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The Application of High-speed Digital Image Correlation in Vibration Analysis of a Rotating Object

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Abstract: Experimental analysis of vibrations is commonly used for instance in operational monitoring, vibrodiagnostics of machines, or as a part of inspection tests. For measuring of basic vibration parameters such as displacement, velocity and acceleration are particularly used measurement methods which are easily applicable and also more available. In this paper the way of using DIC method for analysis of automobile cooling fan is described. This optical method enables to perform high-speed contactless measurement of spatial displacements. Opposite to the conventional processes when the probes (e.g. accelerometers) are applied to the stationary places in this instance the amplitudes of vibrations were measured directly on the rotating part.

Keywords: digital image correlation, oscilation analysis, rotating object

1. Introduction

Mechanical vibration of machines or their parts which perform rotating motion are commonly assessed upon measurements performed on non-rotating parts [1]. In these instances conventional probes for measurement of displacements, velocities and accelerations are used [2], which cannot be applied on rotating object.

Digital image correlation is an optical method which enables to perform full-field measurement of spatial displacements of moving object [2-6]. According to this method where high-speed cameras are engaged one can determine coordinates of arbitrary point in arbitrary time. For instance when body performs rotational movement about fixed axis of rotation the circle with radius r_0 is trajectory of a point. Every deviation Δr from this value can be considered as amplitude of vibration (Fig.1).

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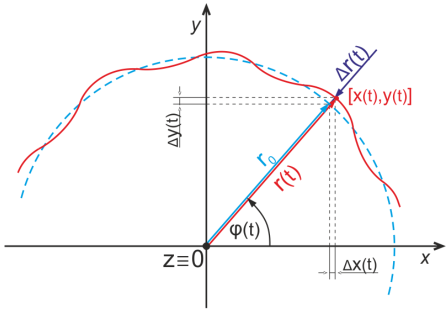

Fig. 1. Estimation of vibration amplitudes of a rotating object

Providing that a plane in which the point is moving is perpendicular to a axis of rotation, components of this deflection to x and y axis can be computed according to expressions:

$$\Delta x(t) = x(t) - r_0 \cos\varphi(t), \quad \text{where:} \quad \cos\varphi(t) = \frac{x(t)}{\sqrt{x(t)^2 + y(t)^2}},$$

$$\Delta y(t) = y(t) - r_0 \sin\varphi(t), \quad \text{where:} \quad \sin\varphi(t) = \frac{y(t)}{\sqrt{x(t)^2 + y(t)^2}}.$$

Time dependences of vibration amplitudes acquired this way can be subjected to the additional frequency analysis (e.g. for the purpose of vibration intensity assessment) [7].

2. Vibration amplitudes analysis of rotating object computer model

Presumptions for determining of vibration amplitudes by direct measuring on rotating part were verified during creation phase of computational algorithms with the help of cooling fan model created in MSC.Adams/View (Fig.2).

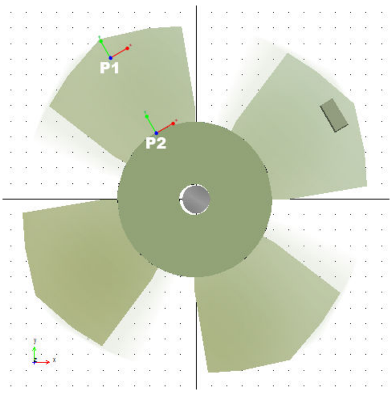

Fig. 2. Model of cooling fan created in MSC.Adams/View

The redundant mass was deliberately added to a one of the cooling fan blade and consequently the backlash of 1mm in radial direction occurred in bearing. Unbalanced system and backlash in support result in generation of vibration during model rotation. The angular velocity of rotation during simulation was constant - 20π rad.s^{-1} what correspond to frequency 10Hz.

Amplitudes of vibration were determined in points P1 and P2. The time dependences of these points coordinates (Fig.3) were imported from Adams to Matlab where they were numerically processed in order to acquisition of vibration amplitudes of cooling fan model. There are plotted trajectories of points P1 and P2 on Fig.4 and there are also their reference trajectories for instance of ideal support without vibration.

