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LOW-COHERENT INTERFEROMETRY DEFECTS MEASUREMENTS

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Abstract: Profile measurement of the surface defects (with the depth of dozens of microns), based on the low-coherent interferometry, is discussed in this paper. The major challenge for production of such devices is selecting interference zones, which are used to determine the isolines of the defect depth. A direct way to find low-contrast interference zones in a large dynamic light range appears to be an extremely difficult procedure. We propose an effective interference zones localization technique based on the reference wave phase modulation that against others provides high measurement accuracy and reliability. The reconstructed 3D-image and depth isoline map of 50 µm deep defect on the metallic surface of the fuel element are also presented.

Keywords: surface defects, interferometry

1 INTRODUCTION

Noncontact control of the surface defects of different products is the actual problem in many branches of industry [1]. It is especially important for the critical products manufacturing when the presence of the surface defects (with the depth of dozens of microns) is directly related to reliability and safety of module and equipment operations in the machine-building, power engineering and nuclear power.

Among the devices designed for the surface defect control the special place is given to the profilometers, based on the low-coherent interferometry methods [2]. Unlike the traditional laser interferometry, in this case, on account of the small coherence length of the used polychromatic light source, interference field has the dimension along the object depth of the order of several microns. That allows selecting the information, corresponding to the different sections of three-dimensional object and, thus, reconstructing its profile. Such the devices have got the name «coherent radar» [2]. Potentially they have high accuracy of measurements and speed of response, which are very important while solving a number of problems of the exact control of industrial products. The main difficulty in realization of such profilometers relates to the selection of the interference zones, which define the isolines of the defect depth. In Ref. [3] it was proposed the device, using two conjugated recording channels for selecting the interference zones. But the using of this device does not allow obtaining high accuracy characteristics on account of the difficulty in providing with the identity of these channels.

We propose to use the worked out single-channel device of the surface defect measurement, based on the low-coherent interferometry, which provides high accuracy and reliability of the measurements. In this case, the required measurement information is obtained with the help of the light wave phase modulation in the single-channel scheme. Thus, the sources of errors, related to the two-channel recording device of the measurement information, are totally excluded.

We represent below surface profile measurement principle, based on the low-coherent interferometry, then single-channel device of interference zone selecting, based on the phase modulation, and experimental results.

2 MEASUREMENT PRINCIPLE OF THE SURFACE PROFILE

The measurement of the surface profile is based on the phenomenon of interference of partially coherent in time light waves, emitted by polychromatic light source (filament lamp, for example). Figure 1 represents the scheme of the measuring device on the base of Michelson interferometer, using the mentioned measurement principle.

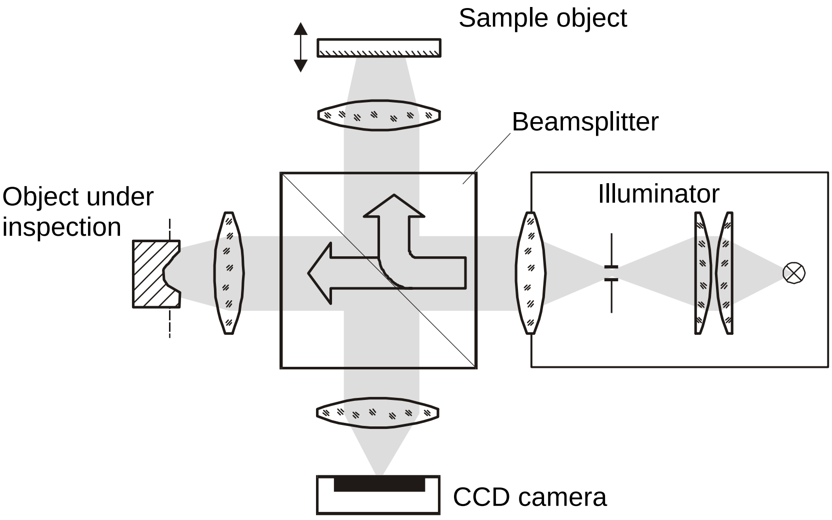

Figure 1. Measurement device scheme on the base of Michelson interferometer.

The measurable surface is placed in one of the interferometer arms. The collimated beam of the partially coherent light, leaving the illuminator, with the help of the beamsplitter, is divided into two parts. One part of the beam enters the interferometer reference arm and illuminates the sample object. Phase profile of the wave, reflected by this object, is determined by its surface profile. Measurable surface is illuminated by another part of the beam. In this case also the form of measurable surface determines the phase profile of the reflected wave.

