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CONTROL OF OIL PRESSURE IN TEST ROOM FOR CAR TUBES

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ABSTRACT

The paper deals with a control of oil pressure in a car tube test room during material endurance testing. Car tube test room is equipment designed for mechanical and pressure testing of car tubes for cooling water circuit. In the test room there it is simulated an engine compartment. In the primary circuit the oil circulates by tube specimen in agreement with given pressure characteristic, liquid and ambient temperature. The aim of control was pressure control in primary pressure circuit of the equipment.The controlled process is described as the second order system. The self – tuning control approach is applied for control of this nonlinear process. The used feedback controllers are based on pole placement. The test room is controlled by PC. The communication between the test room and PC is established by Datalab IO/USB unit and the control is assured by ControlWeb 2000.

Keywords: self – tuning control, pole – placement, recursive identification.

1. INTRODUCTION

The car tube test room is equipment designed for mechanical and pressure testing of car tubes for cooling water circuits. It is required so that oil pressure in tested tubes tracks sinusoidal and ramp reference signals for a long time during executed tests. Detailed description of this apparatus is in [1]. It is a nonlinear stochastic process with variable parameters. A suitable approach to the control of nonlinear processes is application of self – tuning controllers [8], [2]. Self – tuning control is one of the approaches to adaptive control. The other two basic classes of adaptive controllers are controllers based on a heuristic approach and model reference adaptive systems. These two approaches are limited by the fact that they are only suited to control of deterministic systems. That is why self – tuning controllers have better prospects for their wider use in industrial practice.

The nonlinear dynamics is described by a linear model in the neighbourhood of a steady state. A suitable model of the real object for control with self – tuning controllers is an input – output model. This is a standard approach in self tuning controller area. Instead of often tedious construction of a model from the first principles and then calculating its parameters from plant dimensions and physical constants, general type of model is chosen and its parameters are identified from data. Advantages of this kind of model are its simplicity and accuracy in an operational range in which the input – output dependence is measured.

In this paper, a self – tuning controller based on polynomial methods [3] and pole– placement was applied to control the process. In the identification part of the self – tuning controller the recursive least squares method [5] supported by adaptive directional forgetting [7], [6] was applied.Control is performed by means of ControlWeb 2000 [4].

2. DESCRIPTION OF THE TEST ROOM

The test room consists of an isolated test chamber, vibration unit which generates signals with specified amplitudes and frequencies, hydraulic system, heating circuit with liquid circulation which simulates cooling mixture, a heating circuit which heats air inside the chamber and a control panel. The heating circuit and the vibration unit are controlled by PLC. The test room is depicted in Figure 1. The test chamber with a tube sample is shown in Figure 2.

Figure 1. The test room

Figure 2. Test chamber and tube samples

Second ends of tube samples are mounted to a supporting grid of chamber and are connected to steel tubes which transfer liquid to an output cube. Mechanical oscillations are transferred through the steel tubes from the vibration unit to the vibration grid. Secondary circuit is parallel connected to a closed circuit of liquid. The hydraulic system provides required pressure in tubes. The hydraulic system consists of primary and secondary circuits. A source of pressure is a hydraulic unit. The primary circuit consists of a proportional valve, main and auxiliary hydraulic cylinder. The pressure is set up by main hydraulic cylinder (piston) which compresses the liquid. Position of the piston and consequently value of the pressure are set up by the auxiliary cylinder (piston). The aim of control is manipulating of this auxiliary piston by speed of inflow and outflow of oil in the cylinder. This is performed by a proportional valve Rexroth 4WRA6 which is controlled by current signal.

It is not possible to measure static characteristics of the process because the pressure in the primary circuit always stabilizes on the same value. We control speed of inflow and outflow of oil, the piston is always stopped at the end position or at the time when the pressure of the oil is not able to overcome forces of the main piston.

The process is nonlinear and sample properties and oil temperature vary in time during a test. These facts justify application of a self – tuning controller.

The test room is controlled by PC. The communication between the test room and pc is established by modular unit with industrial inputs and outputs Datalab IO/USB. Control of the test room is performed by graphic object-oriented system Control Web 2000.

