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ASSESSMENT OF RELIABILITY, CAUSES AND CONSEQUENCES OF FAILURES OF REFINERY AUTOMATED SYSTEMS BASED ON APPLICATION OF A COMMON DESIGNING AND OPERATIONAL DATA BASE OF INDUSTRIAL CONTROL SYSTEMS

The reliability of management and technical control systems is an important constituent of their quality and indispensable condition of safety ensurance of hazardous production facilities of oil refining. Assessment of reliability and maintainability of automated control systems are provided for by national and international standards and other regulations. The purpose of this assessment is to obtain quantitative information about the properties of systems required to develop and implement well-grounded, effective design and operational decisions to ensure the dependability and safety of industrial facilities.

Construction of a common database of life cycle stages of automated control systems, including design and operational data, e.g. of ICS, as regards hardware and software failures, allows us to define real dependability indices of equipment in operation in view of design solutions and installation peculiarities.

Keywords: *oil refining, production process, automated control system, reliability, causes and consequences of failures, analysis.*

Reliability parameters in operation of safety instrumented systems (SIS) for refineries should be computed using actual statistics.

Typical failures during the operation of SIS technical facilities include failures of electronics, communication line breaks, metrological failure, jamming of rods of cutoff pipeline accessories, loss of electrical and pneumatic power supply.

Table 1 shows typical kinds of failure causes of SIS components leading to their failures during operation.

The structural model of ensuring the reliability of ICS is shown in Fig. 1.

Expressions for calculating the probabilities of failure and failure-free operation for the components presented in Table 1, obtained on the basis of logical functions of availability (reliability), are as follows:

1. For measuring sensor:

$$Q_{sensor} = q_1 + q_2 + q_3 + q_4 - q_1q_2 - q_1q_3 - q_1q_4 - q_2q_3 - q_2q_4 - q_3q_4 + q_1q_2q_3 + q_1q_2q_4 + q_1q_3q_4 + \\ + q_2q_3q_4 - q_1q_2q_3q_4;$$

$$P_{sensor} = 1 - Q_{sensor} = 1 - q_1 - q_2 - q_3 - q_4 + q_1q_2 + q_1q_3 + q_1q_4 + q_2q_3 + q_2q_4 + q_3q_4 - q_1q_2q_3 - q_1q_2q_4 - \\ - q_1q_3q_4 - q_2q_3q_4 + q_1q_2q_3q_4,$$

where q_1, q_2, q_3, q_4 are probabilities of failures of electronics, communication lines, metrology, and failure as a result of power loss, respectively, P is the probability of failure-free operation, Q is the probability of failure.

2. For spark protection barrier:

$$Q_{barrier} = q_1 + q_2 + q_3 + q_4 - q_1q_2 - q_1q_3 - q_1q_4 - q_2q_3 - q_2q_4 - q_3q_4 + q_1q_2q_3 + q_1q_2q_4 + q_1q_3q_4 + \\ + q_2q_3q_4 - q_1q_2q_3q_4;$$

