POSSIBILITY OF TORSIONAL VIBRATION EXTREMAL CONTROL

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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 article is to confirm, by methods of technical diagnostics, the possibility of the use of extremal control in a laboratory torsional oscillating mechanical system built on 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 a built laboratory mechanical system.

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

MOŻLIWOŚĆ REGULACJI EKSTREMALNEJ DRGAŃ SKRĘTNYCH

Streszczenie
Regulacja ekstremalna to optymalizacja wykonywana eksperymentalnie bezpośrednio podczas pracy badanego układu. W naszej katedrze zajmujemy się regulacją ekstremalną drgających skrętnie mechanicznych układów zawierających wały połączone za pomocą pneumatycznych sprzęgieł podatnych. Sztywność skrętna tych sprzęgieł i częstotliwości własne drgań skrętnych układu mogą być zmieniane poprzez regulację ciśnienia powietrza w pneumatycznych elementach podatnych. Celem niniejszego artykułu jest potwierdzenie metodami diagnostyki technicznej możliwości wykorzystania ekstremalnej regulacji w laboratoryjnym drgającym skrętnie układzie mechanicznym zbudowanym w naszej katedrze. Przedstawiono w nim działanie rozwijanego przez nas algorytmu regulacji ekstremalnej. Efekty działania tego algorytmu regulacji ekstremalnej są prezentowane w artykule.

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

1. INTRODUCTION

On our department we deal with the extremal control [7, 9, 10, 14, 15, 16, 18, 19] of torsional oscillating mechanical systems by means of pneumatic flexible shaft couplings [3, 4, 5, 8, 11, 13]. 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. Big advantage of this method is that we need not to know the exact mathematical model of the system. We must know only that the objective function of the mechanical system has an extreme (for our case a local minimum) [4, 6, 17] Objective function in torsional oscillating mechanical systems is the value of torsional vibration.

The necessary condition of extremal control in torsional oscillating mechanical systems is the use of proper control element. Today's the pneumatic flexible shaft couplings developed on our department are the only applicable control element for this purpose, [4, 12]. 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 [2, 3]. In the term of extremal control the air pressure in pneumatic flexible coupling is the actuating variable [12].

The goal of this article is to confirm, by methods of technical diagnostics, the possibility of the use of extremal control in a laboratory torsional oscillating mechanical system built on 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 on our department for research of torsional oscillation and mechanical vibration [3, 12]. 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 a IRO type thyristor controller *(11)*. The *3-JSK-S* type air compressor *(2)* has no flywheel, hence the compressor has bigger dynamic torque [1]. 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 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.

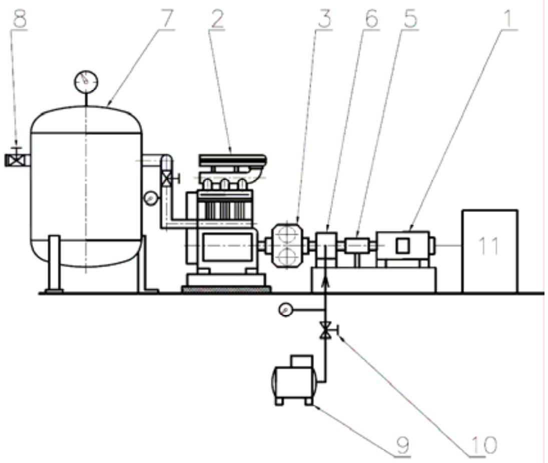

Fig.1. Investigated torsional oscillating mechanical system

3. OBJECTIVE FUNCTION OF INVESTIGATED MECHANICAL SYSTEM

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) [3, 12, 17]. 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).

On Fig. 2 are shown the dependencies of dynamic torque effective value on air pressure in pneumatic coupling for regular operating compressor and on Fig. 3 for compressor with disabled cylinder [12]. 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 [4, 12]. So we must find the optimal value of air pressure in pneumatic coupling for actual operating speed and failures, where the value of torsional vibration is minimal. 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 optimal pressure is shown on *Fig. 4*.

