Determining Optimum Air Pressure Value in Pneumatic Flexible Shaft Coupling

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Abstract. At our workplace, we deal with research in the broad field of machine parts and mechanisms. It is very appropriate and needful to utilize the knowledge gained from our extensive research also in an educational process. Therefore, the aim of this paper is to present one of our educational activities, based on the research in the field of continuous tuning of mechanical systems in terms of torsional vibration magnitude using pneumatic flexible shaft couplings – pneumatic torsional vibration tuners. The main task of the activity – laboratory measurement, prepared for students in the subject "Design of machines and machine elements" is to determine experimentally an optimum air pressure value in a pneumatic coupling, which is mounted in an experimental mechanical system of piston compressor drive for a given operating mode of the system. So the students can apply gained knowledge from multiple subjects, especially from subjects "Dynamics" and "Machine parts" in practice and also gain the practical experience.

Keywords: Pneumatic Flexible Shaft Coupling · Torsional Vibration · Continuous Tuning · Laboratory Measurement · Students · Education

1 Introduction

At our Department of Construction and Transport Engineering, we deal with research in the broad field of machine parts and mechanisms, e.g. [1, 2, 3, 4, 5]. In order to continuously increase the quality of an educational process at our Faculty of Mechanical Engineering, the knowledge gained from our extensive research is also utilized in the education of our students of all degrees of study [6–8]. The utilization often includes experimental measurements, prepared for our students in our laboratories so the students can gain a practical experience and join it with the theory [9–14].

The aim of this paper is to present one of our educational activities, based on the research in the field of continuous tuning of torsional vibrating mechanical systems in terms of torsional vibration magnitude using pneumatic flexible shaft couplings – pneumatic torsional vibration tuners [15, 16]. The activity is a laboratory measurement prepared for students within the subject "Design of machines and machine elements". The students should experimentally determine an optimum air pressure value in a pneumatic flexible shaft coupling, which is mounted in an experimental mechanical system of piston compressor drive for a given operating mode of the system [17–21].

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2 Materials and Methods

As an output of the exercise, students have to submit a written account, which contains the following sections:

Determine the optimum value of the air pressure in compression space of pneumatic coupling type 4-1/70-T-C, where the torsional vibration magnitude is also minimum in a torsional vibrating mechanical system of piston compressor drive for a given operating mode of the system.

2.1 Theoretical Background

Excessive torsional vibration in mechanical systems causes noise and various serious failures, such as breakages of shafts, gear teeth and machines feet, pressure damages of shaft keys and keyways, failures of flexible couplings and others so we try to reduce it. The value of torsional stiffness of a flexible shaft coupling applied in a mechanical system directly influences the natural frequencies of the mechanical system (*The natural frequency of a torsional mechanical system is demonstrated to students using the free oscillation method*). By suitable value of torsional stiffness k ($k_2 < k_1 < k_3$) (Fig. 2), resonances from individual harmonic components of excitation can be moved from the operational speed range (OSR) of a mechanical system and herewith the value of dynamic component M_D of the transmitted load torque can be reduced, i.a. [22–28]. Thus, we say that we can **tune** the mechanical system in terms of the magnitude of torsional vibration. The dependence of the M_D on the speed n of a mechanical system (Fig. 1) is the so-called resonance curve of the mechanical system. The speed of a mechanical system at which the natural and the excitation frequencies match (peak of the resonance curve) is called **critical speed**.

The torsional stiffness of a pneumatic flexible coupling, and so the natural frequencies of a torsional system can be changed by adjusting the air pressure in its pneumatic flexible elements. Pneumatic couplings allow us to tune the mechanical system even during its operation after changing its operating mode; then, we talk about the **continuous tuning** of the mechanical system during its operation (if we want to change the torsional stiffness of a flexible shaft coupling with flexible elements made of rubber, plastic or steel, we have to replace the elements when the mechanical system is out of operation).

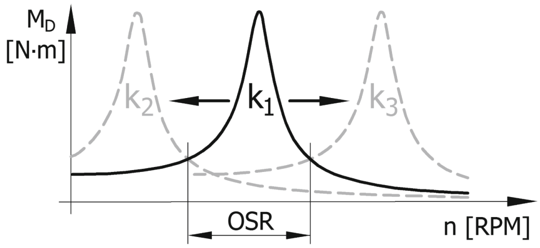

Fig. 1. Mechanical systems tuning principle.

