EXPERIMENTAL VERIFICATION OF THE POSSIBILITY USING PNEUMATIC FLEXIBLE SHAFT COUPLINGS FOR THE EXTREMAL CONTROL OF TORSIONAL OSCILLATING MECHANICAL SYSTEM

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Summary

Extremal control is an optimization performed by experimenting with optimised device directly during operation. On our department we deal with the extremal control of torsional oscillating mechanical systems by means of pneumatic flexible shaft couplings. The torsional stiffness of these couplings and so the natural frequencies of torsional systems can be changed by adjusting the air pressure in their pneumatic flexible elements. The goal of this optimisation is to minimize the value of torsional vibration by changing the pressure of gaseous medium in the used pneumatic flexible shaft coupling. The goal of this article is to confirm the possibility of the use of extremal control in a laboratory torsional oscillating mechanical system built on our department.

Keywords: Extremal control, torsional vibration, pneumatic flexible shaft coupling, optimization

EKSPERYMENTALNE SPRAWDZENIE MOŻLIWOŚCI ZASTOSOWANIA PNEUMATYCZNYCH SPRZĘGIEŁ ELASTYCZNYCH W CELU REGULACJI EKSTREMALNEJ UKŁADÓW MECHANICZNYCH DRGAJĄCYCH SKRĘTNIE

Streszczenie

Regulacja ekstremalna to optymalizacja uzyskiwana poprzez eksperymentowanie na optymalizowanym urządzeniu bezpośrednio podczas jego pracy. W naszej katedrze w tej dziedzinie wykonuje się badania, mające na celu przeprowadzenie ekstremalnej regulacji układów mechanicznych drgających skrętnie przy pomocy sprzęgieł pneumatycznych. Sztywność skrętną danych sprzęgieł, a przez to także częstotliwość własną układu, możemy zmieniać bezpośrednio podczas pracy układu, zmieniając ciśnienie w komorze sprężania sprzęgła. Celem takiej optymalizacji jest zminimalizowanie wielkości drgania skrętnego przy pomocy zmiany ciśnienia medium gazowego w zastosowanym sprzęgle pneumatycznym. Celem niniejszego artykułu jest potwierdzenie możliwości przeprowadzenia ekstremalnej regulacji w laboratoryjnym układzie mechanicznym wykonanym w naszej katedrze.

Słowa kluczowe: regulacja ekstremalna, drganie skrętne, pneumatyczne sprzęgła elastyczne łączące wały, optymalizacja

1. INTRODUCTION

On our department we deal with the extremal control [1, 2, 3] of torsional oscillating mechanical systems [4, 5] by means of pneumatic flexible shaft couplings. Extremal control gives us the possibility to minimize the value of dangerous torsional vibration in torsional oscillating mechanical systems directly during operation by adapting the dynamic properties of the oscillating systems to actual operating parameters and failures. Big advantage of this method is that we do not need to know the exact mathematical model of the system, which was required e.g. in publications [6, 7, 8]. We must know only that the objective function of the mechanical system has an extreme (for our case a local minimum) [9, 10, 11]. In this case the objective function (controlled variable) is the value of torsional vibration.

The necessary condition of extremal control in torsional oscillating mechanical systems is the use of proper control element. In the present the pneumatic flexible shaft couplings developed on our department are the only applicable control element for this purpose [12, 13, 14]. The torsional stiffness of these couplings and so the natural frequencies of torsional systems can be changed by adjusting the air pressure in their pneumatic flexible elements [15, 16, 17, 18]. In the term of extremal control the pressure of gaseous medium (air) in pneumatic flexible coupling is the actuating variable [11].

The goal of this article is to confirm the possibility of the use of extremal control in a laboratory torsional oscillating mechanical system built on our department.

2. INVESTIGATED MECHANICAL SYSTEM

Described torsional oscillating mechanical system was built on our department in order to research torsional oscillation and mechanical vibration (*Fig. 1.*) This mechanical system consists of 3-cylinder air compressor driven by *DC* electromotor through pneumatic flexible shaft coupling.

