Genetic Algorithms applied in Parameter Optimization of Cascade Connected Systems

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***Abstract* – In this paper, rubber cooling system in tyre industry, as a represent of complex, nonlinear, stochastic, cascade-connected systems, is considered. A simple genetic algorithm has been applied in adaptive and optimal control of the system.**

***Keywords* - Genetic algorithms, Nonlinear system, Parameter optimization**

I. Introduction

In every tyre factory in the world, there are one or more tyre thread cooling systems. That tyre thread is used to form external (stripped) part of a tyre. It's estimated that there are about 25000 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 thread 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 (see Fig.1.).

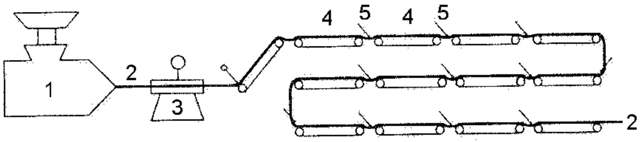

Fig. 1. Cascade system for the rubber strip transportation (1-extruder 2-rubber strip 3-balance 4-transporters 5-transitions)

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

- Tyre thread accumulates at transition places (points 5 at Fig. 1), because of integration of velocities difference.
- Nonlinear dependencies are formed at the cascade transitions, between transporters.
- During the tyre thread movement along a transporter, rubber runs cold and contracts. Because of that, velocity at transporter's end is smaller 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 at Fig. 1) and also a compensation for the entire system using adjustable parameters. Until now, these parameters have been adjusted manualy. This paper presents a new method for adjusting parameters using genetic algorithms with optimal control in the sense of the mean square error.

II. Cascade connected system for the rubber strip cooling

Figure 1. shows a cascade connected transporters for the rubber strip cooling. This system in a real factory is given at figure 2.

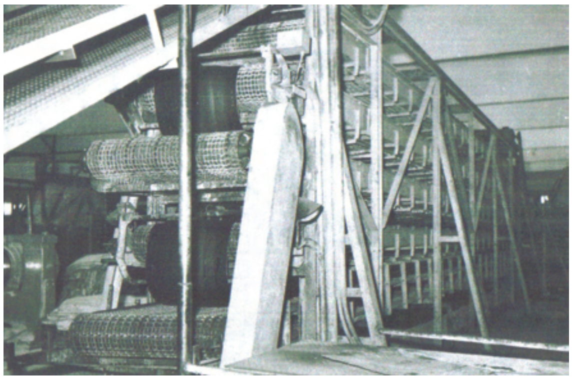

Fig. 2. Rubber cooling system in tyre industry "Tigar-Michelline", Serbia

The rubber strip comes from extruder (point 1 at Fig. 1.), pass through the balance (point 3 at Fig. 1.) and goes to the cooling system. It's 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 μ<1. During that contraction, rubber velocities at transporter's ends are not equal to the transporter's velocities,

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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:

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

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

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

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

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 compression coefficient for the i-th transporter.

Figure 3. shows a transition between two transporters. To regulate transporter's velocities, it's necessarily to measure the lenghts of rubber between transporters (Δl_i). These measurements are being done by special sensors (potenciometers – P at Fig. 3.). Measurer's (potenciometer) angle β_i satisfies the following relation:

$$\beta_i = \Phi(\Delta l_i) \tag{5}$$

where Φ represents nonlinear dependency.

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].

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

$$T_1 T_2 \frac{dV_i^2}{dt^2} + (T_1 + T_2)\frac{dV_i}{dt} + V_i = u_i \tag{7}$$

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

According to (7), the transfer function for *i*-th transporter has the following form:

$$W(s) = \frac{V_i(s)}{u_i(s)} = \frac{1}{T_1 T_2 s^2 + (T_1 + T_2)s + 1} \tag{8}$$

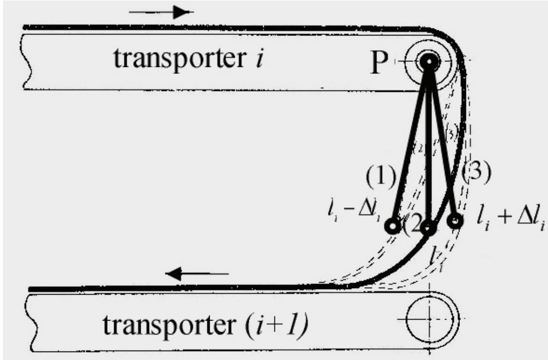

Fig. 3. Measuring the length of the rubber between transporters

Using stated equations (1)-(8), the block diagram of the entire system, given at Figure 4, is obtained.

