Peter KAŠŠAY[1], Matej URBANSKÝ[2], Silvia MALÁKOVÁ[3],
Jozef KRAJŇÁK[4]

Supervisor: Robert GREGA[5]

DOI: https://doi.org/10.53052/9788366249837.13

WERYFIKACJA EKSTREMALNEGO STEROWANIA DRGAŃ SKRĘTNYCH

Streszczenie: Jednym z obszarów badań realizowanych w naszej macierzystej Katedrze są zagadnienia sterowania ekstremalnego (regulacji ekstremalnej) drgań skrętnych układów mechanicznych przy użyciu podatnych wałowych sprzęgieł pneumatycznych. Istota postępowania polega na możliwości bieżącej zmiany sztywności skrętnej sprzęgieł, a tym samym częstości drgań własnych połączonych nimi wałów, poprzez zmianę ciśnienia w pneumatycznych elementach sprężystych będących elementami składowymi tych sprzęgieł. Układ sterowania ekstremalnego uzyskuje się poprzez uzupełnienie zasadniczego układu regulacyjnego członem optymalizującym, którego zadanie polega na automatycznym doborze wartości zadanej tak, aby uzyskana wielkość sygnału sterującego zapewniała osiągnięcie ekstremum wartości wielkości regulowanej. W artykule przedstawiono algorytm opracowany w celu realizacji sterowania ekstremalnego drgającego skrętnie układu mechanicznego zbudowanego w Katedrze. Jego działanie sprawdzono, bazując na modelu matematycznym opracowanego układu.

Słowa kluczowe: ekstremalne sterowanie, optymalizacja, podatne wałowe sprzęgło pneumatyczne, kompresor

VERIFICATION OF TORSIONAL VIBRATION EXTREMAL CONTROL

Summary: At 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. Extremal control is an optimization method performed by experimenting with optimized device directly during operation. The goal of this article is to confirm the possibility of the use of extremal control in a laboratory torsional oscillating mechanical system built at our department and present the function of an extremal

---

[1] Technical University of Košice, Peter.Kassay@tuke.sk
[2] Technical University of Košice, Matej.Urbansky@tuke.sk
[3] Technical University of Košice,Silvia.Malakova@tuke.sk
[4] Technical University of Košice, Jozef.Krajnak@tuke.sk
[5] Technical University of Košice, Robert.Grega@tuke.sk
[1-5] Faculty of Mechanical Engineering, Department of Design and Transport Engineering

control algorithm developed by us. The function of extremal control algorithm is presented with a simulation on a mathematical model of a built laboratory mechanical system.

Keywords: extremal control, optimization, pneumatic flexible shaft couplings, compressor

1. Introduction

At our department we deal with the extremal control of torsional oscillating mechanical systems by means of pneumatic flexible shaft couplings [2], [3]. This optimisation method gives us the possibility to minimize the value of 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.

The necessary condition of extremal control in torsional oscillating mechanical systems is the use of proper control element. Pneumatic flexible shaft couplings developed at our department are suitable for this purpose, [3], [4]. 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 [1], [2]. In the term of extremal control the air pressure in pneumatic flexible coupling is the actuating variable [4], [6], [7].

The goal of this article is to confirm the possibility of the use of extremal control in a laboratory torsional oscillating mechanical system built at our department and present the function of an extremal control algorithm developed by us. The function of extremal control algorithm is presented with a simulation on a mathematical model of the built laboratory mechanical system.

2. Investigated Mechanical System

Described torsional oscillating mechanical system (*fig. 1*) was built at our department for research of torsional oscillation and mechanical vibration [2], [4]. This mechanical system consists of 3-cylinder air compressor driven by DC electromotor through pneumatic flexible shaft coupling.

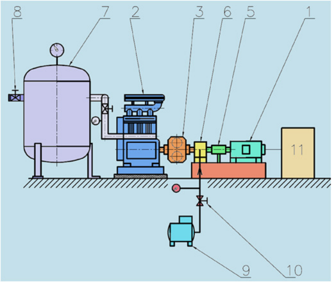

Figure 1. Investigated laboratory torsional oscillating mechanical system

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 at our department can be adjusted during operation by changing of air pressure in the pneumatic elements of the coupling. 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.

