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INVESTIGATION OF MEASUREMENT OF LARGE AMPLITUDE VIBRATIONS BY USING THE METHOD OF REFLECTION MOIRÉ

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Abstract

This paper is a full article on the basis of the material presented in a conference paper. In agricultural devices vibrations of high frequency take place. Their precise measurement is an important engineering problem. Time averaged moiré methods are used for this purpose. Reflection moiré is applicable for the measurement of bending vibrations of structures of plate or beam type. Conventional applications are for small amplitude vibrations and interpretation of results is performed in the usual way. But interpretation of results is more complicated when the amplitudes of vibrations are large. Investigation of time averaged reflection moiré measurements of large amplitude vibrations of a simplified model problem is performed in this paper. For this purpose, a special simplified one-dimensional numerical model is developed and the possibilities of application of this method of measurement of large amplitude vibrations are investigated.
Keywords: *one-dimensional model, large amplitude vibrations, time averaged moiré, reflection moiré, measurement of vibrations.*

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1. Introduction

This paper is a full article on the basis of the material presented in a conference paper (Maskeliūnas R. *et al.*, 2019).

In agricultural devices vibrations of high frequency take place. Their precise measurement is an important engineering problem. Time averaged moiré methods are used for this purpose. Reflection moiré is applicable for the measurement of bending vibrations of structures of plate or beam type.

Conventional applications of reflection moiré techniques are for small amplitude vibrations and interpretation of results is performed in the usual way described in a number of papers. But interpretation of results is more complicated when the amplitudes of vibrations are large. Investigation of time averaged reflection moiré measurements of large amplitude vibrations of a simplified model problem is performed in this paper. For this purpose, a special simplified one-dimensional numerical model is developed and the possibilities of application of this method of measurement of large amplitude vibrations are investigated.

Measurement of vibrations by moiré methods, time averaging and related problems are investigated in (Ragulskis K. *et al.*, 2006), (Ragulskis K. *et al.*, 2020), (Maskeliūnas V. *et al.*, 2018), (Maskeliūnas V. *et al.*, 2016), (Maskeliūnas R. *et al.*, 2016), (Maskeliūnas R., Ragulskis K., Paškevičius P., Pauliukas A. *et al.*, 2015), (Maskeliūnas R., Ragulskis K., Paškevičius P., Patašienė L. *et al.*, 2015), (Ragulskis M. *et al.*, 2005), (Ragulskis M. *et al.*, 2002), (Saunorienė L., Ragulskis M., 2010), (Soifer V. A., 2001), (Timoshenko S. P., Goodier J. N., 1975), (Vest C., 1982). Moiré methods are among the basic engineering methods for analysis of vibrations of elements of various structures in agricultural engineering.

2. Model for investigation of reflection moiré for large amplitude vibrations

Further x and y denote the axes of the system of coordinates. The investigated structure in the status of equilibrium is assumed to coincide with the x axis. Moire grating and the photographic plate are assumed to be one over another at the same value of the y coordinate. Moiré grating and the photographic plate are parallel to the surface of the structure and the distance between them and the surface of the structure is constant and equal to d.

Schematic representation of reflection moire for measurement of large amplitude vibrations is presented in Fig. 1.

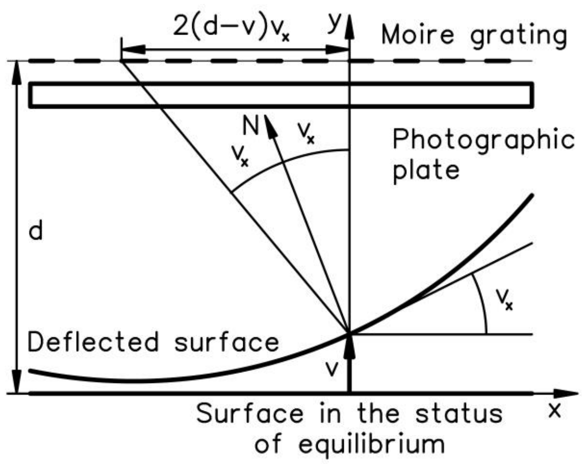


Fig. 1. Schematic representation of reflection moire for measurement of large amplitude vibrations: surface of the structure in the status of equilibrium coincides with the x axis, moiré grating and the photographic plate are parallel to the surface of the structure in the status of equilibrium, d is the distance between them and the surface of the structure, v is the displacement of the structure in the direction of the y axis, v_x is the derivative of deflection of the structure v with respect to x, N is the normal vector to the deflected surface of the structure