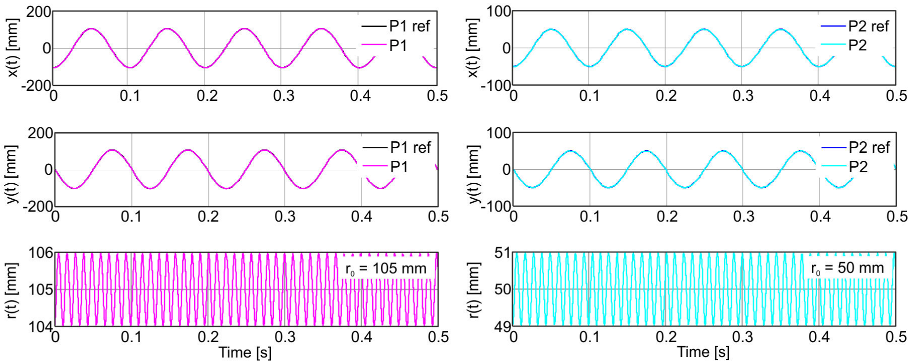

Fig. 3. Time dependence of points coordinates P1 and P2

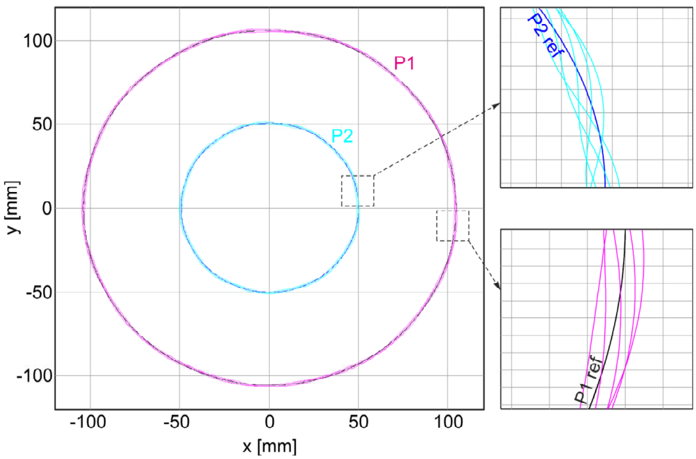

Fig. 4. Trajectory of cooling fan model points P1 and P2

Because the cooling fan was modelled as ideal rigid body the deflections of both points from reference trajectory should be equal. This assumption is confirmed by their time and frequency dependences showed in Fig.5 and 6.

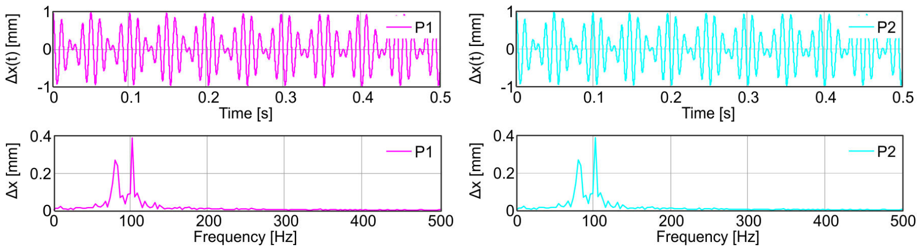

Fig. 5. Time and frequency dependence of oscillation displacement of cooling fan model of points P1 and P2 in x direction

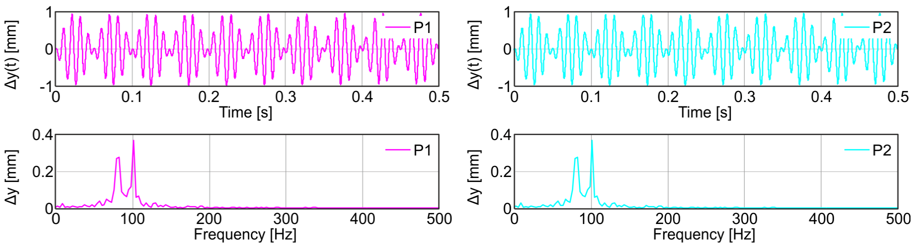

Fig. 6. Time and frequency dependence of oscillation displacement of cooling fan model of points P1 and P2 in y direction

From time dependences on Fig.5 and 6 results that maximal vibration amplitudes of cooling fan model run to 1mm what means value equal to radial backlash in bearing.

