ЛИТЕЙНОЕ ПРОИЗВОДСТВО

The approach to measure defect of mill products during their rolling is considered. The performance of supposed scheme is analyzed for real time conditions.

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MEASURING OF DEPTH PROFILE OF DEFECTS OF HOT ROLLED STEEL SHEET BY IMAGING THE GRATING ON SHEET SURFACE

The purpose of a surface inspection system is to detect and classify surface defects that impair product quality with regard to the requirements set by the user. Automatic inspection systems for metal surfaces have been available for some time, but not until recently, the development of electronics and information technology have made the actual image analysis applications possible. Manual inspection of end products slows down the entire process as it becomes costly, time consuming and also may impact the effectiveness of human labor due to the hazardous atmosphere of industry. Today automatic inspection systems use CCD-sensors to produce images of the defects [1–5].

For satisfactory exact measurement of depth profile at high speed we propose using of stationary light illuminance lattice on sheet surface and detect deformations of such lattice by some number of cameras. We propose to use power light source of blue light as illuminance source. Now such scheme is possible owing to development of ultra-bright blue and violet light emitting diodes with very narrow spectral band of light, less then 30 nm. Power blue lasers was developed too. Using of such sources and corresponding narrow spectral light filters give the possibility suppress proper steel red-yellow emission and detect only light, reflected from blue source. For correct illumination of overall depth profile of defect, vertical direction of incident light must be used.

To demonstrate how our scheme works let's consider only one line from sheet surface. This line is perpendicular to the direction of rolling. Let the light distribution on sheet surface is periodically linear (periodical triangles on our line, see Fig. 1).

Now let the coefficient of reflectance for all points of sheet on this line is the same (uniform reflectance from sheet). Then if sheet is flat, camera, positioned on some angle from vertical, will detect uniform grate as set of triangles (Fig 2, *a*). If we have deviation from flat surface, camera will detect another point. This detection point is situated in another place of our illuminance triangle and its brightness will differ from brightness of point, which can be placed on flat surface. (Fig 2, *b*). In this simplest case, difference of brightness is proportional by depth in this point.

Real situation is more complex than principal scheme described above. Really, the sheet surface points can have different reflectance coefficients, for example, impurity on surface can exist on sheet without depth changing. For such reason, we must measure reflectance coefficient separately. For such goal, another camera with optical axis perpendicular to the sheet's plane is necessary. So the data grabbed from cameras with inclined optical axes must be processed with account of reflectance coefficient distribution.

Existence of periodical grate with exact period and two cameras give the possibility to easy autocalibrate cameras periodically in time with high frequency. In principle, our grate can have any profile, and non-periodical structure. For example, we can place on grate two elements with double period. Searching of these elements on both cameras images is simple

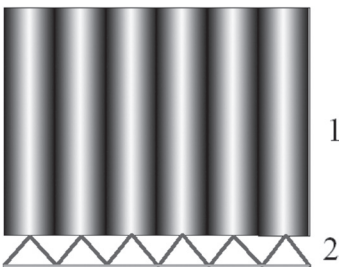

Fig. 1. Light intensity distribution on sheet surface for uniform reflectance coefficient: *1* – image of test object; *2* – intensity profile

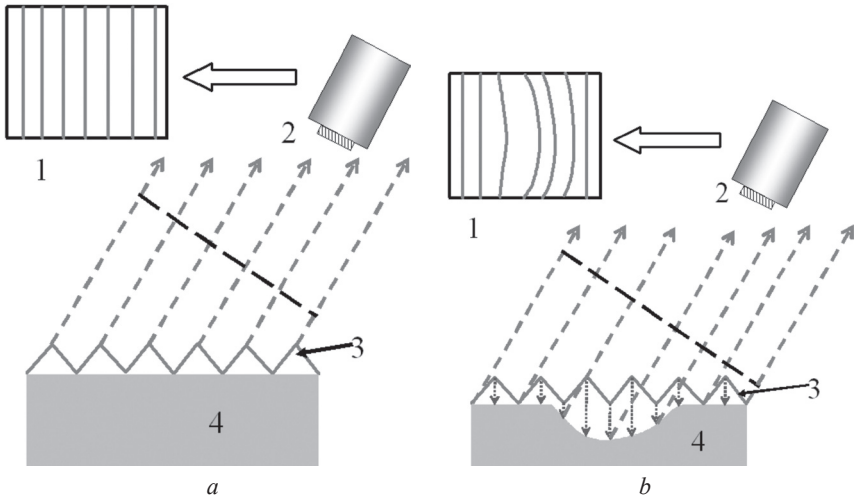

Fig. 2. Periodical light illumination imaging: *1* – grate pattern as result; *2* – digital imaging camera; *3* – intensity profile on the surface of flat steel sheet; *4* – steel sheet; *a* – without distortion for flat surface; *b* – with distortion for depth changing

task, and cameras calibration can be fulfilled for very small time.