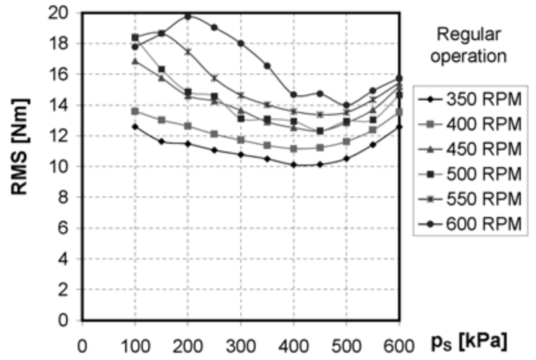

Fig.2. Effective value of dynamic torque (RMS) for regular operation

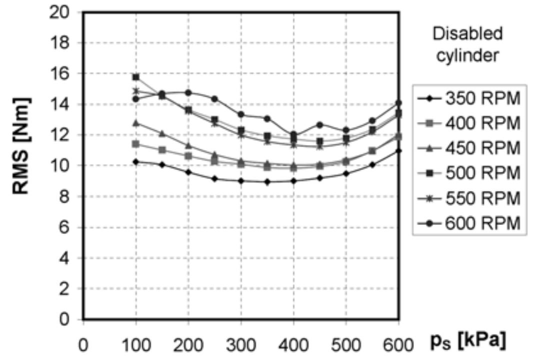

Fig.3. Effective value of dynamic torque (RMS) for disabled cylinder

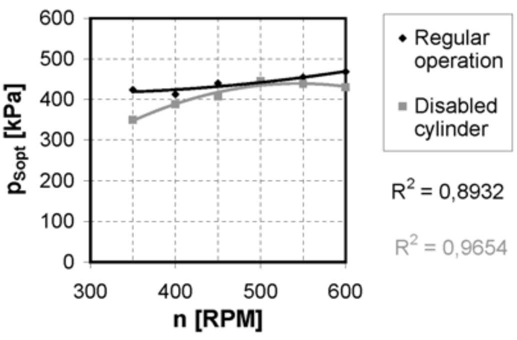

Fig.4. Optimal air pressure in pneumatic flexible shaft coupling

We can see that optimal 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 [11, 12].

4. ALGORITHM OF EXTREMAL CONTROL

The algorithm of extremal control shown on *Fig.5* was developed on our department [3, 6, 12]. This algorithm takes into count the limitations of maximal and minimal 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 optimal value is eliminated. When the operation state of system changes the pressure step Δp returns to initial value Δp_z.

