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# RECOGNITION OF FAULTS IN THE DIAGNOSING PROCESS[†]

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**The paper presents a general diagram of a supervisory system realizing functions of diagnosing and protection of an object. The formalized description of the object and the diagnosing process have also been given, assuming two–stage interpretation of diagnostic test results (residual values). Quotient sets have been applied for analysis of differentiation of faults and differentiation of the object states. Measures of diagnosing quality and an example of their calculation have been given. Also practical diagnosing problems have been formulated.**

## 1. Introduction

System approach to problems of diagnostics and protection of continuous industrial processes has been the subject of many research works for over twenty years. An idea of analytical application redundancy for fault diagnostics and methods of self–reorganization for protection of control system operation have been presented for the first time probably by Beard (1971) and by Mehra and Peschon (1971). A lot of research since those times have been done in the field of fault detection, isolation and accommodation (FDIA) in dynamic processes.

Known, analytical methods of fault detection can be divided into two groups (Frank, 1990; Isermann, 1984): methods applying state estimation and methods applying parameter estimation. To the first group of methods one can count parity space approach (Chow and Willsky, 1984; Lou *et al.*, 1986), diagnostic observers approach (Clark, 1978; 1989; Frank, 1987; 1990) and Kalman filters approach (Willsky, 1976; Basseville, 1988; Mehra and Peschon, 1971). Parameter estimation methods have been developed, among others, in papers (Isermann, 1984; 1991; Geiger, 1985).

Isolation of faults on the grounds of a vector (set) of generated residuals is executed accordingly to one out of two following ideas (Gertler, 1991):

- structural residuals — a single fault causes that only thespecific subset of residuals becomes non–zero,

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- fixed–direction residuals — a single fault causes change of the residual vector in specific direction (Patton and Chen, 1991).

With structural residuals there corresponds also the diagnostic concluding suggested by Frank (1990) according to the following rules:

$$\begin{array}{lll} \text{if} & [r_k \text{ and ... and } r_m \neq 0] & \text{and} \\ & [r_p \text{ and ... and } r_s = 0] & \text{then the fault } e_k \text{ occurs.} \end{array}$$

Another way of concluding that leads to diagnosis formulation is the fault–symptom tree presented by Isermann (1991).

## 2. General Diagram of the Diagnosing Process and the Object Protection

The diagnosing process consists of two basic parts: detection and isolation of faults. Detection of faults is performed on the grounds of knowledge of measuring signal values. These signals are called process variables $z_i \in Z$. Detection ends upon discovery of fault symptoms which are signalized as alarms. These alarms indicate incorrect operation of the object but do not specify its reasons. Usually many different faults can be a reason of existence of one fault. Also one fault causes several different symptoms. Action aiming to detect the single symptoms is called the diagnostic test.

Isolation of faults is performed on the grounds of a set of observed symptoms (i.e. set of diagnostic test results). It is based upon knowledge of a relation existing between the faults and their symptoms. As a result of fault isolation, there is formulated a diagnosis which shows possible faults. One the grounds of generated diagnoses, an evaluation of existing danger is performed and a decision concerning protection of the object is taken.

Such protecting actions are realized most often by means of re–configuration of the object structure or change of the object way of operation. These protections are carried into effect automatically or by the object operators. Supervisory loop is being closed only in cases of existence of faults (Isermann, 1984).

The general diagram of such diagnosing and protection process has been presented in Figure 1.

Accuracy of generated diagnoses has essential influence on decisions concerning protection of the object. This accuracy should enable to take decisions about choice of a way and an algorithm of the object protection. Diagnosing accuracy, defined by the number of faults shown in diagnoses, is connected also with their differentiation. Such problems have been dealt with in this paper.

