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TORSIONAL NATURAL FREQUENCY TUNING BY MEANS OF PNEUMATIC FLEXIBLE SHAFT COUPLINGS

Summary. This article deals with the use of pneumatic flexible shaft couplings as device for tuning torsional natural frequencies of mechanical systems. These couplings are using air bellows as flexible elements. Their torsional stiffness can be changed by air pressure change, the natural frequencies of whole mechanical system may be adjusted on desired value.

Keywords: torsional vibration; pneumatic flexible shaft coupling; semi-active vibroisolation

1. INTRODUCTION

Development and application of pneumatic flexible shaft couplings are in the center of our department research activities for a long time [1], [2]. These couplings are able to change torsional stiffness by changing pressure in their flexible elements – air bellows. Mechanical drives with periodically alternating load torque (reciprocating engines and compressors) are prone to resonance, pneumatic flexible shaft coupling are ideal device for protecting them from excessive torsional vibration. This article deals with a problem of avoiding resonance state on an example of diesel engine – electric generator mechanical drive.

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2. EXAMINED MECHANICAL SYSTEM

The selected mechanical system consists of a 10-pole synchronous generator driven by a 6-cylinder diesel engine. This mechanical system works on a constant operating speed resulting from the required electric network frequency. It is necessary to use a flexible shaft coupling with a proper torsional stiffness to avoid resonance. The technical parameters of mechanical system are as follows [3]:

Parameters of engine:

- Turbocharged diesel line engine type ČKD 6-27,5 A2L
- Nominal power by 600 RPM: P_M = 515 kW
- Mass moment of inertia: I_M = 137 kg.m^2,

Parameters of generator:

- Synchronous generator type SIEMENS 1FC2 561-10
- Input power: P_G = 492 kW
- Operating speed: n_o = 600 RPM
- Number of poles: 10
- Mass moment of inertia: I_G = 61,0 kg.m^2

Parameters of shaft coupling:

- Pneumatic flexible shaft coupling type 4–1/310–T–C
- Dynamic torsional stiffness:

$$k_{dyn} = 195{,}6 \cdot p_{p0} + 5516 \text{ N.m.rad}^{-1} \tag{1}$$

where p_{p0} kPa is air pressure in the coupling

- Mass moment of inertia of one hub: $I_{1S} = I_{2S} = 29{,}86\ kg.m^2$

Static and dynamic torsional stiffness of coupling depends on air pressure p_{p0} kPa.

3. TORSIONAL VIBRATION ANALYSIS

This mechanical system can be considered as a two-mass torsional oscillating mechanical system, where the first mass J_1 consists of masses J_M and J_{1S}, and second mass consists of masses J_{2S} and J_G (Fig. 1).

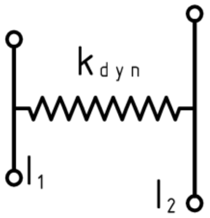

Fig. 1. Two mass torsional oscillating mechanical system

The major harmonic component of load torque for a six-cylinder four-stroke reciprocating engine is the third harmonic component, the minor harmonics are the integer multiples of half harmonic component. Minor harmonic may occur only by uneven cylinder operation.

The natural frequency of mechanical system can be computed as:

$$\Omega_0 = \sqrt{\frac{k_{dyn}}{\left(\frac{I_1 \cdot I_2}{I_1 + I_2}\right)}} \quad \text{rad.s}^{-1} \tag{2}$$

If resonance occurs during operation, it can be determined from Campbell diagram (Fig. 2), where the natural frequencies in RPM by different pressures (100, 200 ... 700 kPa) and harmonic frequencies of *i*-th order are displayed. Where the frequency of torque harmonic is equal to natural frequency, a resonance occurs.