Further v denotes the displacement in the direction of the y axis. It is assumed that the displacement of the one-dimensional structure has the form:

$$v = kx^2 \sin \omega t, \tag{1}$$

where ω is the frequency of vibrations, t is time and k is a coefficient.

Intensity of the time averaged reflection moiré image is defined as:

$$I_1 = \overline{\cos^2 \frac{2\pi}{\lambda}\left(x - 2d\frac{dv}{dx}\right)}, \tag{2}$$

where the upper dash denotes time averaging and λ determines the width of moiré lines.

Intensity of the time averaged reflection moiré image is calculated as:

$$I_1 = \frac{1}{m}\sum_{i=1}^{m} \cos^2 \frac{2\pi}{\lambda}\left(x - 2d\left(2kx \sin 2\pi \frac{i-1}{m}\right)\right), \tag{3}$$

where m is a large integer number.

But for large amplitude vibrations this equation is to be modified: instead of d the distance $d - v$ is to be substituted. Thus intensity of the time averaged reflection moiré image for large amplitude vibrations is defined as:

$$I_2 = \overline{\cos^2 \frac{2\pi}{\lambda}\left(x - 2\left(d - v\right)\frac{dv}{dx}\right)}. \tag{4}$$

Intensity of the time averaged reflection moiré image for large amplitude vibrations is calculated as:

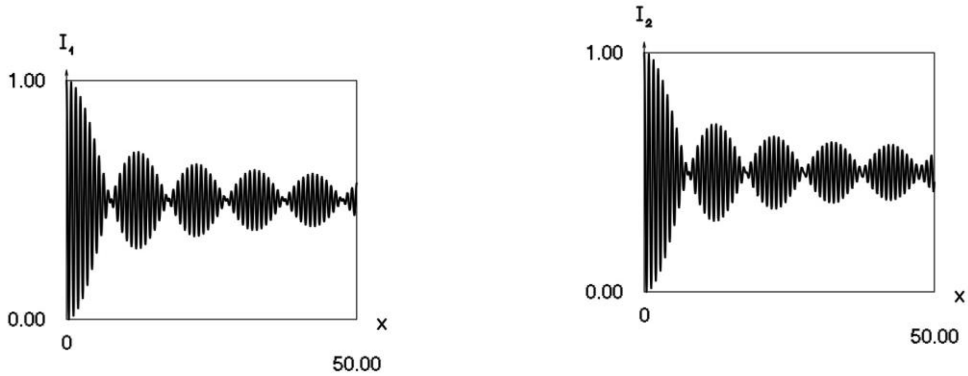
$$I_2 = \frac{1}{m}\sum_{i=1}^{m}\cos^2 \frac{2\pi}{\lambda}\left(x - 2\left(d - kx^2 \sin 2\pi \frac{i-1}{m}\right)\left(2kx \sin 2\pi \frac{i-1}{m}\right)\right). \tag{5}$$

