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Method for Multiple Fault Isolation and Identification

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Abstract

The paper presents a new method for the multiple fault identification in complex installations. Current state of investigations and the necessity for the multiple fault isolation in the diagnostics of industrial processes were shortly characterised. A simple isolation algorithm was given that assumes the three-value evaluation of residuals. Fault identification is conducted on the grounds of equations of residuals that take effects of faults into account. It was shown that if the number of possible faults indicated during the isolation does not exceed the number of primary residuals, values of which do not stray from zero then the identification is possible. Two fault identification examples in a tank set are presented.

Keywords: fault detection and isolation, the three-value evaluation of the residuals, diagnostic system.

Metoda lokalizacji i identyfikacji uszkodzeń wielokrotnych

Streszczenie

Przedstawiono nowa metodę identyfikacji uszkodzeń wielokrotnych w obiektach złożonych. Krótko scharakteryzowano stan badań i potrzebę rozpoznawania uszkodzeń wielokrotnych w diagnostyce procesów przemysłowych. Podano prosty algorytm lokalizacji uszkodzeń, zakładający trójwartościową ocenę residuów. Identyfikacja uszkodzeń prowadzona jest na podstawie równań residuów uwzględniających wpływ uszkodzeń. Pokazano, że jeśli liczba wskazanych przy lokalizacji możliwych uszkodzeń jest nie większa niż liczba residuów pierwotnych, których wartości odbiegają od zera, to identyfikacja jest możliwa. Przedstawiono dwa przykłady identyfikacji uszkodzeń w zespole zbiorników.

Słowa kluczowe: lokalizacja i identyfikacja uszkodzeń, trójwartościowa ocena residuów, system diagnostyczny.

1. Introduction

The majority of known diagnostic methods were invented on the assumption that only single faults exist [2, 11, 14, 18, 21]. Such an assumption causes a significant simplification of the fault isolation algorithm. It can be applied, however, for installations having a relatively small number of elements since the probability of existence of simple faults is much higher than the probability of existence of multiple ones.

Problems of the multiple faults isolation were relatively seldom considered in the Fault Detection and Isolation (FDI) papers. In [4, 8], a case of the multiple fault diagnostics of measurement devices and actuators was analysed with the use of the bank of observers to the residual generation, and the classic logic to the decision taking. Moreover, it was assumed that other faults do not exist what significantly limits the practical aspects of such an approach.

For linear installations, there exist methods for the disturbance and fault decoupling that allow us to shape the residual susceptibility to faults [9, 10, 11]. One aims to obtain the diagonal diagnostic matrix. Such form of the matrix is the best since it ensures that only one residual is susceptible to each one of the faults. Each value of the residual that strays from zero indicates the existence of another fault. Thus, the problem of multiple faults is possible to be solved. However, the diagonal diagnostic matrix may be obtained only in the case in which the number of faults does not exceed the number of the installation outputs [11, 18]. In reality, the number of the installation outputs is equal to the number of the measurement device faults. If one takes all faults into account, i.e., faults of the measurement devices, actuators and components of technological installation, then the number of faults is always higher than the number of the installation outputs. Therefore, this approach is not suitable in the industrial practice.

The AI method [5, 6, 7, 20] also known as the model-based diagnosis (MBD) method [6, 7] based on the Reiter theory [22], allows us to indicate not only single faults but also the multiple ones [6, 7, 13]. The diagnoses are generated as minimal hitting sets of all minimal conflicting sets [6, 7, 22]. The advantage of this approach is the fact that some cases of the fault effects compensation are taken into account. This method, however, was applied to the simple installations up to date. Due to the complex form and high costs of its design, the method is not suitable for large-scale industrial installation diagnosing. A two-level model suggested in [19] is an interesting development of this method.

An alternative approach in comparison with methods based on the Reiter theory is the multiple fault isolation on the grounds of the table of the state. In the table, signatures for states with multiple faults are created as alternatives for signatures for single faults [10, 11, 15, 16, 23]. In these cases, the main problem consists in the reduction of the number of states taken into considerations during the inference process due to the very high number of possible states. Algorithms designed for the large-scale processes that include an efficient mechanism of such a reduction were presented in [15, 16, 17, 18].

