PARTIAL RESULTS OF EXTREMAL CONTROL OF MOBILE MECHANICAL SYSTEM

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Summary

At our department we deal with continuous tuning of torsional oscillating mechanical systems during their operation, mainly in terms of torsional oscillation size, whereby we use the methods and means of technical diagnostics. One of the manners of continuous tuning realization is the application of the extremal control – experimental optimization. The main advantage of this is that we need not know the mathematical model of the mechanical system. Actuating variable in this regulation is the pressure of gaseous medium in the pneumatic flexible shaft coupling – pneumatic torsional oscillation tuner. By changing the pressure of the gaseous medium in pneumatic flexible elements of the coupling we change its torsional stiffness and thereby dynamic properties of the mechanical system too. The objective of this paper is to present partial results of extremal control operation on the newly built mobile torsional oscillating mechanical system.

Keywords: torsional oscillation, extremal control, pneumatic flexible shaft coupling.

CZĘŚCIOWE WYNIKI REGULACJI EKSTREMALNEJ RUCHOMEGO UKŁADU MECHANICZNEGO

Streszczenie

W naszej katedrze zajmujemy się ciągłym dostrajaniem drgających skrętnie układów mechanicznych w trakcie ich pracy, głównie zaś zagadnieniem wielkości drgań skrętnych. W trakcie badań używamy metod i środków diagnostyki technicznej. Jednym ze sposobów realizacji ciągłego dostrajania jest zastosowanie regulacji ekstremalnej, czyli doświadczalnej optymalizacji. Główną zaletą tego typu regulacji jest to, że nie jest konieczna znajomość modelu matematycznego układu mechanicznego. Wielkością sterującą regulacji jest wartość ciśnienia medium gazowego w pneumatycznym sprzęgle podatnym – pneumatyczny "tuner" drgań skrętnych. Poprzez zmianę ciśnienia medium gazowego w elementach podatnego sprzęgła, zmienia się tym samym jego sztywność skrętna i jednocześnie dynamiczne warunki pracy układu mechanicznego. Celem artykułu jest przedstawienie częściowych wyników działania regulacji ekstremalnej na nowym ruchomym drgającym skrętnie układzie mechanicznym.

Słowa kluczowe: drganie skrętne, regulacja ekstremalna, pneumatyczne sprzęgło wałowe elastyczne.

1. INTRODUCTION

At our Department we deal with continuous tuning of torsional oscillating mechanical systems (TOMS) during their operation, i.a. publications [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11] mainly in terms of torsional oscillation size, whereby we use the methods and means of technical diagnostics.

Resonances from individual harmonic components of excitation (Fig.1) can be ejected from the operational speed range (OSR) of mechanical system by suitable value of torsional stiffness k ($k_2 < k_1 < k_3$) and herewith the value of dynamic component M_D of the transmitted load torque can be reduced [12], [13], [14], [15], [16].

The torsional stiffness of pneumatic flexible shaft couplings (pneumatic torsional oscillation tuners, thereinafter „pneumatic tuners“) developed in our department, and so the natural frequencies of torsional systems can be changed by adjusting the gaseous media (most commonly air) pressure in their pneumatic flexible elements.

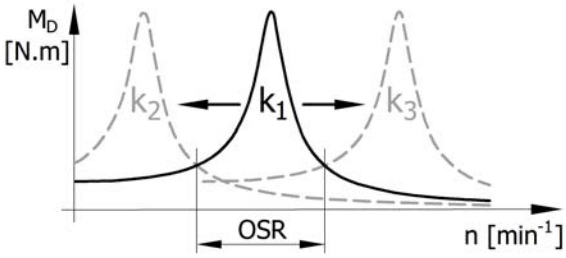

Fig. 1. Mechanical system tuning principle

One of the methods of continuous tuning is the application of the extremal control – experimental optimization. Extremal control gives us the possibility to minimize the value of dangerous torsional vibration in torsional oscillating mechanical systems during their operation directly by adapting the dynamic properties of the oscillating systems to actual operating parameters and failures. Actuating variable in this regulation is the pressure of gaseous medium in the pneumatic flexible shaft coupling – pneumatic torsional oscillation tuner. The main advantage of the extremal control is that we do not need to know the exact mathematical model of the system. We must know only that the objective function of the mechanical system has an extreme [1], [2], [3], [4], [5], [6], [7], [8], [9], [10].

