Application of the method of the nonparametric identification of nonlinear dynamic control objects for the crushed vulcanization modification

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Abstract. Solving a problem of building the automatic control system of the industrial rubber article technological process by means of modeling software is one of the essential parts of providing the technological effectiveness. The work concerns the problem of application of the method of the nonparametric identification of a nonlinear dynamic control object for the process of modification of crushed vulcanized rubber. This process is an explicit nonlinear and nonstationary system of control parameters. The application of this method allows to obtain reliable information on an object without difficult computation, and the reliability of the method is corroborated graphically and with the computation. Depending on the degree of complexity of an object this method can be deterministic or probabilistic, can describe only time development, only spatial development or time-spatial development of an object. The influence of the process type on the identification results was analyzed in the work. Therefore, the task of increasing the quickness of information selection about the object is still a topical problem for the non-parametric identification. Conclusions about a possibility of activation of the identification procedure were made. The elaborated algorithm allows to apply it for other technological processes with self-adjusting systems when the condition of quasi-stationarity is fulfilled.

Key words: control object, identification, adaptive control system, crushed vulcanized rubber, modification.

INTRODUCTION

One of the important scientific problems of natural science is solving the problem of predicting the behaviour of an object under study in time and space on the basis of specific knowledge of its initial state. This problem consists in finding a law that allows to predict the object motion at any time $t > t_0$ on the basis of the existing information about the object at the initial time t_0 at the point x_0. Depending on the degree of complexity of an object this law can be deterministic or probabilistic, can describe only time development, only spatial development or time-spatial development of an object.

The subject of our analysis is a specific object of a dynamic system in mathematical conception of the term.

Crushing equipment for obtaining crushed vulcanizate is evident non-linear and non-stationary control object which characteristics and parameters depend on the properties of the processed recyclable materials and vary in a wide range.

A research of real systems consists in the study of mathematical models, which improvement and development are determined by the comparative analysis of experimental and theoretical results. In this regard, under the dynamic system we will imply its mathematical model.

In mathematics, a dynamical system is a set of relationships among two or more measurable quantities, where there are fixed ruledescribes as the quantities which evolve over time in response to their own values. Examples include the mathematical models that describe the swinging of a clock pendulum, the flowing of water in a pipe, and the number of fish in a lake in springtime. At any given time a dynamical system has a state which had been given by a set of real numbers (a vector) that can be represented by a point of an appropriate state space (a geometric manifold).

The evolution rule of the dynamical system is a function that describes that future states will follow from the current state. Often the function is deterministic; in other words, only one the current state has an influence on the one future state for a given time interval;[1,2] However, some systems are stochastic, random events have also affect on the evolution of the state variables.

The concept of a dynamical system has its origins in Newtonian mechanics. There, as in other natural sciences and engineering disciplines, the evolution rule of dynamical systems is an implicit relation that gives the state of the system for only a short time into the future. (The relation is either a differential equation, difference equation or other time scale.) To determine the state for all future times requires iterating the relation many times – each advancing time a small step. The iteration procedure is referred to as solving the system or integrating the system. If the system can be solved, given an initial point it is possible to determine all its future positions, a collection of points known as a trajectory or orbit.

Before the advent of computers, finding an orbit required sophisticated mathematical techniques and could be accomplished only for a small class of dynamical systems. Numerical methods implemented on electronic computing machines have simplified the task of determining the orbits of a dynamical system [3]. For simple dynamical systems, knowing the trajectory is often sufficient, but most dynamical systems are too complicated to be understood in terms of individual trajectories. The difficulties arise because:

- The systems studied may only be known approximately – the parameters of the system may not be known precisely or terms may be missing from the equations. The approximations used bring into question the validity or relevance of numerical solutions. To address these questions several notions of stability have been introduced in the study of dynamical systems, such as Lyapunov stability or structural stability. The stability of the dynamical system implies that there is a class of models or initial conditions for which the trajectories would be equivalent.
- The type of trajectory may be more important than one particular trajectory. Some trajectories may be periodic, whereas others may wander through many different states of the system. Applications often require enumerating these classes or maintaining the system within one class. Classifying all possible trajectories has led to the qualitative study of dynamical systems, that is, properties that do not change under coordinate changes. Linear dynamical systems and systems that have two numbers describing a state are examples of dynamical systems where the possible classes of orbits are understood.
- The behavior of trajectories as a function of a parameter may be what is needed for an application. As a parameter is varied, the dynamical systems may havebifurcation points where the qualitative behavior of the dynamical system changes. For example, it may go from having only periodic motions to apparently erratic behavior, as in the transition to turbulence of a fluid.
- The trajectories of the system may appear erratic, as if random. In these cases it may be necessary to compute averages using one very long trajectory or many different trajectories. The averages are well defined for ergodic systems and a more detailed understanding has been worked out for hyperbolic systems. Understanding the probabilistic aspects of dynamical systems has helped establish the foundations of statistical mechanics and of chaos.

THE ANALYSIS OF RESEARCHES AND PUBLICATIONS

An important source of saving of input materials in rubber production is the use of waste tyres and waste products of different rubber goods. Technical properties of the materials of the tyres and other elastomeric products are preserved to the utmost when processed by shredding-recycling method. Products of crushing are then re-used in the production process. The structure and properties of rubber crumb particles strongly depend on the ways of crushing (processing) of worn tyres and crushing of tyre rubber. The following energy treatments are used:

- cutting;
- shearing;
- electromagnetic and ultrasonic waves;
- electrical discharge;
- laser beam;
- shock action [4; 5].

Crushed vulcanizate can be used effectively when reclaiming it or modifying surface with active materials [6-9].

In these processes the destruction of the vulcanization network occurs as a result of increasing the rate and uniformity of penetration of a destructurizing agent into rubber crumb particles. Polymer degradation is a change in the properties – tensile strength, colour, shape, etc. – of a polymer or polymer-based product under the influence of one or more environmental factors such as heat, light or chemicals such as acids, alkalis and some salts. These changes are usually undesirable, such as cracking and chemical disintegration of products or, more rarely, desirable, as in biodegradation, or deliberately lowering the molecular weight of a polymer for recycling. The changes in properties are often termed "aging"[4].

In a finished product such a change is to be prevented or delayed. Degradation can be useful for recycling/reusing the polymer waste to prevent or reduce environmental pollution. Degradation can also be induced deliberately to assist structure determination.

Polymeric molecules are very large (on the molecular scale), and their unique and useful properties are mainly a result of their size. Any loss in chain length lowers tensile strength and is a primary cause of premature cracking [10, 11].

The specific character of mechanical failure of worn tyres is that at either low or normal or not very high temperatures the crushing process leads to the formation of rubber particles with a smooth surface, which looks like broken glass [12-16]. Such particles have a low adhesion to raw rubber and to the majority of polymeric thermoplasts. They are poorly soluble in bitumen and poorly sorb oil products. To modify their surface and to make it less smooth, rubber particles expose to various factors that promote devulcanization of the surface layer: flash heating of the particles with superheated steam, heating with a laser, treating with gamma rays with the following grafting of different monomers to the surface, sulfur deposition on the surface, ets. At present the search and the development of new ways for rubber crumbs modification are carried out in the areas:

1.chemical modification and softening the surface of rubber particles;

2.physicochemical crushing by breaking polymeric bonds (similarly to the regeneration);

3.physicochemical treatment with the aim of sulfure bonds breakage.

Rubber crumbs with particles size up to 5 mm obtained on roll crushers and rotor crushers were selected for the study [17-18].