The method of directional residuals [Gertler 1998, Patton et al. 2000] has a high potential to discern the multiple faults. The detection filters method [3] and the application of the bank of the decoupled Kalman filters [1] also have such a potential. They require the user to know the models of the installation that take into account the effect of faults on the residual values.

Multiple faults can appear as a sequence of successive or simultaneous faults. The simultaneous ones are the most dangerous and the most difficult to isolate. One can think that such a situation may exist very rarely in practice, if one takes into account independent faults. In the case of large-scale installations, however, the probability of multiple faults is higher than zero. Moreover, the problem exists practically during every start-up of the system that diagnoses a large technological plant. During the start-up, all of the earlier faults are seen by the system as the simultaneous ones. The lack of a mechanism that isolates such faults can lead to an incorrect operation of the diagnostic system. Therefore, the problem should be solved. This paper presents a new solution of the problem of the multiple fault isolation and identification.

2. Fault Identification Conception

The fault identification consists in the definition of the fault dimensions, and – if it is possible – the character of their change in time. The implementation of the fault isolation is possible in the case of inference on the grounds of the installation models.

The dynamic system complete description that takes into account the effect of faults and disturbances (Fig. 1) is as follows [2, 11, 14]:

$$\dot{x}(t) = \phi[x(t), u(t), d(t), f(t)] \quad (1)$$

$$y(t) = \psi[x(t), u(t), d(t), f(t)] \quad (2)$$

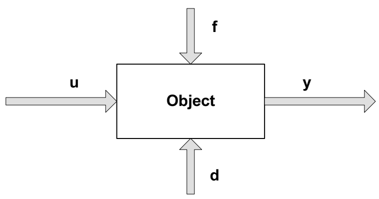

Fig. 1. Diagram of the system being the model of the diagnosed installation (f-faults, u-inputs, y-outputs, d-disturbances)

Rys. 1. Schemat systemu będącego modelem obiektu diagnozowania (f-uszkodzenia, u-wejścia, y-wyjścia, d-zakłócenia)

If one could describe the vector of faults *f* on the grounds of the installation inputs and outputs on the assumption that disturbances do not exist,

$$f(t) = \psi[y(t), u(t)]; \quad d = 0 \quad (3)$$

then the problem of the installation diagnostics would be solved.

Usually this problem is insolvable. The main difficulty consists in obtaining the mathematical description of the diagnosed installation that would take into account the effect of disturbances. Even if Eqs. (1) and (2) are known, then the definition of models inverse to the form in (3) is usually not possible since in reality, the number of faults is always higher than the number of equations that describe the installation. Therefore, different simplified models and methods of the conclusion are used in the diagnostics [14]. They allow us to detect and isolate the existing faults.

It is assumed that non-linear or linear equations of residuals that take into account the effect of disturbances are known. Let us also assume the lack of disturbances, d=0. Each one of the residuals is defined by the following equation:

$$r_j = q(y, u, f, t); \quad j = 1,2,...,J \quad (4)$$

If the set of possible faults $F(1)$ will be indicated as a result of the fault isolation, and if the force of this set is lower than the number of independent equations of the residuals:

$$|F(1)| < J \quad (5)$$

then the set of equations (4) may be solvable on the condition that all remaining faults have values equal to zero: $f_i \notin F(1) \Rightarrow f_i=0$. In this case, the fault isolation can be conducted. The most important here is fault isolation phase since the force of the set $F(1)$ depends on it.

Below, the multiple fault identification method is presented on the grounds of the set of equations of residuals taking into account the effect of faults. The method is based on the above described conception.