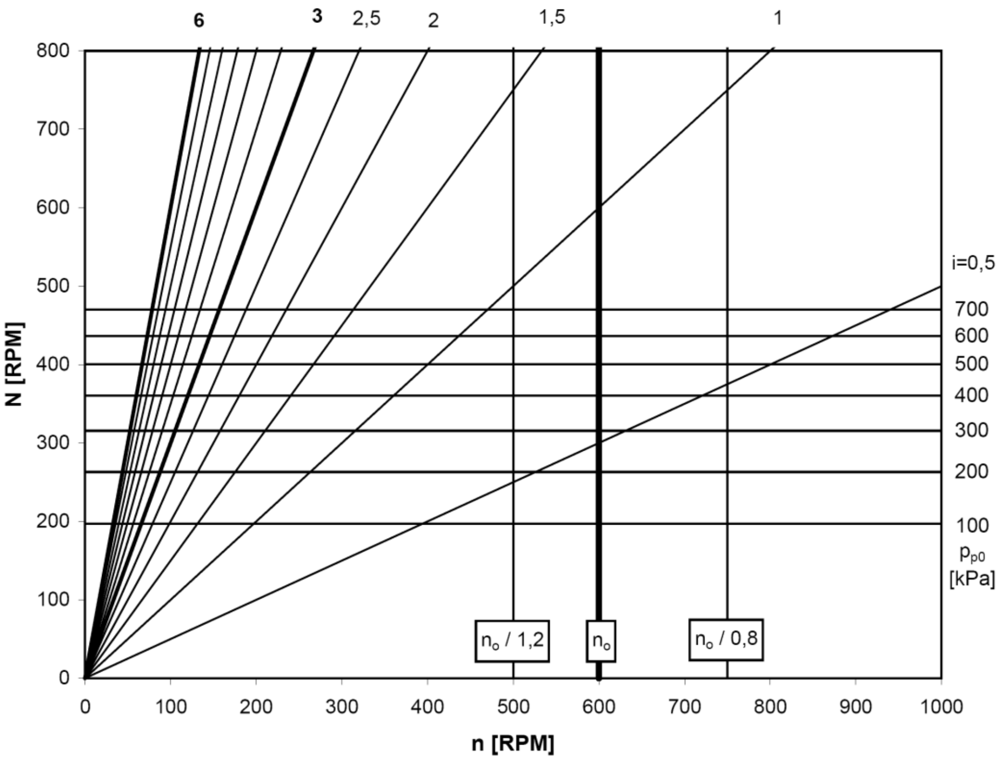

Fig. 2. Campbell diagram of examined mechanical system

Speeds where resonances occur are called critical speeds n_{kri}. How critical speeds n_{kri} depend on pressure p_{p0} is displayed on fig. 3. By the operating speed n_o = 600 RPM, only one resonance from *0,5*-th order may occur by pressure p_{p0} =264 kPa.

Resonance state is dangerous because of increased torsional oscillation, which can damage the whole mechanical system. According to several authors, the frequency ratio $\eta_i = \omega \cdot i / \Omega_0$ between *i*-th harmonics and natural frequency must satisfy the condition: $0{,}8 < \eta_i < 1{,}2$. On the Campbell diagram (Fig. 1), no resonance should lie between n_o /1,2 and n_o /0,8. The given mechanical system can operate by pressures p_{p0}=100, 500, 600 and 700 kPa. By other pressures a resonance from *0,5*-th order occurs near the operating speed.

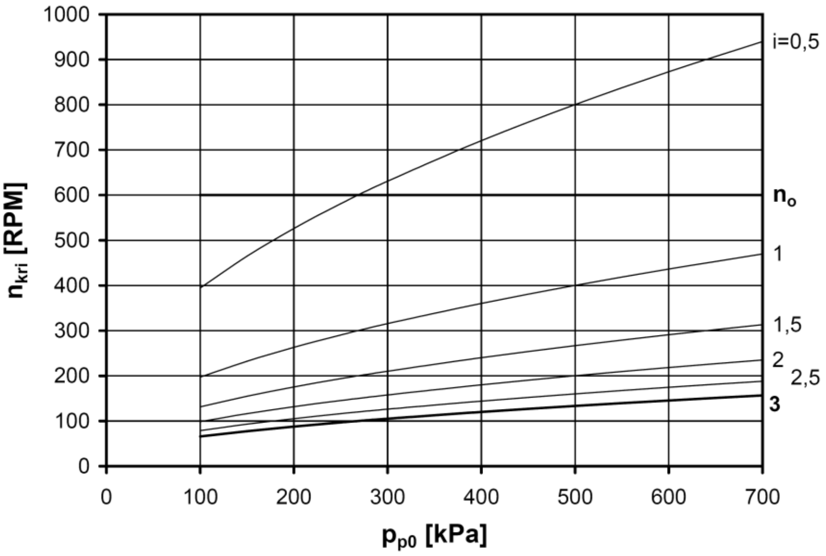

Fig. 3. Critical speeds, pressure graph

4. CONCLUSION

Based on presented results, we can say that the natural frequency as well as critical speeds of a torsional oscillating mechanical system can be tuned (changed) by using a pneumatic flexible shaft coupling. Pneumatic flexible shaft couplings are therefore considered not only as plain flexible shaft couplings, but pneumatic tuners of torsional oscillation.

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