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EXPERIMENTAL MODAL ANALYSIS OF WASHING MACHINE PULLEY

M. Schrötter[*], M. Hagara[**], P. Lengvarský[***]

Abstract: *The aim of the experiment was to perform experimental modal analysis of the pulley, which serves for propulsion of washing machine, and consequently to estimate its modal parameters. There are presented results of the experimental measurement in this article, verified by finite element method. Also there is showed several problems which occurred during the measurement. The end of the article is devoted to result discussion.*

Keywords: Pulley, Modal analysis, Natural frequencies.

1. Introduction

Nowadays the big emphasis is devoted to the ecology of domestic appliances and energy losses related with them, which emerge with their running. From this aspect our attention was focused on investigation of washing machine's pulley modal parameters – natural frequencies and mode shapes. The measurement was performed on the pulley attached to a drum of a washing machine. This method can be considered as clamped, owing to mechanical blocking of the drum rotation.

2. Modal Analysis of the Pulley

2.1. Experimental modal analysis

Experimental modal analysis was performed by Bruel and Kjaer's PULSE system. As an exciter Bruel and Kjaer's modal hammer was used, type 8206. Owing to the frequency band of interest, 3200 Hz, the plastic tip of hammer was used. To not influence the natural frequencies the contactless transducer had to be used because of low pulley weight. Also the shape of the pulley was not suitable for using of conventional accelerometer so as a transducer the laser vibrometer Polytec PDV 100 was used. It measures the velocity of vibration by Doppler effect (Randall).

Before the measurement the sufficient number of measuring point (DOF's) had to be created on the pulley to sufficiently render the mode shapes. From that reason the pulley was theoretically divided into three parts: the middle, the rim and the three arms. There were created twelve points in the middle of pulley, five points on each arm and 24 points on the rim.

With respect to fact that the response of both the pulley middle and the ring was significantly different also by free support, the middle was significantly stiffer than the rim, the reference point was chosen on the pulley arm.

The measurement was performed in two stages. The first one, the exciter and transducer were oriented axially (front side) and second one when the transducer and exciter were oriented in radial direction.

[*] Ing. Martin Schrötter: Department of Applied Mechanics and Mechatronics, Technical University of Košice, Letná 9; 042 00, Košice; Slovakia, martin.schrotter@tuke.sk

[**] Ing. Martin Hagara, PhD.: Department of Applied Mechanics and Mechatronics, Technical University of Košice, Letná 9; 042 00, Košice; Slovakia, martin.hagara@tuke.sk

[***] Ing. Pavol Lengvarský: Department of Applied Mechanics and Mechatronics, Technical University of Košice, Letná 9; 042 00, Košice; Slovakia, pavol.lengvarsky@tuke.sk

After the measurement the particular frequency response functions were converted to the Pulse Reflex and modal parameter extraction was performed by rational fraction polynomial method with maximum iteration of 40. Upon the stability diagram and phase shift diagram the natural frequencies were obtained (Bilošová, 2011).

The rational fraction polynomial method (frequency domain - single input single output - multi degree of freedom) was used owing to its suitability for investigation of close modes of vibration with respect to the effect of residuals outside the frequency range of interest. The close modes of the pulley were expected by the reason of symmetric pulley shape.

2.2. Numerical modal analysis

Numerical modal analysis is performed in the simulation program SolidWorks. The geometry of washing machine pulley with maximal diameter 300 mm is created in 3D background. Then frequency study is selected and the material AL 46000 is defined. Material properties of AL 46000 are presented in Tab. 1 (SolidWorks).

The mesh on the washing machine pulley is generated automatically by SolidWorks, while the spatial element SOLID187 is used. The element is defined by 10 nodes while each node has three degrees of freedom. The SOLID187 has a quadratic shifting behavior and is suitable for modeling of the finite element irregular mesh. The size of the element is 3.6 mm with tolerance 0.18 mm. The mesh in Fig. 1 is created of 38362 elements and of 77421 nodes (SolidWorks).

Fig. 1: Mesh of finite elements on the washing machine pulley.

Tab. 1: Material properties of AL 46000.

