Contribution to the Creation of Virtual Models of Rotary Machines

Zdenko Šavrnoch[1,a], Alžbeta Sapietová[1,b], Vladimír Dekýš[1,c] and Barbora Drvárová[1,d]

[1]*University of Žilina; Univerzitná 1, 010 26 Žilina, Slovakia;*

[a]*zdenko.savrnoch@fstroj.uniza.sk,* [b]*alzbeta.sapietova@fstroj.uniza.sk,* [c]*vladimir.dekys@fstroj.uniza.sk,* [d]*barbora.drvarova@fstroj.uniza.sk*

Abstract: This paper presents a review of rotordynamics with a specific emphasis on the Laval rotor. The authors describe the development of a virtual model of the Laval (Jeffcott) rotor using the MSC.ADAMS software. The study focuses on analyzing parameters related to the stability of the rotor's operation, such as the critical angular velocity and the trajectory of the rotor's center of gravity (CoG orbit). These parameters were monitored and evaluated throughout the analysis.

Keywords: Laval's rotor, Jeffcott rotor, rotordynamics, Adams, rotary machines, MATLAB

1 Introduction

Currently, the primary objective of advancements in rotor dynamics is to attain increasingly higher operating speeds. This is because higher rotational speeds in energy machines lead to greater energy generation or transformation, particularly in production settings, resulting in enhanced productivity gains [1]. Although there has been progress in this field in recent years, rotor dynamics remains an extensively researched area, with studies aimed at effectively utilizing existing concepts in new domains and gaining a better understanding of the behaviour of rotating systems. Non-linear and non-stationary rotor dynamics are specific areas that require extensive and in-depth research [2].

2 Rotordynamics

Field of applied mechanics that focuses on studying the behaviour, operation and diagnostics of rotating machinery and equipment [1]. The most basic form of rotating machinery consists of a rotating component (such as a shaft or disk) that is supported by a structure and bearings (called a Laval's rotor). As the rotational speed of the machine increases, the unbalance of the system causes an increase in the magnitude of the oscillations. At critical speeds, the amplitude of these oscillations reaches a maximum value. Examples of rotating machines are steam and gas turbines, crankshafts of internal combustion engines, gearboxes etc.

3 Laval's rotor

When examining the shaft bending and center of gravity (CoG) trajectories of rotating masses, a simple model of an immaterial shaft and point mass representing rotating masses that are attached to it, can be used [3]. If we want to add more complexity to the numerical (or analytical) model, we can include shaft mass in the total mass of the system. The system can be classified as being damped or not. Additional parameters that can be used to describe the system include the method of shaft mounting and deformability of the bodies that form the system [4].

Laval's (Jeffcott) rotor can be assembled in three ways:

- Flexible (compliant) shaft system

- System with rigid shaft and compliant bearings
- System with flexible (compliant) shaft and compliant bearings

4 Computational model of undamped Laval's rotor

System characterized by its placement in rigid rotating supports [3]. A rigid disk is mounted symmetrically on a flexible shaft without any eccentricity. The initial deflection of the center of gravity (CoG) from the central axis (which is the centerline of the rigid rotational support) occurs in the vertical direction of the y-axis and is proportional to the gravity of the system.

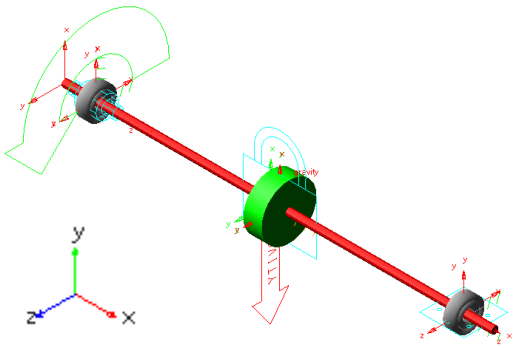

Fig. 1 Disk symmetrically mounted on flexible shaft and rigid supports.

All material constants are based on the material Steel S235 chosen from the material library of MSC.Adams.

Table 1. Other parameters used in the computational model.

Parameters	Denotation	Nominal value	Units
Shaft length	L_h	585	[mm]
Shaft diameter	d_h	10	[mm]
Disk width	b_k	25	[mm]
Disk diameter	d_k	75	[mm]
Shaft mounting distance from disk	l_b	250	[mm]

5 Simulation results

Table 2. Simulation parameters.

End Time	25 [s]
Step size	0.0001 [-] / 10 [kHz]
Solver	WSTIFF/I3

Rotor's angular velocity starts at 130 [rad/s] and its linear ramp is given by the function 130+15·time [rad/s]. Rotor rotates clockwise (CW) and starts at equilibrium.

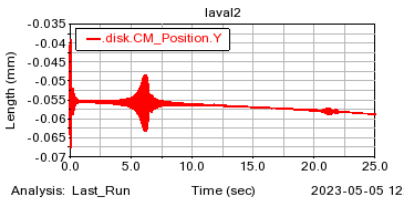

Fig. 2 Deflection in Y axis.

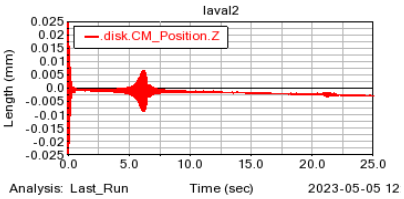

Fig. 3 Deflection in Z axis.