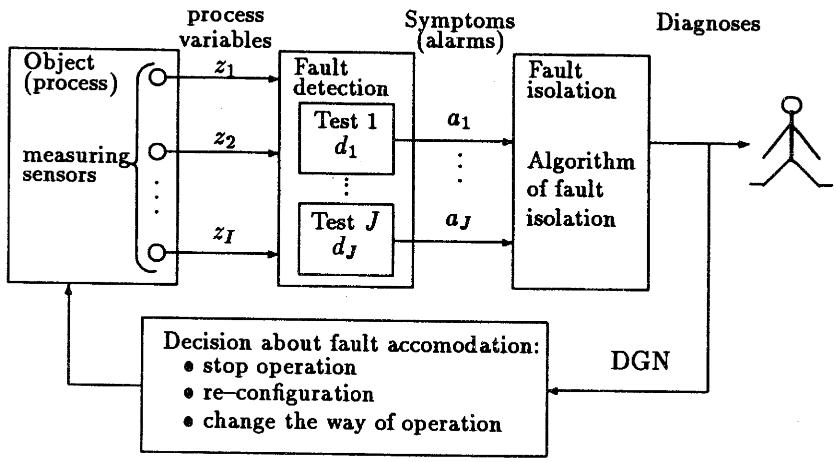


Fig. 1. Diagram of the diagnosing process and the object protection.

## 3. Formalized Description of the Diagnosing Object

### 3.1. Faults

The diagnosing object is described by set of faults:

$$E = \{e_k : k = 1, 2...., K\} \tag{1}$$

including failures of the object elements and other faults, which should be detected and identified by the diagnosing system. With each element $e_k$ of the set $E$ of faults there corresponds the state $s(e_k)$ defined as follows:

$$s(e_k) = \begin{cases} 0 - \text{the fault dod not occur,} \\ 1 - \text{otherwise.} \end{cases} \tag{2}$$

Occurring faults $e_k \in E$ are detected by diagnostic tests executed on–line in the system.

### 3.2. Diagnostic Tests

In order to detect faults it is necessary to know values of the process variables composing the set $Z$

$$Z = \{z_i : i = 1, 2, ..., I\} \tag{3}$$

As diagnostic test $d_j$ one should understand a sequence of operations performed by software on values of measuring signals (i.e. process variables) to check the accuracy of operation of a specified part of the diagnosing object. To isolate the faults, there is a set of diagnostic tests executed on–line in the system:

$$D = \{d_j : j = 1, 2, ..., J\} \tag{4}$$

Algorithm of the test has two parts (Fig. 2): detection one, which realizes calculation of residual values and decision one, which on the grounds of calculation results and accepted decision rules defines the test result $\alpha_j$ as follows:

$$\alpha_j = \begin{cases} 0 - \text{when the result of the test is positive,} \\ 1 - \text{when otherwise.} \end{cases} \tag{5}$$

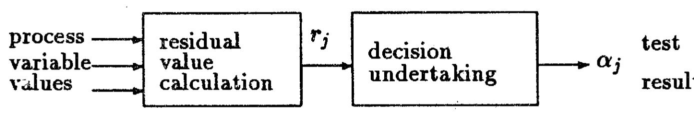


Fig. 2. Diagnosing test diagram.

### 3.3. Diagnostic Relation

Diagnostic relation is the most important dependence enabling isolation of faults:

$$R_{DE} \subset D \times E. \tag{6}$$

Expression $d_j R_{DE} e_k$ means that the test $d_j$ detects the fault $e_k$. Matrix of relations $R_{DE}$ (Fig. 3) is known as the table of tests (Rozwadowski, 1983) or the diagnostic matrix (Tabakow, 1975) or Boolean structure matrix (Gertler, 1991). Element $r_{jk}$ of the diagnosing matrix is defined as follows:

$$r_{jk} = \begin{cases} 0 \Leftrightarrow \langle d_j, e_k \rangle \notin R_{DE} \\ 1 \Leftrightarrow \langle d_j, e_k \rangle \in R_{DE}. \end{cases} \tag{7}$$

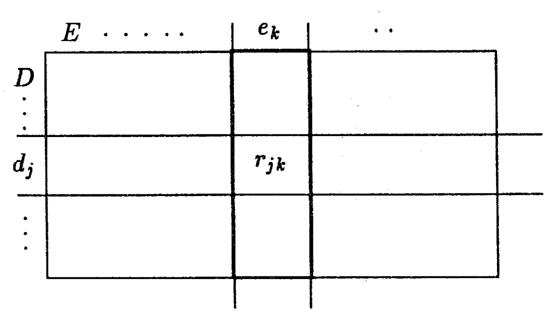


Fig. 3. Diagnosing matrix RDE.