Operating effectiveness of the system is determined by the quickness and reliability of selection of the information about the object which is necessary for object identification. Building a self-adjusting system is possible if it is assumed that its structure is invariable and known a priori. Thus, the identification problem consists in finding the unknown parameters [19]. A much more common approach is therefore to start from measurements of the behavior of the system and the external influences (inputs to the system) and try to determine a mathematical relation between them without going into the details of what is actually happening inside the system. This approach is called system identification. For the selection of the necessary information a long-time interval is required, which may lead to a quasi- stationarity breakdown. Therefore, the task of increasing the quickness of information selection about the object is still a topical problem for the non-parametric identification [20; 21].

Adaptive system (self-adjusting system) automatically changes the algorithms of its operation and its structure in order to maintain or achieve an optimal state as external conditions change [22; 23].

Under the dynamic system is implied any object or process for which clearly defined the concept of the state as a combination of certain variables at a point of time and determined the function that describes the time change of the initial state. This function allows to predict a state of a dynamic system on the basis of an initial state, and it is called the law of evolution. Dynamic systems are mechanical, physical, chemical and biological objects, computation processes and information conversion processes which are performed according to the specific algorithms. Descriptions of dynamic systems for defining the law of evolution are also diverse: with the help of differential equations, discrete mapping, graph theory, the theory of Markov chains, etc. The choice of the way of describing sets a specific form of a mathematical model of a dynamic system [24]. A mathematical model is a description of a system using mathematical concepts and language. The process of developing a mathematical model is termed mathematical modeling. A mathematical model of a dynamic system is considered to be set if system coordinates are entered and they uniquely determine the system state, and the law of evolution is defined. Depending on the degree of approximation various mathematical models can be assigned to the same system. In many cases, the quality of a scientific field depends on how well the mathematical models developed on the theoretical side agree with results of repeatable experiments. Lack of agreement between theoretical mathematical models and experimental measurements often leads to important advances as better theories are developed.

Dynamic systems, simulated by a finite number of ordinary differential equations, are called single-site or point systems. They are described with a finite-dimensional phase space and are characterized by a finite number of degrees of freedom. The same system in different conditions can be regarded either as point or as distributed system. Mathematical models of distributed systems are partial differential equations, integral equations or ordinary equations with lagging argument [25,26]. A number of degrees of freedom of a distributed system is infinite, and infinite data set is required to determine its state. On the basis of energy characteristic the dynamic systems are divided into conservative and nonconservative. Conservative systems are characterized by the energy content which is invariable in time. In mechanics they are called Hamiltonian. For conservative systems with n degrees of freedom the Hamiltonian of the system $H(p,q)$ is set, where q_i are the generalized coordinates, p_i are generalized pulses of the system, $i = 1, 2, \_, n$. The Hamiltonian completely characterizes the dynamic nature of the system and in terms of physics it in most cases represents the total energy of the system. The time evolution of conservative systems is described by the Hamiltonian mechanics [27-29].

Dynamic systems with time-varying energy content are called nonconservative. Systems in which energy decreases in time due to friction or dissipation are called dissipative. Accordingly, systems in which energy increases in time are called negative friction systems or negative dissipation. Such systems can be regarded as dissipative when the time direction is changed into the opposite [30, 31].

OBJECTIVES

The aim of the work was to establish the possibility of the application of the method of nonparametric identification for the control of the nonlinear dynamic system of parameters for the process of modification of crushed vulcanizate.

THE MAIN RESULTS OF THE RESEARCH

To solve the problem of building automatic control system of the process of modification of crushed vulcanizate we used the mathematical model [32] which describes nonstationary nonlinear system of the process parameters. The system includes a tandem of nonlinear inertialess and linear dynamic elements. The model is shown in Fig.1.

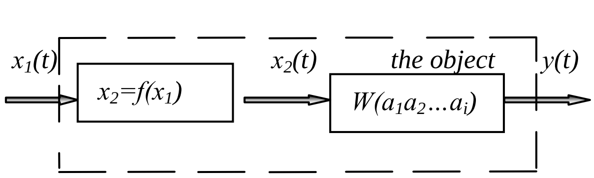

Fig. 1. Block diagram of the process of modification of crushed vulcanizate

The structure of the operator $W(a_1a_2 \ldots a_i)$ is known. From the measured input parameters $x_1(t)$ and output parameters $y(t)$ of the process within a time interval $0 \div T$ it is necessary to determine the steady-state characteristic of the object $x_2=f(x_1)$ and parameters $a_1a_2 \ldots a_i$ of the operator W.