3. CONTROLLER DESIGN

The basic requirement on control is long – time asymptotic tracking of reference signals of sinusoidal and ramp shapes. The nonlinear dynamics of the process is described by a linear model in the form of transfer function in the neighbourhood of a steady state. The transfer function is described by the following expression:

$$G_P(z) = \frac{Y(z)}{U(z)} = \frac{B(z^{-1})}{A(z^{-1})} = \frac{b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}} \qquad \text{... (1)}$$

The second order model proved to be effective for control of a range of processes in the industrial practice.The feedback controller with the traditional 1DOF (one degree of freedom) configuration was used.Transfer function of the controller have the form:

$$G_R(z) = \frac{U(z)}{E(z)} = \frac{Q(z^{-1})}{P(z^{-1})} = \frac{q_0 + q_1 z^{-1} + q_2 z^{-2}}{\left(1 - z^{-1}\right)\left(1 + \gamma z^{-1}\right)} \qquad \text{… (2)}$$

Transfer function of the closed loop system is given by

$$G_W(z) = \frac{Y(z)}{W(z)} = \frac{B(z^{-1})Q(z^{-1})}{A(z^{-1})P(z^{-1}) + B(z^{-1})Q(z^{-1})} \qquad \ldots (3)$$

Denominator of this transfer function is the characteristic polynomial D (z^{-1}) of the closed loop. We can choose a desired characteristic polynomial in the Diophantine polynomial equation. This choice determines pole – placement of the transfer function (3).

4. SYSTEM IDENTIFICATION

The described controller was applied as a self - tuning controller with recursive identification of parameters of a model of the process. This approach is suitable for control of nonlinear processes and processes where parameters vary in time. The recursive least squares method proved to be effective for self – tuning controllers and was used as the basis for our algorithm.

The transfer function (1) can be transcribed into a difference equation which can be written in vector form

$$y(k) = \boldsymbol{\Theta}^T(k-1)\phi(k) + e_s(k) \qquad \ldots (4)$$

$$\boldsymbol{\Theta}^T(k-1) = \left[\hat{a}_1, \hat{a}_2, \hat{b}_1, \hat{b}_2\right] \qquad \ldots (5)$$

$$\phi^T(k) = [-y(k-1), -y(k-2), u(k-1), u(k-2)] \qquad \ldots (6)$$

The vector Θ^T(k-1) contains the process parameter estimations computed in previous step and the vector Φ^T(k) contains output and input values for computation of current output y.

The main disadvantage of pure recursive least square method is an absence of original weighting. Each input and output affect result by the same weight, but actual process parameters can change in time. Thus newer inputs and outputs should affect output more than older values. This problem can be solved by directional forgetting method, which uses forgetting coefficient φ and decreases the weights of the data in previous steps. Parameter estimations are computed according to following equation:

$$\hat{\mathbf{\Theta}}(k) = \hat{\mathbf{\Theta}}(k-1) + \frac{\mathbf{C}(k-1)\boldsymbol{\varphi}(k-1)}{1 + \xi(k-1)} \cdot \left(y_k - \Theta^T(k-1)\varphi(k)\right) \qquad \ldots (7)$$

Recursive least squares method supported by the directional forgetting was applied.

5. REAL – TIME EXPERIMENTS

5.1 Application for control of test room

The application for control of the test room was created in software ControlWeb 2000. It is divided into two panels. Each panel consists of several tools which are necessary for proper function of the panel. The first one may be considered as the main panel of the application. There are incorporated tools for operating and monitoring of the process. The second panel was designed for displaying of the control in one sampling period. The application can run in two modes. The first one enables automatic and the second one manual control. The control algorithm is implemented by means of ConrtrolWebs procedure.