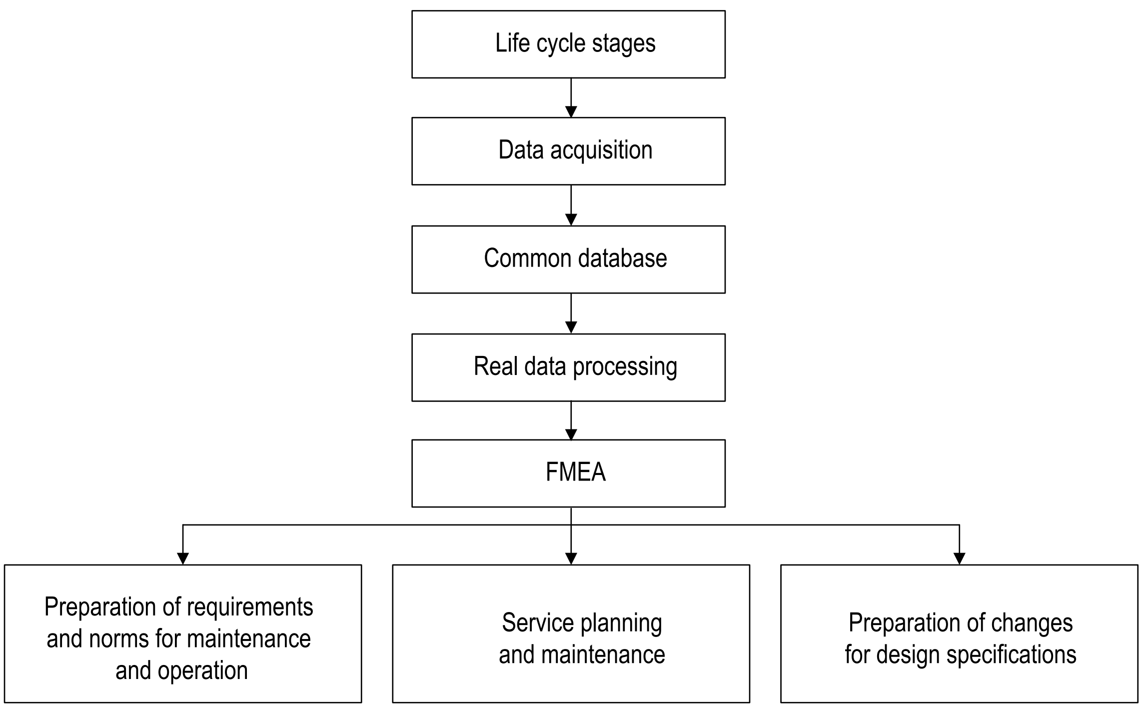

Fig. 1. The structural model of ensuring the reliability of ICS

Table 1. Types of SIS components' failure causes

System component / Failure causes	Electronics failure	Communication line break	Metrological failure	Rod jamming	Loss of electric and pneumatic power
Measuring sensor	+	+	+		+
Barrier	+	+	+		+
Valve	+	+	+	+	+
Input/output unit	+	+	+		+
Controller	+	+	+		+
Power supply unit	+				+

$$P_{barrier} = 1 - Q_{barrier} = 1 - q_1 - q_2 - q_3 - q_4 + q_1q_2 + q_1q_3 + q_1q_4 + q_2q_3 + q_2q_4 + q_3q_4 - q_1q_2q_3 - q_1q_2q_4 - \\ - q_1q_3q_4 - q_2q_3q_4 + q_1q_2q_3q_4,$$

where q_1, q_2, q_3, q_4 are probabilities of failures of electronics, communication lines, metrology, and failure as a result of power loss, respectively, P is the probability of failure-free operation, Q is the probability of failure.

3. For cutoff valve with electro-pneumatic positioner:

$$Q_{valve} = q_1 \vee q_2 \vee q_3 \vee q_4 \vee q_5 = q_1 + q_2 + q_3 + q_4 + q_5 - q_1q_2 - q_1q_3 - q_1q_4 - q_1q_5 - q_2q_3 - q_2q_4 - q_2q_5 - \\ - q_3q_4 - q_3q_5 - q_4q_5 + q_1q_2q_3 + q_1q_2q_4 + q_1q_2q_5 + q_1q_3q_4 + q_1q_3q_5 + q_1q_4q_5 + q_2q_3q_4 + q_2q_3q_5 + q_2q_4q_5 + \\ + q_3q_4q_5 - q_1q_2q_3q_4 - q_1q_2q_3q_5 - q_1q_2q_4q_5 + q_1q_2q_3q_4q_5,$$

where q_1, q_2, q_3, q_4, q_5 are probabilities of failures of electronics, communication lines, metrology, and failure as a result of power loss and rod jamming, respectively, P is the probability of failure-free operation, Q is the probability of failure.

4. For I/O unit:

$$Q_{I/O} = q_1 + q_2 + q_3 + q_4 - q_1q_2 - q_1q_3 - q_1q_4 - q_2q_3 - q_2q_4 - q_3q_4 + q_1q_2q_3 + q_1q_2q_4 + q_1q_3q_4 + \\ + q_2q_3q_4 - q_1q_2q_3q_4;$$

$$P_{I/O} = 1 - Q_{I/O} = 1 - q_1 - q_2 - q_3 - q_4 + q_1q_2 + q_1q_3 + q_1q_4 + q_2q_3 + q_2q_4 + q_3q_4 - q_1q_2q_3 - q_1q_2q_4 - \\ - q_1q_3q_4 - q_2q_3q_4 + q_1q_2q_3q_4,$$

where q_1, q_2, q_3, q_4 are probabilities of failures of electronics, communication lines, metrology, and failure as a result of power loss, respectively, P is the probability of failure-free operation, Q is the probability of failure.

5. For controller:

$$Q_{controller} = q_1 + q_2 + q_3 + q_4 - q_1q_2 - q_1q_3 - q_1q_4 - q_2q_3 - q_2q_4 - q_3q_4 + q_1q_2q_3 + q_1q_2q_4 + q_1q_3q_4 + \\ + q_2q_3q_4 - q_1q_2q_3q_4;$$

$$P_{controller} = 1 - Q_{controller} = 1 - q_1 - q_2 - q_3 - q_4 + q_1q_2 + q_1q_3 + q_1q_4 + q_2q_3 + q_2q_4 + q_3q_4 - q_1q_2q_3 - \\ - q_1q_2q_4 - q_1q_3q_4 - q_2q_3q_4 + q_1q_2q_3q_4,$$

where q_1, q_2, q_3, q_4 q_4 are probabilities of failures of electronics, communication lines, metrology, and failure as a result of power loss, respectively, P is the probability of failure-free operation, Q is the probability of failure.