When the supposition about the quasistationarity within the interval is made, the same values of x_1 correspond to the same values of x_2. Characteristic x_2 cannot be measured directly, however, it can be calculated from the $y(t)$ by the inverse transformation which looks like:

$$x_2(t)= W^{-1}[y(t)] \qquad (1)$$

Parameters $a_1a_2...a_i$ of the linear operator *W* are unknown and identification problem consists in the finding the values of $a_1a_2...a_i$ to meet the supposition in the best way, and the criterion is the within-group variance.

Realizable algorithm:

1. It was supposed that the measured parameters $x_1(t)$ within the interval $0 \div T$ have a variability in the operating range from x_{1min} *to* x_{1max}. The range was divided into *n* small intervals with an increment:

$$h = (x_{1max} - x_{1min})/n.$$

It was assume that x_{1j} was the middle of the j^{th} interval, where *j* was an integer series from *1* to *n.*

2. For the set values of parameters $a_1a_2...a_i$ the inverse transformation was performed which looks like:

$$x_2(t) = W^{-1}(a_1a_2...a_i)*[y(t)] \qquad (2)$$

3. The characteristic $x_2(t)$ within the time interval $0 \div T$ was written in the form of discrete equidistant values x_{2i} where *i* was an integer series from *1* to *k* with a time sampling interval:

$$\Delta t = .T/k.$$

4. The array x_{2i}, where *i* was an integer series from *1 to k*, was divided into *n* groups of appropriate intervals x_{1j}, where *j* was an integer series from *1 to n*.

5. For each j^{th} group the group average x_{2j} and the group variance *Dj* were computed.

6. For the entire array x_{2i} the within-group variance *Dv* was computed.

7. The computations for items 2÷6 were iterated for the new values of parameters $a_1a_2...a_i$ until for a certain set of values the minimum value of within-group variance is found.

That is this algorithm solves the problem:

$$Dv \rightarrow min_{a1...am} \qquad (3)$$

The values of parameters $a_1a_2...a_i$ provides the minimum of within-group variance and are the result of the identification.

It was advisable to analyze the influence of the $x_1(t)$ type on the results of the identification. The identification procedure can be activated when changing the input parameters $x_1(t)$ within the entire operating range (Fig. 2).

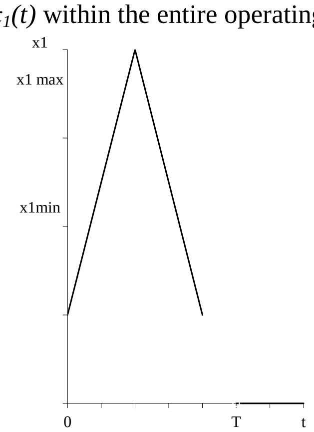

Fig. 2. The transient process $x_1(t)$ in operating range.

It can significantly reduce the time $0 \div T$ required for the selection of the information about the object when the input effect had been preset as in Fig. 3.

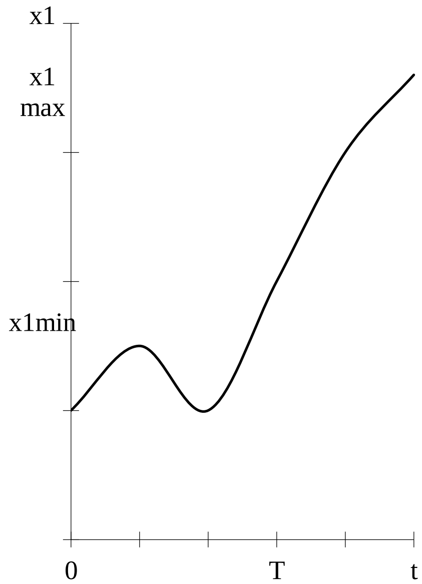

Fig. 3. The transient process $x_1(t)$ with preset input effect

The above process can be illustrated according to the flow-circuit control method (Fig. 4).