Property	Value with units
Elastic modulus	**75 000 MPa**
Tensile Strength	**140 MPa**
Yield Strength	**250 MPa**
Mass density	**2000 kg/m^3**
Poisson´s ratio	**0.3**

In SolidWorks the axial, radial and circumferential movements are constrained. These fixtures are applied in middle of the pulley.

3. Obtained Results and their Comparison

The obtained natural frequencies are presented in Tab. 2 and the obtained mode shapes are depicted in Figs. 2 to 7. The mode shapes presented below are for Pulse and SolidWorks respectively.

Tab. 2: The comparison of pulley natural frequencies.

Frequency number	PULSE	SolidWorks
1.	***80 Hz***	***84 Hz***
2.	***120 Hz***	***129 Hz***
3.	***182 Hz***	***194 Hz***
4.	***262 Hz***	***281 Hz***
5.	***594 Hz***	***618 Hz***
6.	***784 Hz***	***800 Hz***
7.	***930 Hz***	***951 Hz***
8.	***1176 Hz***	***1204 Hz***
9.	***1848 Hz***	***1885 Hz***
10.	***2622 Hz***	***2683 Hz***
11.	***3146 Hz***	***3227 Hz***

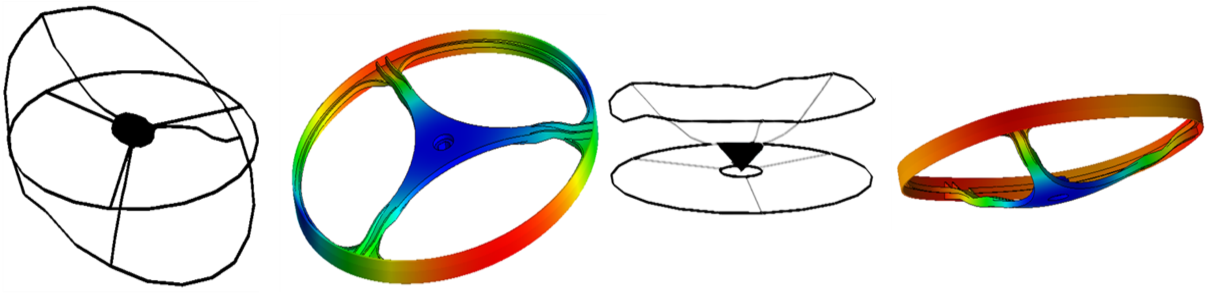

Fig. 2: The first and the second mode shape.

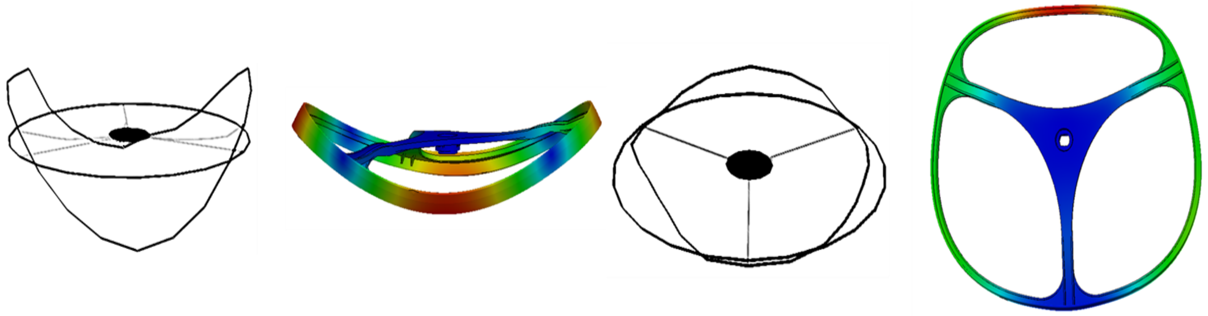

Fig. 3: The third and the fourth mode shape.