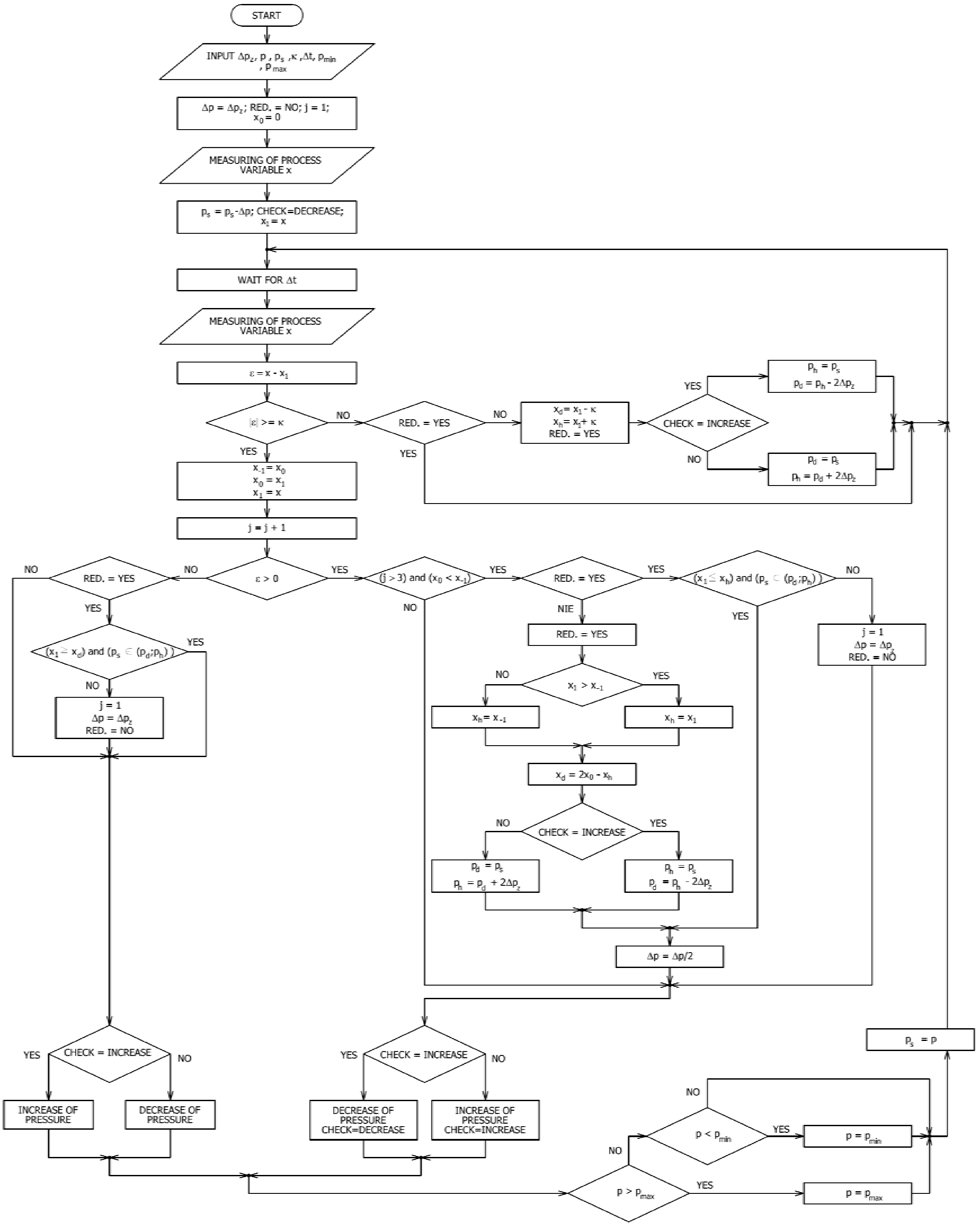

Fig.5. Algorithm of extremal control

5. SIMULATION OF EXTREMAL CONTROL

The objective function for extremal control simulation (*Fig.6*) was created from measured values of torsional vibration on our laboratory mechanical system [12]. The simulation was realized for regular operating compressor. The dead band was set to κ=0,1 N.m. 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.

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

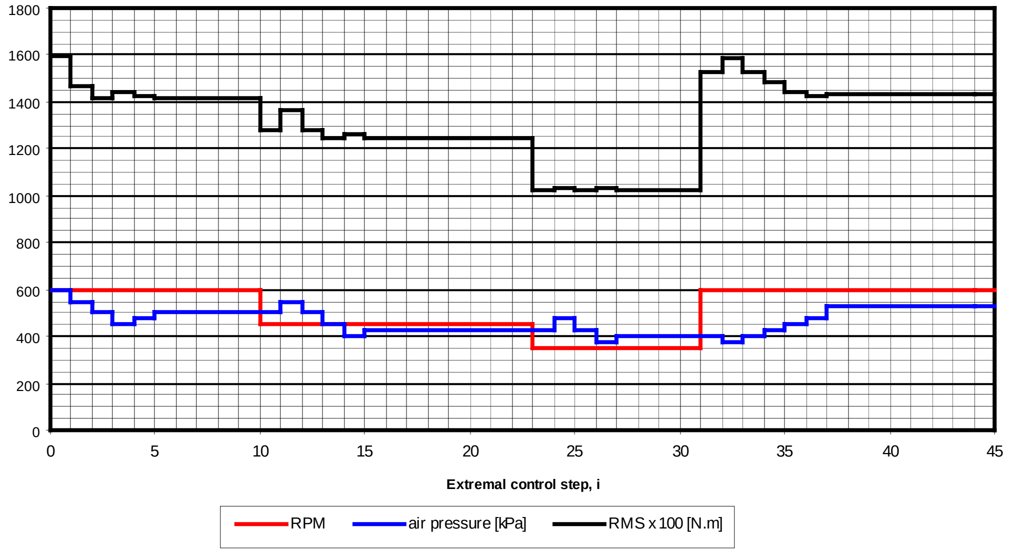

Fig.6. Simulation of extremal control

Tab. 1. Simulation of extremal control

i	**1**	**2**	**3**	**4**	**5**	**6**	**11**	**12**	**13**	**14**	**15**	**16**
RMS [Nm]	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 [RPM]	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 [Nm]	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 [RPM]	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 (k=0,1 N.m).

6. CONCLUSION

Based on our diagnostic results, the possibility of extremal control in the torsional oscillating mechanical system built on 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.

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