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INTRODUCTION OF FLATNESS GAGE IP-4 ON THE CONTINUOUS WEAN-DAMIRON HEAT-TREATMENT LINE AT THE SAMARA METALLURGICAL PLANT

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Results are presented from the practical application of opto-electronic flatness gage IP-4 on a continuous heat-treatment line. The gage is being used to increase the flatness of aluminum alloys after their quenching and combination straightening by bending and tension. The gage allows quality adjustment of straightening machines and makes it possible to quantitatively measure flatness in real time. The machine operator can adjust the parameters of the straightening operation and significantly improve the quality of the product. When coils are being straightened, the gage makes it possible to reliably predict the flatness of the rolled product at the outlet of the machine and decide on the need for additional straightening without having to prepare samples of the metal.
Key words: *flatness gage, continuous heat-treatment line, straightening of sheets.*

The authors of this article previously reported on the characteristics and capabilities of flatness gage IP-4 on hot- and cold-rolling mills used to roll alloys of ferrous and nonferrous metals [1–5]. The regime that is used to measure the geometric dimensions of sheets as they move along a roller conveyor was also described [6–7]. The flatness gage is considerably more sensitive and has better spatial resolution in the transverse direction than existing triangulation-type laser height gages, and it costs appreciably less than gages with stress-measuring rollers. Thus, the gage offers several new possibilities for rolled products manufacturing.

In particular, it makes economic sense to install flatness gages on the straightening machines. This makes it possible to more quickly and more accurately adjust the operating parameters of the machines. This was the situation that arose on the Wean–Damiron continuous heat treatment line (henceforth referred to as the CHTL) at the Samara Metallurgical Plant. Plant management decided to also equip the line with an IP-4 gage. This article discusses the initial results obtained from using the IP-4 gage on this line.

The CHTL at the Samara Metallurgical plant usually operates in two regimes – annealing and quenching. The line includes a 133-m-long furnace in which strip, moving on a blanket of air, is heated to 180–320°C in the annealing regime and 470–545°C in the quenching regime. The line also has a quenching chamber and a straightening section, the latter in turn

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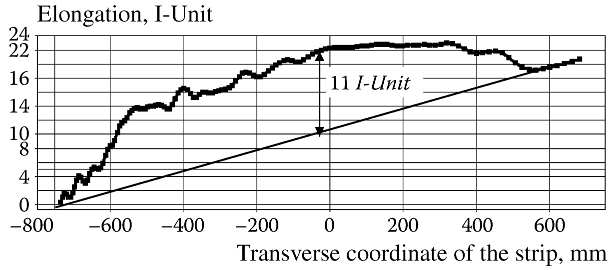

Fig. 1. Typical distribution of elongation.

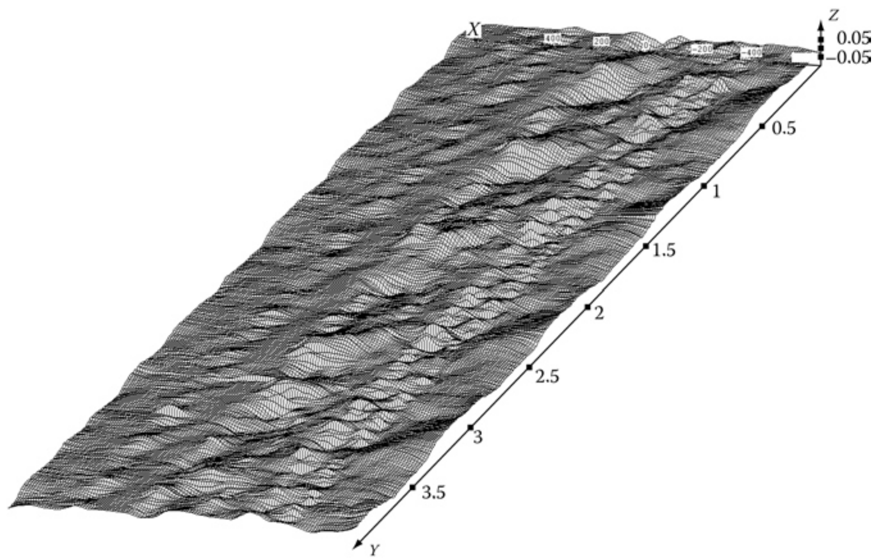

Fig. 2. Axonometric image of the "surface of angles" on an unstraightened strip. The measurements were made with an IP-4 gage.

including tensioning stations and a straightening machine. The straightening is done in three ways: by the application of tension (with the percentage elongation being measured); by the overlapping of the Preflex rollers in the section; by overlapping of the rollers on the six-roller straightening machine.

