A testing method for the machine details state by means of the speckle image parameters analysis

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Abstract. Non destructive testing method, allowing to define a residual resource of power details of mechanical engineering designs under the analysis of registered speckle-image parameters, it is discussed. The "chessboard" algorithm based on calculation of correlation between the given speckle-image and the a chessboard image is considered. Experimental research results of an offered non destructive testing method are presented. It is established, that to increase in quantity of a power detail tests cycles there is an increase in roughness parameters that conducts to reduction of correlation factor between reference and to resultants the image at the given stage of test. Knowing of correlation factor change dynamics, it is possible to define a residual resource of power details while in exploitation.

1. Introduction
Speckle image method is commonly used nowadays. Correlative analysis is usually used for the speckle images processing [1,2,3]. In [4] are defined the effectiveness limits of the correlative algorithms of speckle image processing for the roughness measurement of transparent and non-optically-transparent objects. To increase the sensitivity of speckle image method we brought new algorithm [5]. This algorithm uses the information of whole speckle image. Known methods utilize the information from the only row for wavelet analysis or correlogram along the X or Y axis or diagonal of the image [6]. The presented new method of speckle image processing makes it possible to detect the correlation between speckle image and chessboard structure leading to the possibility of defect parameters history observation.

2. "Chessboard" algorithm
This method makes possible the calculation of the correlation between the spots of speckle image and chessboard structure squares. For the simple one-dimensional model:

\[ t(p) = \sum_{n=-\infty}^{+\infty} \text{rect} \left( \frac{x}{d_{sp}} + nd_{sp} \right), \]

\[ t(d) = \sum_{m=-\infty}^{+\infty} a_m \text{rect} \left( \frac{x}{d_{ch}} + md_{ch} \right). \]
t(p) – brightness distribution of speckle image pixels, t(d) – brightness distribution of chessboard structure, $a_m=0$ with even m, $d_{sp}$ – size of speckle spot, $d_{ch}$ – size of chessboard structure square, $rect(x) = \begin{cases} 
 1 & |x| \leq \frac{1}{2} \\
 0 & \text{rest.} 
\end{cases}$ – rectangular function.

Equations (1) require that speckle image spots are all of the same size (or at least most of them).

To process the indiscrete brightness distribution described by equations (1) and (2) we need to digitalize them, for that we use Dirac comb function [2], as a result, we get the following:

$$t(p) = rect\left(\frac{x}{d_{sp}}\right) \ast comb\left(\frac{x}{d_{sp}}\right)$$

$$t(d) = rect\left(\frac{x}{d_{ch}}\right) \ast comb\left(\frac{x}{d_{ch}}\right)$$

* - convolution sign, $comb(x) = \sum_{n=-\infty}^{\infty} \delta(x - n)$ – Dirac comb function.

To find the Fourier spectrum of discrete functions (3) and (4) we use the direct Fourier transform, as a result, we get the following:

$$\hat{F}\{t(p)\} = \text{sinc}(f_{x}d_{sp}) \text{comb}(f_{x}d_{sp})$$

$$\hat{F}\{t(d)\} = \text{sinc}(f_{x}d_{ch}) \text{comb}(f_{x}d_{ch})$$

Getting the Fourier spectrums we multiply them together and use the inverse Fourier transform, which results in function of correlation between speckle image and chessboard structure.

If $d_{ch}=d_{sp}$ then multiplication of spectrums (5) and (6) gives us $\text{sinc}^2(f_{x}d_{ch})$ components, inverse Fourier transform of which equals $\text{rect}^2\left(\frac{x}{d_{m}}\right)$, which is triangular function $tri(x) = \begin{cases} 
 1-|x| & |x| \leq 1 \\
 0 & \text{in other cases.} 
\end{cases}$

Switching from one-dimensional case to two-dimensional case, we get the pyramid structure inside the single chessboard square. Chessboard structure with pyramid elements appears in case there are enough speckle spots of the same size (fig. 1).

If $d_{ch}>d_{sp}$ or $d_{ch}<d_{sp}$ then multiplication of spectrums (5) and (6) gives us unbalanced resulting image structure indicating the change of speckle size, and that means the increase or decrease of surface roughness with respect to chessboard square size.
3. Numerical simulation
During the research, we conducted the studies of the change process of roughness parameters and micro crack size. We simulated the life cycle of structural elements from initial values of roughness parameters to micro cracks with afterward destruction. To do that we had probed the surface with radiation of 0.65 $\mu$m wavelength after 5, 10, 15, 30 and 45 thousands of twist and bend cycles, which gave us speckle images with resolution of 512x512, thereby the surface roughness changed from 0.1 to 1.3 $\mu$m.

At the first stages of research before the experiment at Ra=0.1 $\mu$m we got the regular pyramid-like structure (fig. 1). We got this picture using correlation between speckle image and chessboard structure with cell size from 5x5 to 100x100 pixels and step of 5 pixels.

The regular structure was taken as reference. In the following analysis steps we analyzed the speckle images with the chessboard chosen after each cycle of the test. After that we calculated the correlation index between the original image and each of the following images, which is shown on Table 1, bottom row along with the chessboard images.

**Table 1.** Experimental data. Top row – speckle images, middle row – speckle images processed with chessboard method, bottom row – index of correlation between reference image and study sample.

| standard | 5000 cycles | 15000 cycles | 30000 cycles | 45000 cycles |
|----------|-------------|--------------|--------------|--------------|
| ![image](image1.png) | ![image](image2.png) | ![image](image3.png) | ![image](image4.png) | ![image](image5.png) |
| $K=1$ | $K=0.944$ | $K=0.87$ | $K=0.5$ | $K=0.03$ |
Outcome of the study is that with increase of cycle number roughness Ra also increases, and that leads to the disruption of regular chessboard structure (it turns into the chain). This causes the fall of correlation index from 1 to 0.5. With that micro cracks start appearing on the surface of the test subject resulting in crack after 30000 cycles. Subsequently the complete destruction of regular structure occurs.

Correlation coefficient dependence from of cycles number is presented on fig. 2, its left limit is the initial value of correlation index, its right limit is the test subject destruction.

![Graph showing correlation coefficient dependence from cycles number](image)

**Fig. 2 Experimental data**

Summing up, the diagnostic method described above is useful for non-destructive testing and determine to a remaining life of the power details in exploitations.

**References**

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