ЛИТЕЙНОЕ ПРОИЗВОДСТВО

УДК 621.74.08 *Поступила 16.02.2015*

МЕТОД ИЗМЕРЕНИЯ КАЧЕСТВА ПОВЕРХНОСТИ ВАЛКОВ ДЛЯ ПРОИЗВОДСТВЕННОЙ ЛИНИИ НЕПРЕРЫВНОГО ГОРЯЧЕГО ЦИНКОВАНИЯ СТАЛЬНОГО ЛИСТА

THE METHOD OF ROLL SURFACE QUALITY MEASUREMENT FOR CONTINUOUS HOT DIP ZINC COATED STEEL SHEET PRODUCTION LINE

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Описывается разработанная система анализа поверхности валка в процессе горячего цинкования стального листа на производственной линии, в частности, проблема налипания металлических включений от валка к поверхности стального листа в процессе отжига, так называемое налипание. Сконструирована и испытана машина для проверки поверхности покрытий валков. Система позволяет анализировать качество поверхности валка в соответствии с явлением налипания от различных покрытий в зависимости от режима работы валков в печи отжига. Разработан алгоритм регистрации прочных налипаний на поверхность на основе обработки нескольких оптических изображений поверхности. Разработаны параметры для оценки качества поверхности с налипаниями. Оптическая система для регистрации изображений и обрабатывающая электронная схема могут использоваться в реальном времени на линии обработки.

The present paper describes a developed analyzing system of roll surface during the process of continuous hot dip zinc coated steel sheet production line, in particular, adhering problem by transferred inclusions from roll to steel sheet surface during annealing process so called the pickup. The simulated test machine for coated roll surface in processing line has been designed and performed. The system makes it possible to analyze roll surface condition according to pickup phenomena from various roll coatings concerning operating conditions of hearth rolls in annealing furnace. The algorithm of fast pickup detection on surface is developed on the base of processing of several optical images of surface. The parameters for quality estimation of surface with pickups were developed. The optical system for images registration and image processing electronics may be used in real time and embed in processing line.

Ключевые слова: *Налипание, поверхность печного валка, оцинкованный стальной лист.*

Keywords. *Pickup, hearth roll surface, zinc coated steel sheet.*

Introduction

Development of new systems of testing and surface quality inspection of roll surface in production processes is impossible without development of new methods of measurements adapted for solution of specific problems in connection with methods of data accessing and processing.

The present paper describes a developed system of analyzing method for roll surface quality, in particular, with the pickup problem, i. e. adhering by transferred inclusions to roll surface from the steel sheet surface in annealing process.

The simulation test makes it possible to analyze pickup phenomena from various roll coatings concerning operating conditions of hearth rolls of annealing furnace in which heat treatment of steel sheets is performed in the process of hot galvanizing in the CGL line at metallurgical works. In operating conditions, when steel strip contacts the roll surface, dry friction at low imposed load is of dominant importance.

In general, mechanisms of the pickup process strongly depend on many factors [2, 4] namely temperature, slippage between the strip and the roll, compositions of steel and steel sheet inhomogeneities, composition and roughness degree of the coating, and gas environment.

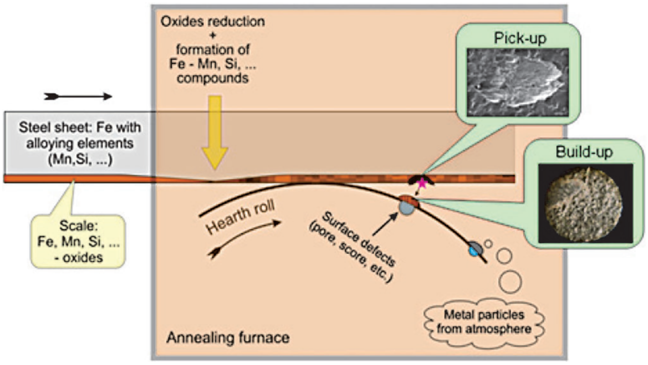


Figure 1. Formation of pickup and build up between steel strip and roll surface

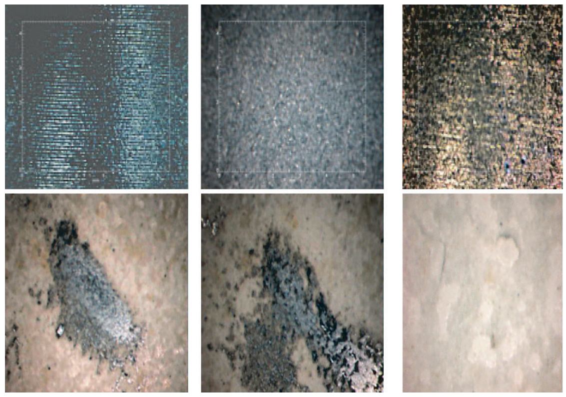


Figure 2. Roll surface images of different coatings after testing

Scientists of the Institute of Technology Metals of Belarus have developed an installation for testing of various roll coatings under simulated conditions, which are close to real ones of the heat treatment process in annealing furnace during continuous hot dip zinc coated steel strip production.

