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APPLICATION OF THE MULTIPLE-VALUED LOGIC TO DETECTING IRREGULAR STATES IN THE ELECTRO-PNEUMATIC SYSTEMS

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Abstract. *The paper discusses application of THE multiple-valued (three-valued) logic to diagnosing the electro-pneumatic system operation as well as to detecting irregular states in actuating elements. In doing this, the work fluid pressure values are divided into three ranges so that for each range there is one of the logical values of three-valued variable* $x_i \in \{0,1,2\}$ *corresponding to it. The respective signal generation is done by means of built-in transducers for translating non-electric values into electric ones. By the combining multiple-valued digital circuit whose input variables* x_i, *signals are generated on the basis of which the process flow is controlled as well as an irregular device operation is detected.*

Key words: *Pneumatic System, State Diagnostics, Multiple-valued (Three-valued) Logic, Actuating Element, Electromagnetic Manifold*

1. INTRODUCTION

In modern hydraulic and pneumatic systems the requirements are made for permanent following of proper functioning, and, in connection with it, for detection of irregular operation. In order to satisfy these requirements, it is necessary to build in appropriate transducers as well as additional circuits for generation and processing of the obtained signals. The way of solving this problem has been based so far upon technical

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possibilities offered by the binary logic [2].

In this paper, the problem of monitoring and diagnosing the state of actuating the defined technological operations is discussed from the standpoint of the multiple-valued (three-valued) logic, implying that the characteristic variables are given three logical values, on the basis of which further signal processing is carried out. The industrial air pressure (p), as energetic medium in the actuating element, is taken as a characteristic value in the system operation. In this particular case, the analysis is done upon a pneumatic actuating element in the form of the double-ended effect cylinder, fed by the pneumatic manifold 5/2 with electromagnetic control, without excluding the possibility of generalizing the problem so as to include other pneumatic actuating elements.

2. LOGICAL INTERPRETATION OF THE SYSTEM STATE

The following of any value changes of the characteristic variable parameters can be realized on the basis of the signal obtained from the transducers built in in the pneumatic system. Within the interval of possible values for each of variable x_i, three ranges can be defined corresponding to:

- state when the pressure value (p) as a variable is equal or less than the atmospheric pressure (p_0), that is, when there are no signals from the transducers;
- state when the pressure values are within the range between the atmospheric (p_0) and the nominal work pressure (p_n), that is, when the transducer signal is present, but the values of the variable are in the work range which is not allowed for operation;
- state when the pressure values (p) are equal or somewhat greater than the nominal pressure (p_n), that is, within the safe work range;

Each of the variables $x_i \in \{0,1,2\}$, concerning the defined ranges, can be adjoined three logical states:

$$x_i = \begin{cases} 0, & p \le p_0 \\ 1, & p_0 < p < p_n \\ 2, & p \ge p_n \end{cases} \quad (1)$$

The output signal generation for indicating the system state at work - on the basis of logical values of chosen parameters $x_i \in \{0,1,2\}$ - can be realized by the logical processing with the use of the three-valued logic.

In the general case, output function y_j (j = 1,2, ..., m), which is characteristic for some irregular state of the u_k system state can be expressed in the form:

$$y_j = F_j(x_1, x_2, ..., x_i, ..., x_n) \quad (2)$$

where $y_j \in \{0,1,2\}$ or, in a special case, $y_j \in \{0,1\}$, that is, $y_j \in \{0,2\}$, when the binary output is required.

The previous function can be expressed in the form of expressions similar to polynomials in common algebra, so that the use of an adequate mathematical apparatus makes easy the procedure of scheme analysis, synthesis and minimization. It should also be noted that, in comparison with the possibilities and efficiency of Bull algebra, the existing mathematical apparatus of the three-valued logic is faced with a set of limitations of theoretical and practical nature.

However, by applying some of the proposed functional complete three-valued system used so far, [3,5], particular classes of problem can be solved efficiently. At the basis of the proposed functionally complete three-valued systems there is a possibility of a relatively simple realization of the basic operators in some of the modern technologies as well as a possibility of a much simpler analytical expression.

In this paper, we will concentrate upon the application of a functionally complete three-valued system [3] formed by the following functions presented in Table 1. In addition to the basic functions of the functionally complete three-valued system the paper will also make use of the derived, characteristic threshold functions [5,6] of a variable:

$$ {}^{i}X^{i} = \{0,2\}, \quad i = 0,1,2 $$

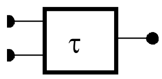
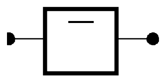
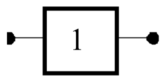
that is:

$$ {}^{0}X^{0} = f_{200} = \overline{\bar{x}\tau 2},\ {}^{1}X^{1} = f_{020} = \overline{x\tau\bar{x}} \text{ and } {}^{2}X^{2} = f_{002} = \overline{x\tau 2} \tag{3} $$

as well as the cycling function (cyclic negations):

$$ \vec{x} = \overline{x\tau 1} \quad \text{and} \quad \overleftarrow{x} = \bar{x}\tau 1 \tag{4} $$

Table 1. Functionally complete three-valued system.