Operating speed of *SM 160 L* type electromotor (*1*) is adjusted by an *IRO* type thyristor controller (*11*). The *3-JSK-S* type air compressor (*2*) has no flywheel, hence the compressor has bigger dynamic torque. The load of mechanical system depends on the compressors delivery pressure adjusted with valve (*8*) on the pressure vessel (*7*). The torsional stiffness of pneumatic flexible shaft coupling (3) developed on our department can be adjusted during operation by changing the air pressure in the pneumatic elements of the coupling [19]. Compressed air is fed into the coupling from a pressure vessel of couplings compressor (*9*) through valve (*10*) and air input (*6*). Between the air input and electromotor a torque sensor (*5*) is mounted.

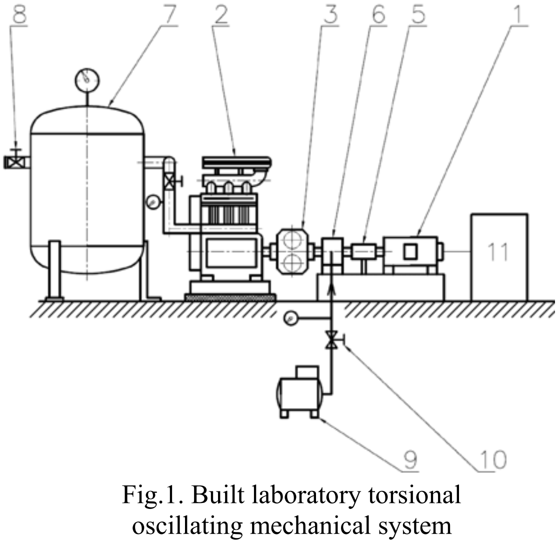

Fig.1. Built laboratory torsional oscillating mechanical system

3. MEASURING THE SIZE OF TORSIONAL VIBRATION IN STEADY STATE

To perform extremal control it is important to know that the objective function of system has an extreme (in our case a local minimum). The objective function for a torsionally oscillating mechanical system described in previous chapter is the value of torsional vibration. The value of torsional vibration is the value of selected static value computed from the time record of transmitted load torque [19, 20, 21, 22].

To measure the value of transmitted torque a contact torque sensor was applied. Thist is a *7394* type torque sensor type manufactured by the *MOM Kalibergyár* company with nominal torque 500 Nm. For signal recording and processing an eight-channel measuring device *QuantumX MX840* from *HBM* company was used. The signal was recorded with sample rate 1200 Hz with automatic filter (Bessel, low-pass 100 Hz, with antialiasing). The measurement was performed by different constant operating speeds (350, 400, 450, 500, 550, 600 RPM), by constant delivery pressure 0,1 MPa of the compressor. By these conditions the air pressure in pneumatic flexible coupling was set on different constant values (100, 150, 200, ..., 600 kPa). The measurements were performed by regular operation (cylinders evenly running) and then with one disabled cylinder [18]. The cylinder was disabled by opening the suction valve of the compressor cylinder. On the *Fig.2.* is ilustrated a time record of transmitted load torque M by operating speed n = 400 RPM, pressure of gaseous medium p_S = 300 kPa and by regular operation.

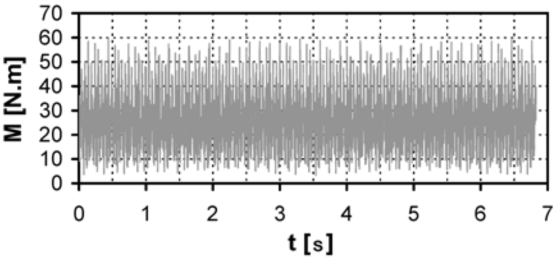

Fig.2. Time waveform record of the transmitted torque

From the measured time record of transmitted load torque were computed the of following static values:

- *MAX* – Maximum value of load torque.

$$MAX = \max\{M_i | i = 1,2,...,N\} \tag{1}$$

- *PEAK* – Peak value of dynamic torque.

$$PEAK = \max\{(M_i - M_S) | i = 1,2,...,N\} \tag{2}$$

- *PEAK-PEAK* – Peak to peak value of load torque.

$$PEAK - PEAK = \max\{M_i\} - \min\{M_i\} \tag{3}$$

- *RMS* – Effective value of dynamic torque.

$$RMS = \sqrt{\frac{1}{N} \cdot \sum_{i=1}^{N} (M_i - M_S)^2} \tag{4}$$

where: N– number of samples,
M_i – i-th sample of load torque,
M_S – Static (average) load torque.

Number of samples N was 8192, corresponding for the selected sample rate 1200 Hz to signal length 6,827 s.

On *Fig.3 – Fig.6*. are presented the graphs of load torque static values depending on the air pressure in the pneumatic flexible shaft coupling by regular operation. On *Fig.7 – Fig.10* are presented the graphs of load torque static values depending on the air pressure in the pneumatic flexible shaft coupling by disabled cylinder.

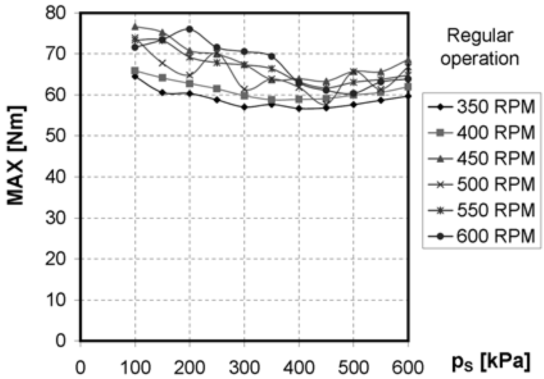

Fig.3. Maximum value of torque MAX

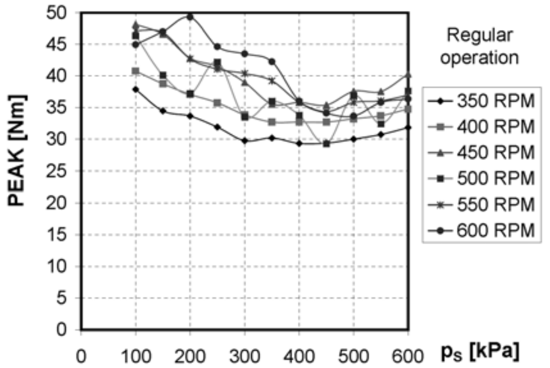

Fig.4. Peak value of dynamic torque PEAK

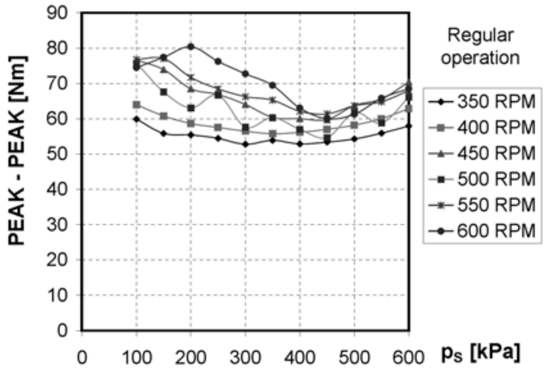

Fig.5. Peak to peak value of load torque PEAK-PEAK

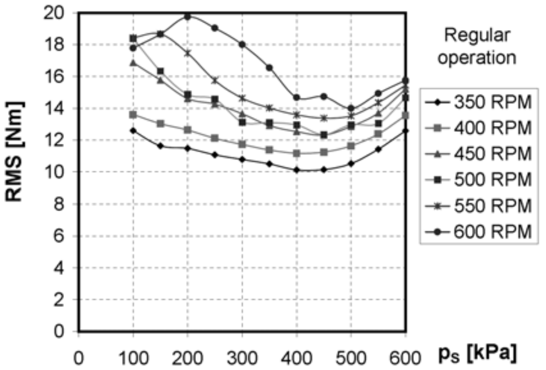

Fig.6. Effective value of dynamic torque RMS

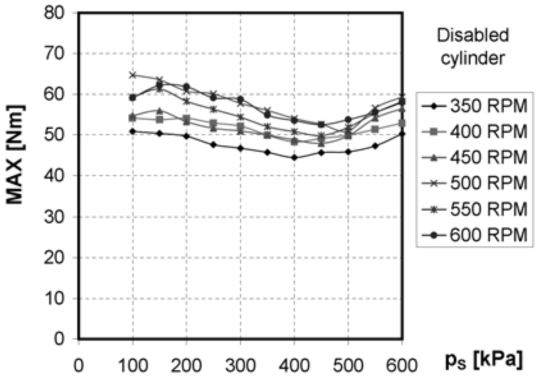

Fig.7. Maximum value of torque MAX

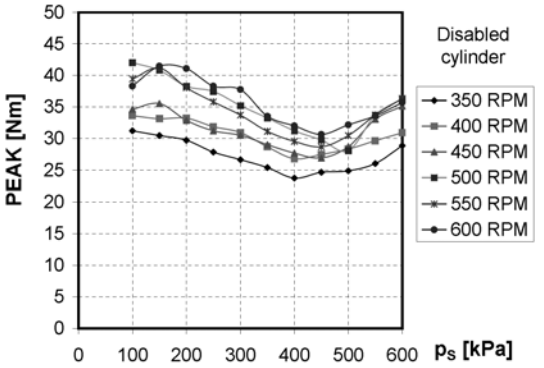

