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LABORATORY OPTICAL MEASUREMENT OF MODEL BLADE VIBRATION UNDER ROTATION

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Abstract: *The optical method for the accurate laboratory measurement of blade vibration under rotation was proposed in IT AS CR. This method is based on the fast optical-elements that register time passages of the blades. The description of the method and first experimental results of the model blade vibration under rotation will be discussed.*

Keywords: ***blade, tip timing, optical measurement.***

1. Introduction

The turbine blade and blade disc dynamics research started in the laboratory Vibrodiagnostics and non-linear dynamics, IT AS CR in late 70th years of the last century with turbine blade development and testing in Skoda Works, Plzen. After 1989 the blade disc research was first aimed on vibration diagnostics of blades in service and their residual life estimation Daněk et al. (1993,2001). The latest research of dynamic behaviour of blade discs deals with non-linear blade couplings and usage of high-damping materials Pešek et al. (2008, 2009 and 2010).

For laboratory accurate contactless measurements of blade vibration under rotation the new optical method based on the optical displacement sensor was developed in IT AS CR. At first the optical sensor was assembled and tested under a static condition. Then the time responses of the sensor was tested under rotation and at last the circumferential vibration of the model blade wheel was evaluated. For the evaluation of the circumferential displacement of the blades the tip-timing method was used.

2. Design and static calibration of the optical sensor

The optical displacement sensor consists of minilaser FP-65/1A-LWL-SMA with the emissive power 10mW coupled with the optical fiber and the light beam detector Si-PIN diod SD200-11-31-241 with circular surface (∅5 mm) and response time 8ns. Homogennous parallel light beam transmission from the optical fibers is ensured by the collimators F-C5-S2-543 placed on the free ends of the fibers. For the light transmission between the laser and the collimator and the collimator and the PIN DIODE the optical multimode fibers ended by SMA connectors on both sides of the fibers.

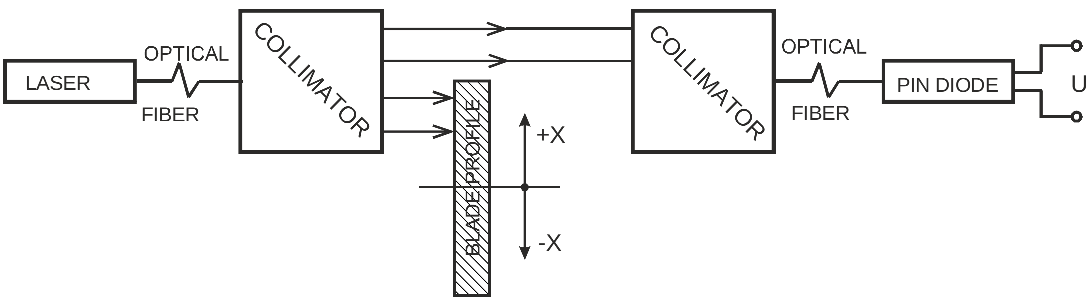

Fig.1 Scheme of the optical sensor measurement

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The output voltage change of the light detector is proportional to the intersection of the laser beam foot mark and the blade profile. Transfer relations between the output voltage and the incursion of the profile into the beam foot mark was ascertained by the calibration of the sensor by means of the x-y coordinate table SOND A1 with a step 0,01 mm (Fig.2).