5.2 Experimental results

Speed of inflow and outflow of oil ranges from 0 to 11,4 l/min under the pressure to 315 bar in both directions. Control voltage ranges within ±10V. The pressure in the primary circuit always stabilizes on the same value. It is possible to control only speed of inflow and outflow of oil, the piston is always stopped at the end position or at the time when the pressure of the oil is not able to overcome forces of the main piston. The time response of the control when the initial parameter estimates were chosen without any prior information is shown in Fig. 1. It has to be supposed that the adaptive version would not work perfectly from very beginning. But it is possible to assume that the most important for practical use of an adaptive controller is its performance after adaptation phase. Fig. 2 shows an example of the time response of the identified parameters. The convergence of the parameters is satisfactory. Subsequent experiment was carried out in such a way that initial parameter estimates were set as the last parameter estimates obtained at the end of the previous experiment.

Time responses of this experiment are shown in Fig. 3 for the ramp shape of the reference signal and in Fig. 4 for the sinusoidal shape of the reference signal.

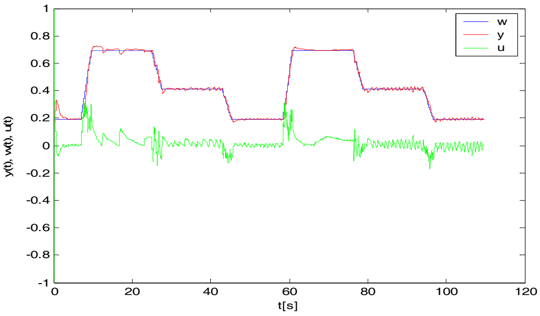

Figure 1. Adaptive control of pressure

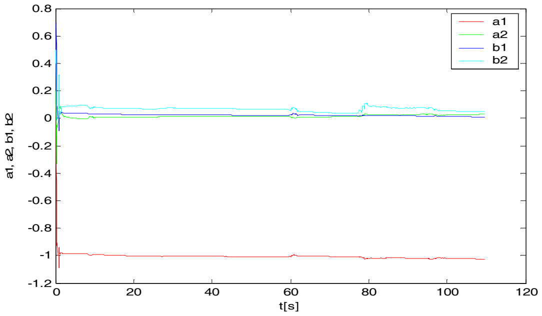

Figure 2. Time response of identified parameters

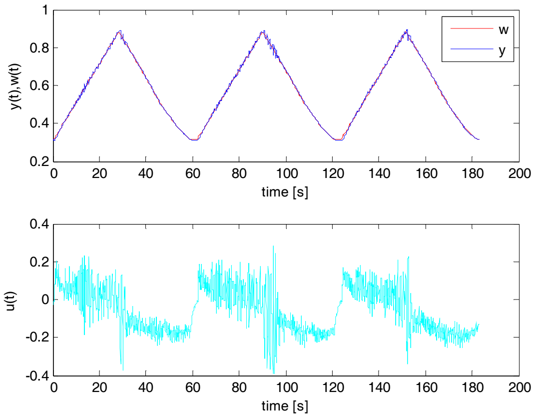

Figure 3. Adaptive control of pressure – experiment with steady parameters (ramp shape of the reference signal)

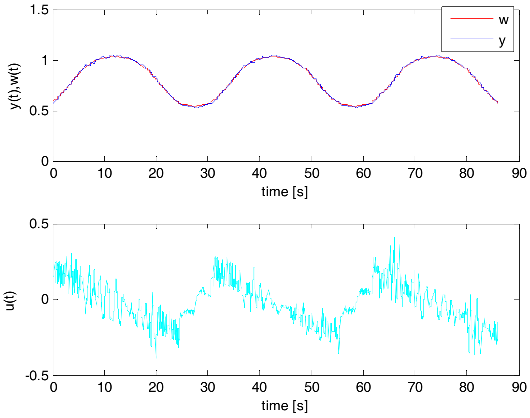

Figure 4. Adaptive control of pressure – experiment with steady parameters (sinusoidal shape of the reference signal)

6. CONCLUSION

The adaptive control of the test room for car tubes was realized. The tests require a long time control of pressure (one test takes 30 000 control loops, one loop takes 60 s). Typical shapes of reference signals for endurance testing are ramp and sinusoidal ones. Despite the fact, that the nonlinear dynamics of the process was described by the linear model, satisfactory results of control suitable for the endurance testing were achieved. Control application is used during car tube testing in company ITC Zlin.

7. ACKNOWLEDGMENTS

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