3. Determination of automobile cooling fan vibration amplitudes by using DIC method

The investigated object was a cooling fan of automobile Skoda Felicia whose frame was situated on a pedestal made from polyurethan foam. A high-speed correlation system Q-450 Dantec Dynamics [6] comprised by two SpeedSense Phantom CCD cameras was used to measure amplitudes of fan vibration. These cameras sampled fan’s front side during rotation (Fig. 7).

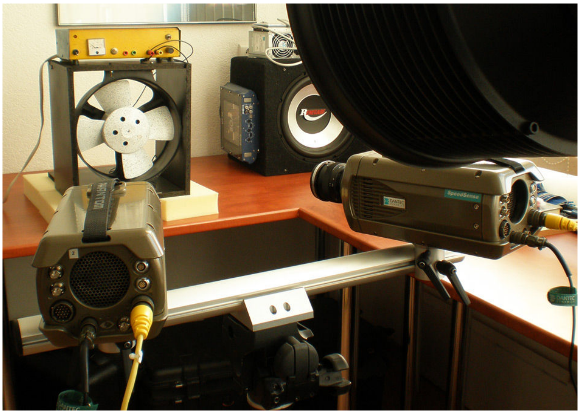

Fig. 7. Cameras configuration during the measurement

The redundant mass added to one of the blades was used to ensure excessive amplitudes of fan vibration. The fan was powered by stabilized generator. Totally three measurements by constant voltage of 3V, 5V and 7V were performed. Sampling frequency of cameras was adjusted to 5000 fps and total acquisition time was prescribed to 0,5s.

By using of DIC methods a results accuracy is affected by correlation and 3D reconstruction errors [3]. When the displacements of investigated points captured in two successive time steps are larger in terms of their higher velocity, more inaccuracy by higher frequencies of rotation can be assumed. In this respect the influence of correlation errors is increased also with growing distance from rotation axis. In this case the image sharpness is decreased what causes that the captured snapshots become gradually fuzzy. With respect to these facts just results of the most negative case (cooling fan powered by constant voltage of 7V) are introduced. By this voltage the cooling fan performed 950 rpm and thus the rotation frequency was 15,83 Hz.

There is a reconstructed spatial contour of investigated cooling fan part in the Fig. 8. The amplitudes of vibration were evaluated in two points P1 and P2 lying on a line going through the axis of rotation. For correct evaluation it was necesarry to define a coordinate system whose z axis was parralel to axis of rotation. Due to this reason tools integrated in correlation system software Istra4D were used [5].

Time dependences of P1 and P2 coordinates were consequently imported into Matlab and processed in the same way like in the case of computer model. Their graphical dependences are depicted in the Fig. 9. The Fig. 10 represents deviations of P1 and P2 trajectories from reference trajectories. Time and frequency dependences of vibration amplitudes of these points in x and y directions are plotted in the Fig.11 and in the Fig.12.

