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Control of Airflow Speed in Laboratory Model of Hot-Air Tunnel

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Abstract

The main purpose of this contribution is to present an approach for controlling the airflow speed in laboratory plant of hot-air tunnel which is modelled as a system with parametric uncertainty. The 1DOF and 2DOF controller design is based on algebraic technique and closed-loop robust stability is analyzed via combination of the value set concept and the zero exclusion condition. Practical applicability of the method is demonstrated through real control experiments.

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Keywords: Airflow speed control; algebraic synthesis; parametric uncertainty; robust stability; hot-air tunnel

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1. Introduction

Many real control applications are typically burden with some kind of uncertainty. Common scenario includes a simple but reliable fixed controller and controlled plant modelled as a system with parametric uncertainty, i.e. as a system with no variations in the structure but only in individual parameters [1], [2], [3], [4].

This contribution is focused on control of airflow speed in laboratory model of hot-air tunnel [5] which is identified as a plant with parametric uncertainty. The applied controller design method (both for 1DOF and 2DOF configurations) is based on general solutions of Diophantine equations in the ring of proper and stable rational functions (R_{PS}), Youla-Kučera parameterization and additional divisibility conditions [6], [7]. The subsequent test of robust stability takes advantage of the value set concept in combination with the zero exclusion condition [1]. The similar ideas as in this work have been already published – e.g. in the paper [8]. Moreover, the representatives of works aimed to control of temperature in the same hot-air tunnel are e.g. [9] or [10].

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2. Laboratory model of hot-air tunnel

The control experiments have been performed on laboratory model of hot-air tunnel constructed in VŠB – TU of Ostrava [5]. The apparatus is composed of the bulb, primary and secondary ventilator, and array of sensors covered by tunnel as depicted in Fig. 1. The bulb is powered by controllable source of voltage and serves as the source of light and heat energy while the purpose of ventilators is to ensure the flow of air inside the tunnel. All components are connected to the electronic circuits which adjust signals into the voltage levels suitable for CTRL 51 unit [11]. Then, the control unit is connected with the PC via serial link RS232 [12].

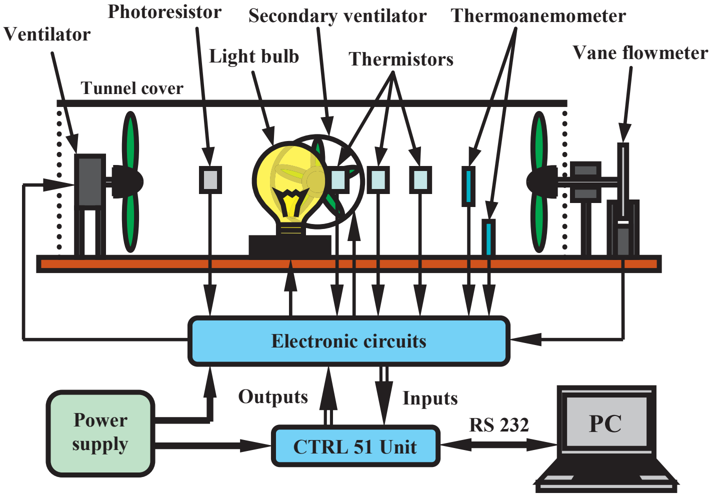

Fig. 1. Scheme of hot-air tunnel and whole control system.

The controlled object can be generally seen as multi-input multi-output (MIMO) system. However, the presented control experiments have been accomplished in one selected single-input single-output (SISO) loop which consists of primary ventilator voltage $u2$ (input, actuating signal) and airflow speed measured by vane flowmeter $y7$ (output, controlled variable). The other actuating signals were set to constant values – bulb voltage $u1$ to 0 V and secondary ventilator voltage $u3$ to 0 V. The identification experiments done in various operational points have led to the description of the system via second order double time constant mathematical model with parametric uncertainty [8]:

$$G(s,K,T)=\frac{K}{(Ts+1)^2}=\frac{[0.3;1.2]}{([1;3]s+1)^2} \tag{1}$$

where the time constant is given in seconds and gain is dimensionless.

3. Algebraic design of controllers

The employed continuous-time controller design technique is based on fractional approach developed in [6], [7] and discussed e.g. in [13], [14], [15]. The method supposes description of systems and signals in R_{PS}. Usually, standard one-degree-of-freedom (1DOF) or two-degree-of-freedom (2DOF) control structures are used.

The control synthesis itself consists of solution of Diophantine equation(s) in R_{PS}, Youla-Kučera parameterization which leads to expression of all stabilizing controllers, and application of divisibility condition(s) which assists with the selection of the controller from the stabilizing pool according to the user requirements such as asymptotic tracking, disturbance rejection, etc. [13], [14]. Finally, the controller can be tuned and its dynamical properties can be influenced via the single parameter $m>0$ [15].

Possibly, robust stability of the closed control loop can be additionally analyzed, among other methods, by means of graphical approach based on combination of the value set concept and the zero exclusion condition [1].