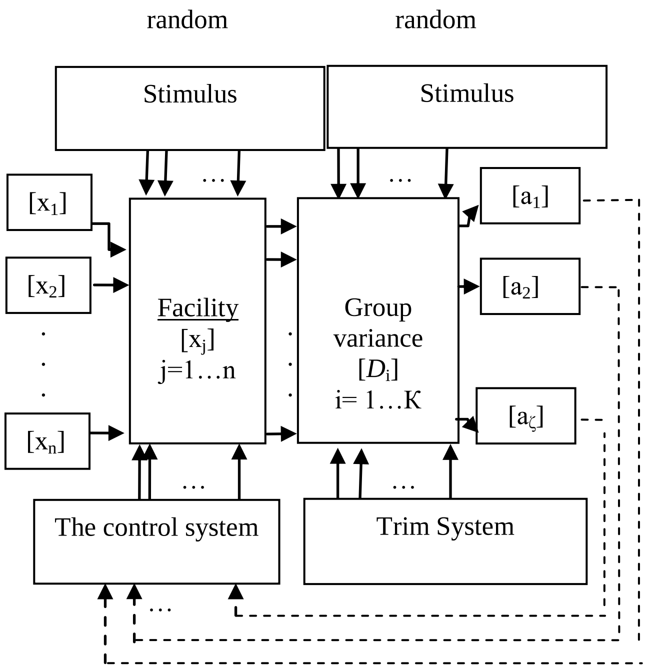

Fig. 4. A block diagram of the control method

where:

$[x_1], \ldots, [x_n]$ – matrix of the component input parameters,

$[a_j], j=1,\ldots,i$ – the reaction matrix of the object to the input component,

$[x_i], i = 1,\ldots,k$ – matrix parameters,

$[a_\zeta]$, $\zeta = 1, \ldots, l$ – output parameters of matrix system.

The calculations which were carried out in this work can be represented graphically (Fig. 5).

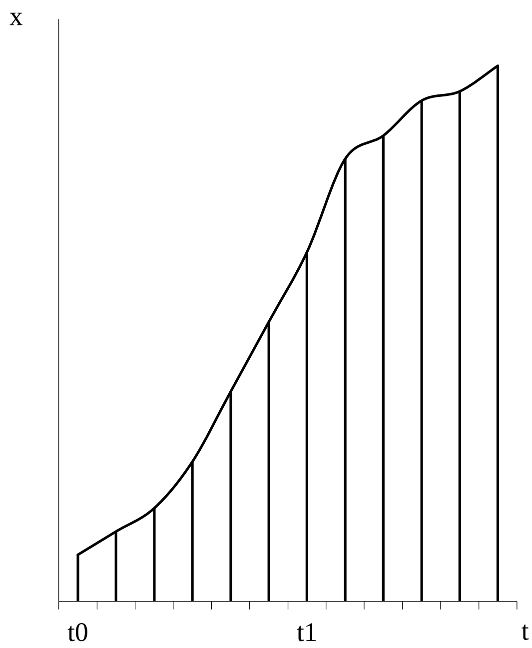

Fig. 5. Diagram of experimental dependence $x_1(t)$

CONCLUSIONS

1. Given method of nonparametric identification of nonlinear nonstationary objects allows to reduce the time of selection of the information about the object, and it is a decisive factor of the efficient operation of adaptive control systems.

2. It was solved the problem:

$$Dv \rightarrow min_{a1 \ldots am}$$

It provides a minimum intra-dispersion.

3. The effect of the type of $x_1(t)$ on the results of identification was analyzed.

4. The activation of the identification procedure over the entire operating range was shown.

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