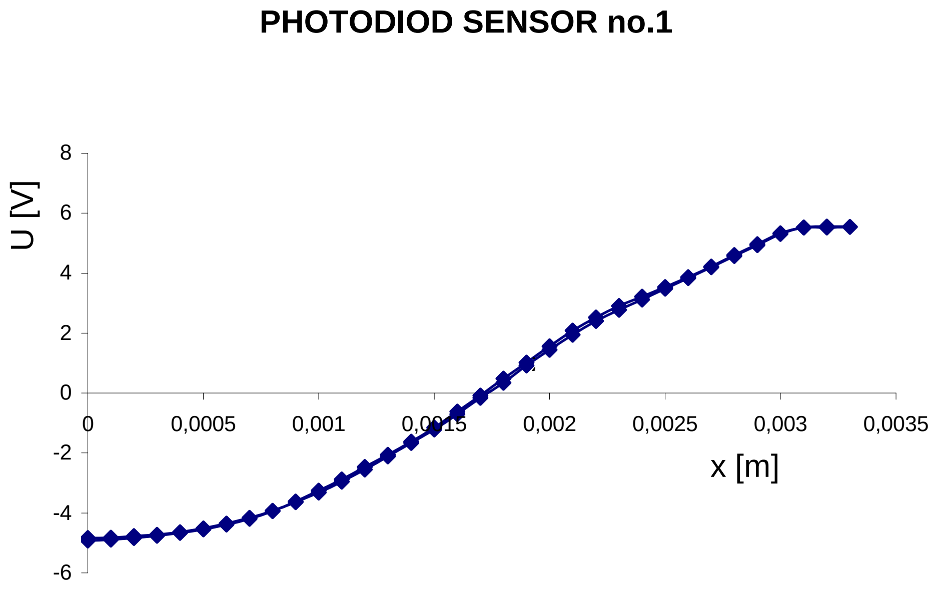

Fig.2 Output voltage of the light detector versus the blade incursion into the beam light

3. Experiment under rotation

The fixtures of the optical sensor were manufactured for the dynamic calibration on the test blade wheel. The cut view of the tested bladed disc with the electromagnet (EM) and the optical displacement sensor (ODS) is shown in the Fig.3. Diameter of the disc was ∅505mm. The disc is equipped with sixty prismatic beam blades (190mm length). The picture of the ODS set-up is visible on the Fig.4.

The strain-gauge was glued on the side surface of the blade at its root for measuring of the circumferential displacement. Its calibration was performed by the acceleration measurement of the blade tip at the impact excitation. The electromagnet UTM4 (Fig.3) excited the blades under rotation. The components of the electromagnetic force are both in axial and circumferential directions of the wheel (Pešek, 2009). Due to the position of the magnet, however, the axial force prevailed over circumferential force. Therefore for maximizing the excitation effect in the circumferential direction, the excitation frequency was tuned to the resonance frequency 332Hz of the first circumferential flexural mode of the blade and the revolution speed was set to the value 83rpm corresponding the 4^{th} engine order excitation.

The strain gauge, ODS, supply current of the electromagnet and phase mark signals of the forced vibration of the blade B30 were recorded with a sampling frequency 2MHz by the digital oscilloscope YOKOGAWA DL750.

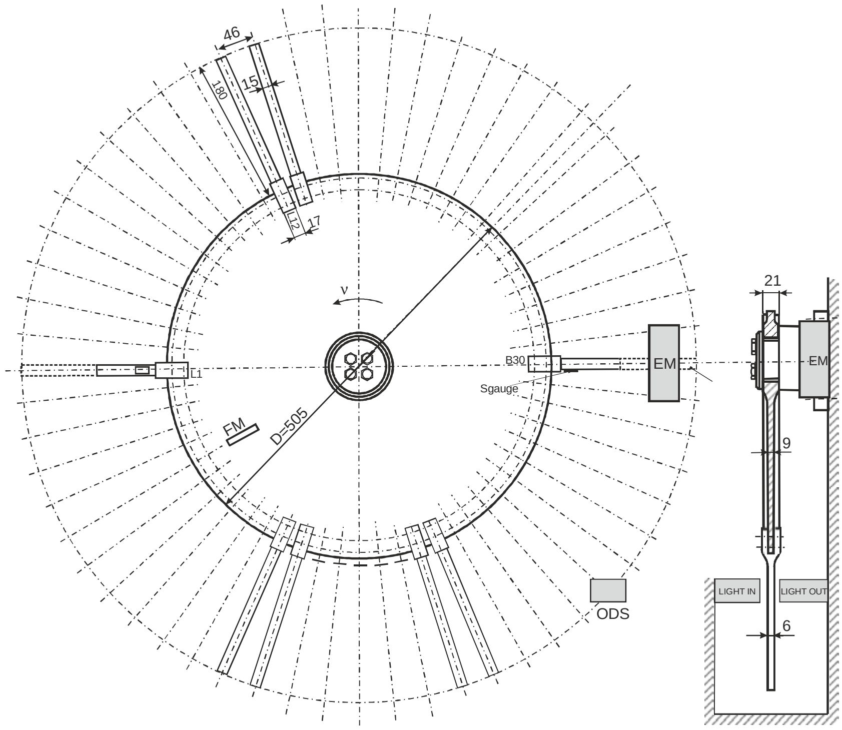

Fig.3 Sketch (front and side views) of the blade wheel with the electromagnet excitation (EM), strain gauge (Sgauge) and optical displacement sensor (ODS).