Objective of this paper is presentation of partial results of extremal control operation of the newly built (for presentation purposes) mobile torsional oscillating mechanical system.

2. IMPLEMENTED MECHANICAL SYSTEM

The extremal control algorithm requires for its functioning to scan the torsional oscillation size in time, because just the torsional oscillation size in TOMS is the regulated parameter. In this TOMS we express torsional oscillation size by the size of dynamic component of load torque, which is transmitted by the pneumatic tuner and its effective value RMS.

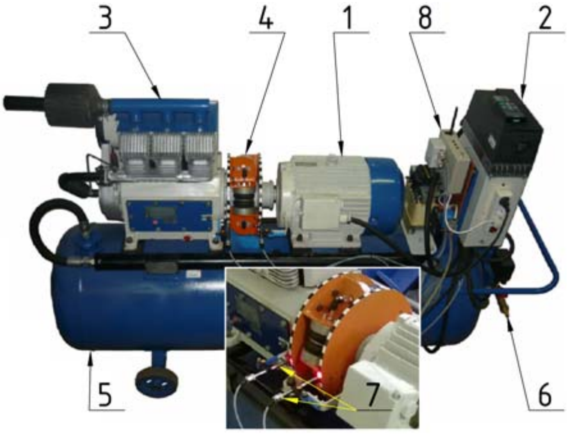

Fig. 2. Implemented torsional oscillating mechanical system

In Fig.2 we can see that the TOMS consists of 3-phase asynchronous electromotor MEZ 4AP132M-4 (7,5 kW, 1450 min^{-1}) (1), whose rotation speed is continuously vector-controlled by the frequency converter Sinamics G120C (2). Electromotor drives the 3-cylinder piston compressor ORLIK 3JSK-75 (3) through the pneumatic tuner of type 4-2/70-T-C (4). The compressor has no flywheel; hence its bigger dynamic torque [1], [7]. Compressed air from the compressor streams into air pressure tank (5) of 300 l volume. Throttling valve (6) controls the air pressure in the tank and thereby the output load of TOMS too. Maximum air overpressure in the pressure tank is 800 kPa.

Sensors have to be selected in accordance to specific requirements [8], [9], [10]. Danfoss sensor MBS3000 with metal membrane (ST) was used for measuring the air pressure in compression space of the pneumatic tuner. Its accuracy (combined fault – nonlinearity, hysteresis and reproducibility) is 0,5% of its measuring range (0 to 1 MPa), i.e. 5 kPa.

For torsional oscillation size measurement we have applied Dewetron optical sensors type SE-TACHO-PROBE-01 (7). These sensors measure the reflection from reflective black-white moving tapes that are glued-on to both pneumatic tuner flanges. These sensors can work at maximum frequency of 10 000 Hz but the quality (crossing area sharpness, cleanness, etc.) of reflective tapes must be excellent. Measurement is based on the time-determination of mutual angular twisting of pneumatic tuner flanges at load torque, transmitted by the pneumatic tuner. The whole process of data measuring and evaluation is described in great detail in [16]. Electromagnetic valves Danfoss EV210B were used for the inflation and deflation of compression space of the pneumatic tuner according to current requirements.

Signal from sensors is executed by the PLC, programmed by specially developed extremal control algorithm. This PLC is the heart of the electronic extremal control system [8], [9], [10] called MESLER, which was developed in our Dept. MESLER sends subsequent data to PC by Wi-Fi.