Name of Function	**Analytical Expression**	**Symbol**
TOR Function (Function of Two Variables)	$f(x_i,x_j) = x_i \tau x_j = \begin{cases} \max(x_i, x_j) \text{ za } x_i \neq x_j \\ 0 \quad \text{za } x_i = x_j \end{cases}$	
Unary Function of Three-valued Inversion	$f(x) = \bar{x} = (2 - x) \bmod 3$	
Logical Constant "1"	$f(x) = 1$	

3. Pneumatic System Model

The system operation can be followed through values of the air work pressure (p) in the pneumatic cylinder chambers K_1 and K_2.

Figure 1 shows the principle that the pneumatic actuating element scheme is based upon, namely the element consisting of a double-ended effect cylinder and an electro-pneumatic control manifold 5/2.

In the real engineering systems, the air pressure values in the cylinder chambers can be registered by means of appropriate transducers D_1, D_2. According to equation (1) logical values of three-valued variables $x_1, x_2 \in \{0,1,2\}$ will be defined within the following boundaries:

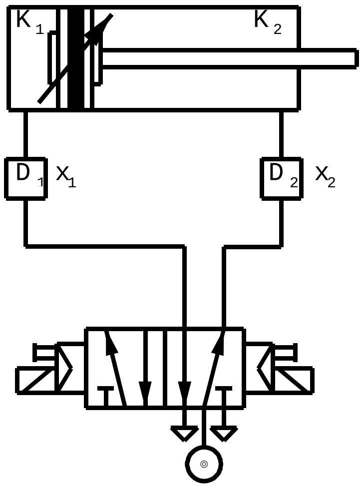


Fig. 1. Pneumatic system model

$p_a = p_0 + \Delta p$ for logical 0

$p_b = p_n \pm \Delta p$ for logical 2

$p_a < p < p_b$ for logical 1

where Δp is permitted deviation from the pressure value being accepted depending on the system operating conditions;

Since the number of possible combinations for two input three-valued variables x_1 and x_2 amounts to 3^2, it is possible to define 9 different system states, some of which being regular, while the others appear in the case of degradation of the system characteristics.

Table T-2 gives the description and denotations of the diagnosed states upon the actuating element, decimal equivalents and their three-valued code, as well as the (A - E) state denotations.

Table 2. Combination table for diagnostics.

Dec. Equiv.	Input x_1	Input x_2	Output y	Diagnostics: Description and Denotation of the State Diagnosed on the Actuating Organ	
0	**0**	**0**	y_0	*No Feeding - Break on the Principle Pipeline*	***E***
1	**0**	**1**	y_1	*Failure in the Chamber Connection 2 PCDD*	***B***
2	**0**	**2**	y_2	*Regular State - Cylinder Piston Rod Pulled In (C_i -)*	***A***
3	**1**	**0**	y_3	*Failure in the Chamber Connection 1 PCDD*	***B***
4	**1**	**1**	y_4	*Irregular Piston Sealing - Piston Leakage*	***C***
5	**1**	**2**	y_5	*Irregular Chamber 1 PCDD Discharge*	***D***
6	**2**	**0**	y_6	*Regular State - Cylinder Piston Rod Pulled In (C_i +)*	***A***
7	**2**	**1**	y_7	*Irregular Chamber 2 PCDD Discharge*	***D***
8	**2**	**2**	y_8	*No Discharge of Chamber PCDD - Clogging*	***F***
Weight	3^1	3^0	**Actuating Element Model - Pneumatic Cylinder with Manifold 5/2**		

The possibilities of diagnosing irregular states with respect to kind and location in the system in which irregularity emerges are shown in Fig. 2. Regarding equation (1) the presence of logical value 1 in the code combination points to an error; for this reason, combinations 01 and 10 represent an irregular fluid supply, combinations 12 and 21 represent an irregular fluid drainage, while combination 11 is an error in the piston sealing (Fig. 2.a).

On the basis of logical values when $x_1 = 1$ or $x_2 = 1$ the location of irregular state emergence can be more closely located as shown in Fig. 2b. Thus, for instance, if $x_1 = 1$ a

$x_2 \in \{0,2\}$, then an irregular state is present on connection K_1, while, in the case that $x_1 \in \{0,2\}$, while $x_2 = 1$ an irregular state is on connection K_2. When logical values of variables $x_1 = x_2 = 0$ there is a feeding break on both the connections, while, when $x_1 = x_2 = 2$, no discharge of chambers K_1 and K_2 takes place.