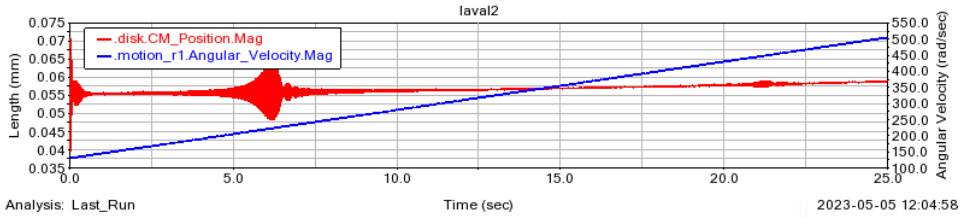

Fig. 4 Deflection magnitude.

Analysis shown the presence of the first critical and the second critical angular velocity in the projected time interval of 25 [s]. Deflection of CoG (Fig. 4) of the first angular velocity ω_{1crit} = 223,7 [rad/s] (located at t_1 = 6,23 [s]) has much higher amplitude than the second critical angular velocity ω_{2crit} = 447,6 [rad/s] (located at t_2 = 21,18 [s]). This difference between the amplitudes is caused by the different shapes of the first and the second modal frequencies (Fig. 5, 6) [5].

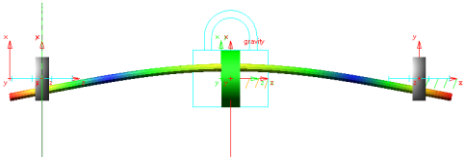

Fig. 5 First mode.

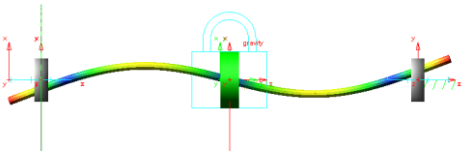

Fig. 6 Second mode.

For a better visualisation of the CoG defflection, it can be projected to the 3D plot (Fig. 7), where the bottom plane axes represent deflection in particular axis of the rotor and the vertical axis represents time or angular velocity (these are interchangable).

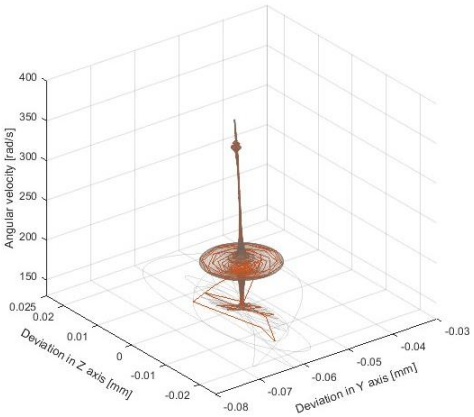

Fig. 7 3D representation of CoG deflection.

For a better display and wider option of diagram modification, were the output data exported from MSC.Adams to MATLAB.

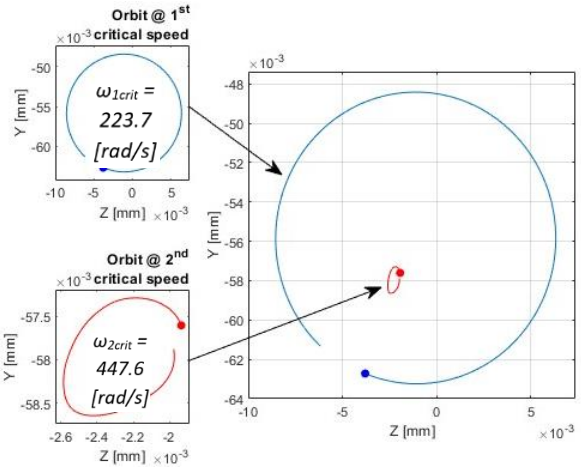

Fig. 8 Square diagrams of system CoG orbit at different speeds and size comparison.

To inspect the CoG orbits we have to cut diagrams in the points of interest. Usually, these points are located at and around the desired operating speeds of the machine or at critical velocities. Therefore, the orbits of analysed rotor model are evaluated at the time of first two critical velocities (Fig. 8).

Summary

The deflection amplitude for both the Y and Z axes steadily increases (as shown in Fig. 4), with the maximum amplitude being reached at 1st critical velocity (as might be seen on Fig. 2,3,4). The rotational supports exhibit equal stiffness in both the Y and Z axes, which causes the first and second critical angular velocity of the rotor to remain the same for both axes. The weight of the disk acting on the flexible shaft causes deflection (as seen in Fig. 2 - Deflection in Y axis) from the initial position of the center of gravity of the bent rotor. Second critical velocity is equal approximately double the first critical velocity. In compare with the circular orbit of 1st critical velocity its orbit has elliptical shape (Fig. 8).

Acknowledgements

This research work was supported by the project KEGA 011ŽU-4/2022.

References

[1] Gash, R. and Pfützner, H. *Dynamika rotorů* (SNTL – Nakladatelství technické literatury, Praha, 1980). Číslo publikace 04-226-80.

[2] Ságа, M., Vaško, M., Handrik, M. and Kopas P. "Contribution to Random Vibration Numerical Simulation and Optimisation of Nonlinear Mechanical Systems," *Scientific Journal of Silesian University of Technology – Series Transport*, **103**, pp. 143-154 (2019).

[3] Byrtus, M., Hajžman, M. and Zeman, V. *Dynamika rotujících soustav* (Západočeská univerzita v Plzni, 2010).

[4] Záhorec, O. and Caban, S. *Dynamika* (Olymp, Košice, 2002).

[5] Černohlávek, V., Svoboda, M., Štěrba, J., Chalupa, M. and Sapieta, M. "Analytical and Experimental Solution of Vibrations of a System of Bound Bodies," *Manufacturing Technology*, **20**(6), pp. 699-707 (2020).