3. MEASURED OBJECTIVE FUNCTIONS OF THE MECHANICAL SYSTEM

For the realization of extremal control it is necessary, that [1], [2], [3], [4], [5], [6], [7]:

- the objective function of mechanical system has an extreme in operating range of gaseous media pressure in compression space of pneumatic tuner (in this case a local minimum),
- mechanical system is in a stable state of operation during searching for the extreme (in our case rotation speed, air pressure value in the pressure tank and disturbing variables values are constant in time).

For example, the resultant resonant curves of the mechanical system at various air pressures in the tuner (Fig.3) were measured.

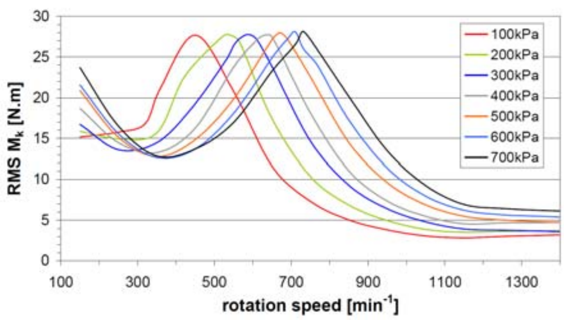

Fig. 3. Resonant curves of the mechanical system at various air overpressure in the tuner p_{pS}

Constant air overpressure value in the pressure tank was 400 kPa. We can see that with increasing the pressure in the pneumatic tuner the resonant curve of the mechanical system moves to the right. It occurs because the dynamic torsional stiffness of the tuner k_{dyn} increases with the increase of air pressure in the tuner, as we can see in Fig.4.

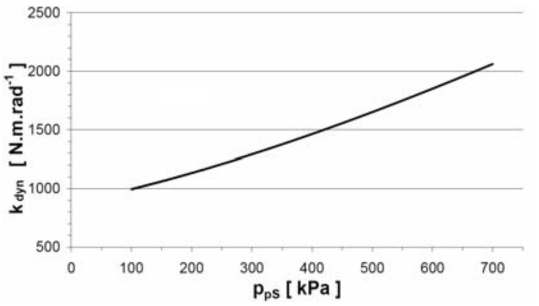

Fig. 4. Dynamic torsional stiffness of the tuner k_{dyn} dependent on overpressure p_{pS} in the tuner

When we plot the chart of effective value RMS of a load torque M_k dynamic component in relation to the overpressure p_{pS} in the pneumatic tuner at various stable states of the mechanical system operation (Fig.5), we can obtain the objective functions of the mechanical system (we have used data from measured resonant curves, Fig.3).

As we can see, these functions feature a required local minimum extreme within operating range of gaseous media pressure in compression space of pneumatic tuner, so necessary condition for extremal control is fulfilled i.a. [1], [2].

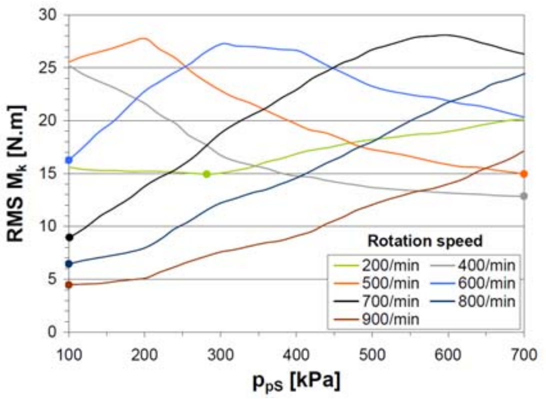

Fig. 5. Objective functions at various stable states of the mechanical system operation

