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EXCITATION OF ROTATING DISK BY STATIONARY PERMANENT MAGNETS

L. Půst*, L. Pešek*

Abstract: *Flexural vibrations of rotating disk contain forward and backward traveling waves can be excited at certain speed of rotating disk also by a standing constant single point force or by multiple points standing forces, realized e.g. by permanent magnets fixed in non-rotating space. Presented paper is contribution to the theoretical background of a new experimental excitation technique elaborated in Institute of Thermomechanics for investigation of a bladed turbine disk model with imperfection by addition several damping heads on ends of blades. Mathematical model of imperfect rotating disk was derived by using data gained experimentally and by FE computed for three lowest split modes of vibrations. It was shown how either the whole spectrum of modes of vibrations can be recorded or some resonance of selected mode can be suppressed on emphasized by means of appropriate number and positions of permanent magnets.*

Keywords: ***Rotating disk, traveling backwards waves, constant force excitation, resonance suppression, resonance isolation.***

1. Introduction

The need of more exact design of machinery particularly from the dynamic properties increases with higher demand on power and reliability. Among general engineering structures, the rotating machines have a specific place and the knowledge of rotordynamics and vibrations of disk with blades have a important role. Since the beginning of last century a great attention has been given to the theoretical and experimental investigations of bladed disk vibrations at rotation (Lalanne & Ferraris, 1990; Malenovský & Lošák, 2007; Rao, 1991; Tobias & Arnold, 1957; Tondl, 1965).

In order to test a disk for dynamic investigation, it is usually excited by an external force. When the real structure or its model does not rotate, various methods of excitation – as electro-dynamic shaker, instrumental hammer, mechanic exciter in single point or multi-point excitation technique - are applied. Excitation of rotating structure is more difficult. Two methods of rotating disk excitation have been developed in the Institute of Thermomechanics ASCR, v.v.i. These methods are based on influence of magnetic forces of the electromagnetic or permanent magnets vibrator in space fixed on rotating disk (Půst & Pešek, 2009, 2010). Electromagnetic vibrator with suitable frequency of feeding current is more general apparatus as it can excite various forms of rotating disk vibrations – fixed vibrations with nodal diameters standing on the disk, backward and forward traveling waves. The excitation apparatus using permanent magnets is considerable simple, but it can excite only backward traveling waves. In spite of this limitation it is valuable method for laboratory experiments, because it enables to determine dynamic parameters, separate modes of vibration, etc.

Presented paper is a contribution to the theoretical background for analysis of results of measurement on the experimental model of bladed mistuned disk in dynamic laboratory IT ASCR.

2. Motion equations of rotating disk

Experimental model of bladed disk consist of a steel disk with 60 blades of rectangle cross-section. Two bunches of five blades lying on opposite ends of one diameter are provided by damping heads. Such bladed disk losses its perfect central symmetry and the double eigenfrequencies split owing to

* Ing. Ladislav Půst, DrSc and Ing. Luděk Pešek, CSc.: Institute of Thermomechanics AS CR, v.v.i., Dolejškova 5, 182 00 Praha 8 CZ, e-mails: pust@it.cas.cz, pesek@it.cas.cz

disk imperfection. Modes of split eigenfrequencies are orthogonal with imperfections either on one of the nodal diameters (mode b) or in the place of anti-node position (mode a). The split eigenfrequencies of three lowest modes with 1, 2 and 3 diameters and no nodal circle ascertained on experimental bladed disk IT ASCR are: Ω_{1a} = 287.8, Ω_{1b} = 370.8, Ω_{2a} = 456.8, Ω_{2b} = 490.0, Ω_{3a} =673.5, Ω_{3b} = 759.9 rad/s.