6. For power supply unit:

$$Q_{power} = q_1 + q_2 - q_1 q_2;$$

$$P_{power} = 1 - Q_{power} = 1 - q_1 - q_2 + q_1 q_2,$$

where q_1, q_2 are probabilities of failures of electronics, and failure as a result of power loss, respectively, P is the probability of failure-free operation, Q is the probability of failure.

For reliability assessment by using statistical data, the relative failure rate per month is determined by the following formula [1]:

$$q_i = \frac{n_i}{N},$$

where n_i is the number of failed components due to the i-th type of failures, N is the total number of operating components of the installation.

The probability of components' failure per year can be estimated based on the following formula for a failure rate:

$$\lambda_i = \frac{N_1 - N_2}{N_{cp} \Delta t},$$

where N_1 is the number of components operating at the time point t_1, N_2 is the number of components operating at the time point t_2, $\Delta t = t_1 - t_2$, N_{cp} is the average number of operating components, i is the index corresponding to the component type.

The calculated failure rate allows together with the recovery rate planning maintenance of SIS automated systems [2].

The probability of failure of all the components of technical equipment can be determined by the formula of a total probability:

$$Q(A) = \sum_{K=1}^{N} Q(H_K) \cdot Q(A \mid H_K),$$

where $H_1, H_2, ..., H_K$ are the complete set of hypotheses, $Q(H)$ is the probability of technical equipment component failure (hypotheses). Therefore, if the system includes a measuring sensor, spark protection barrier, valve, I/O unit, controller, power supply unit, then the total probability formula, provided that all components may fail with an equal probability, will have the following form:

$$Q = \frac{1}{6} \cdot Q_{transducer} + \frac{1}{6} \cdot Q_{barrier} + \frac{1}{6} \cdot Q_{valve} + \frac{1}{6} \cdot Q_{I/O} + \frac{1}{6} \cdot Q_{controller} + \frac{1}{6} \cdot Q_{power\,\sup ply};$$

In this case, the probability of failure-free operation is equal to $P = 1 - Q$.

Table 2, as an example of the application of ICS common database, shows a fragment of calculation of the reliability of SIS 37-10 installation system of oil refining per 12 months in 2010, using data from equipment failures of the system.

Table 2. Calculation of SIS reliability indices

Name of equipment	Total number of equipment, N	Number of failed equipment, n	Relative density (probability) of failure	Relative density (probability) of failure-free operation	Failure rate	Relative density (probability) of failures in SIS	Relative density probability) of failure-free operation of SIS	Failure rate of SIS
Pressure measuring sensors	14	0	0	1	0	0	1	0
Flow measuring sensors	2	0	0	1	0			
…								
Shutdown valves and cutoff devices	8	0	0	1	0			

The data in Table 2 show that SIS failures during a month are unavailable, which can be explained by sufficiency of maintenance.

To develop recommendations and standards for maintenance of automation systems, it is possible to apply the methodology of FMEA (failure mode and effect analysis). Table-based FMEA is applied for assessment of ratings of failure frequencies and their detection, as well as for development of regulations for maintenance of automation systems that enhance their dependability.

As an example, Table 3 and Table 4 show the results of FMEA application for construction of ratings of failure frequency and the probability of failure detection for SIS of a furnace for heating of extractive solution of the 37-10 installation for selective oil cleaning.

Table 3. Rating of failure frequency

Rating	Frequency of occurrence	Interval between failures, hour	Criterion
10	Almost always	Under 2	
9	Very high	2 – 10	
8	High	11 – 100	Downtime is over 8 h.
7	Sufficiently high	101 – 400	Downtime is over 4 h.
6	Average probability	401 – 1000	Downtime is 1 – 4 h.
5	Low probability	1001 – 2000	Downtime is 0,5 – 1 h.
4	Rare	2001 – 3000	Downtime is under 30 min. Without product loss
3	Very rare	2001 – 3000	The process needs to be adjusted
2	Single instances	3001 – 6000	The process is under control, but needs some adjustment
1	Almost never occur	6001 – 10000	The process is under control

Table 4. Rating of the probability of failure detection

Rating	The probability of detecting	Criterion
10	Virtually undetectable	Preventive maintenance (PM) does not allow detecting potential causes of failures
9	Detected very rarely	Negligible chances that PM will allow detecting potential causes of failures
8	Detected rarely	Extremely small chances of failure cause detection when carrying out PM
7	Very small probability	Very small chances of failure cause detection when carrying out PM
6	Small probability	Small chances of failure detection when carrying out PM
5	Moderate probability	Moderate chances of failure detection when carrying out PM
4	Average probability	Average chances of failure detection when carrying out PM
3	High probability	High chances of failure detection when carrying out PM
2	Very high probability	Very high chances of failure detection when carrying out PM
1	Failure is practically always detected	PM allows practically always detecting potential causes of failure

Thus, the paper shows the expedience of building up a common database of design and operational data as regards failures of control systems' equipment and its application for the analysis of failure cause and consequences and the development of measures to prevent them.

References

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