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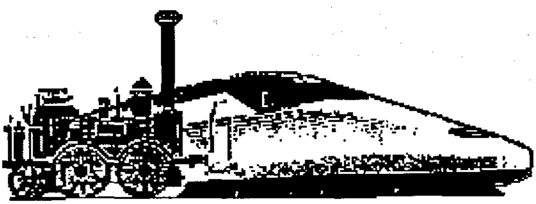

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INTELLIGENT BRAKING SYSTEM AND IMMUNE ALGORITHM FOR ROLLING STOCK

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Summary: Immune algoritlun is proposed for diagnostics controller of train's braking system. Mathematical models and algorithms are developed. Results of computer experiments show the possibility of controller to detect and warn about changes in the system and to prevent emergencies immediately. The primary task of the research is to separate dangerous states of braking system of rolling stock by critical measurements of sensors from the regular states of the system, detect and warn about changes in the system and to prevent emergencies immediately. The control of railway braking system is concerned with a large quantity of parameters, such as temperature, pressure, mass, acceleration, velocity etc., to be monitored.

1. Introduction

The primary task of the research is to separate dangerous situations in braking system by critical values of sensor measurements from the regular states of the system, detect and warn about changes in the system and to prevent emergencies immediately.

The control of railway braking system is concerned with a large quantity of parameters, such as temperature, pressure, mass, acceleration, velocity etc., to be monitored. The permanent monitoring of all sensor data is necessary to detect dangerous, unstable or unusual changes in the system.

Proposed intelligent device for braking system diagnostics may control actions and reliability of existing braking system. The specific goal of this product is to prevent dangerous situations, breakdowns and accidents caused by condition of technical state of braking system. The system allows stopping the train timely before the problem is occurred.

The device uses wireless communication network and receives the signal from the satellite navigation getting position and speed of rolling stock. Data base of the route relief allows calculating braking force of the rolling stock.

Main advantages of the device are:

- the possibility to prevent dangerous situation and crash corresponding to condition of the braking system of rolling stock and allows stopping the train before dangerous failure time point;

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- possibility of using of already existing measurement devices and sensors together with new sensors.

2. Mathematical Model of the System

2.1. Proposed Structure of Braking System of Rolling Stock

Objects of braking system of rolling stock are: steel rails - S, locomotive - L; wagon - V; steel wheels - R; brake pads - K; brake cylinder - BC, stopping transmission levers - PS; air splitter - G; stock air tank - KR; main reservoir - GR; air pipe with fittings - GV; compressor – LK; brake control devices - BV; release valve - AV, automatic mode - AR.

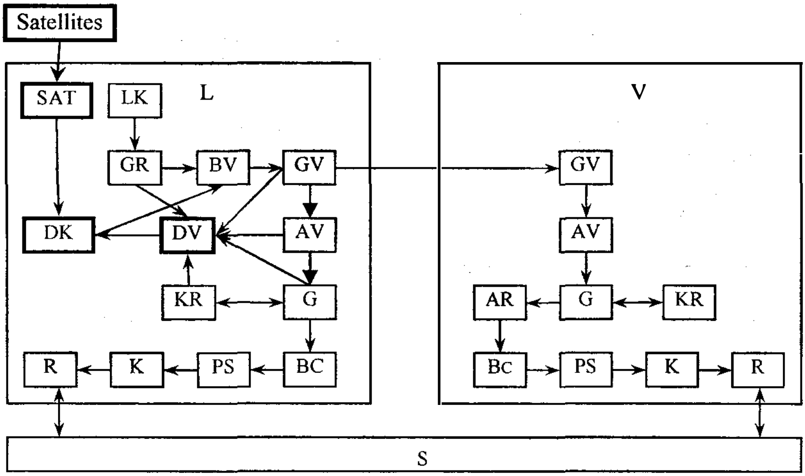

Fig. 1. Structure of proposed braking system with diagnostics devices

Fig.1. presents structure of existing braking system improved with new devices for diagnostics of braking system:

- DK – diagnostics controller;
- DV – sensors, that measures current state of the braking system;
- SAT – receiver of satellite navigation signals.

2.2. Calculated values for diagnostics

K – car brake pads permissible coercion force, kN;

P_r – static load on the wheel, attributed to a single brake pads, kN;

q_0 - load of the wheel-pair on the track;

Ψ_{κ} – wheel coefficient of adhesion to the rail during braking;

P_{kat} – cylinder piston stem strength, N

Q_{bremz} – consumption of compressed air braking process, cm^3/h;

Q_{nopl} – Consumption of compressed air leaks from the brake pipe and brake devices in the system, cm^3/h;

Q_{cit} – other consumptions, cm^3/h;

Q_{komp} - compressor rated supplies, cm^3/min;

K_r – car brake pads real power of coercion, kN;

$\varphi_K \cdot K_r$ - braking force between wheel and rail;