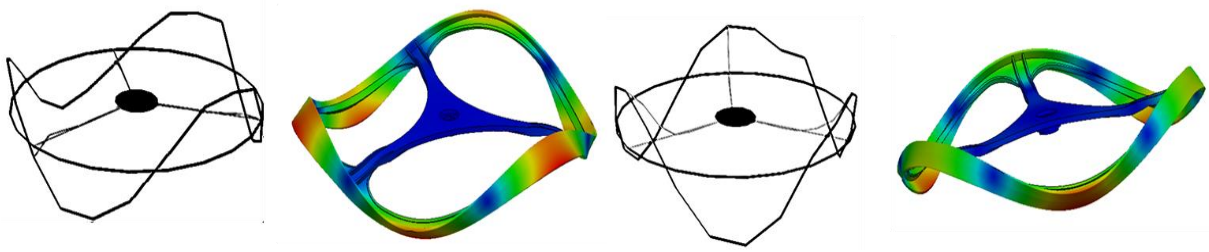

Fig. 4: The fifth mode shape and the sixth mode shape.

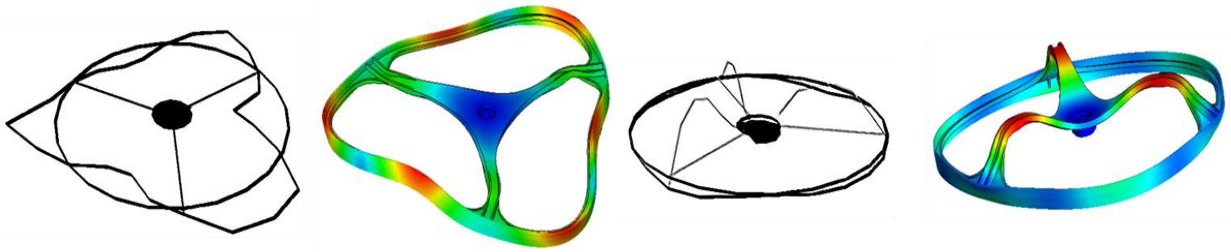

Fig. 5: The seventh mode shape and the eighth mode shape.

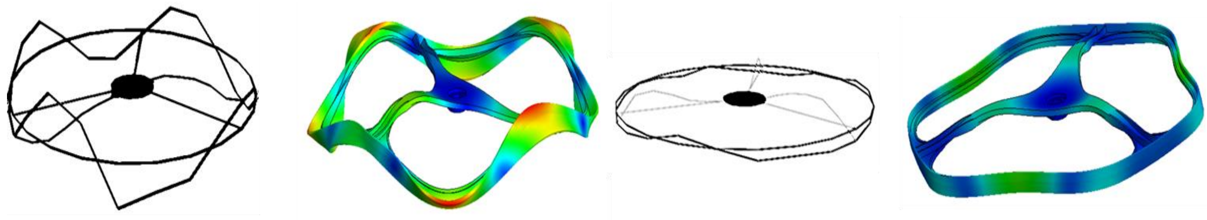

Fig. 6: The ninth mode shape and the tenth mode shape.

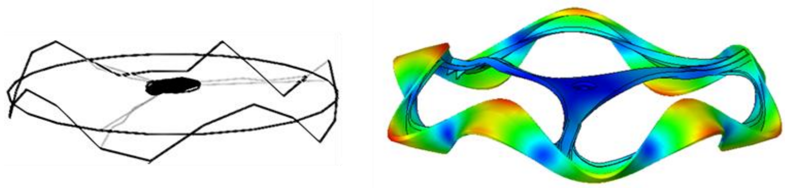

Fig. 7: The eleventh mode shape.

4. Conclusions

The usual washing machine revs are in the range from 0 to 1200 rpm. The drum and the pulley are connected rigidly so their revs are same. From the upper table we can see that there are 8 natural frequencies in this range. All of these natural frequencies but one are measured from the first measurement stage – the axial measurement. Their particular mode shapes, as it is possible to see from Figs. 2-7, are mostly presented in the axial direction. It is worth to point out the fifth frequency – 594.Hz. This frequency is acquired from the second measurement stage – the radial measurement. Its mode shape (deformation) is in radial direction, so the washing process at this frequency (rpm) can create creeping of the pulley belt, what lead to the unwanted energy losses.

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