Graph $G_{DE}$, which set of nodes includes two sets $D$ and $E$, set of vertices shows the relations existing between them, defined by the relation $R_{DE}$:

$$G_{DE} = \langle D, E, R_{DE} \rangle \tag{8}$$

is called the Konig's bipartite graph or the diagnostic graph (Tabakow, 1975).

Relation $R_{DE}$ can be defined at the design stage by attribution of the subset of faults $E(d_j)$, which are detected by the test $d$, to each of the tests $d_j \in D$:

$$E(d_j) = \{e_k \in E : d_j R_{DE} e_k\}. \tag{9}$$

It also can be defined by attribution of the subset of diagnostic tests $D(e_k)$ detecting the fault $e_k$, to each of the faults $e_k \in E$:

$$D(e_k) = \{d_j \in D : d_j R_{DE} e_k\}. \tag{10}$$

On the Cartesian product of the set $D$ of diagnosing tests and the set $Z$ of process variables one can define the relation $R_{DZ}$:

$$R_{DZ} \subset D \times Z. \tag{11}$$

Expression $d_j R_{DZ} z_i$ means that the value of the process variable $z$ is utilized by test $d_j$.

One can define the König's bipartite graph $G_{DZ}$:

$$G_{DZ} = \langle D, Z, R_{DZ} \rangle \tag{12}$$

which set of vertices is composed by the set $D$ of diagnosing tests and the set $Z$ of process variables. The set of graph arcs is described by the compound relation $R_{DZ}$.

### 3.4. States of the Diagnosing Object

The state s of a diagnosing object is defined by states of all elements of the set $E$:

$$s = \{s(e_1), s(e_2), ..., s(e_K)\}. \tag{13}$$

The set $S$ of all states $s_i$ of the diagnosing object

$$S = \{s_i : i = 0, 1, ..., 2^K - 1)\} \tag{14}$$

can be expressed as follows

$$S = \bigcup_{m=0}^{K} S_{(m)}, \tag{15}$$

where

$$S_{(m)} = \{s_i \in S : \sum_{k=1}^{K} s(e_k) = m\} \tag{16}$$

is the subset of the object states having simultaneous $m$ faults.

The state $s_i$ of the object can be unmistakably described by a set $E(1)_i$ of faults existing in the state. Therefore to each state $s_i$ one can attribute the subset $E(1)_i$ defined in the following way:

$$E(1)_i = \{e_k \in E : s(e_k)_i = 1\}, \tag{17}$$

where $s(e_k)_i$ denotes state of the fault ek in the state si of the object.

The term *fault isolation* is commonly used in literature and refers to occurrence of single faults. However, in general cases containing also multiple faults, the term *object state identification* (or *object state isolation*) seems to be more proper.

### 3.5. Table of States

Isolation of faults is realized with help of set $D$ of diagnostic tests, results of which create the set of results $A$:

$$A = \{\alpha_j : j = 1, 2, ..., J\}. \tag{18}$$

The aim of the diagnosing process is to describe the state of the diagnosing object. It is convenient to know the function $f$ describing pattern results of the tests in all states $s_i \in S$ of the object:

$$F_A : D \times S \to \widehat{A}. \tag{19}$$

Matrix corresponding with this function is called the table of states (Fig. 4).

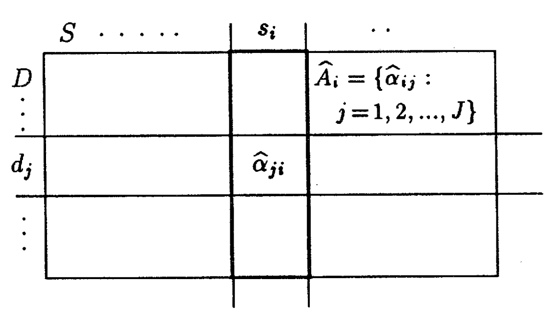


Fig. 4. Table of states.