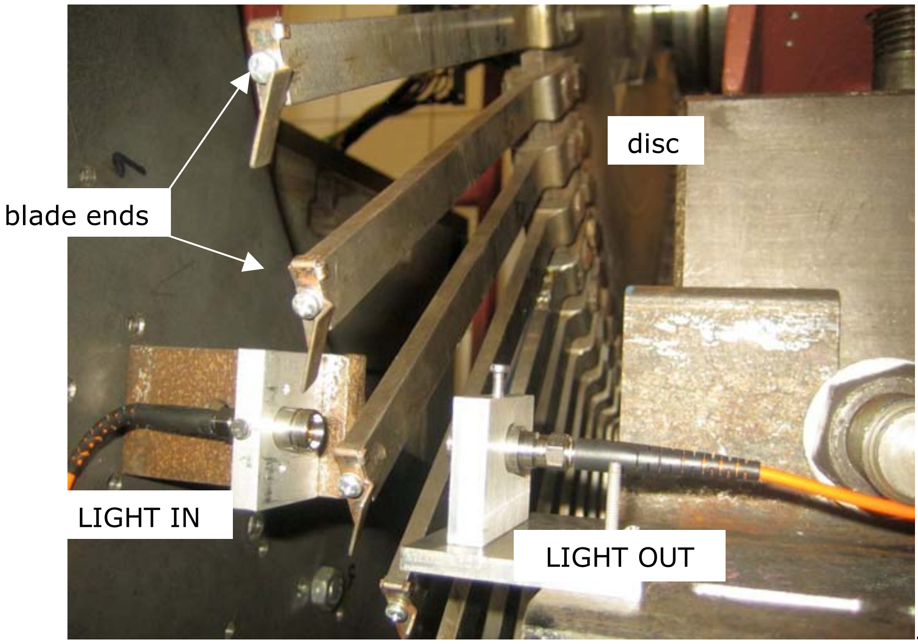

Fig.4 Picture of the experimental set-up.

First the time characteristics of the output voltage of the DIODE detector without the collimator and optical fiber were analyzed without the electromagnetic excitation for different revolution speeds (300, 700, 800rpm). The optical sensor ODS placed on the stator registered time passages of all blades. The results of voltage characteristics transformed from time to angle-position dependences are depicted for the six blade passage in the Fig. 5. Despite the high response time of the DIODE detector, the dependence of the characteristics on the revolution speed appears. Nevertheless the gradient of the diode opening and closing remains almost same in the operating range of speeds.