Fig.8. Peak value of dynamic torque PEAK

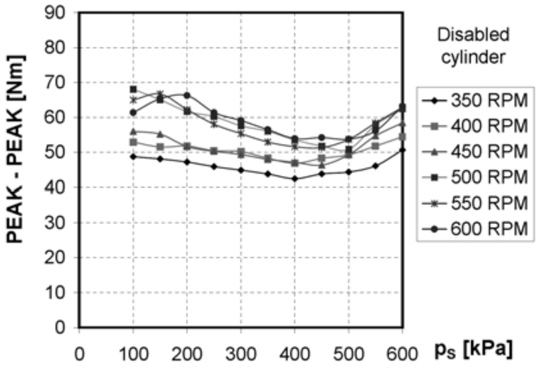

Fig.9. Peak to peak value of load torque PEAK-PEAK

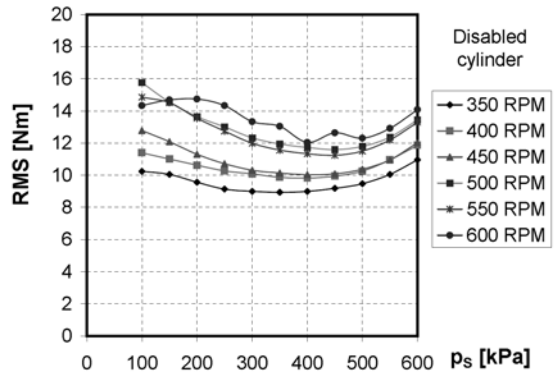

Fig.10. Effective value of dynamic torque RMS

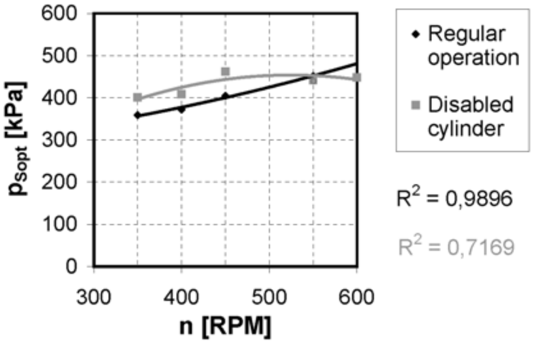

Fig.11. Maximum value of torque MAX

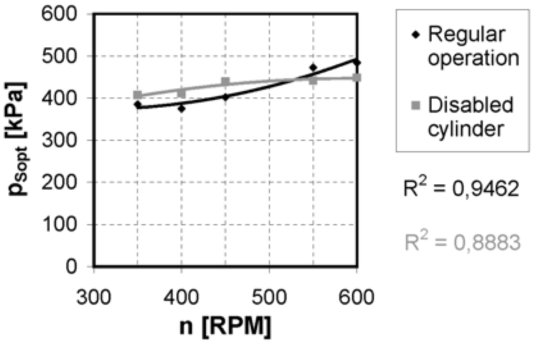

Fig.12. Peak value of dynamic torque PEAK

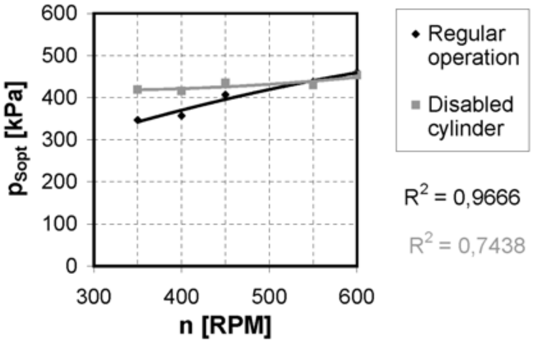

Fig.13. Peak to peak value of load torque PEAK-PEAK

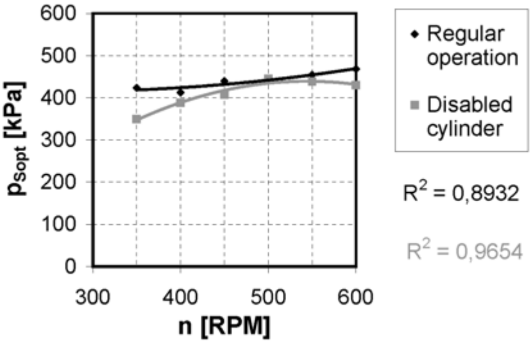

Fig.14. Effective value of dynamic torque RMS

For all static values by regular operation and also by disabled cylinder the global minimum is located in the pressure range 300-500 kPa. For measured values it is important to note that by operating speeds 500 and 600 RPM the curves shows considerable fluctuations caused by the interference of electromotor torque harmonics (integer multiples of electrical network frequency and its side bands in the distance of integer multiples of speed frequency) and compressor torque harmonics (integer multiples of speed frequency).

The goal of torsional oscillating mechanical systems optimisation is the minimization of torsional vibration value in steady-state condition. So we must find the optimum value of air pressure in pneumatic coupling for actual operating speed and failures, where the value of torsional vibration is minimum.

For measured values of torsional vibration by constant speed the locations of minimums for each static value of load torque were found. The locations of minimums were estimated with parabolic interpolation method from three smallest values by each operating speed.

Obtained optimum pressures p_{Sopt} depending on operating speed n are shown on *Fig.11 – Fig.14*.

4. CONCLUSION

The possibility of extremal control in the torsional oscillating mechanical system built on our department was experimentally confirmed. There were measured the static values of load torque. These values have in the operating range of air pressure in pneumatic coupling only one local minimum, which is actually the global minimum.

The location of this minimum depends on operating parameters and failures, therefore the use of static optimisation with extremal control method in this system is a great advantage.

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- diagnostics of torsionally oscillating mechanical systems performed with regard to the characteristics of torsional oscillation and excited mechanical oscillation.

He is a graduate of the Faculty of Mechanical Engineering of the former Technical College (VŠT) of Košice (in 1987). He defended his dissertation thesis in 1990, his habilitation process was finished successfully in 1997 and in March 2004 he was nominated as university professor.

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