Pattern result of the test $d_j$ in state $s_i$ is determined on the grounds of known relation $R_{DE}$:

$$\widehat{\alpha}_{ij} = \bigcup_{k: e_k \in E(1)_i} r_{jk} \tag{20}$$

or subsets $E(d_j)$:

$$\begin{cases} \widehat{\alpha}_{ij} = 0 \Leftrightarrow (E(d_j) \cap E(1)_i = \emptyset) \\ \widehat{\alpha}_{ij} = 1 \Leftrightarrow (E(d_j) \cap E(1)_i \neq \emptyset). \end{cases} \tag{21}$$

It is easy to observe that the sets of pattern test results for object states with assumption of single faults are equal to columns of the diagnostic matrix:

$$(E(1)_i = e_k) \Rightarrow \bigwedge_{j:d_j \in D} (\widehat{\alpha}_{ij} = r_{jk}). \tag{22}$$

## 4. Rules of Fault Isolation

In compliance with Gertler's (1991) definition, signature $A(e_k)$ of fault $e_k$ is represented by column of the diagnostic matrix corresponding with this fault:

$$\widehat{A}(e_k) = \{r_{jk} : j = 1, 2, ..., J\}. \tag{23}$$

With the analogy to above definition, orderly set of pattern test results $\widehat{A}_i$ in the state $s_i$ is called the signature or code of state $s_i$:

$$\widehat{A}_i = \{\widehat{\alpha}_{jk} : j = 1, 2, ..., J\}. \tag{24}$$

If sets of pattern results of diagnostic tests are known in all states $s_i \in S$ of the object and after execution of the tests $d_i \in D$ the set $A$ of their results has been obtained, one can formulate the diagnosis. One should understand the diagnosis as the credible hypothesis about state of the diagnosing object. It is possible to distinguish different shapes of the diagnosis. The diagnosis can show the subset of the object states undifferentiable (non–isolating) with given set of tests $D$, for which pattern results of tests agree with results obtained during measurements:

$$DGN(S) = \{s_i \in S : (\widehat{A}_i = A)\}, \tag{25}$$

where

$$(\widehat{A}_i = A) \Leftrightarrow \bigwedge_{j:d_j \in D} (\widehat{\alpha}_{ji} = \alpha_j) \tag{26}$$

The diagnosis also can be expressed in the shape $DGN(E)$ by describing the sets of faults corresponding with particular undifferentiable states of the object, shown in the diagnosis $DGN(S)$:

$$DGN(E) = \{E(1)_i : (\widehat{A}_i = A)\}. \tag{27}$$

In practice it is sufficient to define the diagnosis including not all states, for which pattern results of the tests agree with the real ones but only states having minimum numbers of faults. The diagnosis $DGN(E)$ in such a case has the following shape:

$$DGN(\widehat{E}) = \{E(1)_i : |E(1)_i| = \min_{i:\widehat{A}_i = A} \{|E(1)_i|\}\}. \tag{28}$$

It should be noted that this diagnosis shows the most probable faults of the object since the probability of existence of particular states decreases with increasing of the number of faults describing any given state.

## 5. Recognition of Faults and Object States of the Diagnosing Process

It is vital in analysis of a diagnosing object to define the subset of the object states $V_r \subset S$ which are undifferentiable on the grounds of set of results of diagnostic test $d_j \in D$. Undifferentiable states have the attribute that pattern results of particular tests in this states are the same. Thus the relation of undifferentiability of the object states $R_{NS}$ can be defined as follows:

$$s_i R_{NS} s_n \Leftrightarrow [(s_i, s_n \in S) \cap \bigwedge_{j:d_j \in D} (\widehat{\alpha}_{ji} = \widehat{\alpha}_{jn})]. \tag{29}$$

Since the relation $R_{NS}$ is the relation of equivalence $R_{NS} \in eq(S)$, i.e. it is reversible, symmetrical and transitive, it is therefore possible to define classes of abstraction $[si]_{S,R_{NS}}$ in the set $S$. They are the sets of states which remain in the relation $R_{NS}$ with any given state $s_i$:

$$R_{NS} \in eq(S) \cap s_i \in S \Rightarrow ([s_i]_{S,R_{NS}} = \{s_n : (s_n \in S) \cap s_i R_{NS} s_n\}). \tag{30}$$