The main task of such test stand is to reproduce as much as possible operating conditions for the roll – sheet real contact in the conditions of annealing furnace. For this purpose the test stand will be designed and assembled taking into account the following factors of the operating conditions:

1. Material and coating selection for roll and sheet;
2. Controlled ambient temperature and gas atmosphere;
3. Controlled slip between roll and sheet;
4. Cyclic loading;
5. Conformal contact with low controlled contact pressure;
6. Controlled sheet tension and velocity.

The main characteristics of the installation are the following.

1. Roll – sheet temperature: up to 900 ^{o}C.
2. Sheet velocity: 3–6 m/s.
3. Rate of roll – sheet slip: 1–100%.
4. Sheet tension: 250–1000 N.
5. Controlled (nitrogen 85% + H_2 15%) atmosphere (normal pressure).
6. Total power of furnace heating and driving engines: 127 kilowatts.
7. Strip thickness: 0.3–1.2 mm.

Figure 3 has shown testing machine and its design for simulation of pickup phenomena.

The basic undesirable manifestation of pickup processes in practice is large volume of formation of metal objects from strip on the roll surface. Such objects can scratch the finished final production of strip with a very smooth surface [7] and cannot pass quality inspection of strip production.

The general mechanism of pickup phenomena has shown as Figure 1.

Testing has been performed using a low-carbon steel strip including large Mn content that can be created higher pickup generation rate.

Tested roll has used ceramic coated rolls which are using for strip production in metallurgical factory currently, and other plasma coated roll has set because of comparison for each roll surface.

After test, many kind of roll surface are presented as Figure 2.

Hence, an evaluation system of irregularity on the roll surface after the test has been presented.

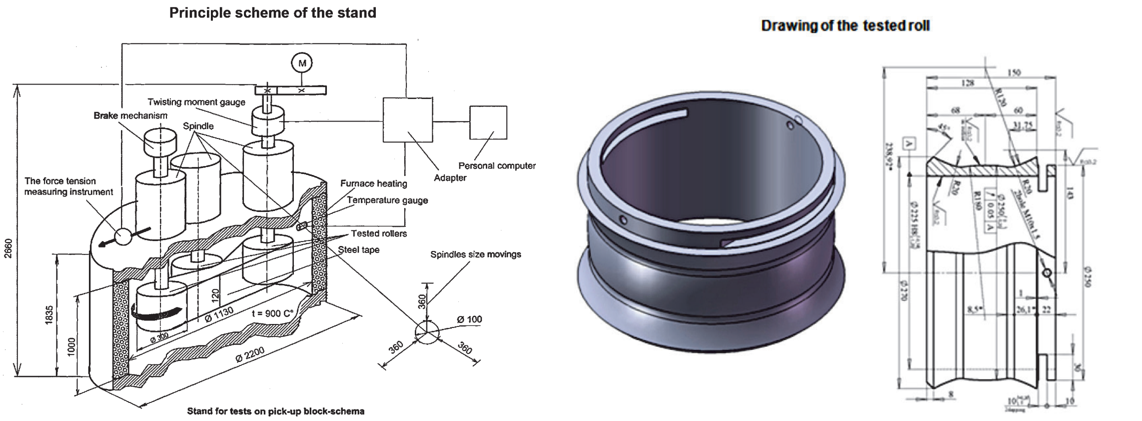
The system should meet the following requirements:

1. There are few sufficiently large pickups on the roll at any one time. That is why irregularity of the **whole** surface of the roll in an area of roll-strip contact is to be studied.

2. The system is to ensure pickup statistics such as mean density and density deviation, mean size and size distribution over the whole surface of the roll.

3. In addition, it has been noted that the roll can often have non-uniform coating sections with essentially changed properties. In this case, the mean values, deviation and other statistical parameters determined for the whole surface do not reflect a spread degree in full.