3. Definition of the Set of Possible Faults

Let us assume that faults belonging to the following set:

$$F = \{f_k : k = 1,2,..., K\} \quad (6)$$

are detected and isolated with the use of the following set of residuals:

$$R = \{r_j : j = 1,2,..., J\} \quad (7)$$

in witch each one of the residuals is susceptible to a specified subset of faults:

$$F(r_j) = \{f_k \in F : r_j = q(f_k)\} \quad (8)$$

Let us assume that the three-value evaluation of the residuals [−1, 0, +1] will be applied to the concluding. The three-value evaluation, in which the sign of the residual is taken into account, allows us to increase the distinguishing of faults in comparison with the two-value evaluation [14, 18]. In this case, the Eq. (8) can be replaced by two values of the residuals that correspond with the negative and positive signs.

$$F(r_j -) = \{f_k \in F : r_j(f_k \neq 0, f_{m \neq k} = 0) < 0\} \quad (9)$$

$$F(r_j +) = \{f_k \in F : r_j(f_k \neq 0, f_{m \neq k} = 0) > 0\} \quad (10)$$

If the sets $F(r_j–)$ and $F(r_j+)$ are not identical, then the three-value evaluation increases the distinguishing of faults. Otherwise, $F(r_j–)= F(r_j+)= F(r_j)$, and the two-value evaluation of faults will do.

The following rules of the type *“if* $r_j<0$ *then* $f_k \in F(r_j–)$*”*, *“if* $r_j>0$ *then* $f_k \in F(r_j+)$*”* correspond with Eqs. (9) and (10), and the rule *“if* $r_j \neq 0$ *then* $f_k \in F(r_j)$*”* with Eq. (8).

Definition of the relation existing between faults and the residual values must be implemented at the stage of the diagnostic system design. The fault isolation is implemented on the grounds of this knowledge and the monitored residual values. If a residual value is close to zero then one infers that no fault belonging to the set $F(r_j)$ appeared:

$$r_j \approx 0 \Rightarrow \forall f_k \in F(r_j) : f_k = 0 \quad (11)$$

If a residual value is not equal to zero one infers according to the above given rules that one of the following faults has come into being:

$$r_j < 0 \Rightarrow \exists f_k \in F(r_j -) : f_k \neq 0 \quad (12)$$

$$r_j > 0 \Rightarrow \exists f_k \in F(r_j +) : f_k \neq 0 \quad (13)$$

The above inference rules are correct if one assumes that there does not appear the phenomenon of the compensation of the simultaneous fault effects on the residual values that consist in that the residual r_j value equals zero despite the existence of two or more faults belonging to the set $F(r_j)$.

On the grounds of the above rules, one can define an initial diagnosis which defines the set of possible faults:

$$F(1) = \bigcup_{j:r_j \neq -1} F(r_j) \cup \bigcup_{j:r_j \neq +1} F(r_j) - \bigcup_{j:r_j = 0} F(r_j) \quad (14)$$

The diagnosis $F(1)$ indicates faults for witch all of the symptoms have been observed. If one wants to obtain a high accuracy of the multiple fault isolation, the most important is the number of the residual equations, in witch particular residuals should be susceptible to different fault subsets. The higher the number of such equations, the lower the number of possible faults $|F(1)|=m$ during the isolation according to Eq. (14). Therefore, the diagnosis accuracy depends mainly on the set of measurement signals. The secondary residual generation is also very important during the design of diagnostic system for multiple faults. The secondary residual generation methods for linear installations were described in [2, 11, 14, 18], and the method of their design for non-linear installations was given in [18]. Furthermore, one can increase the fault distinguishability by the application of the tree-value residual evaluation.

4. Fault Identification

As the result of fault isolation, the set of possible faults $F(1)$ is defined. Let us assume that:

$$f_k \in F(1) \Rightarrow (f_k \neq 0) \vee (f_k = 0) \tag{15}$$

and

$$f_k \in (F - F(1)) \Rightarrow f_k = 0 \tag{16}$$

The number of possible faults equals $|F(1)|=m$. If one wants to know whether the fault identification is possible to be conducted then one should define a set of independent residual equation susceptible to faults belonging to the set $F(1)$:

$$R(1) = \{r_j \in R : [r_j = q(f_k)] \wedge [f_k \in F(1)]\} \tag{17}$$

If the force of this set is equal to, or higher than m, $|R(1)|\geq m$ then the fault identification is possible to be conducted.

In the set $R1$, only primary residuals may be used since the secondary residual equations are not independent from the primary residuals (one obtains identical residual dependences on particular faults).