2.2 Description and Scheme of the Experimental Mechanical System

In following Fig. 2, the scheme of the experimental mechanical system of piston compressor drive is displayed. The mechanical system is made up of a 3-phase asynchronous electromotor Siemens 1LE10011DB234AF4-Z (11 kW/1470 RPM) (*1*). The rotation speed of this electromotor is continuously vector-controlled by the frequency converter Sinamics (FC). Electromotor drives a 3-cylinder piston compressor ORLIK 3JSK-75 (*2*) through a gearbox with gear ratio 1:1 (*3*) and through a pneumatic flexible shaft coupling type 4-1/70-T-C (*4*) (Fig. 1). The piston compressor excites torsional vibration in the mechanical system. Compressed air from the compressor streams into an air pressure tank (*6*) with a volume of 300 l.

Using the throttling valve (*7*), the air pressure in the tank and thereby also the output load of the mechanical system can be controlled. Maximum air overpressure in the pressure tank is 800 kPa, and we can see its value on the manometer (*8*). Through the rotation supply (*5*), the supply of compressed air into the pneumatic coupling is implemented. For the measurement of torsional vibration magnitude, a torque sensor (*9*) (type 7934, producer MOM Kalibergyár with measuring range 0 ÷ 500 N·m) is used. For the measurement of air pressure in the compression space of the pneumatic coupling, a pressure sensor (PS) (type MBS 3000, producer Danfoss with measuring range of overpressure 0 ÷ 1 MPa) is used. Signals from both the sensors are amplified and processed by the universal 8-channel measuring device HBM MX840, and the data is subsequently sent to PC. The accuracy of the MBS 3000 sensor with a metal membrane is 0,5% of its measuring range, i.e. 5 kPa (combined fault – nonlinearity, hysteresis and reproducibility), and the accuracy of the torque sensor is 0,1% of its measuring range, i.e. 0,5 N·m (combined fault).

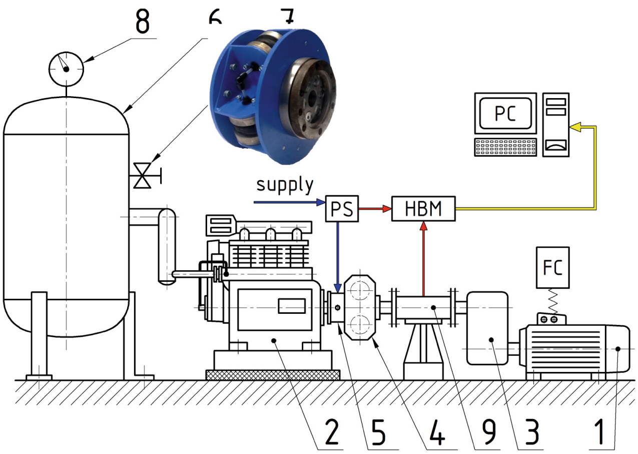

Fig. 2. The experimental mechanical system of piston compressor drive.

2.3 Experimental Measurement Conditions

- An operating mode of the mechanical system is characterized by a constant value of overpressure in the pressure tank and by a constant operational speed of the mechanical system;
- The constant value of overpressure in the pressure tank during measurements is p_{pN} = 500 kPa;
- Assigned constant operational speed of the mechanical system is n_O = ………………………….. Min^{-1} (It can be $\mathrm{n_O}$ = 400; 700 or 1000 min^{-1});
- The overpressure value in the compression space of the pneumatic coupling can be in the range from p_{pS} = 200 kPa (minimum overpressure to ensure the required transfer capacity of the coupling in a given mechanical system) to 800 kPa (maximum overpressure prescribed by the manufacturer of the pneumatic flexible elements);
- It is needed to measure 3 resonance curves of the mechanical system at the values of overpressure in the compression space of the pneumatic coupling p_{pS} = 200 kPa, p_{pS} = 500 kPa, and p_{pS} = 800 kPa;
- The operational speed of the mechanical system will vary in the range $n_O = 300 \div 1100\ \mathrm{min}^{-1}$, with step 50 min^{-1};
- The compressor operates without failure; thus, its cylinders operate evenly. For a 3-cylinder compressor, the main harmonic component is the 3$^{\mathrm{rd}}$ harmonic component. The resonance peaks in our operational speed range arise from the coincidence of the main – 3$^{\mathrm{rd}}$ harmonic component of the excitation with the 1$^{\mathrm{st}}$ natural frequencies of the mechanical system (This fact was verified by the frequency analysis);
- To quantify the torsional vibration magnitude, the effective value RMS of the dynamic component M_D of the load torque was chosen. RMS M_D is computed according to the following equations:

$$\mathrm{RMS}\, M_D = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} (M_{Di})^2} \qquad (1)$$

and

$$M_{Di} = M_i - \left(\frac{1}{N} \cdot \sum_{i=1}^{N} M_i \right) \qquad (2)$$

where N is the number of samples and M_i is i-th sample of load torque time record. For the computation of RMS M_D according to the equations, the average running method is used;

- Torque signal measurement sampling frequency: 1200 Hz.