That is why the statistics over separate sections is significant, too. For example, the roll surface is divided into 100 sections and pickup statistical properties of every section are analyzed separately.



a

b

Figure 3. Pickup test stand machine and its design; a – design of pickup test stand and its roll, b- real pickup testing machine with assembled roll inserted low carbon steel strip

Thus, the measurement method for the roll contour is to ensure rapid measurement of all strongly exserted objects over the surface.

High-usage systems of contouring of the roll surface with the aid of ultrasound or magnetic induction (eddy-current tests) are rather expensive and slow [3, 8, 9] due to sequential measurements of small surface areas.

A usual reflected-light image of the surface does not show stable indications for discrimination between the roll coating surface and the pickup surface, especially for coatings with substantial metal content.

It is valid for both brightness/color indications and the textural ones, for example, based on wavelets, which show themselves to good advantage for analysis of other surface damages [1].

Moreover, there are no similar indications for revealing pickups markedly raised above the roll surface.

These conditions bring to necessity of the optical measurement method of surface irregularity by measuring a set of light sections and shades when several cases of oblique illumination of the surface exist.

In addition, the type of surface irregularities has a certain specification- relatively uniformed surface with isolated eminences. Specified eminence or big size with height of surface should be recognized.

Base scheme of the method

The base scheme of the method involves the analysis of more light sections and shades at oblique illumination of the roll surface.

In general, from the viewpoint of light reflection, clean ceramic and metal or composite coatings with high metal content reflect preferentially diffusely and specularly, respectively. In this case, being in operation, coatings are plated here and there with a relatively thin film transferred from steel sheets. That results in strong dependence of both the surface reflection coefficient and its diffusivity degree on a zone of the surface. In addition, there are significant amounts of metal from the strip, which form pickups and whose surface can also reflect light with considerable variability of the reflection coefficient and its angular dependence.

To describe an algorithm, let us first consider an elementary case. Let reflection of light from the surface be diffusive and drop monotonously along with an increase of the angle between a camera observation line and a light incidence direction. Let a single irregularity tower above a plane surface. We will call the irregularity of that kind as a hill. Then in case of the left-side illumination, the left section of the hill will have higher illuminance in comparison with the plane surface. To the right of the hill a shade (a section with lower illuminance) is formed (Fig. 4).

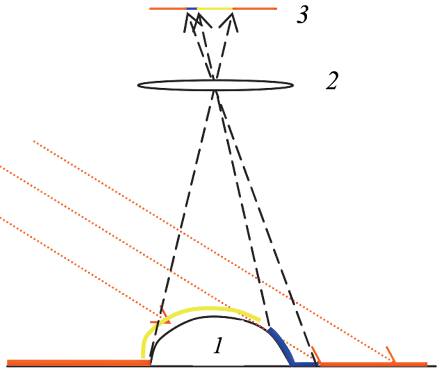


Figure 4. To explanation of formation of an image of a defect at oblique illumination: *1* – defect on the surface; *2* – digital camera lens; *3* – image plane; illuminated and shade sections are marked with yellow and blue colors, respectively

Ideally, these two light-shade sections are sufficient for detection of an irregularity on the surface.

In fact, reflection from metal with strongly irregular surface and presence of oxide films and similar objects on this surface is rather composite, because the same light-shade sections are formed and in case of sticking of a thin flat metal layer to the surface. The flat layer simply has different reflection coefficients in different spatial domains. Thus, this scheme makes it possible to reveal an actual irregularity with a probability of only 20–30%, even in case of trimming the algorithm of selection of light and dark sections with reference to the specified surface. Besides, the trimming operation of that kind is unreliable and inconvenient.

That is why we added the right-side illumination thus symmetrizing the scheme. In this case, we search for sections, which simultaneously, for example, form a shade at the left-side illumination and a lighter area at the right-side illumination and vice versa. Thus, if the same section of the surface has simultaneously lower illuminance at one illumination and higher one at the other, it is one of slopes of the irregularity. Now, when using two light-shade pairs, the probability of false identification of the flat layer as the irregularity becomes sufficiently small. In addition, if illuminance is higher at the left-side illumination and lower at the right-side illumination, it is the slope with a height rising from left to right and vice versa.

If the roll surface is smooth with sporadic irregularities, the further process is obvious, i. e. the algorithm searches for an opposite «pair» for each slope. If that is nearby, a single irregularity is detected. In addition, if the slope with a height increase to the right is situated at the left, and the opposite slope is situated at the right, we detect a hill, otherwise it is a depression.

