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CAN BUS,
tramway diagnostic

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TRAMWAY DIAGNOSTIC SYSTEM

In this paper a system for automatic diagnostics of rail-vehicles is described. Distributed measuring systems in which measurement of instantaneous values of physical quantities takes place in many devices linked by a common bus are more and more commonly used in practice. The paper presents the model and test results of the model which was developed in the Department of Metrology and Nondestructive Testing of the Electrotechnical Institute.

SYSTEM DIAGNOSTYCZNY DLA TRAMWAJÓW

W artykule opisano system automatycznej diagnostyki pojazdów szynowych. Rozproszone systemy pomiarowe, w których pomiar wartości chwilowych wielkości fizycznych ma miejsce w wielu urządzeniach połączonych wspólną szyną, są coraz częściej wykorzystywane w praktyce. Artykuł prezentuje model (i wyniki testu), który został opracowany w Zakładzie Metrologii i Badań Nieniszczących Instytutu Elektrotechniki.

1. INTRODUCTION

Modern tramways are equipped with diagnostic systems fulfilling driver assistance functions in vehicle driving and correcting automatic control of subassemblies.

The tramway engineer gets additional information on the vehicle, displayed on the monitor screen, concerning various analog physical quantities such as velocity, voltage and current at different points of the object [2]. Binary signals characterizing the condition of drive, brakes, supply system, internal and external lighting, heating and other subassemblies or read out apart of the analog quantities.

The CAN BUS gives the possibility to include into monitoring and complex diagnostics all board equipment of the vehicle (Fig.1). The network forms a distributed system [3] which gives possibility to develop software without any need to change the main hardware.

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Due to computer technology many new features were gained, which improve safety and facilitate service. The diagnostic system presented is a part of a greater system comprising all network vehicles as well as vehicles in the depot together with the local depot network.

2. DISTRIBUTED TRAMWAY COMMUNICATION SYSTEM

The presented diagnostic system is a part of a larger network system [9] comprising the vehicle set and the depot system (Fig.2).

Information on the tram board equipment are supplied by the vehicle CAN network. All measuring and control equipment is connected with the network.