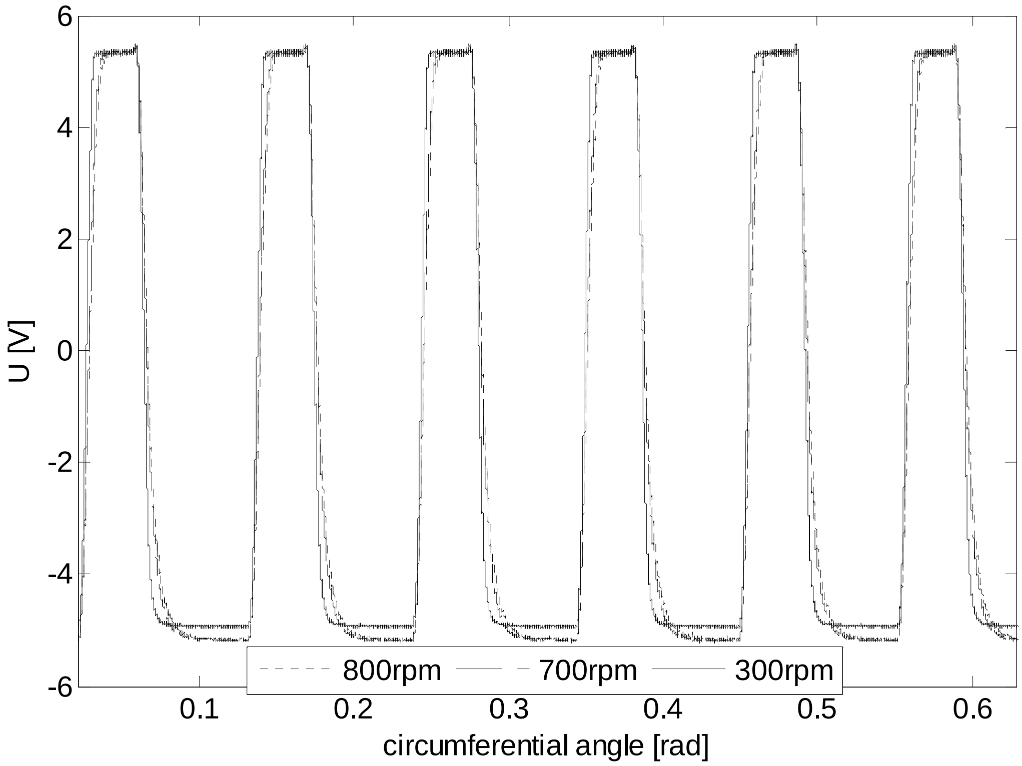

Fig.5 Position versus voltage dependences of the ODS sensor for 300, 700 and 800rpm in the period of the first six blades' passage.

After the analysis of the DIODE detector characteristics under rotation, the optical sensor (Fig.1) was tested for the blade vibration evaluation at the electromagnetic excitation. Besides the optical measurement of the blade passages, the passages of the rigid wheel with 60 notches were registered at the same time. Then the circumferential displacement Δv_{ij} of each blade tip *i*=1,2,..,60 was evaluated from the time differences $\Delta t_{ij} = t_{ijB} - t_{ijR}$ of the leading edge arrivals t_{ijB} of the blade passages and the leading edge arrivals t_{ijR} of the corresponding notch in each revolution *j*=1,2,..,n of the wheel. The displacements Δv_{ij} can be calculated from Δt_{ij} using the simple kinematic relation (Pešek, 2008)

$$\Delta v_{ij} = \Delta t_{ij} \dot{v}_{ij} = \Delta t_{ij} 2\pi f_{ij} r \ , \tag{1}$$

where f_{ij} is a revolution frequency (Hz), *r* is a distance of the ODS sensor from the rotation axis. The revolution frequency is evaluated from differences of trigger times of the phase mark for each revolution. The measured data were processed by the numerical program developed in the MATLAB.

The amplitude spectrum of the blade B30 vibration is drawn in the Fig. 6. The component of the circumferential vibration of amplitude 3μm and frequency 338Hz is close to the resonant frequency 332Hz. The level of vibration, however, was very low almost on the noise level of the strain-gauge measurement. Therefore for the time result comparison with the ODS measurement, the strain-gauge signal was substituted by the "noise-free" sinus characteristic with frequency 338Hz and amplitude 3 μm. The comparison of the ODS displacement of the blade B30 with the "filtered" and downsampled strain-gauge displacement is shown in the Fig.7. The downsampling is inevitable because the ODS blade displacement characteristic is sampled only by the revolution frequency for the configuration of one sensor on the whole perimeter.