3. Results of analysis of time averaged reflection moiré measurement of large amplitude vibrations

The following parameters of the model are assumed: $\lambda = 1.6$, $d = 10$.
Investigation is performed for a number of values of the coefficient k:

$$k = k_{\min} + \left(k_{\max} - k_{\min}\right)\frac{i-1}{7}, \tag{6}$$

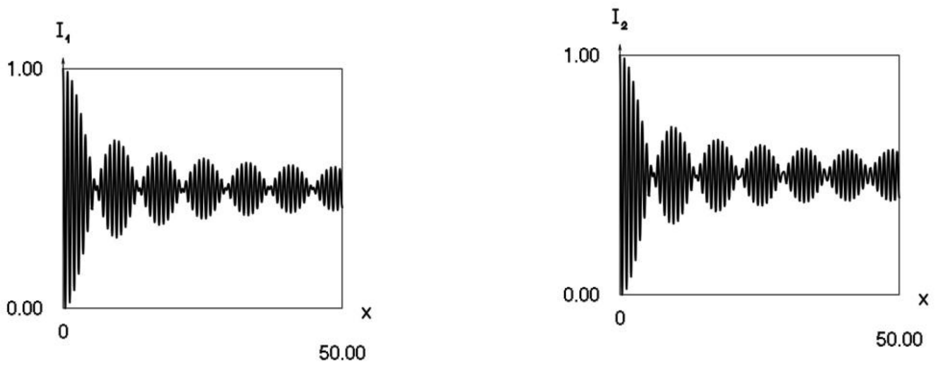
where $i = 1, 2, \ldots, 8.$ It is assumed that $k_{\min} = 0.001$ and $k_{\max} = 0.003.$
Results for $i = 1$ are shown in Fig. 2.



a) Vibrations of small amplitude b) Vibrations of large amplitude

Fig. 2. Investigation of the model for $i = 1$

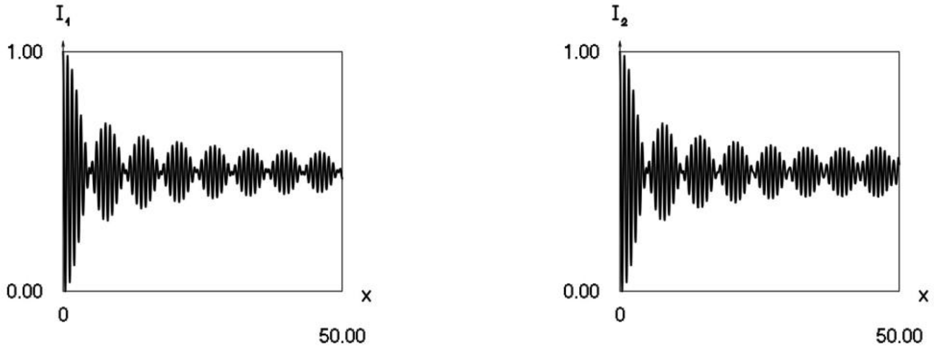
Results for $i = 2$ are shown in Fig. 3.



a) Vibrations of small amplitude b) Vibrations of large amplitude

Fig. 3. Investigation of the model for $i = 2$

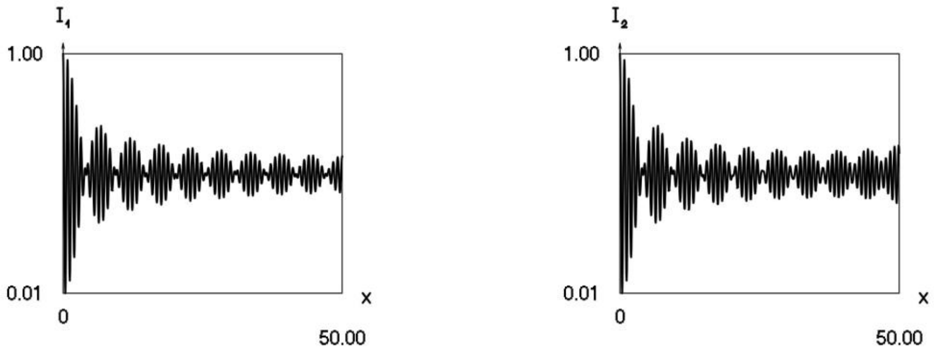
Results for $i = 3$ are shown in Fig. 4.