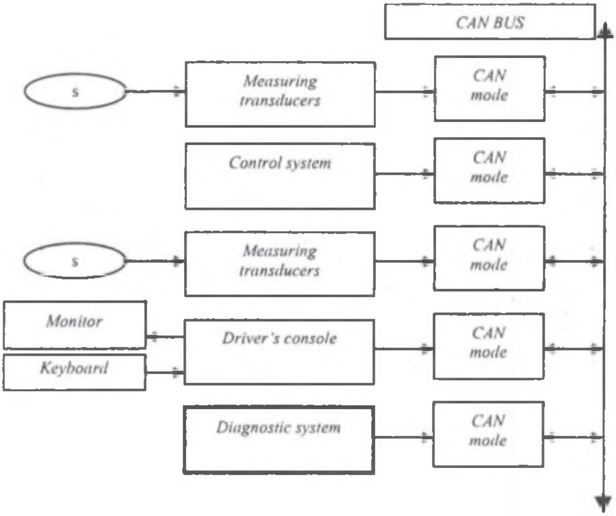

Fig.1. Distributed diagnostic system

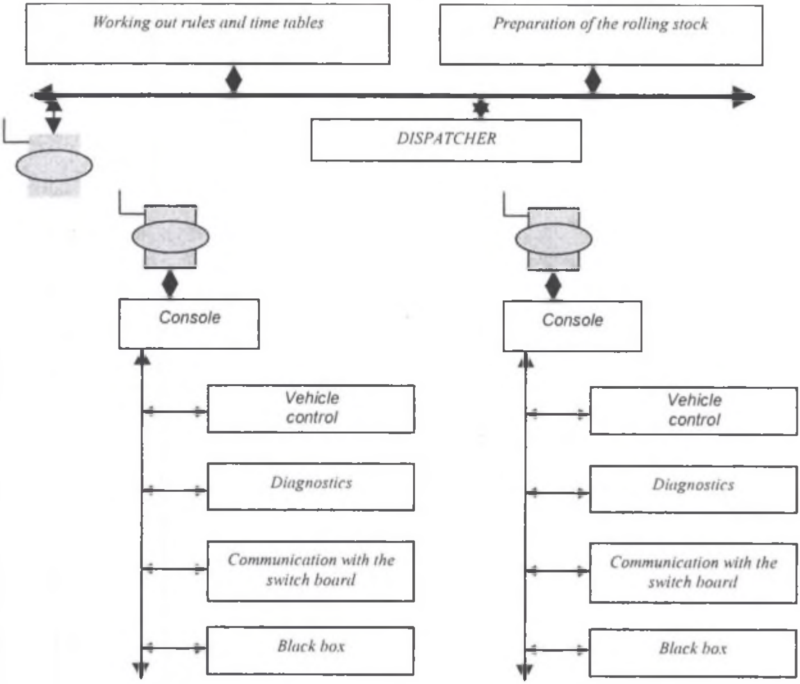

Fig.2. The communication system of tramway depot

Fig.3 shows selected tramway elements under diagnostic control. Consoles 1 and 2 provide communication with the driver and enable the tram to be controlled. The diagnostic system 3 connected with the bus reads data and transfers diagnostic decisions. The drives 7 and 8 transfer its basic parameters to other equipment by means of the network. Brakes 6, doors, lighting and heating are also controlled. The distributed measuring system is a set of independent microprocessor devices controlled by the network. The installation software permits to create an integrated environment of measuring data processing. The devices fulfill functions of intelligent measuring sensors, measuring transducers, diagnostics, monitoring and communication systems controlling the actuator components.

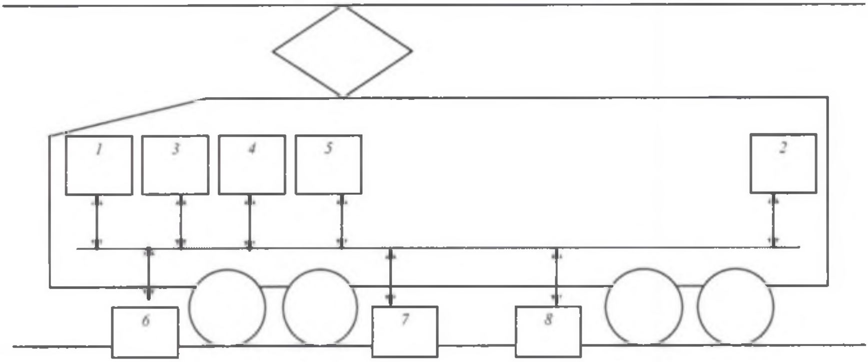

Fig.3. Basic components of tramways

Values of physical quantities are transmitted by the network to systems of further processing and diagnostic systems which in turn control the actuator elements.

3. MEASURING SYSTEM

In measuring systems, the basic problems are time and the sequence of events. Communication by network is connected with transmission of statements with limited speed. Transmission of statements most often, takes undetermined amount of time. Problems of time and coordination as well as synchronization algorithms in distributed systems were discussed in [1].

In measurement applications in distributed systems the sequence of events in different processes is of decisive importance. The measuring model expresses the relationship between the measured input quantities, the influencing and interfering quantities and the value of the measurand. Adopting the notation of [7] [8] we have:

$$y = f(x_1, x_2, .., x_n, w_1, w_2, .., w_m, z_1, z_2, .., z_k) \tag{1}$$

Taking into account correlation between the components of the *X* vector, the standard uncertainty squared can be expressed by relationship [8]:

$$u^2(y) = \sum_{i=1}^{N}\sum_{j=1}^{N} \frac{\partial f}{\partial x_i}\frac{\partial f}{\partial x_j} u(x_i, x_j) \tag{2}$$

In distributed system there is an uncertainty connected with network transmission. The input quantity values in the time t_k are measured t_{kxi}. Uncertainty is introduced by blocs of the functional measuring chain, from the measuring sensor through analog and digital traducers and processing algorithms. Each element processes the value and uncertainty from the input, adding its own uncertainty [4]. The value of the input quantity at the time moment t_k which was measured at the time moment t_{kxi} is determined by the signal prediction method with the signal dynamics taken into account. With the delays taken into account the measurement model is in the form:

$$y = f\left(P\begin{pmatrix} x_1, x_2, \ldots, x_n, \Delta t_{kx1}, \Delta t_{kx2}, \ldots, \Delta t_{kxl}, \\ w_1, w_2, \ldots, w_m, z_1, z_2, \ldots, z_k \end{pmatrix} \right) \tag{3}$$