In order to define the fault size, one should create to following set of equations:

$$r^* = q(y, u, f^*) \tag{18}$$

where the residual vector r^* is created by the residuals $r_j \in R(1)$, and the fault vector f^* contains faults $f_k \in F(1)$. If the number of possible faults equals the number of equations $|R(1)| = m$ then the fault size definition resolves itself into the solution exist, and the fault identification can be implemented by the estimation of the fault size with the use of the method of the least sum of the error squares. From the above considerations it can be seen that the fault isolation accuracy and the number of the primary residual equations are the most important factors if the multiple fault identification is to be possible. In this case, the secondary residuals are not suitable.

5. Example

The set if tree tanks presented in Fig. 2 will be considered the diagnosed installation. The set is described by the four following balance equations [18]:

$$F = k_v(S)\sqrt{\Delta P_Z / \varsigma} \approx \Phi(U); \quad \Delta P_Z, \varsigma \approx const \tag{19}$$

$$A_1 \frac{dL_1}{dt} = F - Q_{12} = F - \alpha_{12} S_{12} \sqrt{2g(L_1 - L_2)} \tag{20}$$

$$A_2 \frac{dL_2}{dt} = Q_{12} - Q_{23} = \alpha_{12} S_{12} \sqrt{2g(L_1 - L_2)} + -\alpha_{23} S_{23} \sqrt{2g(L_2 - L_3)} \tag{21}$$

$$A_3 \frac{dL_3}{dt} = Q_{23} - Q_3 = \alpha_{23} S_{23} \sqrt{2g(L_2 - L_3)} - \alpha_3 S_3 \sqrt{2gL_3} \tag{22}$$

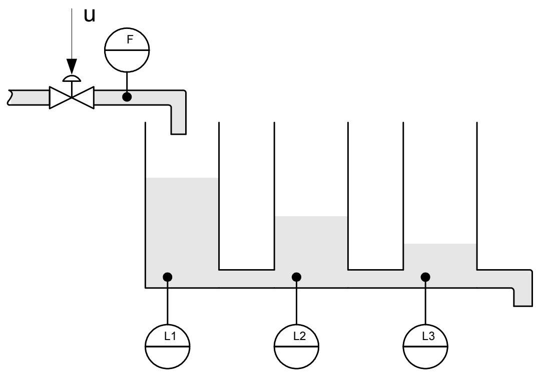

Fig. 2. Diagram of the tree-tank installation
Rys. 2. Schemat zespołu trzech zbiorników

The set of possible faults for this installation is presented in Table 1.

Tab. 1. Set of faults
Tab. 1. Zbiór uszkodzeń

Symbol	Fault Description	Physical Denotation
f_1	inlet flow F measurement path fault	ΔF_1
f_2	level L_1 in tank no. 1 measurement path fault	ΔL_1
f_3	level L_2 in tank no. 1 measurement path fault	ΔL_2
f_4	level L_3 in tank no. 1 measurement path fault	ΔL_3
f_5	actuator (pump, valve, servomotor) fault	ΔF_2
f_6	partial clogging of the channel between tanks nos. 1 and 2	ΔS_{12}
f_7	partial clogging of the channel between tanks nos. 2 and 3	ΔS_{23}
f_8	partial clogging of the outlet from tank no. 3	ΔS_3
f_9	leak from the tank no. 1	Q_1
f_{10}	leak from the tank no. 2	Q_2
f_{11}	leak from the tank no. 3	Q_3

One can design the primary residual set on the grounds of Eqs. (19) to (22):

$$r_1 = F - \Phi(U) \tag{23}$$

$$r_2 = F - \alpha_{12} S_{12} \sqrt{2g(L_1 - L_2)} - A_1 \frac{dL_1}{dt} \tag{24}$$

$$r_3 = \alpha_{12} S_{12} \sqrt{2g(L_1 - L_2)} - \alpha_{23} S_{23} \sqrt{2g(L_2 - L_3)} - A_2 \frac{dL_2}{dt} \tag{25}$$

$$r_4 = \alpha_{23} S_{23} \sqrt{2g(L_2 - L_3)} - \alpha_3 S_3 \sqrt{2gL_3} - A_3 \frac{dL_3}{dt} \tag{26}$$