a) Vibrations of small amplitude b) Vibrations of large amplitude

Fig. 4. Investigation of the model for $i = 3$

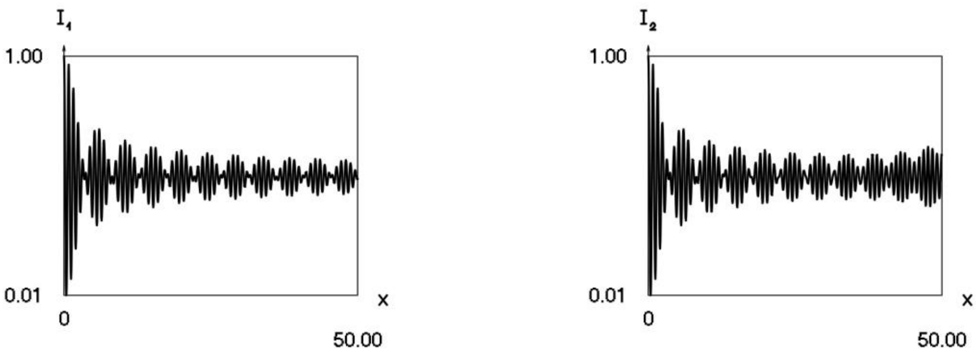
Results for $i = 4$ are shown in Fig. 5.



a) Vibrations of small amplitude b) Vibrations of large amplitude

Fig. 5. Investigation of the model for $i = 4$

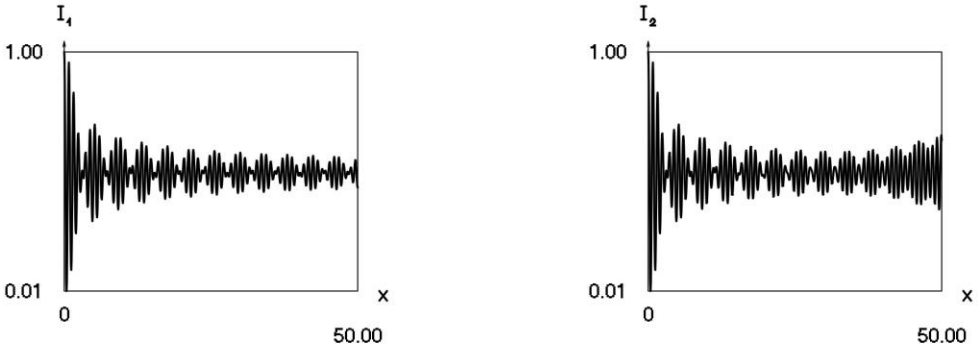
Results for $i = 5$ are shown in Fig. 6.



a) Vibrations of small amplitude b) Vibrations of large amplitude

Fig. 6. Investigation of the model for $i = 5$

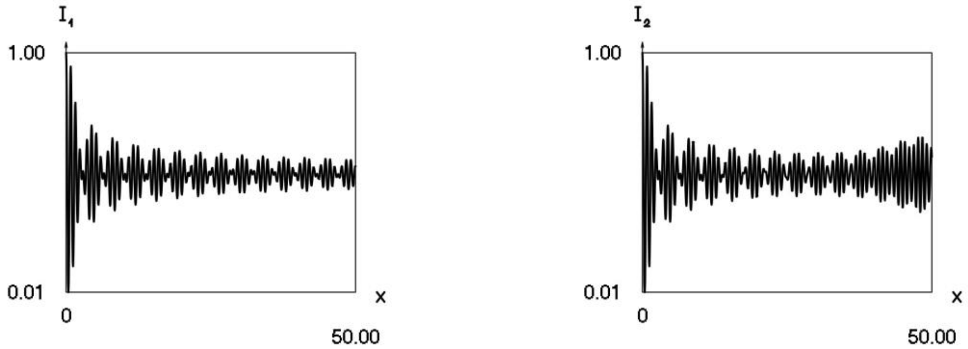
Results for $i = 6$ are shown in Fig. 7.