Integration of velocity between transporters can cause statical error when parameter μ changes (change of used rubber quality or change of ambience temperature). At fig. 3, middle position of the sensor (position (2)) correspondes to normal operating. If μ magnifies, sensor comes in positon (1) and statical error $-\Delta l_i$ occures (the rubber streches). If μ decreases, sensor comes to positon (3) and statical error $+\Delta l_i$ occures (the rubber accumulates). Compensational potenciometers (K_{ri} at fig. 4) are introduced in order to compensate statical errors, so their adjustement bring system back to normal operating (position (2) at fig. 3). 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. GENETIC ALGORITHMS

The principles of genetic algorithms were first published by Holland in 1962 [7]. 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.

Genetic algorithms have been used in many areas such as function optimization, image processing, system identification... They have demonstrated very good performances as global optimizers in many types of applications [8], [9].

A brief description of genetic algorithms is given below.

Encoding: The first step in building a genetic algorithm is to choose the parameters of interest in the search space and to encode and concatenate them in order to form a string or chromosome. Thus, each string represents a possible solution to the problem. The genetic algorithm works with a set of strings, called the population. This population then evolves from generation to generation through the application of genetic operators.

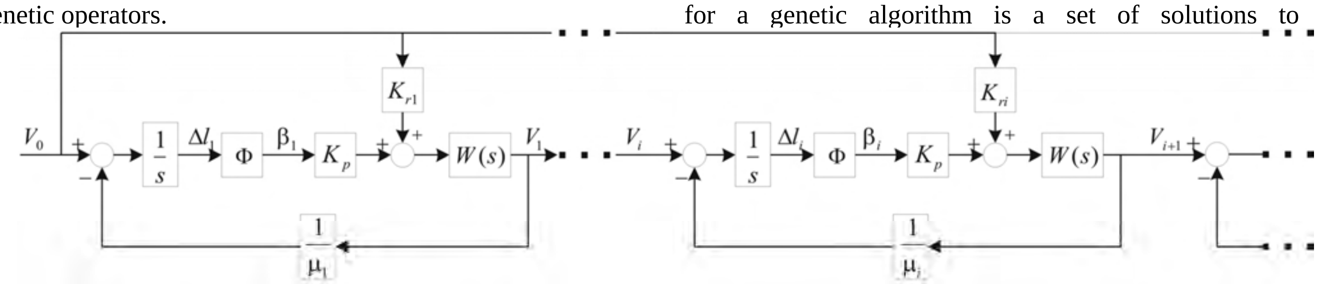

Fig. 4. Block diagram of the cascade connected system in the tyre industry

Initialization and population size: The initial population for a genetic algorithm is a set of solutions to the optimization problem. A common method of population generation is random generation. Population size plays an important role in the success of the problem-solving process. A small initial population size can lead to premature convergence. On the other hand, a large population results in a long computational time.

Fitness function: In genetic algorithms, the fitness is the quantity that determines the quality of a chromosome, in the gene pool and it must reward the desired behavior. The fitness is evaluated by a fitness function that must be established for each specific problem. The fitness function is chosen so that its maximum value is the desired value of the quantity to be optimized.

Selection methods: Reproduction is based on the principle of survival of the fittest. The purpose of selection is to emphasize the fitter individuals in the population in hopes that their offspring will in turn have even higher fitness. The most common method is the "roulette wheel" selection, where, the number of times the gene can be reproduced is proportional to its fitness function. This technique involves selecting the top performers and allowing multiple reproductions of the best performers.

Genetic operators: In each generation, the genetic operators are applied to selected individuals from the current population in order to create a new population. Generally, the three main genetic operators are reproduction, crossover and mutation. By using different probabilities for applying these operators, the speed of convergence and accuracy can be controlled.

- *Reproduction:* A part of the new population can be created by simply copying without change selected individuals from the present population. This gives the possibility of survival for already developed fit solutions.
- *Crossover:* New individuals are generally created as offspring of two parents. One or more so-called crossover points are selected (usually at random) within the chromosome of each parent, at the same place in each. The parts delimited by the crossover points are then interchanged between the parents. The individuals resulting in this way are the offspring.
- *Mutation:* A new individual is created by making modifications to one selected individual. The modifications consist of changing one or more values in the chromosome. In genetic algorithms, mutation is a source of variability.

Figure 5. shows the main steps in genetic algorithm procedure stated above.

