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APPLICATION OF MOIRÉ TOPOGRAPHY FOR INSPECTION OF SHAPE OF PUMP BLADES

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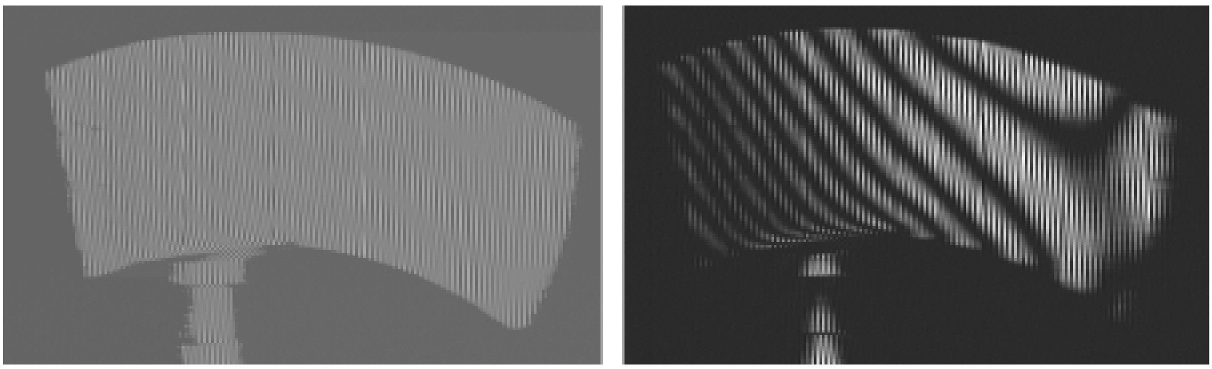
ABSTRACT: *The presented work is intent on the surface topography of space objects, exactly to the measurement of the shape of a pump blade. Such measurement is always said the topography. The aim is obtaining of the entrance data for a control of the accuracy of manufacturing of the given blade. The control is carried out comparing a measured shape with a given one. The projection moiré was used for the measurement (it is one of methods from the geometric moiré group). The reason of choice of this method is especially its experimental and technical simplicity. The principle of this method and possible modifications are introduced. The number of measured data is small and then the sensitivity of the method is small too. This problem can be solved using some special procedures, one of them is introduced here. It is the so called fringe shifting. The experimental set-up and several moiré interferograms as the example of the measurement results are presented at the end.*

KEY WORDS: projection moiré, topography, fringe-shifting method, washing-up method

1. Theory of the projection moiré

Generally the result of the moiré experiment is so called the moiré interference figure (pattern, moiré grating) being described as a system of dark and bright ill-defined bars. They origin as the result of the interaction of two (or generally several) periodic structures which are also called gratings. The example of the moiré grating of a blade is shown on Fig.**Chyba! Chybné propojení.**(a).



(a) (b)

Figure 1: The moiré pattern: (a) original, ill-defined, non-modified; (b) modified video-signal

Moiré methods can be divided from the point of view of the type of interaction into groups of the geometric moiré and the coherent moiré. The type of interaction is the superposition in first case and the interference in second case [**Chyba! Chybné propojení.**, **Chyba! Chybné propojení.**, **Chyba! Chybné propojení.**]. The projection moiré [**Chyba! Chybné propojení.**, **Chyba! Chybné propojení.**] belongs into the first group. The measured object is illuminated from two angles by the device called the slide projector. The schematic set-up of the projection moiré is on Fig.**Chyba! Chybné propojení.**.

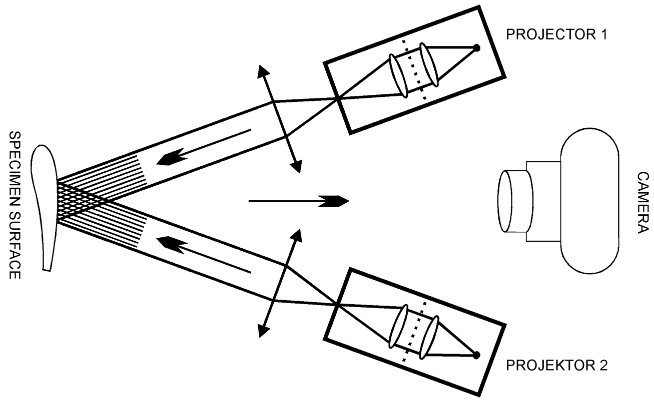


Figure 2: The principle of the projection moiré.