Reflected from the sample object and measurable surface waves interfere in the plane of CCD camera. As well known, the interference of the partially coherent (in time) waves may be observed only if their phase difference does not exceed the coherence length. The condition of the interference existence determines the layer in the measurement zone, which depth is approximately equal to coherence length. The layer middle part coincides with the sample surface projection into the measurement zone (dash line in Fig. 1). Its position in the measurement zone is determined by the equality of the optical paths of the reference and measuring interferometer arms. For opaque, as metallic objects, the position and the cross configuration of the interference zone on the CCD matrix will be determined by the intersection of the sample surface projection (into the measurement zone) with the measurable surface (Fig. 2).

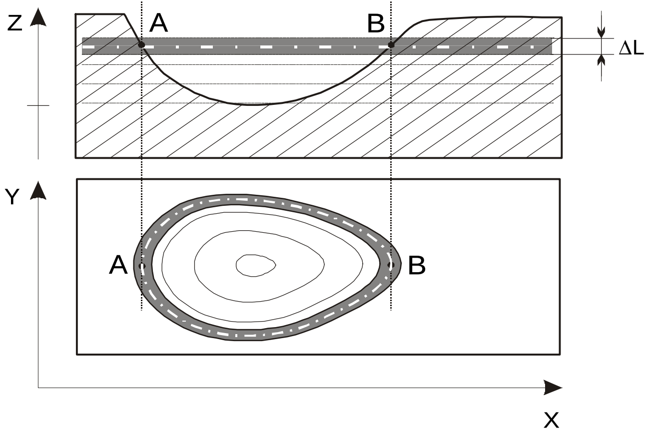

Figure 2. Intersection of projection of sample surface in the measurement zone with the surface under inspection.

That is the intersection, which determines the isoline of the defect, corresponding to the given depth along Z axis in the direction of the light beam, incident on the object. The recording of these CCD zones with camera allows to reconstruct this isoline.

For reconstructing the profile of the whole surface in the measurement zone it is necessary (with a certain step) to change the relative position of the measurable surface and interferometer block, and to extract the isolines of the depth. It can be realized by displacement of the measurable surface along the Z axis. Fig. 2 shows plane sample surface projections into the measurement zone for several values of the relative disposition of the measurable surface and interferometer block. The thick line is the layer in the measurement zone, for which the condition of the interference pattern existence on CCD camera is satisfied. Thus, the calculation of the coherence length for filament lamp (taking into account the spectral response of CCD camera) gives the following: $l_{\mathbf{coh}}$ » 3 µm. It means, that while comparing two waves, considered above, the interference zone will be localized in the layer along the Z axis, equal » 3 µm. In addition, the accuracy of profile measurement is determined by the accuracy of the interference zone shape detection. It depends not only on $l_{\mathbf{coh}}$, but also on the ways of registration of these zones.

The main problem in the registration of the interference zones is the small interference contrast and large dynamic range of light intensity of the interferograms recorded in the measurement zone. Intensity in the sample light wave can be found by selecting the reflectance or the scattering coefficient of the sample surface. Local distribution of the light scattered by measurable surface depends on the orientation of each area element of the surface, surface indicatrix of scattering, local absorption coefficient and many other parameters. In this connection, visibility of interferogram within the measurement zone may vary greatly, thus making difficult its registration. Since the observation plane is conjugated with the measurable surface, the result of interference is a local redistribution of intensity in the image of the measurable surface. A direct way in selecting of low contrast interference zones, superimposed on the image of the measurable surface, is a very difficult task.

This problem can be solved by means of interference zones registration using two conjugated recording channels (which record two-dimensional information). The phase between the channels is shifted on angle p, i.e. half the effective wavelength of the used polychromatic light source (differential interferometry) [3]. However, while using this method, one should mind strict requirements to the identity of recording channels. Thus, accurate characteristics of profilometer are reduced as a result of sensitivity deviation over the field, the disruption of geometrical similarity, and the difference of aberrations in the channels. It is very hard to achieve the channels identity under real conditions. In this case high engineering characteristics of the components of device, its thermostating and reliable protection from vibration are required.

3 LOCALIZATION OF INTERFERENCE ZONES BY MEANS OF LIGHT WAVE PHASE MODULATION

In this paper we propose to consider the measurement device of the surface defects allowing to increase the accuracy and reliability of the devices, based on the interference of partially coherent light. For that it is suggested to eliminate the second recording channel, and to use the light wave phase modulation in the reference arm of interferometer for localization of interference zones.