In addition, we have to measure angle between sheet plane and horizontal plane in real time due to possible vertical shift of sheet during its motion. Grate image processing will be developed with account of this angle.

Comparing with one laser ray method, existence of spaced light grate gives the possibility to calculate depth in great number of sheet points simultaneously. Or, in another words, we measure depth at one concrete point many times. Averaging procedure will be sizeable suppress of noise influence.

The distortions of light propagation in air is maximal near the sheet due to air turbulence, non-uniform smoke distribution. Non-uniform attenuation and scattering which take place here may be significant in case of blue light. This is another reason to use additional camera with vertical optical axis.

As a result of our considerations we conclude to the following. For comprehensive measurement of depth profile we must use pair or better three cameras: one to measures reflectance coefficient and another one or two to measure depth profile (Fig. 3).

Now lets take a look about parameters of possible scheme. Let the grate has 100 periods with period length on sheet surface as 1mm. Let 10 pixels cover one period, i. e. one pixel of camera is projected on 100 mkm size on the sheet. Therefore, length of grate is 10 cm with 1000 pixels covering it.

Let sheet motion speed is 40 m/s. Sheet is moving across light zone during time 10 cm/(40 m/s) = 2.5 ms. In order to make 5 measurement of one point of surface during this time, we have only 0.5 ms or less per frame, so frame grabbing rate should be at least 2000 frames per second. Real exposure time of camera must be satisfactory small to avoid motion blurring during measurement. The image's shift on half of pixel during exposure means half pixel size on the sheet to divide on sheet's velocity, hence the exposure is 50 mkm/(40 m/s) = 1.25 mks. Such illumination condition may be satisfied with pulse laser or with some kind of light switcher (shutter) working at 2000 hertz frequency and pulse duration about 1 mks.

Let sheet width is 3m. To cover such width we need about 3 m / 10 cm × 1000 pixels = 30000 pixels along this direction, so high speed camera should be 30 Mpixels. It is very high value for high speed cameras. So we propose to use some number of camera's sets. Each triplet of cameras operates on its own bar on sheet surface. 10–15 sets of cameras with 2–3 Mpixels frame can be used for measurement (Fig. 4).

Each camera's set operates independently of each other and has data rate flow about 10 Gb/s. Working with this data rate flow excludes possibility for real-time image processing such as metrical and morpho-

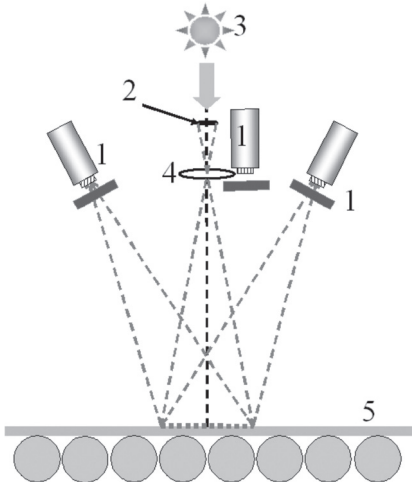

Fig. 3. Optical scheme with three cameras: *1* – Digital imaging camera with blue light filter; *2* – test object; *3* – blue light source; *4* – projecting optical system; *5* – moving hot steel sheet on rolling mill

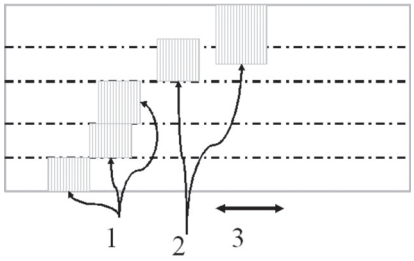

Fig. 4. Several sets of cameras cover whole width of sheet surface: *1*, *2* – non-overlapped and overlapped test areas covering stripes on the sheet; *3* – direction of sheet movement

logical classification of surface defects. Such image processing may be performed later on the recorded data – sequences of images grabbed from cameras. Real-time processing seems to be possible in defects detection mode. Its realization means following. The processing electronics is placed in conjunction with memory buffer for images. Lines from frame buffer of every camera are processed separately and in parallel way. Every scan line of frame buffer is analyzed with its own processor aiming to recognize presence of defects. Moreover, cameras should be adjusted thoroughly for detection mode so that scan lines of camera's sensors to be parallel to lines of illumination grate.

Partial overlapping of field views of cameras may be used for enhancement of reliability of system in the case of malfunction of one camera.

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