The need to measure flatness became particularly evident in quenchings of strip made of alloys that are designed to undergo such heat treatment (alloys D16, D19, V95, 2017, 7075, 6061, and others). In this case, the metal – which was severely warped after the quenching operation (curvature being ≈100 I-Unit) – should have been straightened until the value of the curvature parameter was 3–12 I-Unit. To accurately adjust the straightening regimes, it is necessary to measure the curvature that actually develops on the strip. Accordingly, the adjustment entails setting the force exerted on the strip to offset the amount of curvature measured on it.

Flatness gage IP-4 was installed on one of the tension stations between the straightening machines and the roller that spins the strip into the coiler. This is the most convenient location for the gage because the unit tension on the strip after this station is no greater than 2.5 kg/mm^2, and that makes it easier to calculate the distribution of elongation with allowance for the actual tension on the strip.

The main objectives in using the IP-4 on the CHTL were as follows:

- study the effect of the straightening parameters on the flatness of the strip and optimize the adjustment of the straightening machines;

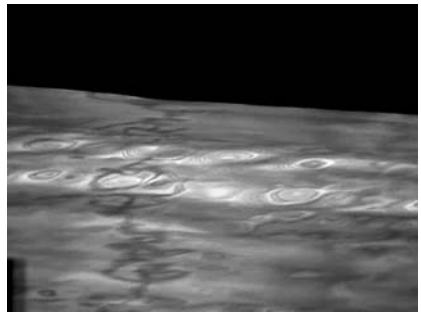

Fig. 3. Photograph of the surface of an unstraightened strip.

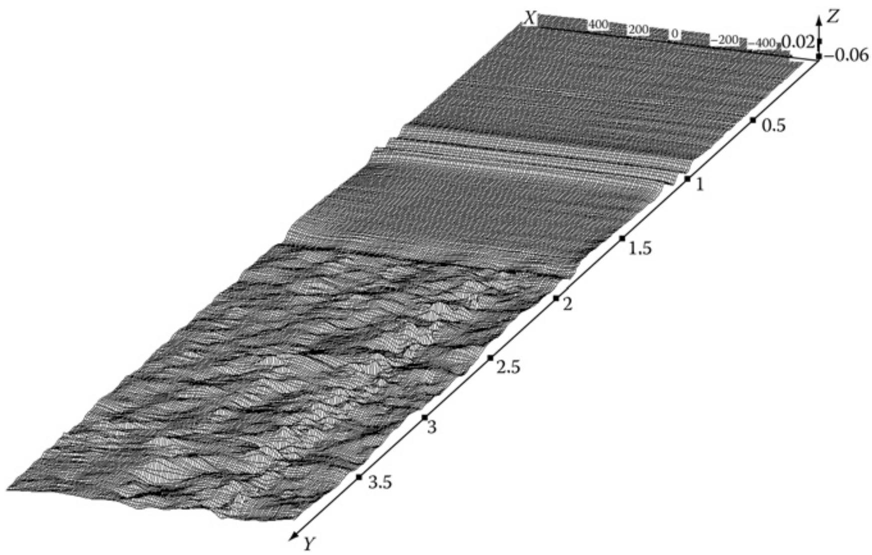

Fig. 4. "Surface of angles" on a section of a strip during the process of opening of the straightening machine.

- study the effect of the quenching regime on strip flatness;
- obtain a preliminary estimate of the flatness of sections of the strip where cuts are to be made to form the ends of coils.

The results obtained from measurements made with the IP-4 on the CHTL are shown in the form of a graph of the distribution of elongation – EDG (Fig. 1). The graph was constructed from measurements made on a section of the strip that passed through the measurement zone over a period of 8 sec. For strip moving at a speed of 0.5 m/sec, this corresponds to a section of strip 4 m long.