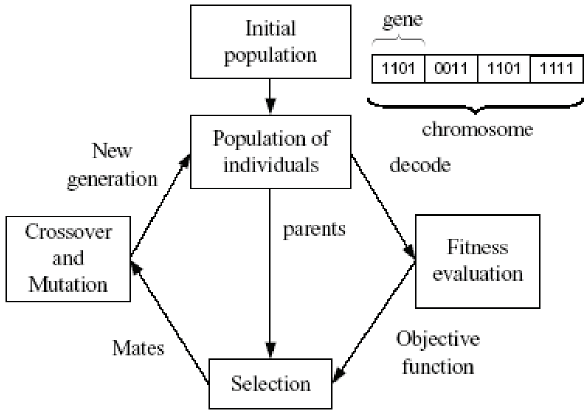

Fig. 5. Genetic algorithm procedure

IV. Experimental results

For experimental purposes, MATLAB model of the cascade connected system with four transporters, based on block diagram at fig. 4., is made. A real system is also made for student laboratory exercise (see fig. 6). Genetic algorithm is applied in a way presented with fig. 7. The purpose of genetic algorithm is to optimize parameters K_{ri} on the bases of measured Δl_i.

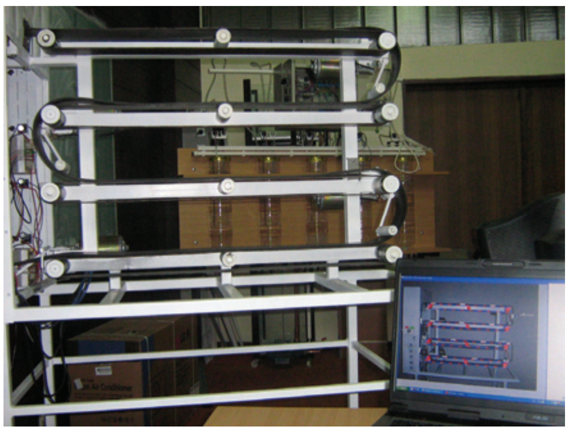

Fig. 6. Laboratory system with four transporters for experimenting

There are four parameters of interest which should be adjusted by genetic algorithm: K_{r1}, K_{r2}, K_{r3} and K_{r4}. They are encoded binary with five bits each (32 values). In this way, 20 bits chromosome is obtained. Initial population is generated randomly with population size of 10.

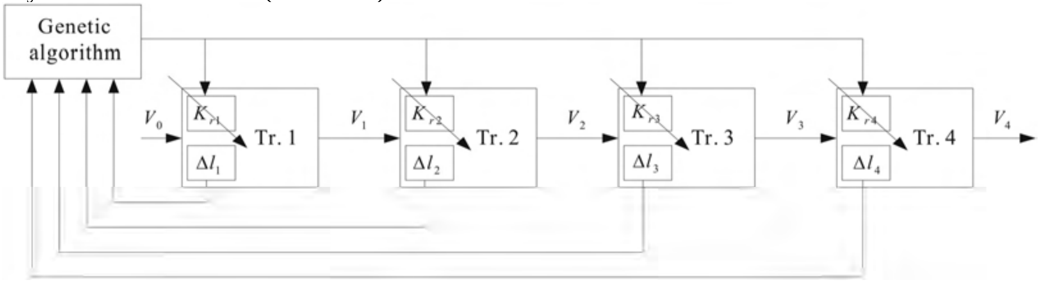

Fig. 7. Block diagram of the laboratory system

Fitness function is the sum of the mean sqare errors at all transporters (9). Smaller fitness fuction means lower error and, therefore, better chromosome.

$$f = \sum_{i=1}^{4} \left(\Delta l_i\right)^2 \tag{9}$$

Selection method is "roulette wheel" with the fittest individual carried forward the next generation in every evolution cycle. Genetic algorithm was performed for 30 generations. To perform the genetic algorithm, Matlab was used in konjunction with the SIMULINK and GAOT toolbox, which is open-source code.

The results for consecutive generations are shown in figure 8. The full line is the fitness function of the best individual, and the dotted line is average fitness function for entire generation. Algorithm converges very fast to the set of K_{ri} parameters which are optimal for the system and give the lowest fitness function.

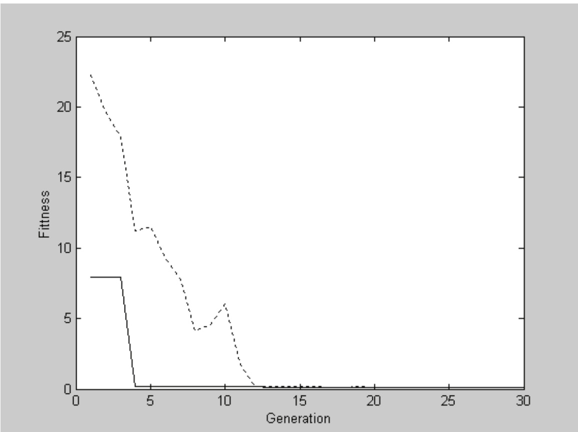

Fig. 8. The best and the average fitness function

V. CONCLUSION

This paper presents the new method for parameter optimization in systems for rubber strip cooling. In this purpose, genetic algorithm is used. Parameters are beeing 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 classical methods in the sense of better speed and adaptation accuracy.

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