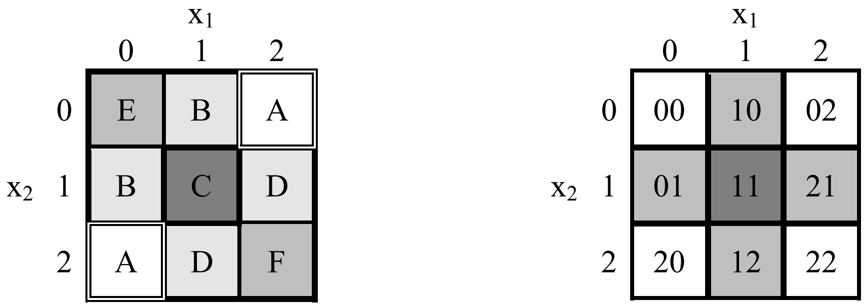


Fig. 2. Possibilities of diagnosing:
a) kinds of irregular states, b) locations of irregular states

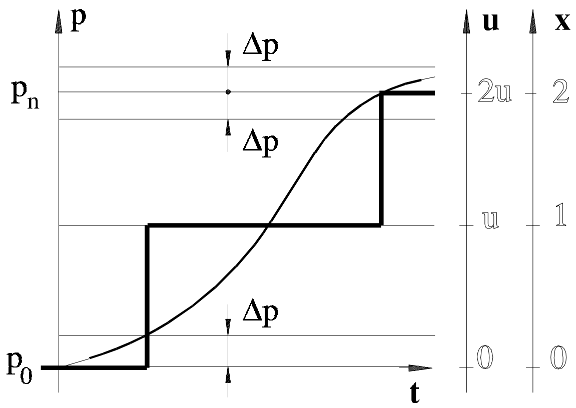


Fig. 3. Defining of logical values

The acquisition of electric signals corresponding to the variable logical values is performed on the basis of the pressure values. At transducer D_X the input value is fluid pressure, while the output value is electric voltage (u). Voltage levels $u \in \{0, U, 2U\}$, corresponding to the accepted logical pressure values (p) and their logical values are defined according to Fig. 3. while the acquisition of respective voltage levels, on the basis of which further processing is done, is provided by the circuit shown in Fig. 4.

Voltage u(p), whose value corresponds to measured pressure p, is led from transducer output D_X to comparator inputs whose referential levels u_{r1} and u_{r2} correspond to the boundary values of pressures $p_0 + \Delta p$ and $p_n \pm \Delta p$, respectively. Since the output voltages from the comparator are discrete, that is, $u = 0$ or $u = U$, while the inverter is fed by voltage 2U, at the circuit output, depending on the input pressure values, voltages 0, U or

2U are obtained, corresponding to the input variable logical values. In this way the function of one variable f_{012} is realized from a set of 3^3 possible functions of one variable.

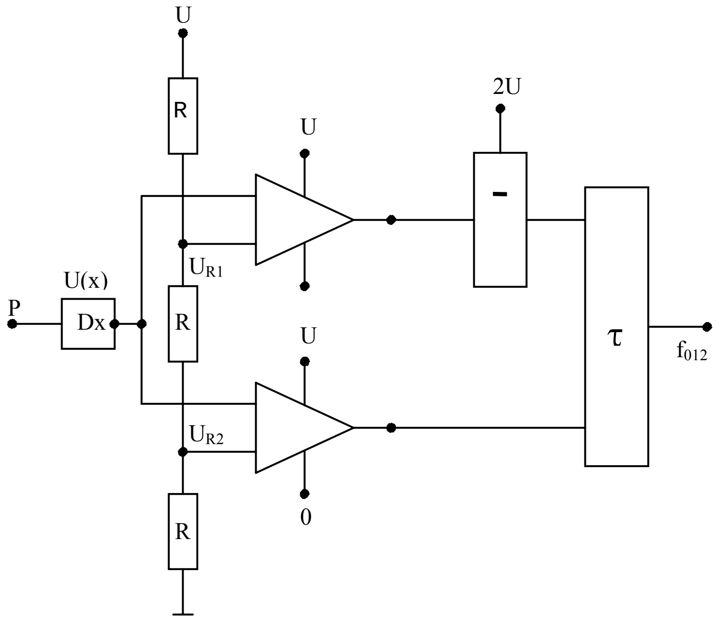


Fig. 4. Circuit realization

While analyzing the way of diagnosing irregular states, it is accepted that by voltage u = 2U, corresponding to logical state 2, the component for indicating an irregular state is activated.