However, sometimes the roll surface is rough in the range of spatial frequencies close to dimensions of pickups. Sometimes it is specially made, because roughness of that kind can reduce a number of stuck particles. In general, of course, it is impossible to select precisely one pair to each slope in this case.

Sometimes the reflection coefficient of light-colored ceramic coatings exceeds that of the stuck metal. In this case, the search can be easily restricted by stuck metal zones only. However, sticking of a thin metal layer to a large ceramic irregularity, of course, cannot be identified in this case.

But now this scheme will not identify some of irregularities (up to 50% in different cases) though it can be used for tentative surface evaluation.

Here the point is in types of irregularities and light reflection. Reflection from ceramic coatings is close to diffuse one and that from pickups and coatings with the high metal content is of a mixed diffuse-specular type. Contrast of light-shade sections will grow along with an increase of directivity of illumination; however, a light beam with a very small beam angle becomes strongly nonuniform after reflection from the surface. An optimum half-width of the beam angle for coatings and pickups under study is 10–15 degrees.

That is for detection of an accurate and stable light-shade boundary one should use illumination close to monodirected one with angles below 10 degrees from a beam axis.

However, even in these conditions, reflection from pickup is sometimes mainly specular and a major part of reflected light misses a lens that results in disappearance of light sections in the image. The other important reason is possible asymmetry of two pickup slopes due to one–way rotation of the roll and irregularity smoothing from the strip climbing side. There are also a number of other reasons requiring practical introduction of new images, which are presented below.

To increase probability of identification of single pickups, the scheme was modified by introduction of oblique illumination at two different angles resulting in recording of four images (Fig. 5). If the mirrors 5,6 will be reposition, the angle of incident light will be change.

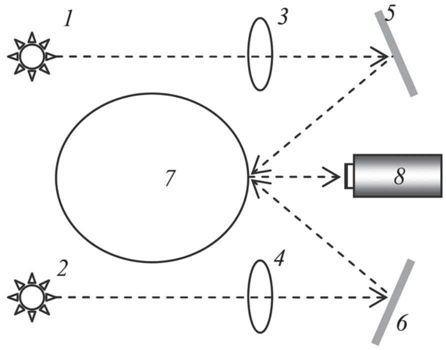
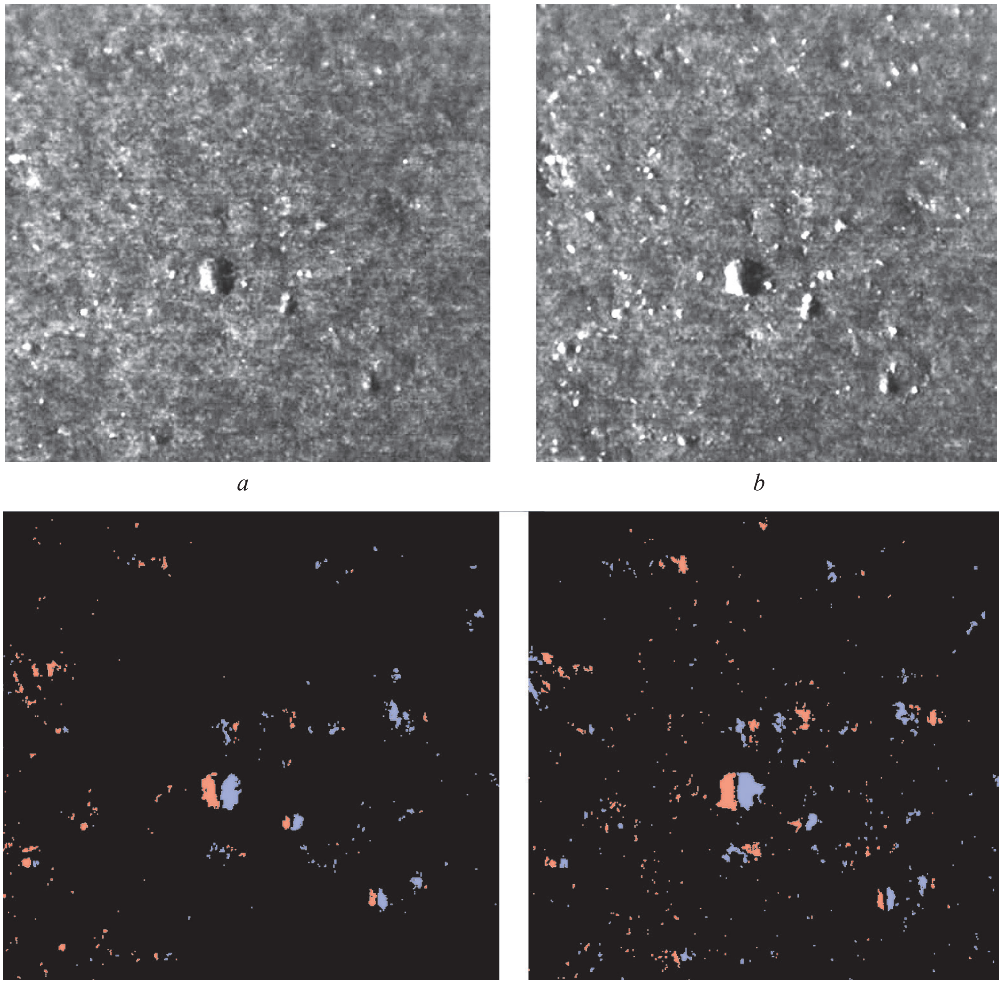