Bringing together elements of the set $S$ into the classes of abstraction one can obtain the family of sets being differentiable among themselves even when states belonging to one of the classes of abstraction are unndifferentiable on the grounds of results of all tests $d_j \in D$. The families are defined by a quotient set:

$$R_{NS} \in eq(S) \Rightarrow [V_r \in S/R_{NS} \Leftrightarrow \bigvee_{s_i \in S} (V_r = [s_i]_{S,R_{NS}})], \tag{31}$$

where:

$$V_r = [s_i]_{S,R_{NS}} \subset S, \tag{32}$$

$$S = \bigcup_{r=1}^{R} V_r, \; R \leq 2^{|E|}, \tag{33}$$

$$\bigwedge_{r \neq i;\, r,i=1,\ldots,R} (V_r \cap V_i = \emptyset), \tag{34}$$

where $R$ denotes the number of subsets $V_r$ (classes of abstraction).

The quotient set $S/R_{NS}$ defines therefore the subsets of the object states being shown in diagnoses $DGN(S)$ expressed with given set of tests $D$. Each diagnosis describes the object states belonging to one class of abstraction:

$$DGN(S) = V_r = [s_i]_{S,R_{NS}} : A = \widehat{A}_i \tag{35}$$

and therefore is the subset of the quotient set:

$$DGN(S) \in S/R_{NS}. \tag{36}$$

The number of object states equals $|S| = 2^{|E|}$, while number of various combinations of test results equals $2^{|E|}$, thus there must exist at least as many diagnosing tests as faults in order to achieve full differentiation of all states of the object. However, fulfillment of this condition does not warrant full fault isolation (it is only prerequisite).

Similarly to the relation $R_{NS}$ one can define the relation $R_{NE}$ referring to undifferentiation of faults. Fault undifferentiation exists when subsets of diagnostic tests detecting two given faults $e_k$ and $e_n$ are identical $D(e_k) = D(e_n)$. Two equal columns of the table of tests (diagnosing matrix) correspond with such faults. It is therefore possible to write:

$$e_k R_{NE} e_n \Leftrightarrow (e_k, e_n \in E) \cap \bigwedge_{j:d_j \in D} (r_{jk} = r_{jn}). \tag{37}$$

Similar definition of not isolation of faults in dynamic linear systems has been given by Gertler (1991). One can also define the subsets of not isolated faults:

$$R_{NE} \in eq(E) \cap e_k \in E \Rightarrow ([e_k]_{E,R_{NE}} = \{e_n : (e_n \in E) \cap e_k R_{NE} e_n\}) \tag{38}$$

and

$$R_{NE} \in eq(E) \Rightarrow [F_m \in E/R_{NE} \Leftrightarrow \bigvee_{e_k \in E} (F_m = [e_k]_{E,R_{NE}})]. \tag{39}$$

Following equations are therefore true:

$$F_m = [e_k]_{E,R_{NE}} \subset E, \tag{40}$$

$$E = \bigcup_{m=1}^{M} F_m, \quad M \le |E|, \tag{41}$$

$$\bigwedge_{l \neq m;\, l,m=1,\ldots,M} (F_l \cap F_m = \emptyset), \tag{42}$$

where $M$ denotes the number of subsets $F_m$.

Not isolation of faults leads to undifferentiability of particular states of the system. Thus the following theorem is true:

**Theorem:** *If for every element $e_k$ belonging to set $E(1)_i$ of existing faults in state $s_i \in S$ there exists such an element $e_n$ belonging to set $E(1)_p$ of existing faults in state $s_p \in S$ being with the element $e_k$ in the relation $R_{NE}$ and vice versa, then the states $s_i$ and $s_p$ are undifferentiable with given set $D$ of diagnostic tests:*

$$\Big( \bigwedge_{e_k \in E(1)_i} \bigvee_{e_n \in E(1)_p} (e_n R_{NE} e_k) \bigcap \bigwedge_{e_n \in E(1)_p} \bigvee_{e_k \in E(1)_i} (e_k R_{NE} e_n) \Big) \Rightarrow s_i R_{NS} s_p. \tag{43}$$

The proof of this theorem has been given by Kościelny (1991).