4. Robust control experiment

The controlled system is given by (1). The nominal system for control design is obtained using the fixed values of interval parameters from (1):

$$G_N(s)=\frac{0.7}{(1.9s+1)^2}=\frac{0.1939}{s^2+1.0526s+0.277} \tag{2}$$

The experimental choice of tuning parameter $m=0.6$ results in the 1DOF realistic PID controller:

$$C_b(s)=\frac{q_2s^2+q_1s+q_0}{s^2+p_1s}=\frac{2.3967s^2+2.5311s+0.6684}{s^2+1.3474s} \tag{3}$$

Then, the family of closed-loop characteristic polynomials for plant (1) and controller (3) can be expressed as:

$$\begin{aligned}p_{CL}(s,K,T)&=(Ts+1)^2\left(s^2+p_1s\right)+K\left(q_2s^2+q_1s+q_0\right)=\\&=T^2s^4+\left(T^2p_1+2T\right)s^3+\left(2Tp_1+Kq_2+1\right)s^2+\left(p_1+Kq_1\right)s+Kq_0\end{aligned} \tag{4}$$

where controller parameters are fixed and taken from (3), and where controlled plant parameters can vary within given intervals from (1).

The robust stability of the family of polynomials (4) with polynomial (quadratic) uncertainty structure can be investigated by using combination of the value set concept and the zero exclusion condition [1]. Convenient tool for practical plotting the value sets is represented by the Polynomial Toolbox for Matlab [16]. It was applied for obtaining the Fig. 2 which shows the moderately zoomed value sets of polynomial family (4). The origin of the complex plane is excluded from the value sets and the family has a stable member which means that the closed-loop polynomial (4) and consequently the whole closed control loop is robustly stable [1]. This is confirmed also by Fig. 3 where real data of airflow speed control (reference, actuating, and output signals) are visualized.

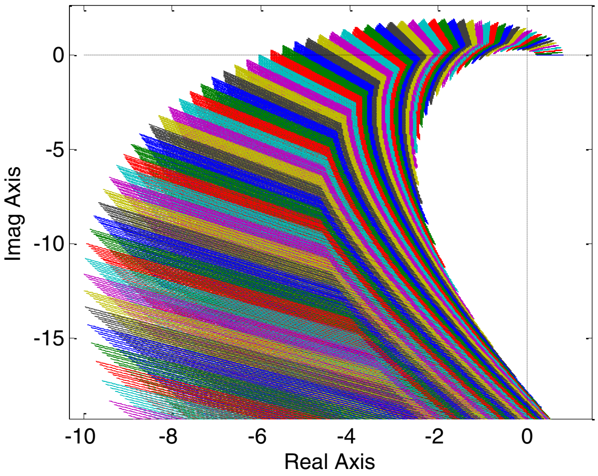

Fig. 2. Value sets of polynomial family (4).

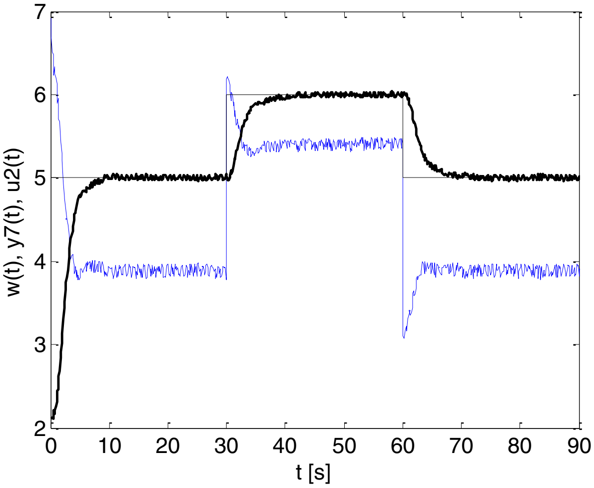

Fig. 3. Control of airflow speed in hot-air tunnel by 1DOF controller (4).

Alternatively, the controller with both feedback and feedforward part (for 2DOF configuration and the same parameter $m = 0.6$) is given by:

$$\begin{aligned} C_b(s) &= \frac{2.3967s^2 + 2.5311s + 0.6684}{s^2 + 1.3474s} \\ C_f(s) &= \frac{1.8566s^2 + 2.228s + 0.6684}{s^2 + 1.3474s} \end{aligned} \tag{5}$$

The feedforward part $C_f(s)$ does influence neither closed-loop characteristic polynomial and so nor its robust stability, but the control performance changes. The final control results can be seen in Fig. 4.

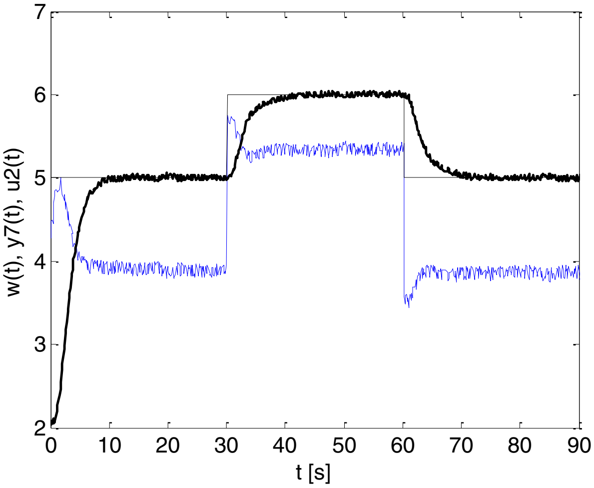

Fig. 4. Control of airflow speed in hot-air tunnel by 2DOF controller (5).

Conclusion

The main aim of this paper was to present a possible application of algebraic approach to control design for airflow speed in laboratory model of hot-air tunnel. The synthesis was based on solution of Diophantine equations in R_{PS}, Youla-Kučera parameterization and conditions of divisibility. Since the controlled plant was modelled as the system with parametric uncertainty, robust stability of the closed control loop was graphically verified using the very universal combination of the value set concept and the zero exclusion condition. The performed control experiments have indicated practical applicability of considered method.

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