$\varphi_{KP} \cdot K_P$ - calculated braking force;

φ_{KP} - calculated friction coefficient;

K_P - calculated brake pad force of coercion;

$\sum K_p$ - calculated summarized coercion force of wagon brake pads, кN;

$\sum K_p^{\,n}$ - calculated summarized coercion force of brake pads of rolling stock, кN;

ϑ_p^{pdb} - calculated full-service braking coefficient;

t_s – brakes preparing time, s;

$V_н$, $V_к$ – train beginning and end of the speed adopted in the speed range, km/h;

$b_т$ – specific braking force, N/kN;

w_{ox} – specific basic resistance of train running at an average speed in each range of locomotive idling, N/kN;

i_s – equalized pitch specific resistance, N/kN;

w'_o - specific basic resistance of locomotive in traction mode, N/kN;

w_{0x} - specific basic resistance of locomotive in idle mode, N/kN;

$w''_{o8}, w''_{o4}, w''_{on}$ - 8-axle, 4-axle, or other type wagon specific resistance, N/kN;

Q_8, Q_4, Q_n - mass of the wagon group, t.

Q_v – total weight of the train, t

2.3. Target Function of Diagnostics Task

The goal of diagnostics task is to compare estimated parameters with actual values of sensors.

Estimated values are received using formulas or using nominal or documented constant values.

Actual values are received from formulas getting data from the sensors and measurement devices.

Target function for immune algorithm of diagnostics is following:

$$\begin{cases} \Delta \rightarrow \{\vec{0}, C_1, C_2, ...\} \\ \Delta = |\Phi(t) - \mathrm{E}(t)| \\ \mathrm{E}(t) = \{\vartheta_p, S_B, \varepsilon_i, t_m, \tau, I_{dcp}, Q_v\} \\ \Phi(t) = \{\vartheta^f, S_B^f, \varepsilon_i^f, t_m^f, \tau^f, I_{dcp}^f, Q_v^f\} \end{cases}$$

where

Δ - difference/similarity vector, which defines difference between estimated and the actual values.

$\vec{0}$ - Zero vector, which means compliance with the normal situation, where the estimates and the actual value of the difference is zero;

C_i – situation of danger classes, according to differences between estimated and the actual values;

$\mathrm{E}(t)$ - vector of estimated values;

$\Phi(t)$ - vector of actual values;

f – index, which represents the actual values.

2.4. Formulas for controlled values

Train braking system efficiency is characterized by the following parameters:

1. $\vartheta_p = \dfrac{\sum K_p^{\ n}}{(P_1 + Q_c) \cdot g}$ - estimated braking coefficient of rolling stock.

2. $S_B = S_S + S_P = \dfrac{V_0 \cdot t_n}{3{,}6} + \sum_1^n \dfrac{500(V_н^2 - V_к^2)}{\xi(w_{ox} + b_m \pm i_c)}$ – braking way.

   where S_S – preparing way for braking,

   S_P – real braking way.

3. $\varepsilon_i = \dfrac{v_н^2 - v_k^2}{2 \cdot 3{,}6^2 \cdot \Delta S_P}$. - average deceleration value,

4. $t_m = t_n + t_r = t_n + \sum_{i=1}^{n} \Delta t_r = t_n + \sum_{i=1}^{n} \dfrac{v_н - v_к}{3{,}6 \cdot \varepsilon_i}$ - braking time,

   kur: t_n - preparing braking time;

t_r - real braking time.

2.5. Total Weight of Rolling Stock

If the train at the same time is located in a number of railway profile elements, the mass of the train can be expressed in the following equation:

$$Q_v = \frac{-\zeta(B(t,v)+W(v))}{g\left(\frac{dv}{dt}+\frac{\zeta}{l_v}\left(s_0 i_1+\sum_{j=2}^{m-1} s_j i_j+(l_v-s_0-\sum_{j=2}^{m-1} s_j)i_m\right)\right)},$$

where

$B(t,v)$ – braking force;

W – resistance force of running rolling stock;

l_v –length of rolling stock;

Q_v – mass of rolling stock;

s_0 – distance from the point of connection of 1st and 2nd profile element to the beginning of the train;

i_j – slope of j-th profile element of the way;

s_j – length of j-th profile element of the way.

3. Immune Algorithm for Diagnostics of Braking Systems of Rolling Stock

Authors pronpose to use immune algorithm for intelligent devices of diagnostics system to increase safety level in railway systems and special grid function for optimizing monitoring time interval.

3.1. Parameters of Immune Algorithm for Diagnostics

Immune algorithm is based on the human immune system to simulate the interaction between antigens and antibodies. Biological immune system's main task is to protect living organisms from invaders antigens such as viruses, bacteria or other parasites. These antigens can be identified with the natural and adaptive immune systems. There follows antigen recognition cells that can recognize antigens from other cells and to classify it with "own" or "stranger". Adaptive immune system generates the following antibodies to counteract another's antigens.