From the above theorem there results conclusion:

$$e_k R_{NE} e_n \cap (s_k, s_n \in s_{(1)}) \cap (E(1)_k = e_k) \cap (E(1)_n = e_n) \Rightarrow s_k R_{NS} s_n. \qquad (44)$$

The quotient set $S/R_{NE}$ defines therefore the subsets of faults which are indicated in diagnosis with assumption of single faults. Faults belonging to the subset $F_m$ are not isolated with given set $D$. Adequate selection of tests in the set $D$ decides therefore about the fault isolation.

## 6. Indices of Diagnosing Accuracy

Accuracy of diagnosing is therefore estimated by available differentiation of the object states.

Index of the object diagnosing accuracy is defined as the ratio of number of differentiable subsets of states $R$ to number of all states of the object:

$$\Delta_S = \frac{|S/R_{NS}|}{|S|} \qquad (45)$$

If $\Delta_S = 1$ then all states of the object are unmistakably isolated and the set of tests enabling this is called the complete one.

Index of accuracy of single fault diagnosing can be defined as the ratio of number of undifferentiable subsets of faults to number of all faults:

$$\Delta_E = \frac{|E/R_{NS}|}{|E|} \qquad (46)$$

If $\Delta_E = 1$ then all single faults are unmistakably isolated and the set of diagnostic tests $D$ enabling this is called the complete one.

## 7. Example

Let us assume that the diagnosing object is described by means of the diagnostic relation $R_{DE}$ presented in Table 1.

Tabl. 1. Diagnostic relation.

| $D \setminus E$ | $e_1$ | $e_2$ | $e_3$ | $e_4$ |
|---|---|---|---|---|
| $d_1$ | 1 | | 1 | |
| $d_2$ | | 1 | 1 | |
| $d_3$ | | 1 | | 1 |

All faults are differentiable for the set of tests $D = \{d_1, d_2, d_3\}$. The relation $R_{NE}$ is an empty set and the quotient set $E/R_{NE}(D) = E$. Assuming that the set of tests includes only two tests $\widetilde{D} = \{d_1, d_3\}$, the faults e1 with $e_3$ and $e_2$ with $e_4$ are undifferentiable. The quotient set $E/R_{NE}(\widetilde{D}) = \{\{e_1, e_2,\}, \{e_2, e_4\}\}$.

Tabl. 2. Table of states.

| $D \backslash^{E(1)}_{S}$ | $\emptyset$ | $e_1$ | $e_2$ | $e_3$ | $e_4$ | $e_1e_2$ | $e_1e_3$ | $e_1e_4$ | $e_2e_3$ | $e_2e_4$ | $e_3e_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | $s_0$ | $s_1$ | $s_2$ | $s_3$ | $s_4$ | $s_5$ | $s_6$ | $s_7$ | $s_8$ | $s_9$ | $s_{10}$ |
| $d_1$ | | 1 | | 1 | | 1 | 1 | 1 | 1 | | 1 |
| $d_2$ | | | 1 | 1 | | 1 | 1 | | 1 | 1 | 1 |
| $d_3$ | | | 1 | | 1 | 1 | | 1 | 1 | 1 | 1 |
| | $S_{(0)}$ | $S_{(1)}$ | | | | $S_{(2)}$ | | | | | |

| $D \backslash^{E(1)}_{S}$ | $e_1e_2e_3$ | $e_1e_2e_4$ | $e_1e_3e_4$ | $e_2e_3e_4$ | $e_1e_2e_3e_4$ |
|---|---|---|---|---|---|
| | $s_{11}$ | $s_{12}$ | $s_{13}$ | $s_{14}$ | $s_{15}$ |
| $d_1$ | 1 | 1 | 1 | 1 | 1 |
| $d_2$ | 1 | 1 | 1 | 1 | 1 |
| $d_3$ | 1 | 1 | 1 | 1 | 1 |
| | $S_{(3)}$ | | | | $S_{(4)}$ |