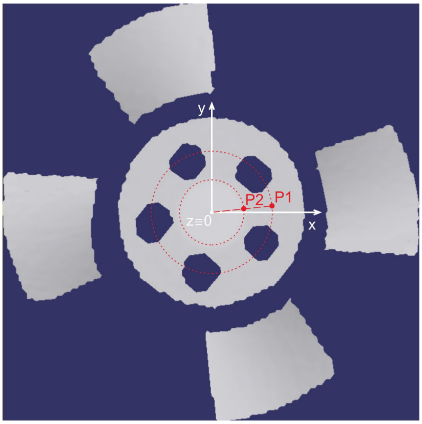

Fig. 8. Reconstructed spatial contour of cooling fan with measurement points

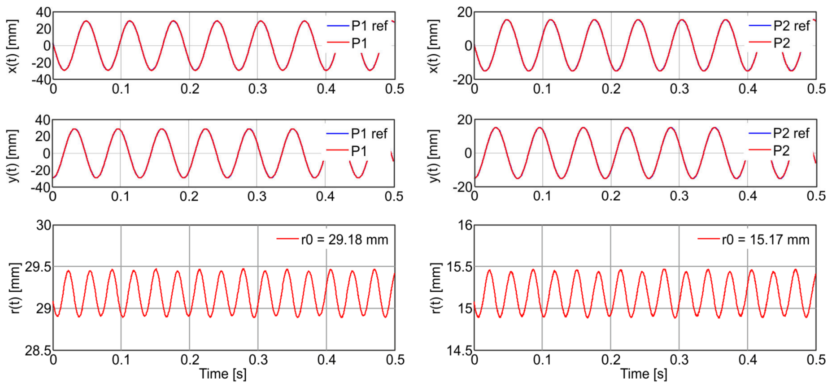

Fig. 9. Time dependence of points P1 and P2 coordinates

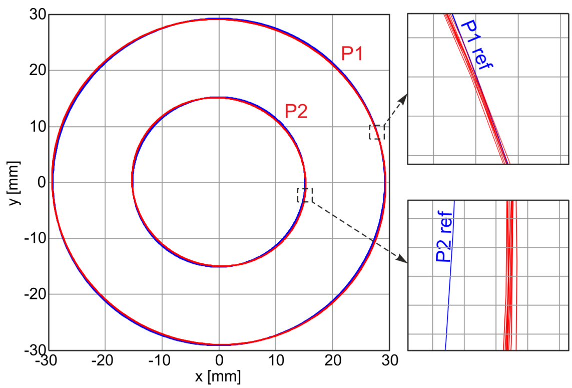

Fig. 10. Trajectories of points P1 and P2

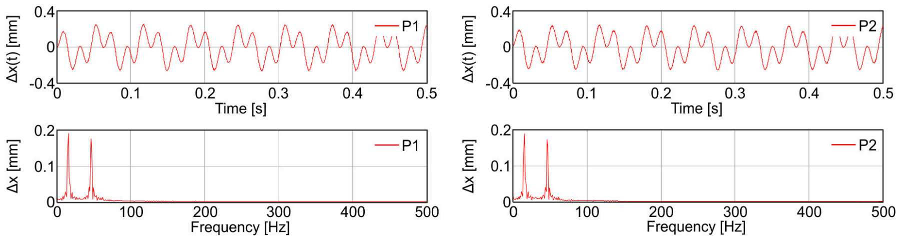

Fig. 11. Time and frequency dependence of automobile cooling fan vibration amplitudes in x direction determined in points P1 and P2

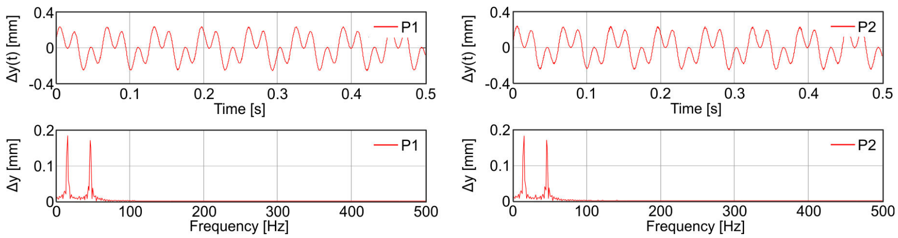

Fig. 12. Time and frequency dependence of automobile cooling fan vibration amplitudes in y direction determined in points P1 and P2

Numerical values of maximal vibration amplitudes deducted from frequency dependences depicted in the Fig. 11 and Fig. 12 are inscribed in the Table 1 by reason of comparison. Differences of P1 and P2 maximal vibration amplitudes obtained in x and y directions are in the range of 0,29 – 0,33%, what can be considered as acceptable.

Table 1. Maximal vibration amplitudes of points P1 and P2

	P1		P2	
f [Hz]	x [mm]	y [mm]	x [mm]	y [mm]
15,87	*0,1902*	*0,1891*	*0,1896*	*0,1885*
46,39	*0,1717*	*0,1751*	*0,1722*	*0,1746*

4. Conclusion

In this contribution the way of using digital image correlation method for measurement of vibration amplitudes of rotational object determined directly on the rotating part are described. The algorithm for numerical processing of time courses of investigated points coordinates was written in Matlab. The results are time dependences and frequency spectra of vibration amplitudes obtained in particular points of tested object. To use the introduced methodics as full-value tool for vibration analysis it is necessary to create a function which enables to visualize operational shapes of vibration by chosen frequencies, that is maximal amplitudes of vibration of the whole investigated object surface in form of some color fields.

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