The measurements were used to adjust the straightening machines and distribute the overlap coefficient over the width of the strip, which sharply improved the quality of the straightening operation.

To be able to use the information shown on the control panel in order to judge whether or not a strip has been straightened in accordance with the results depicted by the EDG curve, it is necessary to connect the extreme lower points of the curve by a straight chord and subtract the chord's length in the corresponding coordinates (see Fig. 1). This is equivalent to removing the excess elongation, which increases linearly from one edge of the strip to the other. Strip with such a distribution of elongation is equivalent to metal with a conical surface that is spread out over a plane. The remaining part (maximum ≈11 I-Unit, see Fig. 1) is not spread out and forms the so-called "tail" (the term used at the Samara plant).

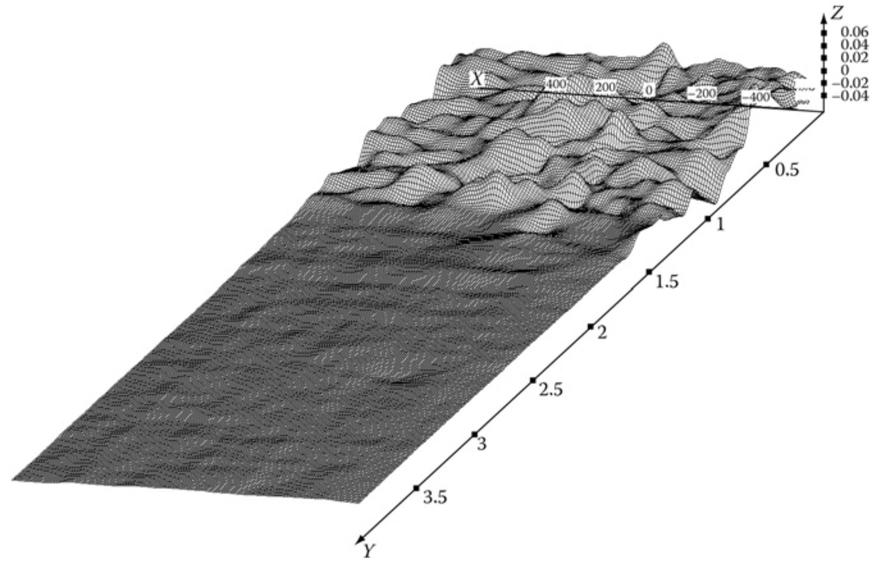

Fig. 5. “Surface of angles” on a section of a strip during the closing of the straightening machine.

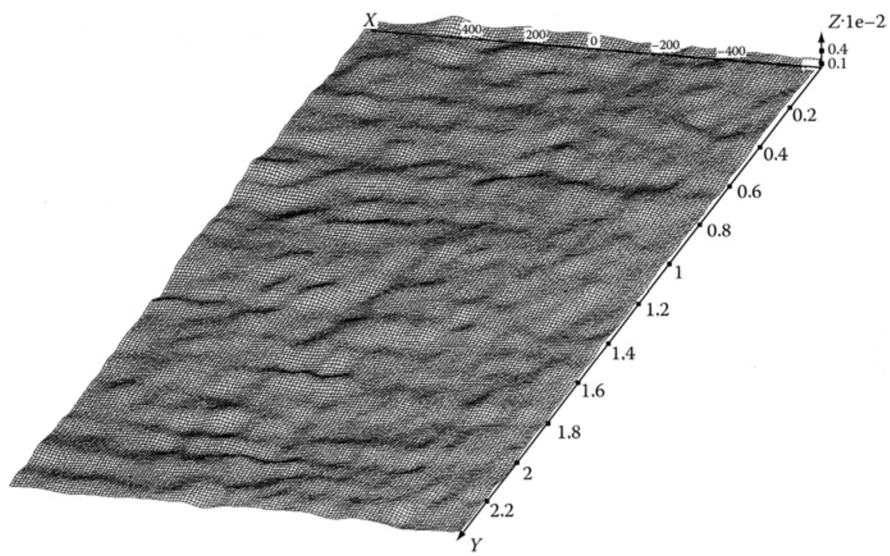

Fig. 6. Section of straightened metal with a 10-fold enlargement of the scale along the *Z*-axis.