Detection of the diagnosed state, on the basis of the pressure values from transducer Dx can be carried out in two ways:

a) on the basis of the expression by means of the functionally complete three-valued system operator for each separate irregular state. Output function y_i corresponding to decimal equivalent for irregular state from Table T-2 can be analytically expressed by means of the system operator. Functions y_1 and y_3 corresponding to failures on the chamber connections (state B) can be expressed by the relation :

$$Y_B=\overline{(x_1\tau x_2)\tau 1} \quad (5)$$

while functions y_1 and y_7, that is, state D on the basis of

$$Y_D=\overline{(\overline{x}_1\tau \overline{x}_2)\tau 1} \quad (6)$$

b) with the use of threshold functions and by decoding; that is, while detecting both regular (y_2,y_6) as well as irregular system states (y_0,y_1,y_3,y_4,y_5,y_7,y_8) threshold functions defined by equations (3) for variables x_1 and x_2 are used.

Fig. 4 shows a block scheme for solving the detection circuit for some regular and irregular states from a set of all possible system states through decoding particular states and in accordance with Table T-2. At the same time, output functions y_i, as has already been mentioned, can have logical values 0 or 2, that is $y_i \in \{0, 2\}$.

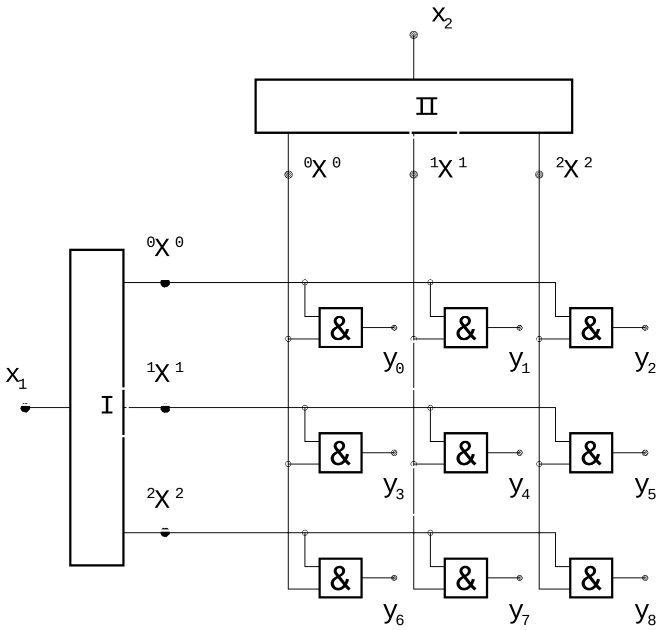


Fig. 4. Signal generation for output states defined on the basis of logical values of variables x_1, x_2 against table 2

Starting from equations 1-3, a synthesis has been done of the circuits presented by blocks I and II with input x_i ($i = 1,2$) and three outputs expressed by equations 3. The decoding of particular states from y_0 to y_8 has been carried out in a way similar to the decoding in the binary digital technique with the use of I-circuits. Further decoding provides, depending on the needs, for recognition of states A-E shown in Table 2.

The signals from the decoding circuit output are used for exciting the irregular state indicator (for instance, visual indicators with LED diodes) or as controlling signals for correction or possible work process cessation (pressure value change, break of feeding and so on).

4. CONCLUSION

In the paper the air pressure values in the pneumatic cylinder chambers for the time intervals of the piston rest are used as relevant parameters for following the pneumatic system state.

The accepted discrete pressure values on the cylinder connections are given logical values of three-valued variables x_1 and x_2 while possible regular and irregular states are defined and denoted in the combination Table. On the basis of the work process analysis as well as of the established Table, it can be concluded that the number of possible defined states is sufficient for reliable following of the system operation. In the paper, a new approach to the signal generation and processing is presented with the use of three-valued logic. The realization of the described electric circuits by which the system functions are realized is possible by means of available components and integrated modules. By this approach, regarding the binary logic, it is possible to reduce the number of the needed transducers as well as of the connecting cables for the signal transmission.

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PRIMENA VIŠEZNAČNE LOGIKE U OTKRIVANJU NEREGULARNIH STANJA KOD ELEKTRO-PNEUMATSKIH SISTEMA

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U radu se razmatra primena višeznačne (troznačne) logike za dijagnosticiranje rada elektro-pneumatskih sistema i otkrivanje neregularnih stanja kod izvršnih elemenata. Pri tome su vrednosti pritiska radnog fluida podeljene u tri opsega tako da svakom opsegu odgovara jedna od logičkih vrednosti troznačne promenljive $x_i \in \{0,1,2\}$. *Generisanje odgovarajućih signala vrši se pomoću ugrađenih pretvarača neelektričnih u električne veličine. Kombinacionim višeznačnim digitalnim kolom čije su ulazne promenljive* x_i, *generišu se signali na osnovu kojih se kontroliše tok procesa i detektuje neregularan rad uređaja.*

Ključne reči: *pneumatski sistem, dijagnostika stanja, višeznačna (troznačna) logika, izvršni element, elktromagnetni razvodnik*