Following definitions are necessary for diagnostics of braking system of rolling stock:

- Set of antigens – $I = \{i_1, i_2, ... \}$, where each $i \in I$, consists of measurements of braking sensors and the vector of estimated values:
  $E_i = \{v_0, a, P_{bc}, T_{fil}, Q_{sum}, I_a, \tau_a, \delta, \vartheta, S_m, \varepsilon_t, t_m, \tau, I_{dcp}\}$;
- Set of antibodies – classes of the states of braking system – $C = \{c_1, c_2, ... \}$;
- Elements of the cluster – knowledge database of the braking diagnostics immune system $M_c = \{m_1, m_2, ... \}$;
- Prototype-vector that characterize classes of braking system states $P_c = \{p_1, p_2, ... \}$;
- Summary vector – similarity or affinity function that compares affinity of antibody to antigen $S_m = P_c \cap E_m = \{s_1, s_2, ..., s_n\}$;
- Precision coefficient of affinity function - ρ $(0 < \rho \leq 1)$;
- Population size – number of known states of braking system - z;
- Antibody population size – z
- Memory pool size – M
- Replacement rate – ρ
- Clonal proliferation rate – κ
- Hypermutation rate – ψ
- Donor rate – δ
- Tournament pressure - γ
- Inducing rate – λ
- Diversity probability - σ
- Bit number in Gene shift - θ
- Bit number of nucleotide - β
- Number of proliferation - η

3.2. Main Steps of Diagnostics Immune Algorithm

Immune algorithm for the braking system diagnostic controller consists of the following steps:

Step 1. Input antigen to the systems – an actual state of the brake system with the defined measurements of sensors and the vector of estimated value for the diagnostics.

Step 2. Initial generation of antibodies according to of the braking system prototype vectors from immune system memory.

Step 3. Evaluation of affinity for each antibody-antigen.

Step 4. Choose of antibody with the best affinity value

Step 5. Clone this antibody according to clonal proliferation rate.

Step 6. Hypermutation of each cloned antibody.

Step 7. Affinity test of each hypermutated antibody with h antigen.

Step 8. Preliminary donor set creation of the best antibodies.

Step 9. Adding new antibodies to memory.

Step 10. Tournament selection from donor antibody - choose from the beginning antibody of donor set.

Step 11. DNA library construction from memory and donor antibodies.

Step 12. Gene fragment rearrangement with the result of generation of new antibodies.

Step 13. Diversification of antibody, which requires a variety of antigens and adequate antibody types of diversity.

Step 14th Algorithm stopping criterion. The process stops when antibody fully consistent with the antigen, which means that the current situation is recognized and classified by the hazard level. Otherwise, the algorithm is repeated from the third pitch.

This way the biological immune system functioning algorithm can be adapted to today's railway transport control system for substantial improvement in developing intelligent, so-called immune system-equipped vehicle diagnostic system, capable of ensuring efficient and safe transport control in standard and in unexpected situations.

4. Computer Experiments

Computer experiments are devoted to test the workability of immune algorithm for diagnostics controller. The states of the braking system are classified to separate dangerous or unusual situations. In case of unusual situation detection the intelligent diagnostics system warns about this or start automatic braking in case of dangerous situation.

For this experiment 10000 states have been generated.

According to the failure percent of all modelling situations, some values from the whole range are generated. Usually it is abnormal or dangerous state of the system process. In case of unusual situation detection the intelligent diagnostics system warns user about this.

Data for the experiment are generated as uniformly distributed random values, which are the part of the sensor range.

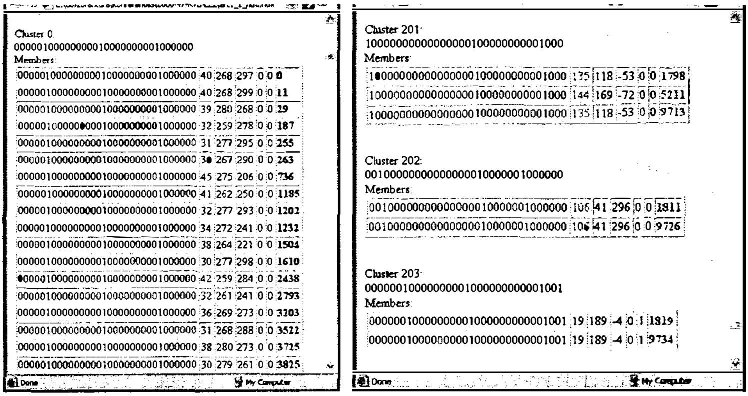

Fig. 9. Results of the immune algorithm

5. Conclusions

However, the object of research is simplified to several abstract sensors of diagnistics system that were taken for the experiment, the results show the ability of immune algorithm to classify dangerous and unusual states among the normal states.

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