2.4 Tasks for Elaboration

A. Measured values of RMS M_D write down into a table;
B. From the measured values, construct graphs of the resonance curves in MS Excel or on graph paper. Using a vertical line, mark in the graph your given operational speed of the mechanical system n_O;

C. For your specific operating mode of the mechanical system select the most appropriate value of the air overpressure in the pneumatic coupling p_{pS} for the smallest value of RMS M_D;
D. Say whether the mechanical system is operating in the sub-resonance or over-resonance area at your operating mode.

3 Results and Discussion

3.1 Task A

See Table 1.

3.2 Task B

See Fig. 3.

3.3 Task C

The most appropriate value of the air overpressure in the pneumatic coupling is $p_{pS} =$ 800 kPa at $n_{O1} = 400$ min^{-1}; $p_{pS} = 200$ kPa at $n_{O2} = 700$ min^{-1} and $p_{pS} = 200$ kPa at $n_{O3} = 1000$ min^{-1}.

3.4 Task D

The mechanical system is operating in the sub-resonance area at $p_{pS} = 800$ kPa/$n_{O1} =$ 400 min^{-1} and in the over-resonance area at $p_{pS} = 200$ kPa/$n_{O2} = 700$ min^{-1} and p_{pS} = 200 kPa/$n_{O3} = 1000$ min^{-1}.

Table 1. Results of task A.

p_{pS} [kPa]	RMS M_D [N·m] at operational speed n [min^{-1}]							
	300	350	400	450	500	550	600	650
200	10,1	11,6	17,2	21,7	23,4	17,2	12,9	10,7
500	8,7	9,4	11,2	13,5	17,3	23,2	26,5	25
800	8,1	8,2	9,3	10,5	12,2	16,3	20,5	25,1
p_{pS} [kPa]	RMS M_D [N·m] at operational speed n [min^{-1}]							
	700	750	800	850	900	950	1000	1100
200	8,4	7,1	6,5	5,5	5,1	4,4	4	3,3
500	20,1	16,2	13,4	10,5	8,9	7,6	6,8	5,5
800	28,2	27,1	22,3	18,3	15,3	11,9	10,1	7,9

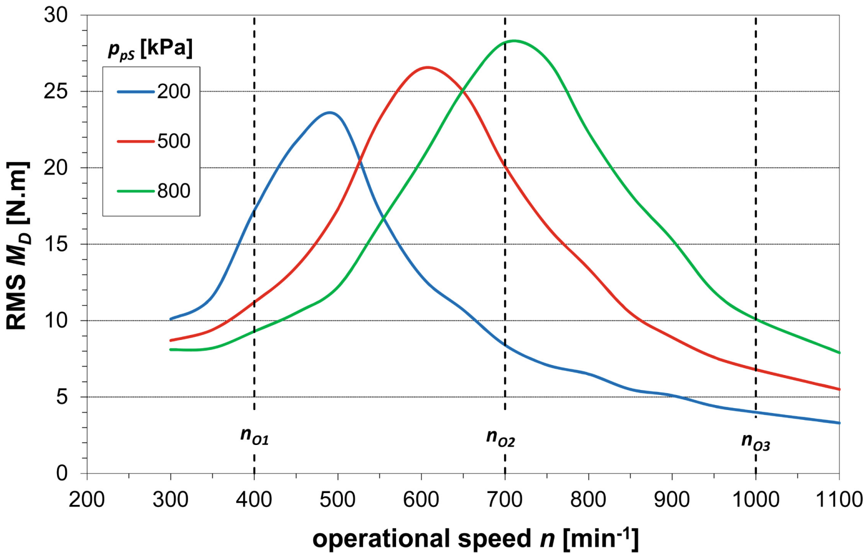

Fig. 3. Results of Task B.

4 Conclusions

The main goal of the presented laboratory measurement is a significant enhancement of the knowledge of our students in the fields of machine dynamics and vibration. The achievement of the main goal is ensured by joining student's practical experience gained in our "Laboratory of measuring and tuning the torsional vibration" with the theoretical knowledge from multiple subjects, especially from the subjects "Dynamics" and "Machine parts", which the students have to use in order to solve the given task. The attractiveness of the solved problem task for students is also proven by the positive feedback of the students.

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