Table of states for this object has been shown in Table 2. One can therefore separate subsets of undifferentiable states. They are described by means of the quotient set:

$$S/R_{NS}(D) = \{\{s_0\},\{s_1\},\{s_2,s_9\},\{s_3,s_6\},\{s_4\},\{s_7\},$$
$$\{s_5,s_8,s_{10},s_{11},s_{12},s_{13},s_{14},s_{15}\}\}.$$

The undifferentiable subsets for the set $\widetilde{D}$ are as follows:

$$S/R_{NS}(\widetilde{D}) = \{\{s_0\},\{s_1,s_3,s_6\},\{s_2,s_4,s_9\},$$
$$\{s_5,s_7,s_8,s_{10},s_{11},s_{12},s_{13},s_{14},s_{15}\}\}.$$

Indices of diagnosing accuracy of this object receive the following values:

$$\Delta_E(D) = 4/4 = 1; \quad \Delta_S(D) = 7/16;$$

$$\Delta_E(D) = 2/4 = 1/2; \quad \Delta_S(D) = 4/16 = 1/4.$$

## 8. Conclusions

Relation of undifferentiability of faults $R_{NE}$ and relation of undifferentiability of states of the object $R_{NS}$ depend on the diagnostic relation $R_{DE}$, i.e., on the set of diagnostic tests $D$. The tests are realized with using of the process variable values $Z$ and the connection between the sets $D$ and $Z$ is described by the relation $R_{DZ}$. The set $Z$ changes during operation of the object. Faults and switch–offs of the object measuring sensors change the set of available tests $\widetilde{Z} \subseteq Z$. Therefore the set of realized tests $\widetilde{D}$ also changes. It is a subset of the set of all tests $\widetilde{D} \subseteq D$. The diagnosis generated on the grounds of the set of tests $\widetilde{D}$ is an element of the quotient set $S/R_{NS}(\widetilde{D})$. Obtained differentiation of faults and states of the object changes in practice, as well as values of indices of diagnosing accuracy.

Possibility of changes of the sets $Z$ and $D$ during operation of the diagnosing object imposes specific requirements on algorithms of fault isolation. All rigid diagnosing algorithms according to planned on the stage of design of the symptom analysis sequence (test results) are useless. This refers to diagnosing algorithms on the grounds of planned diagnostic trees as well as concluding according to rules as *if the symptoms* $\alpha_k$ *and* $\alpha_m$ *and ... and* $\alpha_r$ *appeared then the object is in the state* $s_i$ *or* $s_n$ *or ... or* $s_v$.

Concluding algorithm should describe only rules of choice of adequate subset of diagnostic tests out of set of currently available tests and a rule of diagnosis formulation on the grounds of such chosen subset of tests. It has been accomplished in algorithms presented in papers (Kościelny, 1991; 1993).

The shape of the diagnostic matrix describing the relation $R_{DE}$ is important from the diagnosing accuracy point of view. If each test monitors only one fault then the diagnostic matrix is square and diagonal:

$$\bigwedge_j (E(d_j) = e_j) \Rightarrow |D| = |E| \tag{47}$$

and

$$R_{DE} = \{\langle e_k, d_k \rangle : k = 1, ..., |E|\} \tag{48}$$

Results of the test identify therefore directly particular aults

$$\begin{aligned} \alpha_j = 0 \Rightarrow s(e_j) = 0 \\ \alpha_j = 1 \Rightarrow s(e_j) = 1 \end{aligned} \tag{49}$$

and the state of the object is described by results of all tests:

$$s = \{s(e_1), ..., s(e_{|E|}\} = \{\alpha_1, ..., \alpha_{|E|}\}. \tag{50}$$

Such realization of the diagnostic system is therefore the most profitable. Diagnosing accuracy is the highest possible $\Delta_s = 1$ and the algorithm of fault isolation the simplest possible. It is therefore the structure one should aim to achieve while designing the diagnostic system. In practice, however, this is not fully attainable due to the fact that particular tests usually detect not one but several faults out of the set $E$.

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