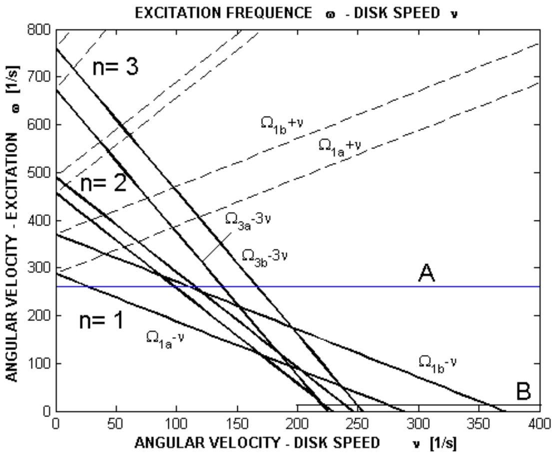

Fig. 1: Frequency – Speed diagram.

Two opposite traveling waves forms stationary vibration of a circular disk. If the disk rotates, these waves are recorded by a standing observer as forward and backward waves in relation to the disk rotation. Graphical representation of angular velocities of traveling waves for various speeds of disk rotation *v* is in Fig. 1. Motion of imperfect disk rotating at angular velocity *v* and forced by a harmonic force $F_0\cos\omega t$ standing in position given by angle λ can excite all vibrations modes (Pešek et al. 2008; Půst & Pešek, 2009). The intersection points of horizontal line A with the oblique lines ascertain the resonance frequencies at variable disk speed $\nu \in (0, 400)$ rad/s and at excitation frequency $\omega = 260$ rad/s. Decreasing this line to horizontal axis *v*, we get the resonance positions at $\omega = 0$, i.e. at excitation by constant force F_0 = const. Flat area B is in increased form drawn in Fig. 2.

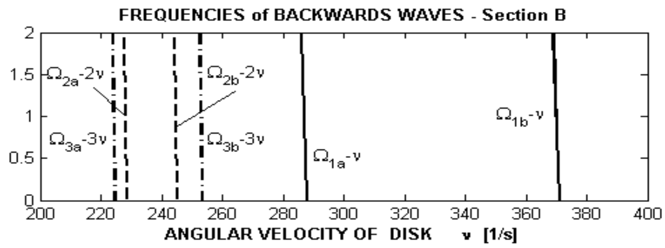

Fig. 2: Velocities of backwards traveling waves.

Using adapted expressions derived for similar case in (Malenovský et al. 2007) after substituting $\omega = 0$ we get for excitation by l = 1, 2, … magnets with constant forces F_l differential equations in general coordinates

$$\begin{aligned} m_{redan}\ddot{q}_{nal} + (b_{redan} + 2\Delta b)\dot{q}_{nal} + c_{redan}q_{nal} &= q_0(r)\sin n\varphi\, F_l \sin n(\lambda_e + \nu t) \\ (m_{redn} + 2\Delta m)\ddot{q}_{nbl} + b_{redbn}\dot{q}_{nbl} + (c_{redn} + 2\Delta c)q_{nbl} &= q_0(r)\cos n\varphi\, F_l \cos n(\lambda_l + \nu t). \end{aligned} \quad (1)$$

$$l = 1, 2, \ldots \qquad n = 1, 2, 3$$

Here *n* is number of nodal diameters, λ_l, $l = 1, 2, 3$ are angles of magnets positions, where one of this locations can be chosen $\lambda_l = 0$.

3. Example

Intersections of axis $\omega = 0$ with lines of angular velocities of traveling waves determine the resonance speeds of rotating disk excited by constant force of magnets. These resonances occur at speeds Ω_{1a},, Ω_{1b}, $\Omega_{2a}/2$, $\Omega_{2b}/2$, $\Omega_{3a}/3$, $\Omega_{3b}/3$. By means of appropriate distribution and orientation of magnets, selected modes can be emphasized or suppressed. Excitation of all six resonances by means of one magnet (l = 1, λ_1 =0) for $q(r_0)F1/m_{red}$ = 1 is shown as response curve in Fig. 3.

