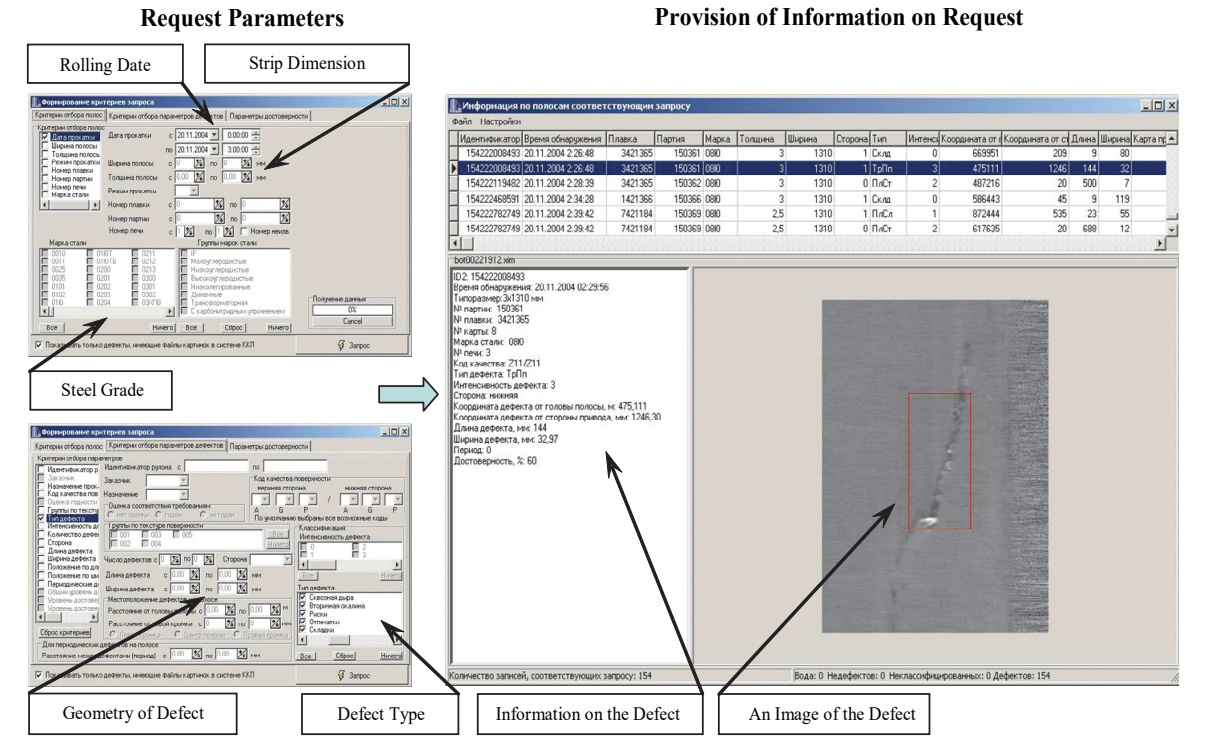

Figure 6: Application of visualization and analysis of rise of defects of surface.Examples: a) – formation of inquiry; b), c), d), e) – results of processing of inquiries

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