Adaptive Control of System for Rubber Transportation

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Abstract – **A new method of adaptive control for cascade-connected transporter systems is suggested in this paper. The main goal of this control is to neutralize the oscillations which could appear due to unappropriate system parameters. Laboratory rubber cooling system has been practically realized and used for experimental purposes. Genetic algorithm has been applied for parameters adjustment in order to minimize the steady state error.**

Keywords – **Adaptive optimization, Transportation system, Genetic algorithm.**

I. INTRODUCTION

In every tyre factory in the world, there are one or more tyre strip cooling systems. That tyre strip is used to form external (stripped) part of a tyre. It is estimated that there are about 2500 systems, like that, all over the world, mostly in China, India, USA and Brasil. These systems consist of a large number (4-24) of cascade-connected transporters along which the tyre strip moves, passing from one transporter to another. Thereby, the rubber is cooled by the water which flows in opposite direction. The velocities of individual transporters are adjusted using local controllers which determine the velocity of the next transporter according to the length of rubber between two consecutive transporters. In this manner, a dynamic system with a lot of cascades is obtained (Fig. 1).

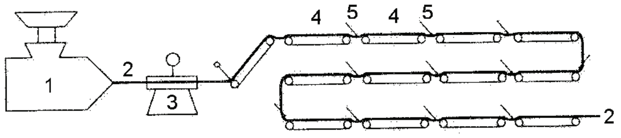

Fig. 1. Cascade system for the rubber strip transportation
(1-extruder 2-rubber strip 3-balance 4-transporters 5-transitions)

Following properties of these systems impact dynamics, stability and system quality:

- Tyre strip accumulates at transition places (points 5 in Fig. 1), because of integration of velocities difference.
- Nonlinear dependencies are formed at the cascade transitions, between transporters.
- During the tyre strip movement along a transporter, rubber runs cold and contracts. Because of that, velocity at transporter's end is less than velocity at transporter's beginning, with contraction coefficient μ. Coefficient μ is stochastic because it depends on rubber quality and environment temperature which are stochastic parameters. Influence of stochastic parameters μ_i on cascade systems stability is analized in [1].

Due to cascade structure and nonlinearities, the system is prone to oscillations [2], [3]. Under certain conditions, deterministic chaos may appear in the system [4], [5]. Because of the stated properties, the referred system is very complex and difficult to control [6]. The only way for successful control is local control of transporters velocities at every transition (points 5 in Fig. 1) and also a compensation for the entire system using adjustable parameters. Until now, these parameters have been adjusted manually. Compensational parameters adjustment has been applied in [7] in order to minimize the steady state error. To avoid these oscillations, we propose adaptive control of the system, i.e. adaptive adjustment of all parameters independently. Thus, genetic algorithm, apllied in [7] for simultaneous optimisation of n parameters, is devided into n consecutive operations where each one is used for only one's parameter optimisation. The same goal is achived, but the algorithm is being executed n times faster which prevents the appearing of oscillations.

II. CASCADE-CONNECTED SYSTEM FOR THE RUBBER STRIP COOLING

Figure 1 shows a cascade-connected transporters for the rubber strip cooling.

The rubber strip comes from extruder (point 1 in Fig. 1), pass through the balance (point 3 in Fig. 1) and goes to the cooling system. It is necessary to cool down the rubber strip to the room temperature. When rubber runs through the cooling system, it is beeing cooled and contracts with contraction coefficent $\mu < 1$. During that contraction, rubber velocities at transporter ends are not equal to the transporter velocities, producing the effect of rubber slipping relatively to transporter.

The length change of the rubber strip between two transporters is described with the following equations:

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$$\frac{dl_i}{dt} = V_{g,i-1}^{(2)} - V_{g,i}^{(1)}, i = 1, 2, ..., n, \tag{1}$$

$$V_{g,i-1}^{(2)} = V_{i-1}, \quad V_{g,i}^{(1)} = \frac{1}{\mu_i} V_i \tag{2}$$

$$\frac{dl_i}{dt} = V_{i-1} - \frac{1}{\mu_i} V_i \tag{3}$$

$$\Delta l_i = \frac{1}{s}\left(V_{i-1} - \frac{1}{\mu_i} V_i \right) \tag{4}$$

where: l_i is the length of rubber strip between i-th and $(i+1)$-th transporter, $V_{g,i-1}^{(2)}$ is rubber velocity at the end of the $(i$-1)-th transporter, $V_{g,i}^{(1)}$ is rubber velocity at the beginning of the i-th transporter, n is the number of transporters, Δl_i is length change of rubber strip between two consecutive transporters, V_{i-1} is the velocity of the (i-1)-th transporter, V_i is the velocity of the i-th transporter, μ_i is the rubber contraction coefficient for the i-th transporter.