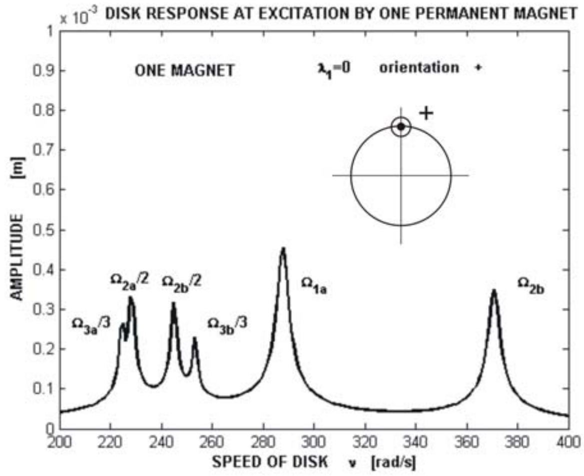

Fig. 3: Response curve excited by 1 magnet.

Adding second magnet (l = 1, 2) into opposite position (λ_1 = 0, λ_2 = π) suppresses modes with add number of nodal diameters (n = 1, 3) and emphasizes mode with even nodal diameter (n = 2) as shown in Fig. 4.

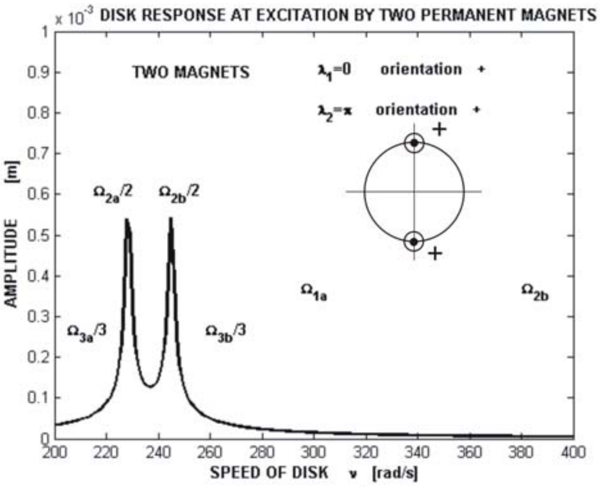

Fig. 4: Response curve excited by 2 magnets.

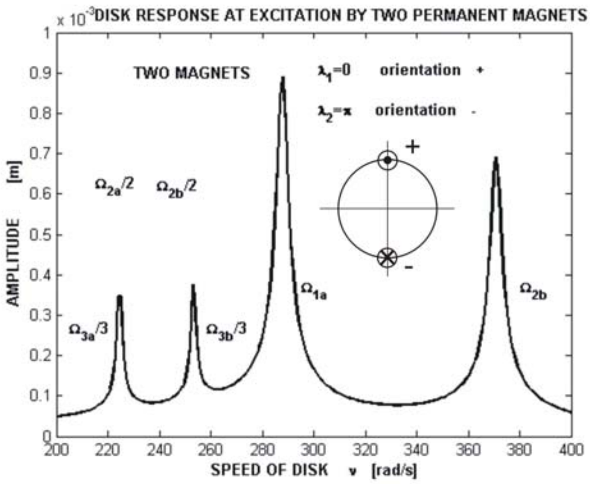

Fig. 5: Response curve excited by 2 opposite acting magnets.

If we change the orientation of attraction force of the second magnet, the even nodal diameters mode is suppressed and on the contrary the odd nodal diameters modes (n = 1, 3) are emphasized as seen in Fig. 5.

Similar method can be applied also for suppressing or amplifying and isolating other selected modes of vibrations by using higher number of permanent magnets.

4. Conclusions

Possibility of application of a simple excitation method for investigation of dynamic properties of rotating disk is studied. Analytical and experimental research of rotating imperfect disk shows the existence of backward and forward traveling waves. Presented study is focused on the excitation of backward traveling waves of modes with 1, 2 and 3 nodal diameters.

Theoretical background of this method is based on equations describing vibrations of rotating imperfect disk excited by an external harmonic transversal force after setting excitation frequency equal zero. On selected examples it is shown that by using appropriate number and positions of permanent magnets, this excitation method enables to measure response curves with resonance corresponding to the split eigenfrequencies of imperfect disk and it enables also suppressing or amplifying some resonance peaks.

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