Vibration Measurements of Rotating Objects Using an Optomechatronical Image Derotator

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Rotating machine elements are exposed to various excitations dependent on the speed of the rotation. Those can lead to lesser performance or even destruction of the rotating components. Therefore it is essential to know the dynamic response of structures to guarantee safety. In this paper an image derotator is used in combination with a laser Doppler vibrometer to investigate vibrations of a model blisk.

1 Introduction

The need of investigations on rotating objects during operation is constantly increasing. Therefore, obtaining detailed information about the dynamic system behaviour (such as vibrations) is essential. Vibrations are described as periodic, deforming mechanical oscillations of a structural component. In general, measurements of vibration amplitudes and frequencies can be performed by using double exposure Holography [1] or laser Doppler vibrometry on a non-rotating measurement object. In order to quantify vibrations of the object during operation, a laser Doppler vibrometer (LDV) can be used in combination with an optomechatronical image derotator [2]. Thus, the laser beam is able to follow the rotating object continuously. In this paper, the conventional measurements at standstill are compared with the measurements on a rotating object by using the derotator to prove the enormous potential of this measuring system.

2 Experimental Set-up

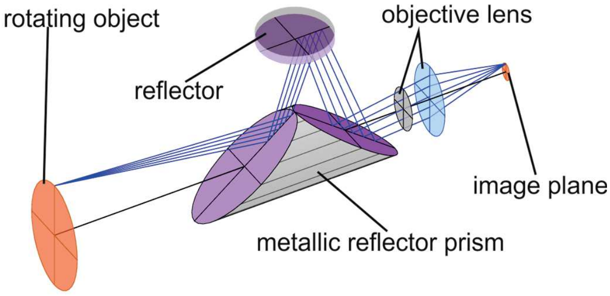

Fig. 1 *Mirror assembly used for derotation.*

The optomechatronical image derotator is the centrepiece of the experimental set-up. Due to its working mechanism based on the mirror assembly as depicted in Fig. 1 the derotator can generate a stationary image, which is described detailed in [3]. Therefore certain constraints have to be fulfilled. The optical axis of the derotator and of the rotating object have to be aligned [4]. Furthermore, the angle and the rotational velocity of the derotator have to be half of the angle and the velocity of the rotating object, which is ensured by the implemented controller.

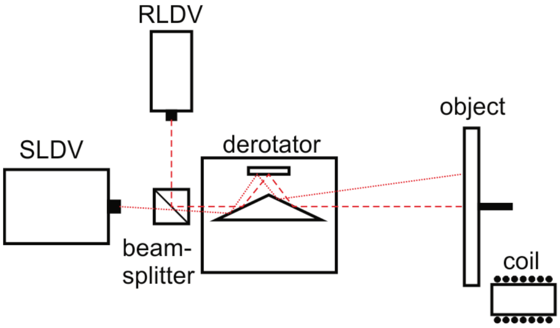

Fig. 2 *Experimental set-up for vibration measurements.*

The experimental set-up for vibration measurements with the derotator is shown in Fig. 2. The vibration measurement unit consist of two different LDVs. The first vibrometer is used as the scanning vibrometer (SLDV) for detecting the eigenfrequencies and deflection shapes with the corresponding nodal diameters (ND) of the blisk. Since the aforementioned LDV looses the phase information during the scanning process, a reference vibrometer (RLDV) is required. The laser beam of the second LDV is coupled into the derotator using a beam splitter. In addition an electromagnetic coil is used to excite the eigenfrequencies of an measurement object selectively.

Hereafter, a blisk inspired model as seen in Fig. 4. is used as the measurement object. The measurements are carried out at standstill and at a sample rotational velocity of $90\mathrm{rpm} = 1.5\mathrm{Hz}$.

3 Measurement Results

First of all, the non-rotating blisk model is excited with white noise to determine the eigenfrequencies and the corresponding NDs. The resulting frequency response spectrum in Fig. 3 shows distinctive max-

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ima for $79.6\mathrm{Hz}$, $85.3\mathrm{Hz}$, $90.8\mathrm{Hz}$, $94.6\mathrm{Hz}$, $115.2\mathrm{Hz}$ and $121.3\mathrm{Hz}$. Due to further investigations of the deflection shapes taken with the SLDV, the correlation between the frequencies and the first to fourth ND was found out (see Tab. 1 and Fig. 4 (a)-(d)). The characteristic behaviour of the NDs is most visible at the hub of the blisk model.