The general model permits to determine the values of the measured quantity and uncertainty, with known M values of signal samples and their delays, of the determined prediction, function P. The network in a measuring system is an element in the processing chain. The probability density distribution of the output random variable, can be determined if there is a determined correspondence rule between input and output. According to the uncertainty propagation model distribution of the output random variable is a convolution of the transformed input distribution and the probability density distribution of the error introduced by the element. By simplifying the relationships to distributions parameters the standard uncertainty is treated as a distribution parameter. Function P determines the method of determining uncertainty values on the basis of the series of input values and delays. Prediction problems are discussed in [5].

4. DIAGNOSTIC PROCESS MODEL

The parameters of the vehicle model are determined on the basis of information from the network. Areas characteristic for normal operation conditions and failure conditions were created in the space of these parameters. The used probabilistic model of decision credibility allows the correctness of diagnosis to be estimated. Representation of the measuring signals can be written in the form of the relationship:

$$\hat{x} = f^{-1}(y) \tag{4}$$

which expresses relations between signal estimation obtained as a result of the representation procedures. According to the model, the measured values are a superposition of the signal generated by the object and of the random process:

$$x(t) = s(t) + n(t) \tag{5}$$

The random process is determined by the probability density function and the autocorelation function. If the analytical function is not known then (with an assumed model) the model parameters should be estimated: the expected value and variance. The expected value the measured signal instantaneous value at each point *k* is given by the relationship:

$$E\{x(t_k)\} = s_k \tag{6}$$

Variance of the signal instantaneous value at each point *k* is given by the relationship:

$$\sigma_k^2 = E\{(x(t_k) - E(x(t_k)))^2\} \tag{7}$$

In the practice the probability density distribution in not known or it is difficult to be estimated in analogical form. Then according to estimation of measurement uncertainty the approximate random spread of the signal at point *k* is determined.

Extraction algorithms perform the function transformation of the represented input values into feature values. Denoting the input quantity value vector by *X*, and the uncertainty vector by *u(X)*, the function determining the i-th feature value has the form:

$$c_i = G(X, u(X), A) \tag{8}$$

With the correlation between vector X components taken into account, the standard uncertainty squared can be expressed by the relationship [7]:

$$u^2(c_i) = \sum_{i=1}^{N} \sum_{j=1}^{N} \frac{\partial G}{\partial x_i} \frac{\partial G}{\partial x_j} u(x_i, x_j) \tag{9}$$

The classification algorithms act basing on determining a set of conditions W and testing the probability of satisfying the logical expression which includes decision rules.

$$W = K(C, u(C), B) \tag{10}$$

The condition is a function of the vector of features/properties C, of uncertainties connected with the features $u(C)$ and the vector of fixed parameters B. The random model causes that the logical expression can assume values of zero or unity, with a probability possible to be estimated. The expression:

$$P(W > 0) > P_1 \Rightarrow D_i = 1 \tag{11}$$

means that the classifier assumes the value of unity for the i-th decision when the probability that $W<0$ is higher than the assumed one. In case when the probability of meeting the opposite condition is higher than the assumed one then the value of zero of the i-th decision is assumed:

$$P(W < 0) > P_0 \Rightarrow D_i = 0 \tag{12}$$

In other cases, it is not possible to decide, with probabilities assumed earlier, what value is to be ascribed to the i-th decision. In such a case, the way of proceeding is decided by the strategy verified in practice. If one of the above conditions is satisfied, the decision on diagnosis is adopted with the assumed probability of correctness. Lack of such a decision leads to a situation when no decision is adopted. A good practical solution is making a decision with a known probability calculated from known data on uncertainty. The receiver gets measurement values and uncertainties with various delays. A delay of one step results from natural cause-effect sequence and it does not introduce any additional uncertainty. If the delay is higher, then the missing data is determined currently according to the prediction principles. In this case the uncertainty is estimated as a parameters of o set of mean-square errors of prediction. For linear uncertainty the function is:

$$u_i(k) = k_i u_{i1} + u_{i0} \tag{13}$$

The value u_{i0} means an uncertainty at the i-tch point at k=0, while u_{i1} is an increase in uncertainty for one delay. Network operations of representation algorithms introduce an uncertainty:

$$u_{xi}(k) = k_{xi} u_{xi1} + u_{i0}(x_i) \tag{14}$$

Transmission between the representation block and the feature extraction block introduces additional uncertainty:

$$c_i = G(\hat{X}, u(\hat{X}), k_{xi} u_{xi1} + u_{i0}(\hat{x}_i), A) \tag{15}$$

Similarly, transmission between the feature extractor and classifier introduce uncertainty:

$$W_i = K_i(C, u(C), u_{iT}(C), B) \tag{16}$$

The components of uncertainty are transferred from measuring inputs and are introduced by consecutive processing stages. According to the adopted propagation model the uncertainty transferred to the diagnostic conditions causes that decisions are made with a non-zero diagnosis error probability.

One of the quantities measured in a tram is the electric current. The consecutive phases of processing in the diagnostic system are shown below:

- measuring N consecutive current values I_i,
- determining the measured signal feature according to:

$$I_{sr} = \tfrac{1}{N}\sum_{i=1}^{N} I_i \tag{17}$$

- determining the probability of meeting the condition deciding on class D according to the classification rule:

$$I_d \leq I_{sr} \leq I_g \tag{18}$$

- making decision on counting the measurement result to diagnostic class D according to formula

$$P(W) \geq P_1 \Rightarrow D = 1 \qquad P(W) \leq P_0 \Rightarrow D = 0$$

- the result is the value D.

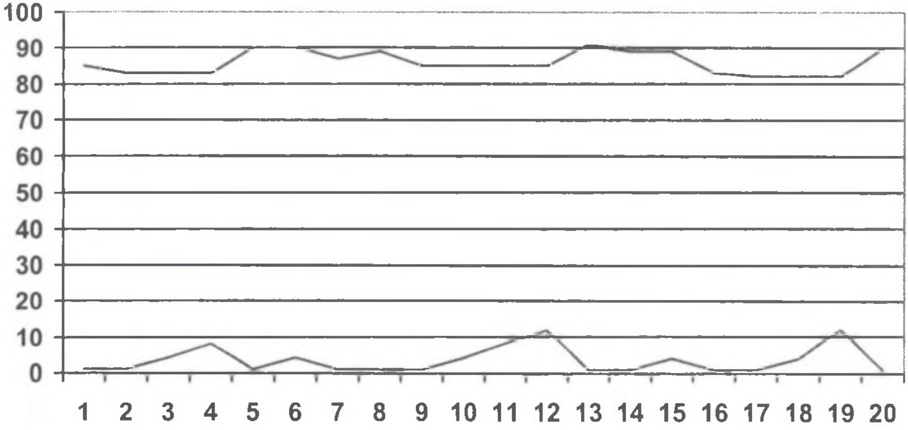

Fig.4. Measurement values and measurement uncertainty

The value of the feature determined from measurements is 85 while the standard uncertainty is 4.6. The distribution of the spread around the mean value is not known. For normal distribution, the probability that the value of the feature is less than $I_g=96$ is $P(I<96) > 0.95$. On the basis of the results obtained it can be stated that D=1 with P=0,9.

5. CONCLUSION

In the Department of Metrology and Nondestructive Testing of the Electrotechnical Institute there was developed and carried out a diagnostic system for an urban tram. Laboratory tests and experimental operation allow the following conclusion to be stated:

- reliability of vehicles is improved,
- continuous monitoring of tram components reduces and facilitates service,
- open programming permits diagnostic rules to be added,
- relatively low cost of the system fully justifies installation.

The solution presented here can be successfully applied in other vehicles equipped with the internal CAN BUS.

6. FINAL REMARKS

The diagnostic system discussed here is being installed in modernized urban tramways in Warsaw. Further work is concentrated on the following problems:

- optimization of processing algorithms,
- implementation of visual diagnostic systems,
- implementation of the local depot network.

The diagnostic computer system is a part of the vehicle local network and the depot network connected with it. This approach permits new functional elements to be introduced into the system and the already implemented ones to be modified.

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