Both light gratings projected into the specimen surface create the moiré grating here on the principle of the superposition. Each fringe of the moiré grating represents the area with the same value of the topographic depth (the distance from some reference plane). The moiré grating can be observed visually or recorded by a camera. The observation by the CCD camera is used for the aim of this article. Result patterns in the digital form are prepared for next processing. The CCD camera is equipped with a special filtration unit making dark moiré fringes more visible and in this way more accurate computer processing possible. The digital filtration in the memory of computer using the Fourier transform is possible **Chyba! Chybné propojení.** alternatively to the filtration by the unit. The moiré pattern modified in such a way is shown on Fig.**Chyba! Chybné propojení.**(b).

1.1. Collimated illumination

The situation is shown on Fig.**Chyba! Chybné propojení.**. The specimen surface between points E and F is illuminated by two collimated beams under angles α and β from the perpendicular line of the reference plane creating by points A, B, C and D. Beams have got the character of light gratings with periods p_1 and p_2 which create in the reference plane an imaginary grating with period p. The following condition has to be valid

$$p = \frac{p_1}{\cos\alpha} = \frac{p_2}{\cos\beta}. \tag{1}$$

It is generally advantageous to describe every of gratings by the help of so called fringe orders [**Chyba! Chybné propojení.**, **Chyba! Chybné propojení.**]. Orders of both original gratings striking the specimen surface are marked by letters L and M, their values in the most important points are

$$\begin{aligned} L(\mathrm{A}) &= -\mathrm{q_A}; L(\mathrm{C}) = \mathrm{L}, \\ L(\mathrm{B}) &= -\mathrm{q_B}; L(\mathrm{D}) = \mathrm{M}. \end{aligned} \tag{2}$$

Values L and M don’t have to be the integer they are the real when there are not right the fringe of gratings on points C and D. The values $\mathrm{q_A}$ and $\mathrm{q_B}$ are numbers from the interval (0;1) and they are called the initial phases. They are generally nonzero because the 0-th fringe orders of both gratings don’t lie right on points A and B.

Originating moiré fringes are subtractive ones [**Chyba! Chybné propojení.**, **Chyba! Chybné propojení.**, **Chyba! Chybné propojení.**]. Following equations are valid for the moiré fringe orders on points E and F

$$N(\mathrm{E}) = L(\mathrm{D}) - L(\mathrm{C}) = \mathrm{M} - \mathrm{L} = \mathrm{N},$$
$$N(\mathrm{F}) = L(\mathrm{B}) - L(\mathrm{A}) = -(\mathrm{q_B} - \mathrm{q_A}) = -\mathrm{q}. \tag{3}$$

By the help of geometric relations the next result equation can be derived for the topographic depth $W(\mathrm{x})$

$$W(\mathrm{x}) = \frac{[N(\mathrm{x}) + \mathrm{q}]p}{\mathrm{tg}\,\alpha + \mathrm{tg}\,\beta}, \tag{4}$$

where $N(\mathrm{x})$ is the moiré fringe order in the point F of the x co-ordinate. That means the number of moiré fringes counted from the beginning in the point E. The value q which means the moiré fringe order in the point E is called the initial phase of the moiré grating. This value is nonzero when the 0-th moiré fringe order doesn't lie right in the beginning E.