a) Vibrations of small amplitude b) Vibrations of large amplitude

Fig. 7. Investigation of the model for $i = 6$

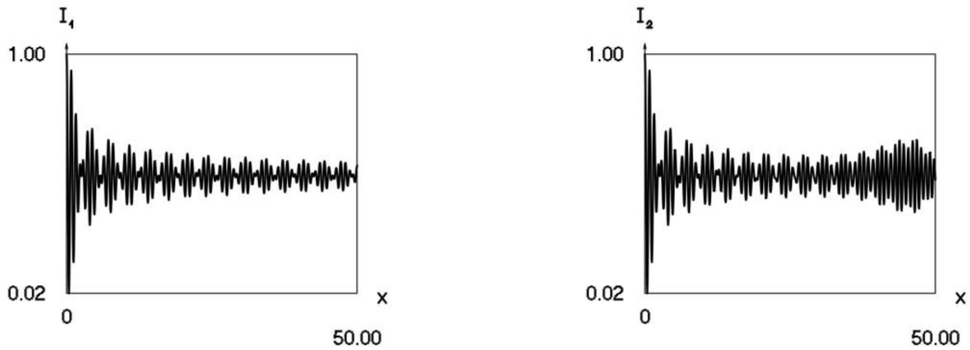
Results for $i = 7$ are shown in Fig. 8.



a) Vibrations of small amplitude b) Vibrations of large amplitude

Fig. 8. Investigation of the model for $i = 7$

Results for $i = 8$ are shown in Fig. 9.



a) Vibrations of small amplitude b) Vibrations of large amplitude

Fig. 9. Investigation of the model for $i = 8$

Graphical relationships show the importance of use of more precise equation for estimation of intensity of time averaged reflection moiré images when vibrations are of large amplitude.

Detailed description of interpretation of experimental time averaged reflection moiré images when vibrations are of small amplitude is presented in (Ragulskis M. *et al.*, 2006). This interpretation is based on the roots of the zero order Bessel function of the first kind and approximate integration from the fastened edge of the structure performing harmonic vibrations according to the eigenmode.

From the figures presented in this paper for the investigated model problem it is seen that the results when vibrations are of large amplitude differ from the results when vibrations are considered to be of small amplitude: this difference is especially evident in the places of the structure where the amplitudes are large and especially at the places where the envelope of the graphical representation of intensity of the image for small amplitude vibrations crosses the value equal to 0.5, that is corresponds to grey color exactly in the middle between black and white.

From the presented results it is concluded that for interpretation of time averaged reflection moiré images for large amplitude vibrations a special procedure based on generalized zero order Bessel function of the first kind should be used.

4. Conclusions

Time averaged reflection moiré is a typical measurement technique applicable for various structures in agricultural engineering. Conventional applications of reflection moiré techniques are for small amplitude vibrations.

Investigation of time averaged reflection moiré measurements of large amplitude vibrations of a simplified model problem is performed in this paper. The presented graphical relationships show the importance of use of more precise equation for estimation of intensity of time averaged reflection moiré images.

Interpretation of experimental time averaged reflection moiré images when vibrations are of small amplitude is based on the roots of the zero order Bessel function of the first kind and approximate integration from the fastened edge of the structure performing harmonic vibrations according to the eigenmode. From the figures presented in this paper for the investigated model problem it is seen that the results when vibrations are of large amplitude differ from the results when vibrations are considered to be of small amplitude: this difference is especially evident in the places of the structure where the amplitudes are large and especially at the places where the envelope of the graphical representation of intensity of the image for small amplitude vibrations crosses the value equal to 0.5, that is corresponds to grey color exactly in the middle between black and white. Thus from the presented results it is concluded that for interpretation of time averaged reflection moiré images for large amplitude vibrations a special procedure based on generalized zero order Bessel function of the first kind should be used.

In agricultural machines vibrations in the process of their operation take place because of disbalances of motors, impacts between their elements and other excitations. In order to investigate those vibrations moiré methods are used usually investigating the motion of a flat surface of the case of the machine. This enables to identify the eigenmode according to which vibrations take place and to estimate amplitudes of vibrations. This paper shows the influence of the fact that vibrations are of large amplitude to the results of time averaged reflection moiré measurements.

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