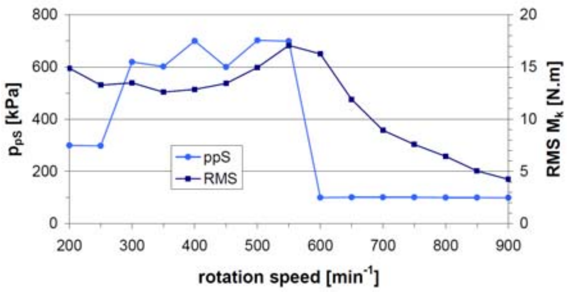

Fig. 6. Optimal air overpressure p_{pS} and RMS M_k value in relation to the rotation speed of mechanical system

The result of our extremal control should be finding the local minimum of objective function at certain stable state of mechanical system operation = minimum of dynamic load torque. Or else air pressure in the pneumatic tuner needs to be adjusted so that dynamic load torque descends to acceptable level.

4. PARTIAL RESULTS OF THE EXTREMAL CONTROL

Our electronic extremal control system MESLER on the new realized mobile TOMS can yield an extreme of objective function of the mechanical system, which operates in stable state; so that it changes air pressure in the pneumatic tuner step by step, in the whole before defined range (Fig.7). Next we can define certain parameters – constant step width, maximum and minimum air pressure in the pneumatic tuner, maximum and minimum allowable dynamic load torque RMS value, initial value of air pressure in the pneumatic tuner, time interval between air pressure changes in the pneumatic tuner (because of transitional effects subsidence).

When operating state of the mechanical system changes or a failure (e.g. cylinder fall-out) occurs, the electronic system responds so that searching of local minimum of objective function of the mechanical system starts again from the beginning.

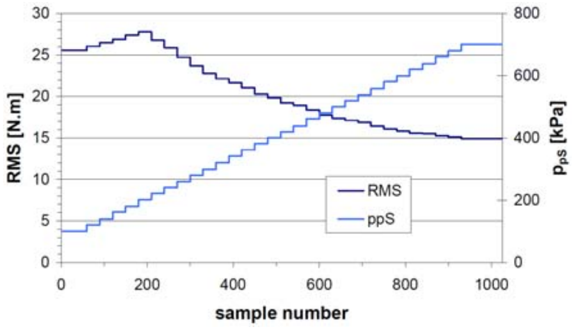

Fig. 7. Example of searching a local minimum of objective function of the mechanical system by the electronic extremal control system MESLER at mechanical system rotation speed *500 min^{-1}*

5. CONCLUSION

In consideration of the present state of given problem solution, in the near future we plan to solve the following tasks:

- Extremal control should work by much more sophisticated algorithm, which was presented in [6]. The advantage will be the more expedient yielding of the extreme in mechanical system objective function, even if operating state of the mechanical system changes or failure occurs; and more accurate extreme finding thanks to various step width.
- Optical sensors used in mechanical system are relatively expensive. For industrial application they are supposed to be less expensive and more weather-resistant, able to operate in dusty, wet, etc. environment.

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Acknowledgement: This paper was written in the framework of Grant Project VEGA: „*1/0688/12 – Research and application of universal regulation system in order to master the source of mechanical systems excitation*".

Prof. Ing. Jaroslav HOMIŠIN, CSc.

is a university professor nominated in the branch of science "Machine Parts and Mechanisms of Machines" with professional specialization oriented to:
optimization of torsionally oscillating mechanical systems with an accent to the control of dangerous torsional oscillations by means of application of flexible shaft couplings, namely by pneumatic flexible shaft couplings,
diagnostics of torsionally oscillating mechanical systems performed with regard to the characteristics of torsional oscillation and excited mechanical oscillation.

Results of his scientific-research activities are summarized in more than 195 original scientific works published in domestic and foreign professional journals, as well as in the form of professional articles presented in many scientific conferences and symposiums at home and abroad. He is owner of 47 technical patents. There are also other important and relevant publication outputs of his professional life: 2 domestic monographs, 1 foreign monograph, 4 university textbooks and several study textbooks.

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