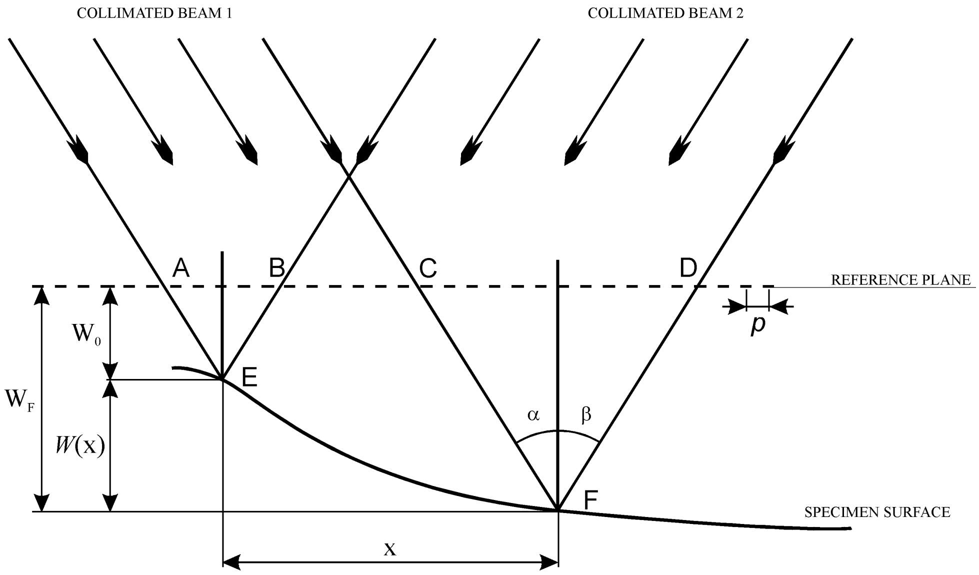


Figure.3: The schematic diagram showing the arrangement with the collimated illumination.

Small dimensions of the measured area are the main disadvantage of this arrangement. It isn't easy to create the collimated light beam of the large enough diameter for the measurement of large areas. This is taken off using the point illumination.

1.2. Point illumination

The basic scheme is shown on Fig.**Chyba! Chybné propojení.**. The principle of this arrangement is the illumination of the specimen surface from two point sources placed at the same distance *l* from the imaginary reference plane. Let's consider this distance is sufficiently large and at the same time the topographic depth *W*(x) is sufficiently small to obtain the same period *p* in the whole reference plane for both beams. Moreover let's consider such arrangement of the experiment the equation similar to **Chyba! Chybné propojení.** is valid for the period *p*

$$p = \frac{p_1}{\cos\frac{\alpha_1 + \alpha_2}{2}} = \frac{p_2}{\cos\frac{\beta_1 + \beta_2}{2}}. \tag{5}$$

For $\alpha_1 \to \alpha_2; \beta_1 \to \beta_2$ the illumination approaches to the collimated one and the equation **Chyba! Chybné propojení.** changes into the form **Chyba! Chybné propojení.**. Like in the previous case geometric formulas help us to derive the equation for the topographic depth [**Chyba! Chybné propojení.**, **Chyba! Chybné propojení.**]

$$W(x) = \frac{[N(x)+q]p(l+W_0)^2}{dl-[N(x)+q]p(l+W_0)}. \tag{6}$$

The equation is relatively difficult but some simplicities can be done. If the reference plane is chosen to pass thorough the point E ($W_0 = 0$) we obtain the following equation

$$W(x) = \frac{[N(x)+q]pl}{d-[N(x)+q]p}. \tag{7}$$

If in addition the condition $d >> [N(x)+q]p$ is realized the equation **Chyba! Chybné propojení.** passes into the form

$$W(x) = \frac{[N(x)+q]pl}{d} \tag{8}$$

This is in fact the same term as the equation **Chyba! Chybné propojení.** for the collimated illumination if we consider $\alpha_1 \to \alpha_2 \equiv \alpha;\ \beta_1 \to \beta_2 \equiv \beta$ and

$$\frac{d}{l} = \mathrm{tg}\,\alpha + \mathrm{tg}\,\beta. \tag{9}$$

From the point of view of the dimension of the measured surface it is more advantageous to use this arrangement with the point illumination. The simpler form of the function dependence can be obtained after approximations which have to be realized in the experimental set-up.