With a typical wavelength, it is easy to determine the maximum deviation of the strip surface from the plane of the control slab. In the example being discussed, this deviation was no larger than 4 mm/m. Thus, the strips are within the tolerance and the coil does not have to undergo additional straightening.

The EDG graph generated by the IP-4 is described by a third-degree polynomial. In addition to the graph, the coefficients of this polynomial are output materials in the method being employed here.

The quantity of the most interest for the CHTL is the coefficient with the quadratic term of the polynomial, which corresponds to the above-mentioned tail. This coefficient provides direct information on the acceptability or impermissibility of the degree of distortion of the metal – distortion that can lead to its rejection at the outlet of the mill. The coefficient is also used as a criterion for regulating the production process. Specialists at the plant established experimentally that the tail

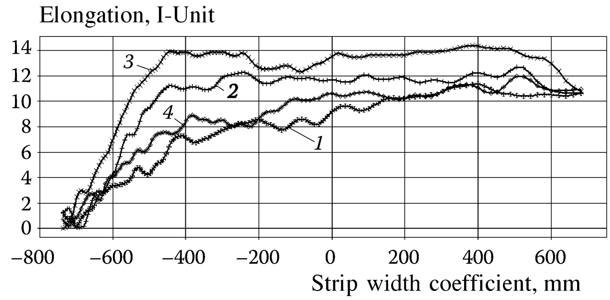

Fig. 7. Distribution of elongation with different levels of tension: *1*) section 1, 0.98% tension; *2*) section 41, 1.5% tension; *3*) section 63, 2.0% tension; *4*) section 176, 0.98% tension.

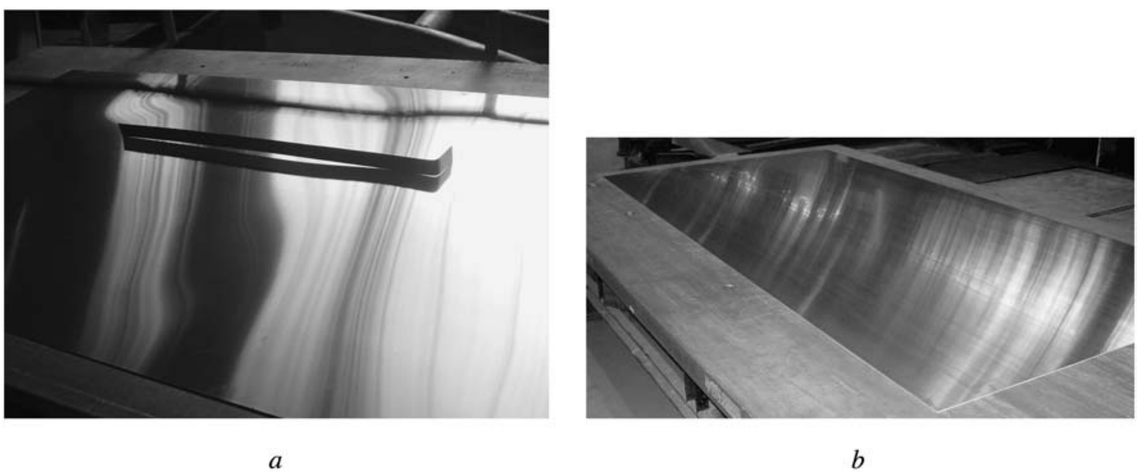

Fig. 8. Appearance of alloy V95 strip from a coil that was quenched and straightened on the CHTL: *a*) before adjustment of the straightening machine with the use of gage IP-4; *b*) after adjustment of the straightening machine and the production process with the use of the IP-4.

must be kept within the range 3–12 I-Unit to obtain the best outcome with respect to the flatness of the product. This ensures that the process will yield a quality flat strip during the final operation involving its cutting into smaller pieces.

As was noted in [1–7], the main physical quantity measured by the IP-4 is the angle of inclination of elementary fragments of the strip's surface. The values obtained for this angle are converted into the distribution of elongation, which makes it possible to study the shapes of different sections of the strip. Although the surface constructed from the measurements is a distribution of angles, it can be used to evaluate the actual shape of the surface of the strip itself. This is evaluated from a comparison of Figs. 2 and 3.