As the source of the partially coherent light a filament lamp was taken ($l_{\mathbf{coh}}$ » 3 µm). Light wave phase modulation in the interferometer's reference arm is achieved by shifting the reference object to a fraction part of the effective wavelength with the help of piezoelectric ceramics. Then, interferograms are recorded for each position of the sample object.

Then they are used to determine and localize the interference zones. The resultant signal $I(x,y)$ in every point of observation is the following:

$$I(x,y)=\sum_{j=1}^{n} A_j\left[I_j^0(x,y)+I_j(x,y,j_j)\right], \qquad (1)$$

where (x,y) determines the particular point of observation in the measurement zone (or the corresponding element on the CCD matrix), j - determines the number of interferogram, j_j is the value of the phase shift for the interferogram with index j, $I_j^0(x,y)$ – the average value of the intensity in the corresponding observation point (x,y) of the interferogram number j (it does not depend on the phase shift j_j), $I_j(x,y,j_j)$ – interference component, which value is determined by the interference of the waves reflected by the sample object and measurable surface, and A_j is the weight coefficient.

In the simplest case, while using two interferograms with the phase shift towards $j_2 - j_1 = p$ may be assumed $A_1 = -A_2$. In addition as the interferograms were obtained in the same recording channel, with high accuracy it may be assumed that $I_1^0(x,y) = I_2^0(x,y)$. Interference components in the intensity $I_1(x,y,j_1)$, $I_2(x,y,j_2)$ differ from zero only within the coherence length l_{coh}:

$I(x,y,j_1,j_2) = I_2(x,y,j_2) - I_1(x,y,j_1)$ for the following $|j_2 - j_1| \le (p \cdot l_{\hat{e}\hat{\imath}\tilde{a}})/l$

$I(x,y,j_1,j_2) = 0$ for the following $|j_2 - j_1| > (p \cdot l_{\hat{e}\hat{\imath}\tilde{a}})/l$

Thus, average intensity in the obtained differential interferogram is fully eliminated. The resultant signal $I(x,y)$ differs from zero only in those zones, where the interference condition is valid. Further signal processing allows to determine easily the defect depth isoline.

This method of interference zones selecting makes the device to be more resistant to vibrations and thermal drifts. As a result, the device becomes simpler, more reliable and has higher measurement accuracy and detecting ability.

4 EXPERIMENTAL RESULTS

Suggested method of interference zones selection is applied here to measure defect profile on the metallic surface of the fuel elements for the nuclear power-stations reactors – TVEL. The measurement results for one defect are presented in Fig. 3, where 12 differential interferograms for different sections in defect depth with a pitch of 5 µm are shown. On this figure one could clearly see the interference zones, which allow easily to reconstruct the surface profile isolines.

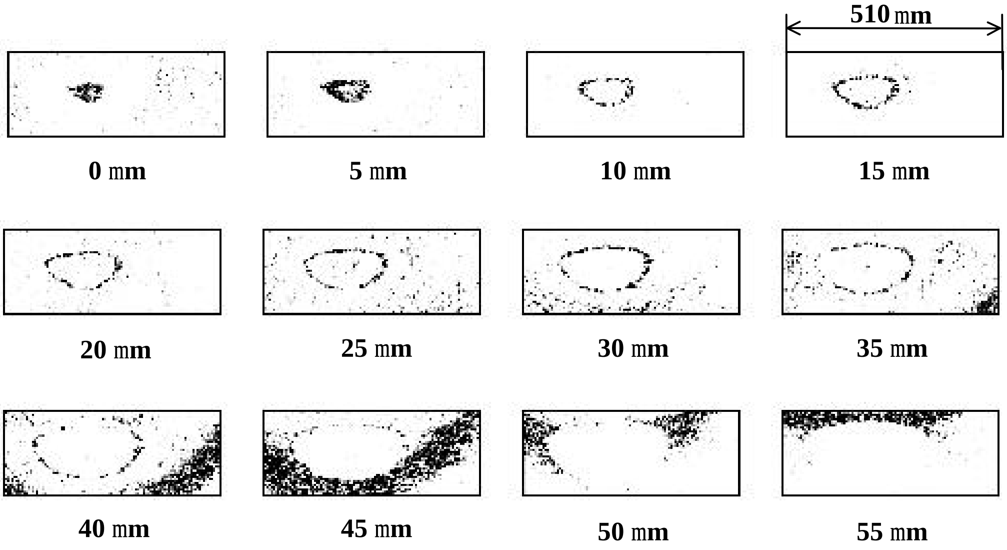

Figure 3. Differential interferograms for the different object shift.