3. Extremal Control Algorithm

The algorithm of extremal control shown in *fig. 2* was developed at our department [2], [3], [4].

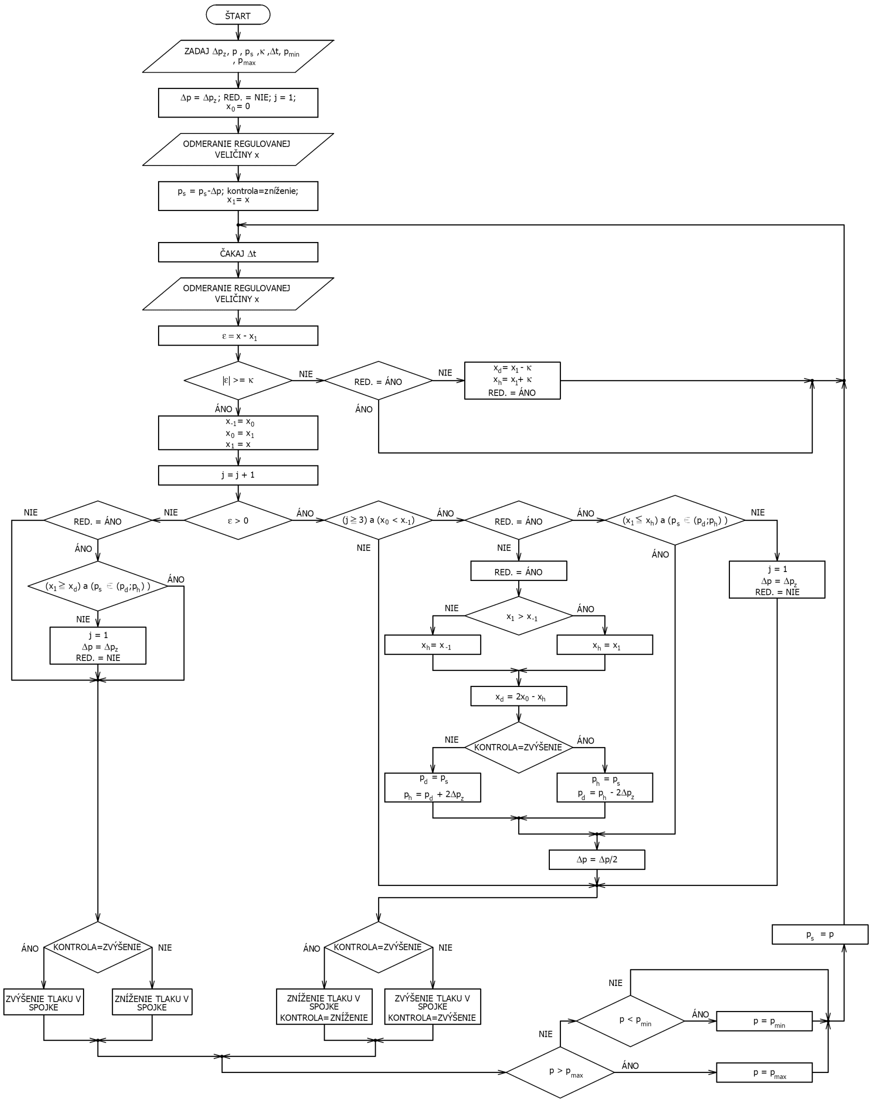

Figure 2. Extremal control algorithm

This algorithm takes into account the limitations of maximum and minimum air pressure in pneumatic flexible shaft coupling (p_{max} and p_{min}). Always after finding the interval of uncertainty (after passing the optimal value) the pressure step Δp is reduced by half until the difference of two consequent values x (value of objective function) is smaller than dead zone κ. After a number of pressure step reductions the pressure oscillation around optimum value is eliminated. When the operation state of system changes the pressure step Δp returns to initial value Δp_z .