We performed a comparative analysis of different sections of a strip at the beginning and end of the coil. The sections had passed through the measurement zone both with the straightening machine in the raised position (leaving the strip unstraightened but free of distortions from the quenching operation) and with sections undergoing straightening. The analysis showed that the warping seen after the quenching chamber is almost completely eliminated by the straightening machine with the use of tension greater than 1% (Fig. 4).

An impression was left on the strip from the opening of the machine and there was a difference in the appearance of the "straightened" and "unstraightened" parts of the product. For example, beginning at the 1.8-m, the shape of the sur-

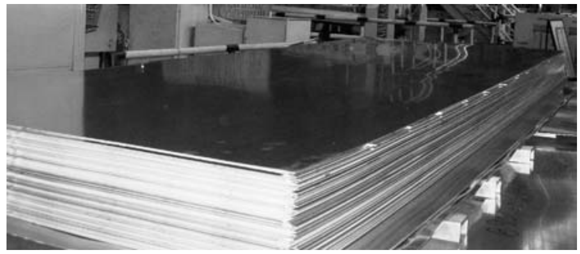

Fig. 9. View of a stack of sheets of alloy D16 from a coil quenched and straightened on the CHTL after adjustment of the straightening machine and production process with the use of gage IP-4.

face was exactly the same as it was after the quenching operation. An analysis of this distortion showed that it was symmetrical relative to the rolling axis. There was a large wave along the side of the strip opposite the drive, and there were large bulges periodically located along the axial line. The degree of distortion of the strip was considerably smaller on the drive side of the mill.

Obtaining the measurements with the straightening machine open provides the best opportunity for adjusting the operating regime of the quenching chamber from the standpoint of keeping the strip flat before it reaches the machine (see Fig. 4).

The process of closing the machine (Fig. 5) creates a sharp boundary between the straightened and unstraightened parts of the strip. It also leaves some distortion within the straightened part, this distortion following the same pattern as on the unstraightened portion of the strip.

The strip also clearly has lengthwise distortions (Fig. 6), and their distribution across the strip is the same as on the unstraightened part of the strip. Thus, applying 1% tension (the standard straightening regime – tension in 1000 I-Unit) to strip at the outlet of the straightening complex is not sufficient to eliminate distortions created in the quenching chamber. That in turn means that the metal is distorted not because the compressed sections of the surface became unstable, but because impressions were made in the strip by the bending moments created from the nonuniform mechanical characteristics formed in the metal during the quenching operation.

To determine the effect of tension on the flatness of the strip, we subjected the latter to increasing amounts of tension (Fig. 7). It became apparent that the size of the tail increases with an increase in the percentage of tension.

Photographs were taken of strips of alloys V95 and D16 obtained on the CHTL during quenching and straightening done with the use of the IP-4 (Figs. 8 and 9).

Conclusion

1. In regulating the flatness of rolled sheet by means of gage IP-4, rolling-mill operators obtain a clear understanding of the effects of the individual components of the CHTL and the quality of their adjustments on the resulting flatness of the product.

2. While the coils are being straightened, it is possible to reliably predict the final degree of flatness of the sheet and make real-time decisions on the need for additional straightening without having to cut out and analyze physical samples of the metal.

3. Quantitative measurements of flatness made using the IP-4 make it possible to accurately adjust the straightening machines. Such adjustments allowed rollers to obtain 100% usable (based on the flatness parameter) metal in one quenching session for the first time ever.

4. After the straightening machines have been carefully adjusted, it becomes possible to more accurately regulate flatness either manually on the basis of IP-4 readings obtained in real time or automatically with the use of an automated feedback system. Work is already under way on instituting such a system.

5. Flatness measurements made on all the rolled coils and recorded in the database of gage IP-4 make it possible to monitor the performance of the different crews and analyze the reasons different results are obtained at different times in regard to the quality of the straightening operation.

6. The output of usable quenched metal on the CHTL has been increased by roughly 10%, and the amount of metal processed on this line and then rejected for excessive curvature has decreased approximately sixfold.

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