Additional secondary residuals are created by the union of neighbouring models. Residuals 5 to 7 base on the balances for the tanks nos. 1-2, 2-3, and 1-2-3, respectively. The flow F in Eq. (24) can be replaced by the expression $\Phi(U)$ calculated from Eq. (19). Such a replacement was applied to residuals 8 to 10.

$$r_5 = F - \alpha_{23} S_{23} \sqrt{2g\left(L_2 - L_3\right)} - A_1 \frac{dL_1}{dt} - A_2 \frac{dL_2}{dt} \tag{27}$$

$$r_6 = \alpha_{12} S_{12} \sqrt{2g\left(L_1 - L_2\right)} - \alpha_3 S_3 \sqrt{2gL_3} - A_2 \frac{dL_2}{dt} - A_3 \frac{dL_3}{dt} \tag{28}$$

$$r_7 = F - \alpha_3 S_3 \sqrt{2gL_3} - A_1 \frac{dL_1}{dt} - A_2 \frac{dL_2}{dt} - A_3 \frac{dL_3}{dt} \tag{29}$$

$$r_8 = \Phi\left(U\right) - \alpha_{12} S_{12} \sqrt{2g\left(L_1 - L_2\right)} - A_1 \frac{dL_1}{dt} \tag{30}$$

$$r_9 = \Phi\left(U\right) - \alpha_{23} S_{23} \sqrt{2g\left(L_2 - L_3\right)} - A_1 \frac{dL_1}{dt} - A_2 \frac{dL_2}{dt} \tag{31}$$

$$r_{10} = \Phi\left(U\right) - \alpha_3 S_3 \sqrt{2gL_3} - A_1 \frac{dL_1}{dt} - A_2 \frac{dL_2}{dt} - A_3 \frac{dL_3}{dt} \tag{32}$$

The above presented residual equations have the calculation form and do not take the effect of faults into account. Despite of this, one can define the subsets of faults the residuals are susceptible to, on the grounds of the analysis of particular residual equations. This knowledge can be presented in the form of the diagnostic matrix shown in Table 2.

Tab. 2. Binary diagnostic matrix for the set of tree tanks (1 denotes that the residual value may equal either –1 or +1)

Tab. 2. Binarna macierz diagnostyczna (1 oznacza, że wartość residuum może być zarówno –1 jak też +1)

S/F	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8	f_9	f_{10}	f_{11}
r_1	1				1						
r_2	1	1	1			-1			+1		
r_3		1	1	1		+1	-1			+1	
r_4			1	1			+1	-1			+1
r_5	1	1	1	1			-1		+1	+1	
r_6		1	1	1		+1		-1		+1	+1
r_7	1	1	1	1				-1	+1	+1	+1
r_8		1	1		1	-1			+1		
r_9		1	1	1	1		-1		+1	+1	
r_{10}		1	1	1	1			-1	+1	+1	+1

The more complete mathematic description of the diagnosed installation takes into account the effect of faults on the residual values. Let us present the residual equations in such a form. The equations presented below constitute the mathematic justification of the binary diagnostic matrix from Table 2.

$$r_1 = \left(F + \Delta F_1\right) - \left(\Phi\left(U\right) + \Delta F_2\right) \tag{33}$$

$$\begin{aligned} r_2 = & -\alpha_{12}\left(S_{12} + \Delta S_{12}\right)\sqrt{2g\left(\left[L_1 + \Delta L_1\right] - \left[L_2 + \Delta L_2\right]\right)} + \\ & - A_1 \frac{d\left(L_1 + \Delta L_1\right)}{dt} - Q_1 + \left(F + \Delta F_1\right) \end{aligned} \tag{34}$$