Figure 5. Measurement scheme with two illumination channels: *1*, *2* – illuminating lamps; *3*, *4* – condensers; *5*, *6* – reflecting flat mirrors; *8* – recording digital camera; *7* – roll under study



a *b*

c *d*

Figure 6. Initial images (*a*, *b*) at different angles of left-side illumination and artificial synthesized images (*c*, *d*). Sections with higher brightness at left light incidence and with lower brightness at right-side illumination are marked with red color. And vice versa are marked with blue color, respectively. Incident angles are 45 degrees (*a*, *c*) and 65 degrees (*b*, *d*)

The first angle is 40–50 degrees relative to the surface normal, the second is close to grazing incidence (about 65–75 degrees). As a rule, the incidence of that kind increases light-shade contrast but the image in this case contains many false details, which are not objects capable to scratch the steel strip.

Because sliding reflection is sensitive to very small irregularities of the surface, high-angle reflected light was averaged by a «running window» with the Gaussian blur function.

Two «left» images at different angles of light incidence are presented in Figures 6*a* and 6*b*.

Sections with higher and lower brightness at left and right light incidence, respectively, are rubricated on artificial synthesized images presented in Figures 6c and 6d. Accordingly, sections with inverse brightness distribution are marked with blue color.

Processing of registered images

Then images were binarized using a histogram and exposed to morphological treatment. At first, we removed «holes» in initial images. The hole is a set of background pixels, which cannot be reached by filling a background beginning from the object boundary line [5].

Then size insignificant details were removed. To do this, we used an operation of erosion of structural elements whose size was less than that of the object to be retained. To smooth area boundaries, operations of closure with a circular element were applied.

Then, to detect single irregularities, we began to search for pairs: for example, for each slope with left-to-right raising we searched for the opposite slope. The pair slope is searched in rectangles whose centers are situated at a specified distance at the left and the right of the center of the initial slope. If the pair slope exists and is unique, the irregularity is considered to be detected.

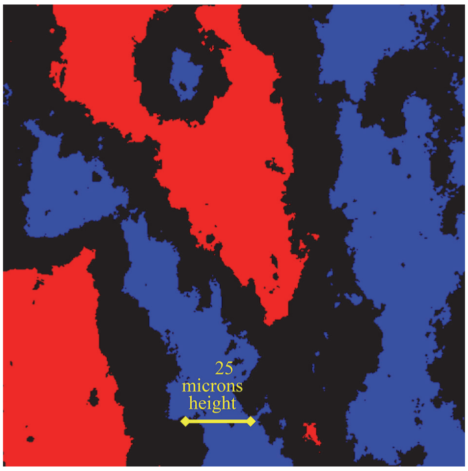


Figure 7. Image, analogous 4c, 4d, for high rough surface

As it was mentioned above, light-shade contrast of rough sections is increased along with growth of the angle of illumination incidence. At the same time, when illuminating at a large angle, there is probability to recognize the irregularity with a very small slope relatively to the surface. In order to avoid this, the recognition algorithm marks a single irregularity when the following conditions are satisfied.

1. There is a coupled pair of slopes detected at high-angle light incidence.

2. There is at least one slope detected at the light incident angle of 40–50 degrees in this section.

This principle of selection makes it possible to exclude irregularities with small depths and heights, but to consider irregularities with one of the slopes, which is gentle or reflects at an angle missing a light recorder.