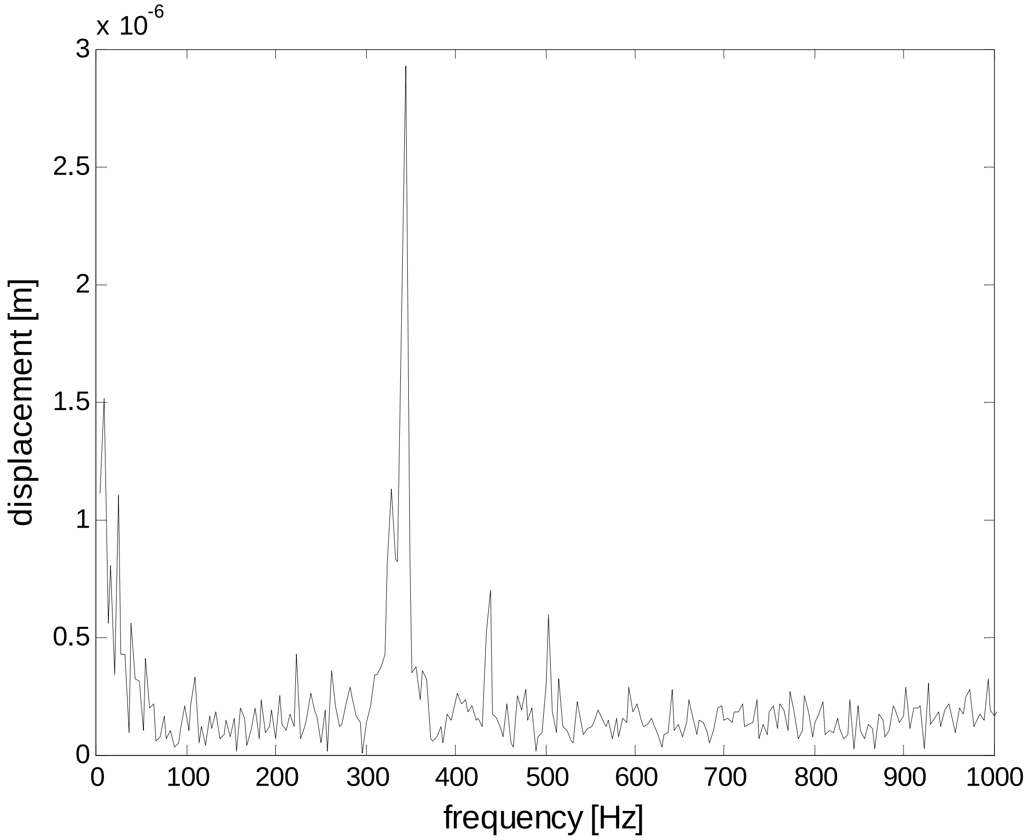

Fig.6 The amplitude spectrum of the blade B30 vibration.

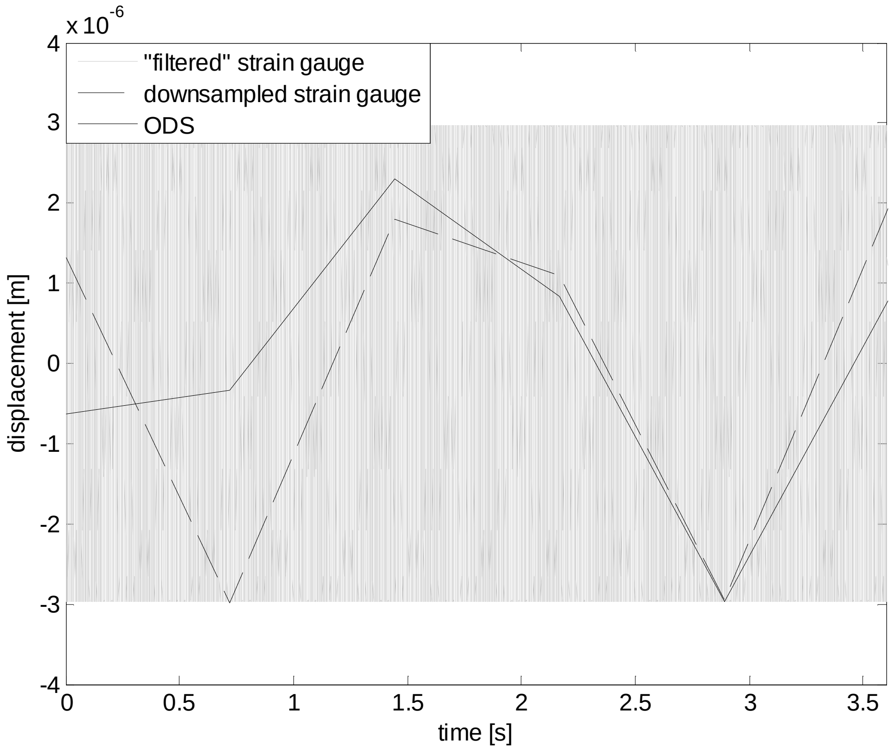

Fig.7 ODS and strain-gauge (filtered and downsampled) displacement time characteristics of the blade B30 at electromagnetic excitation and revolution 83rpm.

4. Conclusion

The new laboratory optical method for evaluation of displacements of rotating and vibrating blades was designed and implemented. The first results of the optical measurement of the blade vibration in non-rotating and rotating states were presented. The displacement of the blades were evaluated by the tip-timing method. The results were compared with the strain-gauge results of the blade vibration. The circumferential amplitudes of blade vibration caused by the weak electromagnetic excitation was very low (cca 3μm) under rotation. Nevertheless the vibration was detected by the optical measurement. The optical method will be futher tested for accurate contactless measurements of blade vibtration and callibrations of the sensors for vibrodiagnostics of the turbine blades.

Acknowledgement

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