$$\begin{aligned} r_3 = & \ \alpha_{12}\left(S_{12} + \Delta S_{12}\right)\sqrt{2g\left(\left[L_1 + \Delta L_1\right] - \left[L_2 + \Delta L_2\right]\right)} + \\ & -\alpha_{23}\left(S_{23} + \Delta S_{23}\right)\sqrt{2g\left(\left[L_2 + \Delta L_2\right] - \left[L_3 + \Delta L_3\right]\right)} + \\ & - A_2 \frac{d\left(L_2 + \Delta L_2\right)}{dt} - Q_2 \end{aligned} \tag{35}$$

$$\begin{aligned} r_4 = & \ \alpha_{23}\left(S_{23} + \Delta S_{23}\right)\sqrt{2g\left(\left[L_2 + \Delta L_2\right] - \left[L_3 + \Delta L_3\right]\right)} + \\ & -\alpha_3\left(S_3 + \Delta S_3\right)\sqrt{2g\left(L_3 + \Delta L_3\right)} - A_3 \frac{d\left(L_3 + \Delta L_3\right)}{dt} - Q_3 \end{aligned} \tag{36}$$

$$\begin{aligned} r_5 = & -\alpha_{23}\left(S_{23} + \Delta S_{23}\right)\sqrt{2g\left(\left[L_2 + \Delta L_2\right] - \left[L_3 + \Delta L_3\right]\right)} + \\ & - A_1 \frac{d\left(L_1 + \Delta L_1\right)}{dt} - A_2 \frac{d\left(L_2 + \Delta L_2\right)}{dt} - Q_1 - Q_2 + \left(F + \Delta F_1\right) \end{aligned} \tag{37}$$

$$\begin{aligned} r_6 = & \ \alpha_{12}\left(S_{12} + \Delta S_{12}\right)\sqrt{2g\left(\left[L_1 + \Delta L_1\right] - \left[L_2 + \Delta L_2\right]\right)} + \\ & -\alpha_3\left(S_3 + \Delta S_3\right)\sqrt{2g\left(L_3 + \Delta L_3\right)} - A_2 \frac{d\left(L_2 + \Delta L_2\right)}{dt} + \\ & - A_3 \frac{d\left(L_3 + \Delta L_3\right)}{dt} - Q_2 - Q_3 \end{aligned} \tag{38}$$

$$\begin{aligned} r_7 = & \left(F + \Delta F\right) - \alpha_3\left(S_3 + \Delta S_3\right)\sqrt{2g\left(L_3 + \Delta L_3\right)} + \\ & - A_1 \frac{d\left(L_1 + \Delta L_1\right)}{dt} - A_2 \frac{d\left(L_2 + \Delta L_2\right)}{dt} - A_3 \frac{d\left(L_3 + \Delta L_3\right)}{dt} + \\ & - Q_1 - Q_2 - Q_3 \end{aligned} \tag{39}$$

$$\begin{aligned} r_8 = & -\alpha_{12}\left(S_{12} + \Delta S_{12}\right)\sqrt{2g\left(\left[L_1 + \Delta L_1\right] - \left[L_2 + \Delta L_2\right]\right)} + \\ & - A_1 \frac{d\left(L_1 + \Delta L_1\right)}{dt} - Q_1 + \left(\Phi\left(U\right) + \Delta F_2\right) \end{aligned} \tag{40}$$

$$\begin{aligned} r_9 = & -\alpha_{23}\left(S_{23} + \Delta S_{23}\right)\sqrt{2g\left(\left[L_2 + \Delta L_2\right] - \left[L_3 + \Delta L_3\right]\right)} - Q_1 + \\ & - A_1 \frac{d\left(L_1 + \Delta L_1\right)}{dt} - A_2 \frac{d\left(L_2 + \Delta L_2\right)}{dt} - Q_2 + \left(\Phi\left(U\right) + \Delta F_2\right) \end{aligned} \tag{41}$$

$$\begin{aligned} r_{10} = & \left(\Phi\left(U\right) + \Delta F_2\right) - \alpha_3\left(S_3 + \Delta S_3\right)\sqrt{2g\left(L_3 + \Delta L_3\right)} + \\ & - A_1 \frac{d\left(L_1 + \Delta L_1\right)}{dt} - A_2 \frac{d\left(L_2 + \Delta L_2\right)}{dt} - A_3 \frac{d\left(L_3 + \Delta L_3\right)}{dt} + \\ & - Q_1 - Q_2 - Q_3 \end{aligned} \tag{42}$$

In order to illustrate the proposed method, some examples of inference with the use of it will be presented. The installation parameters that appear in the residual equations have following values: $A_1=A_2=A_3=193.5$, $\alpha_{12}S_{12}=20.1$, $\alpha_{23}S_{23}=20.4$, $\alpha_3S_3=10$.