In a case, when the algorithm recognizes both shades at two sorts of one-side illumination, it reconstructs not only a size of the irregularity but also its approximate height. The relation between lengths of shades is used for this purpose.

An example of computation of a height difference of the slope, which is detected to be a slope at both angles to the surface, is presented on Figure 7. It is not a pickup, but a slope on strongly rough surface.

Special aspects of method

Various lenses with different magnifications in the range between 5X and 50X and several types of light-sensitive cells were used for recording. The algorithm stably produces equal results in all cases of changing resolution of the light recorder from 100 to 500 pixels per millimeter without any tuning. During the treatment, one just should convert geometrical parameters of a smoothing function, morphological operations, search for a pair and others in such a way that they always correspond to a specified physical distance on the roll surface. When using a sufficiently wide photosensitive matrix with the lens of up to 200 pixel/mm in a macrography mode, the whole surface of the roll with a diameter of up to 70 cm is recorded in a file containing up to 100 frames.

In so doing, the size of frames is to be selected in such a way that differences in light-shade contrast at the center and on boundaries of the frame as well as geometrical distortions are negligible.

It should be noted that the algorithm quite stably works on many types of surfaces, and both the flat surface and the rough one can have reflectivity, which is very variable over the surface at that. The algorithm has been tested on several types of roll coatings and on surfaces with nonuniform heights and reflection coefficients. Even in these conditions, there is practically no false detection of height irregularities.

The probability of omission of a large irregularity of this kind does not exceed 20–30%. The omission mainly occurs at the expense of generally irregular in height background because unique selection of a pair for each slope is impossible in this case.

Being adapted, the algorithm can work in real time measuring the major part of height irregularities on a streaming object surface.

If the surface is sufficiently plane, almost all height irregularities can be detected, even in the presence of essential oscillations of the reflection coefficient over the surface. Hence, these four images obtained at various incident angles are sufficient for recognition in this problem. There is no necessity, for example, to use more compound schemes with shades from a larger number of light sources and a more complicated algorithm of reconstruction [6] or other more exact methods of the irregularity analysis requiring a considerable number of measurements in different ranges of incident angles of incidence, wavelengths, *etc.*

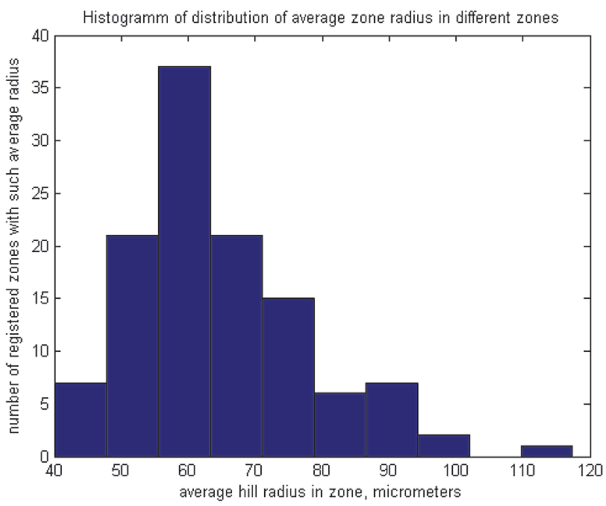


Figure 8. Distribution of average pickup radius in different zones of roll

Thus, this measuring system can embedded in a steel continuous treatment line for control of the roll surface and a degree of dent and scratching of steel sheets.

The example of statistics of metal irregularities arisen on the roll with a composite coating after several our tests at temperatures of 800 degrees with use of the strip made of low-carbon steel with high manganese content. We recognized objects with a radius of 40 microns and more. The mean radius of pickups was approximately 65microns. The total area of these objects was approximately 0.5% of the roll working zone area. Several large objects with a radius of 100–150 microns were also detected on the surface.

If the whole working surface is divided into 120 zones, a number of zones with the specified mean radius is distributed as is shown below (Fig. 8).

Conclusions

Thus, we have created a simple, fast and low-cost universal method for analyzing eminence objects on the surface, wherein the surface can reflect light as similar objects or significantly different type. This method can detect large objects in separate locations on the surface. The method requires little or no adaptation to the type of coating or to the type of recording device for the reflected light.

On this basis, we have obtained statistical data about foreign objects (pickups) on the roll surface, which can damage a steel strip. These data can be used as a criterion of the roll surface quality and for evaluation of quality of the roll surface coating.

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Сведения об авторах

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