4. Objective Function

For the realization of extremal control is necessary to know that the objective function of mechanical system has an extreme (for our case a local minimum) [2], [4], [5], [6], [7]. The objective function of mechanical system described in previous chapter is the value of torsional vibration. As value of torsional vibration the effective value (RMS) of measured dynamic torque signal was selected. Rotational speed and delivery pressure of air compressor are the operating parameters. The failure was simulated by disabling one of compressors cylinders (opened suction valve).

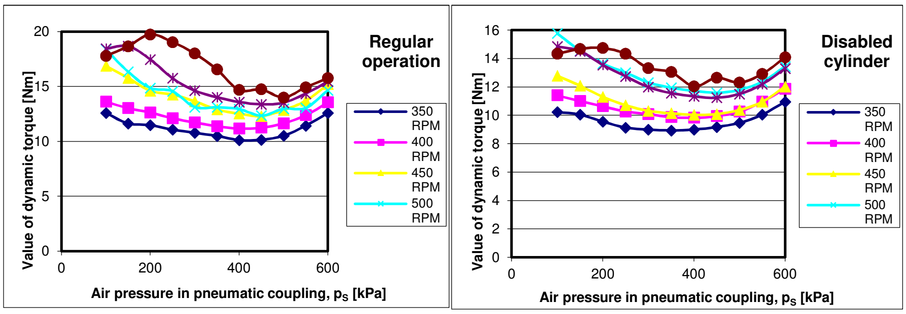

Figure 3. Effective value of dynamic torque (RMS)

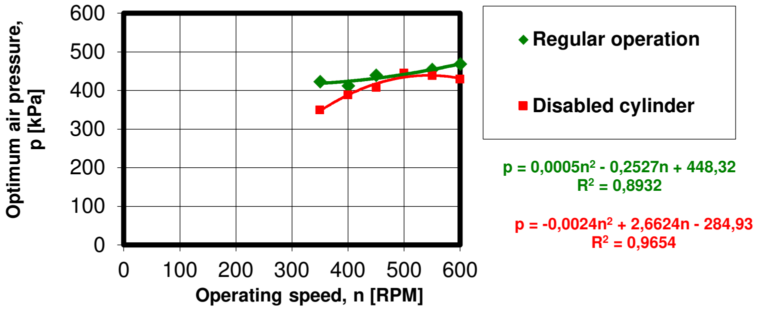

Figure 4. Optimum air pressure in pneumatic flexible shaft coupling

In *fig.3* are shown the dependencies of dynamic torque effective value on air pressure in pneumatic coupling for regular operating compressor and for compressor with disabled cylinder [4]. The delivery pressure of compressor was set on constant value 0,1 MPa.

The goal of torsional oscillating mechanical systems optimisation is the minimization of torsional vibration value in steady-state condition [3], [4]. 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 were found. The locations of minimums were estimated with parabolic interpolation method. The function of optimum pressure is shown in *fig. 4*. We can see that optimum pressure always lies between 300 and 500 kPa for selected operating speed range. 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 favourable [3], [4].

5. Verification of Extremal Control Possibility

The objective function for extremal control simulation was created from measured values of torsional vibration on our laboratory mechanical system [4]. The simulation was realized for regular operating compressor. The dead band was set to $\kappa=0,1$ Nm. The time step in this simulation has no specific value. The initial pressure step was *50 kPa*. The objective function was computed as fourth degree polynomial from measured values for each simulated operating speed. The range of operating air pressure ($p_{min}=350\ kPa$, $p_{max}=600\ kPa$) was selected so that the objective function has only one local minimum on that range.