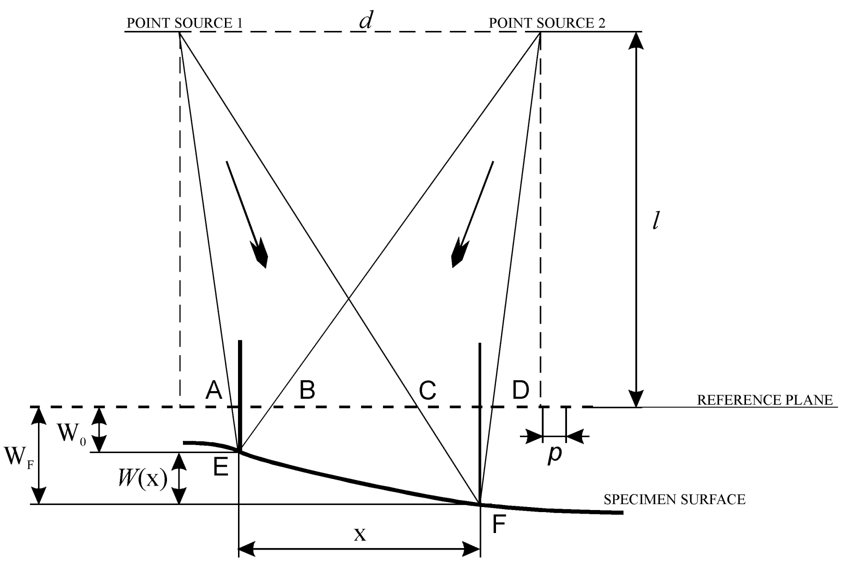


Figure 4: The schematic diagram showing the arrangement with the point illumination.

2. The shifting of projected gratings

2.1. Washing-up method

The relatively often used method founded on shifting of both projected gratings is the so called the washing-up one [**Chyba! Chybné propojení.**, **Chyba! Chybné propojení.**]. The moiré grating is describe by equations **Chyba! Chybné propojení.** and **Chyba! Chybné propojení.**

respectively and its shift depends except the others on the parameter q given by the relation **Chyba! Chybné propojení.**. Let's assume parameters q_A and q_B are changed by the same value. This way the value of the parameter q and certainly also the moiré pattern stay unchanged. Both projected gratings are shifted during all the time of exposition in the direction perpendicular to fringes. The magnitude of the shift is the whole multiple of periods. The result of such exposition is the unchanged moiré pattern without the linear background caused by recording of gratings. The way of realization of shifting in the used set-up is described in the following text.

2.2. Fringe-shifting method

The second more important optical-mechanical transformation makes a change of the moiré pattern possible changing only the one of parameters q_1 and q_2. It is often called the fringe-shifting method. In this case only the one of projected gratings is shifted in the direction perpendicular to fringes of the grating. The value q is changed and the moiré grating is shifted according to the relation **Chyba! Chybné propojení.** or **Chyba! Chybné propojení.** respectively. Because the topographic depth W(x) can be determined in the practice only at positions of moiré fringes (corresponding to integer values of the moiré fringe order $N(\mathrm{x})$) shifting of the moiré grating brings new measured data at other positions of the specimen surface and then increasing of the sensitivity of the measurement. Evidently the value of shifting of the parameter q_2 has to be less than the period of the grating p in the reference plane. The way of the realization of shifting in the used set-up is described in the following text.

3. Experimental set-up

The experimental set-up on Fig.**Chyba! Chybné propojení.** was designed for the realization of above mentioned methods and arrangements. Here the letter B marks the measured surface or its measured part respectively. It is illuminated symmetrically from two point sources realized by a slide projector and a system of mirrors. The slide projector L is equipped with the transparent linear grating G with the micro-shifting T which realize the shift of the grating in the direction perpendicular to fringes. The originated light grating is divided by the symmetrical divider D (the system of two perpendicular mirrors M1 and M2) into a pair of symmetrically placed mirrors M3 and M4 which reflect both beams to the measured specimen surface. One of these mirrors, e.g. M3, is also equipped with the micro-shifting realizing its rotation. The moiré pattern is recorded by the CCD camera C. The measured signal is processed in the unit U making the frequency and amplitude adjustment [**Chyba! Chybné propojení.**]. Such pre-processed signal is more visible on the monitor M or prepared for the next computer processing Cp respectively.