Figure 2 shows a transition between two transporters. To regulate transporter velocities, it is necessary to measure the lenghts of rubber between transporters (Δl_i). These measurements are being done by special sensors (potenciometers – P in Fig. 2). Measurer (potenciometer) angle β_i satisfies the following relation:

$$\beta_i = \Phi(\Delta l_i) = \mathrm{sgn}(\Delta l_i)\frac{\pi}{6}\left(1 - e^{-0.01|\Delta l_i|}\right) \tag{5}$$

where Φ represents nonlinear dependency.

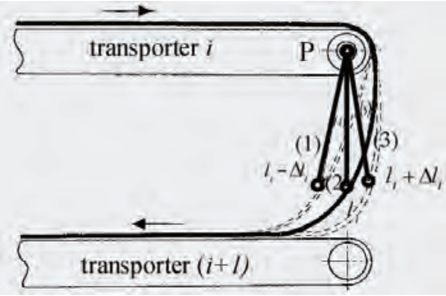

Fig. 2. The length measuring of the rubber between transporters

The value of β_i is between 0 and 90 degrees.

Potenciometer voltage is:

$$u_i = K_P \beta_i \tag{6}$$

where K_P is the potenciometer coefficient [V/rad].

Real coefficent value μ_i, $i = 1, 2, 3, 4$ is in a range of (0.9042 - 0.9620), and when there are 13 transporters, this coefficent is in range of (0.9042 - 1). It is posible to determine the contraction coefficient for every cascade separately, using the next relation which was experimentally derived:

$$\eta_i = \frac{0.7 + 0.3e^{-\frac{i}{2.6}}}{0.7 + 0.3e^{-\frac{i-1}{2.6}}} \tag{7}$$

Potenciometer voltage is being amplified and, through thyristor regulators, the velocities of drive motors are being controled. Dynamics of i-th transporter can be described with following well known equation:

$$T_1 T_2 \frac{dV_i^2}{dt^2} + (T_1 + T_2)\frac{dV_i}{dt} + V_i = u_i \tag{8}$$

where T_1 and T_2 are mechanical and electrical time constants of electromechanical drive.

The transfer function with controller, drive motor, tachogenerator and reductors has the following form:

$$W(s) = \frac{V_i(s)}{u_i(s)} = \frac{k}{s^2 + as + b} \tag{9}$$

where k, a, b are gain functions and functions of time constants, respectively:

$$k = \frac{2\pi R k_r k_m k_t}{T_1 T_2}, \quad a = \frac{T_1 + T_2}{T_1 T_2}, \quad b = \frac{1 + k_t k_m k_{tg}}{T_1 T_2} \tag{10}$$

Constants in previous functions: k_r, k_m, k_t, k_{tg} are thyristor regulator, drive motor, transporter and tachogenerator gain, respectively; and R is drive drum radius.

Using stated equations (1)-(10), the block diagram of the entire system, given in Fig. 3, is obtained.

Integration of velocity between transporters can cause steady state error when parameter μ changes (change of used rubber quality or change of ambience temperature). In Fig. 2, middle position of the sensor (position (2)) correspondes to normal operating. If μ magnifies, sensor comes in positon (1) and steady state error $-\Delta l_i$ occures (the rubber streches). If μ decreases, sensor comes to positon (3) and steady state error $+\Delta l_i$ occures (the rubber accumulates). Compensational potenciometers (K_{ri} in Fig. 3) are introduced in order to compensate steady state errors, so their adjustement bring system back to normal operating (position (2) in Fig. 2). Today, these parameters are being adjusted manually (manual system adaptation). This paper presents a new method, based on genetic algorithms for automatic adaptation and optimization of disscused systems.

III. EXPERIMENTAL RESULTS

The principles of genetic algorithms were first published by Holland in 1962 [8]. Genetic algorithms are optimization techniques based on simulating the phenomena that takes place in the evolution of species and adapting it to an optimization problem.

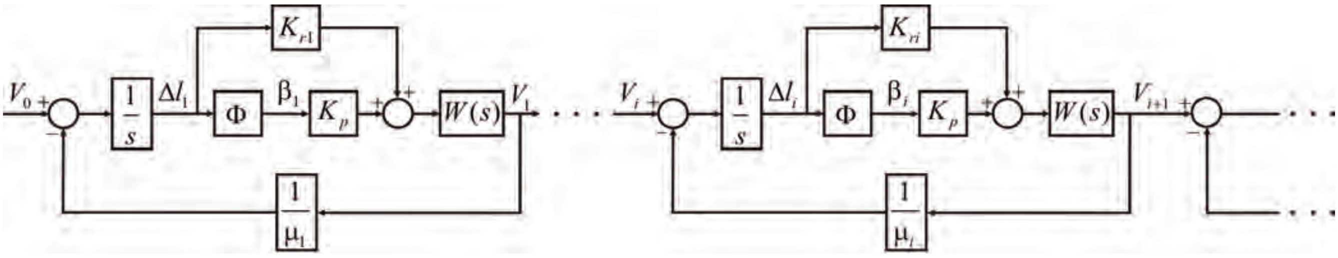

Fig. 3. Block diagram of the cascade-connected system in the tyre industry

Genetic algorithms have been used in many areas such as function optimization, image processing, system identification, etc. They have demonstrated very good performances as global optimizers in many types of applications [9], [10].