A)

Let us assume that faults f_6 and f_{11} came into being, having sizes of $\Delta S_{12}=-4$, $Q_3=5$, respectively. The following residual values: $r_1=0$, $r_2=-54.7$, $r_3=54.7$, $r_4=5$, $r_5=0$, $r_6=59.7$, $r_7=5$, $r_8=-54.7$, $r_9=0$, $r_{10}=5$ are symptoms of these faults. The vector of quantified residual values is as follows: [0,–1,+1,+1,0,+1,+1,–1,0,+1]. Therefore according to Eq. (14), it is possible to obtain: $F(1)=\{f_6, f_{11}\}$. In the process of the fault isolation we obtain the accurate diagnosis that shows both of the existing faults.

In order to identify them, primary residuals will be applied, the value of witch does not equal zero: $R(1)=\{r_2, r_3, r_4\}$. On the grounds of the residual r_2 and r_3 value, it is possible to calculate the fault f_6 value (partial clogging of the channel between tanks nos. 1 and 2), and on the grounds of the residual r_4, the fault f_{11} value (leak from the tank no. 3). They have the following values:

$$\begin{cases} -13.7 \cdot \Delta S_{12} - 54.7 = 0 \\ 13.7 \cdot \Delta S_{12} + 54.7 = 0 \\ 5 - Q_3 = 0 \end{cases} \Rightarrow \begin{cases} \Delta S_{12} \cong -4 \\ Q_3 = 5 \end{cases} \quad (43)$$

B)

Let us assume that faults f_1 and f_{10} came into being, having sizes of ΔF_1=10, Q_2=5, respectively. The following residual values: r_1=10, r_2=10, r_3=5, r_4=0, r_5=15, r_6=5, r_7=15, r_8=0, r_9=5, r_{10}=5 are symptoms of these faults. The vector of quantified residual values has the following form: [+1,+1,+1,0,+1,+1,+1,0,+1,+1]. Therefore according to Eq. (14), it is possible to obtain: $F(1)=\{f_1, f_{10}\}$. This diagnosis is also accurate, and the fault sizes are defined on the grounds of residuals $R(1)=\{r_1, r_2, r_3\}$. They equal:

$$\begin{cases} \Delta F - 10 = 0 \\ \Delta F - 10 = 0 \\ 5 - Q_2 = 0 \end{cases} \Rightarrow \begin{cases} \Delta F = 10 \\ Q_2 = 5 \end{cases} \quad (44)$$

6. Summary

The paper presents a new, relatively simple method for the multiple fault isolation and identification. The fault identification is possible only in the case in which the residual equations take into account not only the installation inputs and outputs but also the faults. Usually when the input and output valves are known, it is not possible to calculate the fault values on the grounds of these equations since the number of faults exceeds the number of equations. However, if the subset of possible faults will be indicated in the process of the fault isolation, and the force of this set is no higher that the number of the primary fault equations, the values of witch do not equal zero, then the solution of such a set of equations is possible since one may assume that the remaining fault values are equal zero.

The most important here is therefore the fault isolation accuracy. It depends on the degree the installation parameter values are measured. The more signal values are measured, the higher is the number of the primary residual equations. The isolation accuracy can be additionally increased when one designed the secondary residuals, and applies the thee-value evaluation of the residuals.

In the presented example, two cases of the multiple fault isolation and identification were shown in which the existing faults were correctly indicated, and their sizes were defined. However, it should be stressed that the fault identification may not be conducted in all cases of the multiple, or even dual faults. The presented example refers to the non-linear installation. Non-linear residual equations were applied to the diagnostics. The method may be applied also to linear installations.

7. References

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