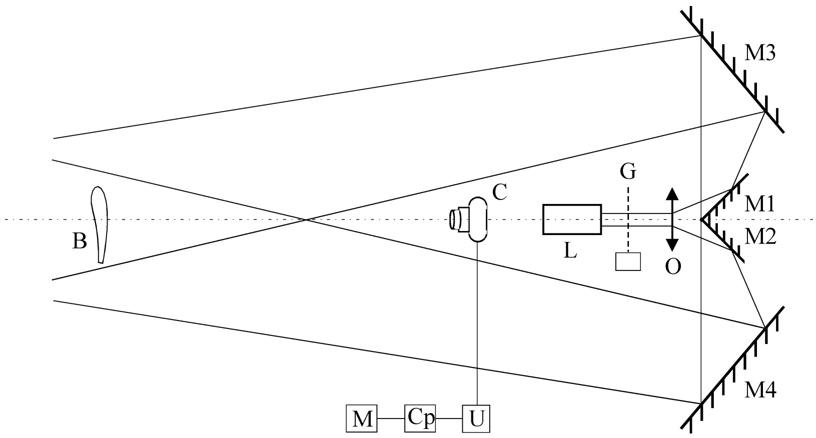
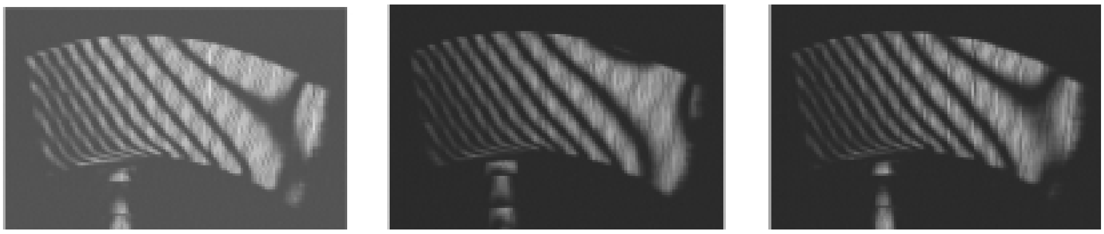


Figure 5: The experimental set-up of the projection moiré topography of a pump blade.

The ways of the realization of methods mentioned in Chap.2 are described now. The method of washing-up is realized by the micro-shift of the grating G. On the other hand the method of fringe-shifting can be achieved by the rotation of the mirror M3.

4. Experimental results

The result of the measurement is the set of moiré patterns obtained for various values of the parameter q_2. The parameter q is changed by the same value Δq as the parameter q_2. Several moiré patterns before computing of contour lines are shown for illustration on Fig.**Chyba! Chybné propojení.**.



(a) (b) (c)

Figure 6: Moiré patterns. The change of the parameter q by value (a)$\Delta q=0{,}2$; (b)$\Delta q=0{,}5$; (c)$\Delta q=0{,}8$.

The counted contour line systems from several moiré patterns are summed into the result map on Fig.**Chyba! Chybné propojení.** describing in the high accuracy the space form of the tested object.

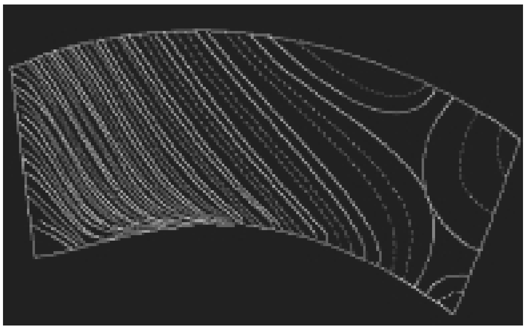


Figure 7: Contour lines describing the space form of the tested surface of a pump blade.

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