MATLAB model of the cascade-connected system with four transporters, based on block diagram in Fig. 3, is made.

For experimental purposes, cascade-connected system with four transporters (Fig. 4) has been practically realized in our Laboratory for modeling, simulation and systems control. Our system is capable for imitating real factory systems in all above-mentioned aspects.

The purpose of genetic algorithm is to optimize parameters K_{ri} on the bases of measured Δl_i .

Compensational parameters adjustment has been applied in [10] in order to minimize the steady state error. Steady state error is defined as deviation of rubber strip position between two transporters in steady and working state. It has been proven that this method is very slow, because a large number of parameters should be optimized at the same time. This could lead to temporary poor rubber quality at the end of the transporter. A poor rubber quality is a consequence of oscillations which are appearing during genetic algorithm execution. To avoid these oscillations, we propose adaptive control of the system, i.e. adaptive adjustment of all parameters independently. Thus, genetic algorithm, apllied in [10] for simultaneous optimisation of n parameters, is devided into n consecutive operations where each one is used for only one's parameter optimisation. The same goal is achived, but the algorithm is being executed n times faster which prevents the appearing of oscillations.

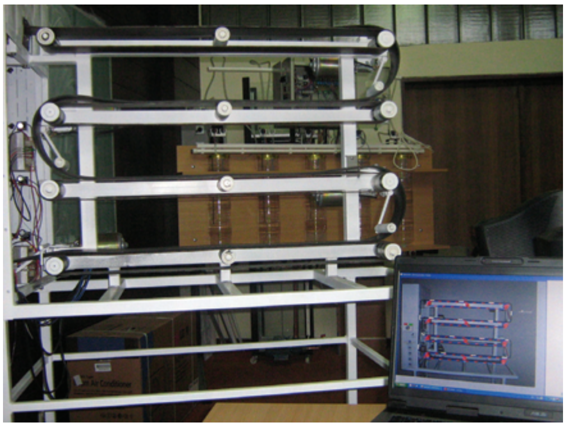

Fig. 4. Laboratory system with four transporters for experimenting

Fitness function is the sum of the mean square errors at all transporters (11). Smaller fitness fuction means lower error and, therefore, better chromosome.

$$J = (\Delta l_1)^2 + (\Delta l_2)^2 + (\Delta l_3)^2 + (\Delta l_4)^2 \tag{11}$$

Algorithm converges very fast to the set of K_{ri} parameters which are optimal for the system and give the lowest fitness function. Genetic algorithm used in simulation has the following parameters: initial population of 150, number of generations 100, stochastic uniform selection, reproduction with four elite individuals, Gaussian mutation with shrinking and scattered crossover. In this way we obtained the following parameter values:

$$\begin{aligned} K_{r1} &= 1.786 \\ K_{r2} &= 1.588 \\ K_{r3} &= 1.401 \\ K_{r4} &= 1.207 \end{aligned} \tag{12}$$

Velocities (normalized values) of individual transporters, for a given step input, are shown in Fig. 5.

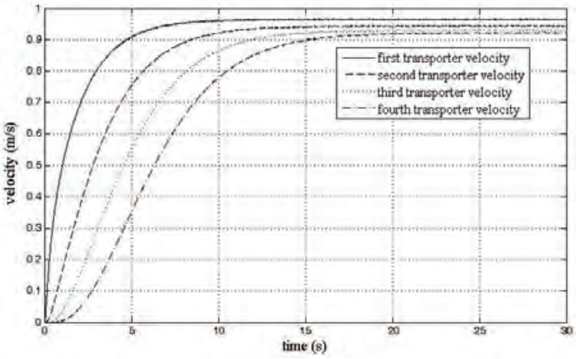

Fig. 5. Step response of laboratory cascade-connected system

IV. CONCLUSION

The new method for parameter optimization in systems for rubber strip cooling is presented in this paper. In this purpose, genetic algorithm is used. Parameters are being adjusted in discrete-time intervals and that gives good results for inert systems like the one considered in this paper. The gained results are better than those which are obtained by [10] in the sense of better speed and adaptation accuracy.

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