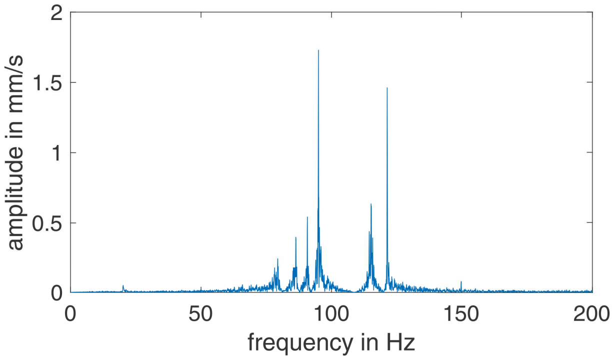

Fig. 3 *Frequency response of the blisk modal by excitation with white noise at standstill.*

Looking at the rotating blisk model, the same behaviour is evident for the NDs (see Fig. 4 (e)-(h)) besides the differing excitation frequency (see Tab. 1). The difference of the excitation frequency corresponds to a shift of $\pm\mathrm{ND} \cdot f_{rot} = \pm\mathrm{ND} \cdot 1.5\mathrm{Hz}$ due to the shift of the excitation from the non-rotating in the rotating system. Taking the fourth ND as an example this leads to a shift of $4 \cdot 1.5\mathrm{Hz} = 6\mathrm{Hz}$ as depicted in Tab. 1.

ND	0rpm	90rpm
1	85.3Hz	86.8Hz
2	94.6Hz	97.6Hz
3	115.2Hz	119.7Hz
4	121.3Hz	127.3Hz

Tab. 1 *Comparison of the non-rotating and rotating system*

4 Conclusion

The aforementioned results demonstrates that the optomechatronical image derotator provides a unique practical solution for analysing the dynamic behaviour of a rotating object by measuring, investigating and interpreting the characteristic eigenfrequencies and deflection shapes of a blade model using a LDV. It is shown that the rotation leads to a shift of the excitation frequency depending on the corresponding nodal diameter.

In future investigations, the possible shift of the eigenfrequencies dependent on the rotational frequency due to an increasing centrifugal force could be examined. Furthermore more complex objects than the one previously used could be measured to show their dynamic response to rotational excitation.

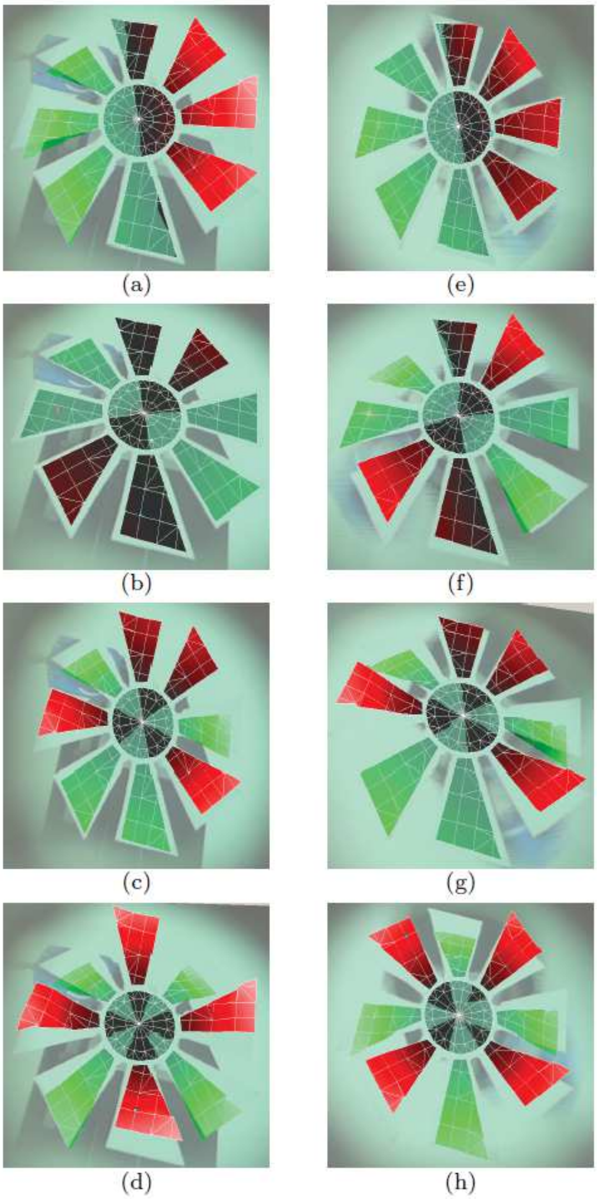

Fig. 4 *Measurement results: (a)-(d) first to fourth ND (0rpm), (e)-(h) first to fourth ND (90rpm)*

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