The coherence length of the used light and local height deviation determines the interference zone width. The height change within the interference zone is equal to the light coherence length (»3 µm). The more precise definition of the interference zone middle part allows increasing the measurement accuracy.

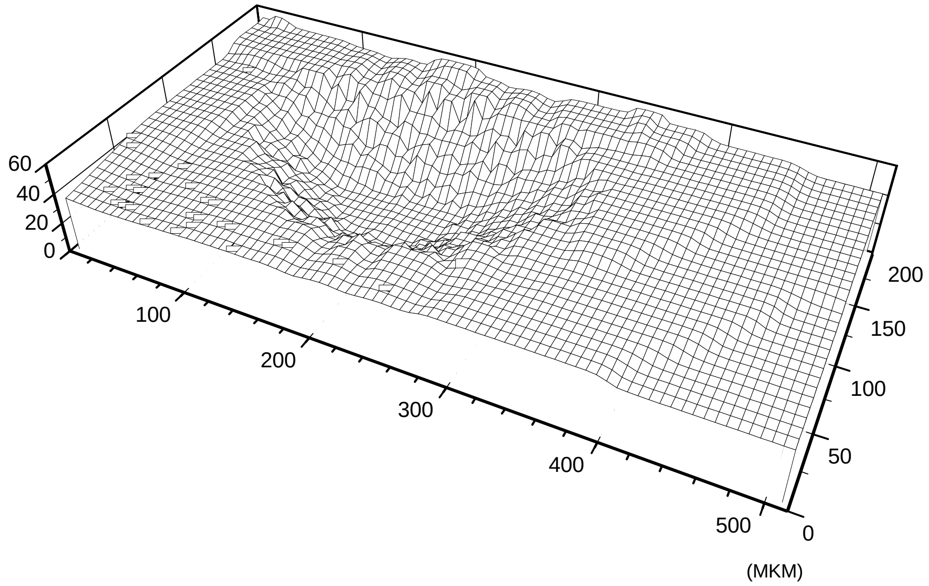

Figure. 4. Three-dimensional representation of the defect (µm).

The measurement results allow obtaining different notions of the measurable defect or the surface profile. Fig. 4 shows three-dimensional representation reconstructed on the discrete grid of depth isolines. Fig. 5 shows the reconstructed map of the depth isolines of the defect. The bottom of the defect determines zero value of the surface level. Using this picture, one can determine depth value for any point of the defect, and its such geometrical characteristics as depth and lateral dimension (the numbers denote the depth value in µm). We can see from the picture that the depth of the measured defect is about 50 µm. Presented measurement results conform to other measurement methods results.

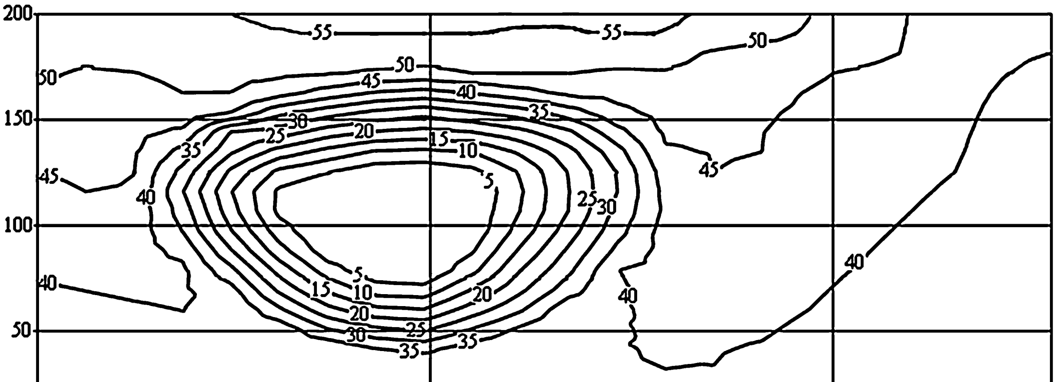

Figure 5. Depth isolines map of the defect (µm).

5 CONCLUSION

In this paper authors suggested the effective method of determination of the surface profile, in general, and the surface defects in particular, based on the low-coherent interferometry. Through using single-channel scheme of the interference zone localization the practical realization of profilometer becomes noticeably simpler and its engineering characteristics are improved. It is shown that the coherence length of the used polychromatic light source determines the resolution along the depth of the inspected object. For example, in case of using filament lamp it may be of several µm; and by the special processing – even the fractions of µm.

The effectiveness of the suggested method is verified by the measurement of the profile defects, including their depth on the metallic surfaces of the fuel elements (TVEL). The results can be used for the development and production of profilometers, having high accuracy and reliability.

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