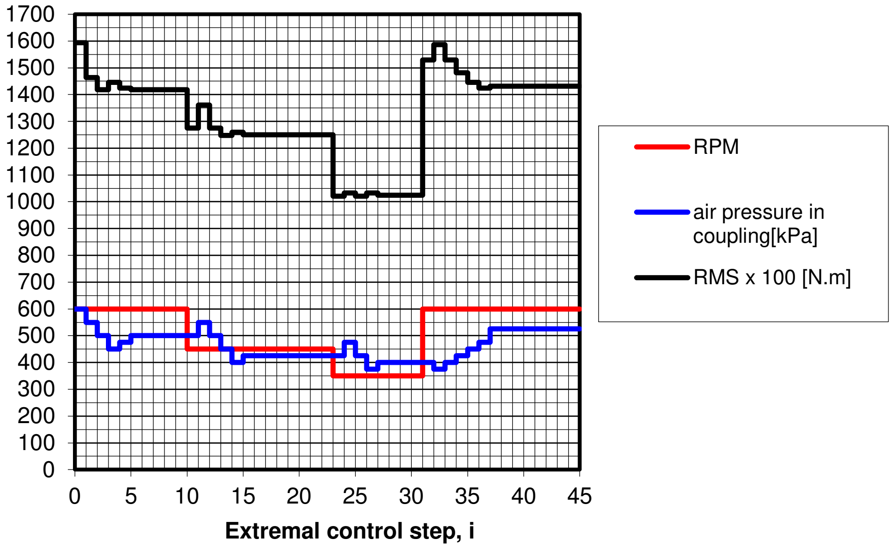

Figure 5. Simulation of extremal control

Numerical values of extremal control parameters after *i*-th step are shown in *tab. 1.*

Table 1. Simulation of extremal control

i	**1**	**2**	**3**	**4**	**5**	**6**	**11**	**12**	**13**	**14**	**15**	**16**
RMS [N.m]	15,94	14,64	14,19	14,46	14,24	14,19	12,75	13,61	12,75	12,48	12,59	12,49
p_s [kPa]	600	550	500	450	475	500	500	550	500	450	400	425
n [min^{-1}]	600	600	600	600	600	600	450	450	450	450	450	450
i	**24**	**25**	**26**	**27**	**28**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
RMS [N.m]	10,21	10,32	10,21	10,33	10,25	15,29	15,86	15,29	14,82	14,46	14,24	14,31
p_s [kPa]	425	475	425	375	400	400	375	400	425	450	475	525
n [min^{-1}]	350	350	350	350	350	600	600	600	600	600	600	600

We can see that for each selected operating speed local minimum of objective function (*RMS*) was found in selected dead zone (*κ=0,1 N.m*).

6. Conclusion

The possibility of extremal control in the torsional oscillating mechanical system built at our department was experimentally confirmed. The effective value of dynamic torque selected as objective function has 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 sytem is a great advantage.

Acknowledgement

This article was written within the framework of grant project VEGA 1/0528/20: „Solution of new elements for mechanical system tuning“*;*

REFERENCES

1. HOMIŠIN, J.: Možnosť realizácie extremálnej regulácie v torzne mechanických sústavách. In: Automatizace. vol. 40, no. 5 (1997), p. 247-251. ISSN 0005-125X.
2. HOMIŠIN, J.: Nové typy pružných hriadeľových spojok, vývoj - výskum – aplikácia, Košice, Vienala 2002, ISBN 80-7099-834-2.
3. KAŠŠAY, P: Algoritmus extremálnej regulácie s redukciou kroku a jeho overenie v nasimulovanej torzne kmitajúcej mechanickej sústave. In: Acta Mechanica Slovaca. roč. 10, č. 4-b (2006), s. 49-54. ISSN 1335-2393.
4. KAŠŠAY, P.: Optimalizácia torzne kmitajúcich mechanických sústav metódou extremálnej regulácie: Doktoranská dizertačná práca. Košice 2008.
5. KUBÍK, S. a kol.: Teorie automatického řízení II, Optimální, adaptivní a učící se systémy, Praha, SNTL/ALFA 1982.
6. LEDERER, P.: Teorie a optimalizace mechanických systémů I, Praha, Ediční středisko ČVUT 1988.
7. RASTRIGIN, L.A.: Sistemy ekstramaľnogo upravlenija, Moskva, Izdateľstvo NAUKA 1974.