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RELIABILITY CALCULATION FOR METALLURGICAL EQUIPMENT CONSIDERING THE PROBABILITY OF OPERATOR'S ERROR

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Keywords: uptime probability; equipment reliability; reliability of technical systems; human factor.
Abstract. A methodology for calculating the probability of failure-free operation of equipment is given considering the influence of human factor. When assessing the numerical characteristics of the studied parameter, the "fault tree" method was used as an organized graphic display of conditions and other factors causing undesirable event called the peak of events. Using a new methodology for calculating the reliability of equipment, this parameter went down by 37% (considering the human factor), which was the goal of this work.

РАСЧЕТ НАДЕЖНОСТИ МЕТАЛЛУРГИЧЕСКОГО ОБОРУДОВАНИЯ С УЧЕТОМ ВЕРОЯТНОСТИ ОШИБКИ ОПЕРАТОРА

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Ключевые слова: вероятность безотказной работы; надежность оборудования; надежности технических систем; человеческий фактор.
Аннотация. Приведена методика расчета вероятности безотказной работы оборудования с учетом влияния человеческого фактора. При оценке численных характеристик исследуемого параметра применялся метод «дерева неисправностей» как организованного графического изображения условий и других факторов, вызывающими нежелательное событие, которое называется вершиной событий. С применением новой методики расчета надежности оборудования, данный параметр снизился на 37% (с учетом человеческого фактора), что являлось целью данной работы.

Among the wide variety of methods for determining the safety of equipment with rather high complexity of this process, the most suitable one is the "fault tree" or "fault tree" method, which, in accordance with [1], is a topological model of reliability and safety that reproduces the logical and probabilistic relationships between separate random initial events in the form of primary or resulting failures, which the aggregate leads to the main event being analyzed.

Close to the above is the definition of the "fault tree" method as an organized graphic representation of conditions and other factors causing an undesirable event, which is called the peak of events. Since the analysis of the "fault tree" is related to determining the possibility of occurrence or not manifestation of the main event – a case of a particular type, its conditions are set by separating from the entire array of initial premises two subsets, which implementation results or does not result in occurrence of the main event. Such subsets are divided into: emergency combinations, which include a certain set of initiating events, which implementation ensures that the final event will take place; cut off combinations, which also represent a set of initial events, but, unlike the previous ones, they guarantee the absence of a main event when any of the components of this set of events occurs.

The most convenient way to identify the conditions for the occurrence and prevention of events is to separate from such subsets the so-called minimal compounds of events, or those of them, which occurrence is minimally required and sufficient to achieve the desired result.

A quantitative analysis of accidents and injuries due to structural functions according to [2] can be performed in the following sequence: the model is divided into separate blocks; in the selected blocks, subsets of events are selected that are connected to the conditions “and” and “or”; the initial “tree” and its corresponding structural function are simplified by their enlargement; the admissibility of an event is calculated.

When assessing the numerical characteristics of the investigated “fault tree”, a number of rules and assumptions should be considered.

1. 1. Events of the “tree” connected by the logical condition “and” are combined according to the principle of their multiplication, while it is believed that the parameter of the main event is calculated as a set of n parameters of the premises (factors): $P = P_1 \cdot P_2 \cdot ... \cdot P_n = \prod_{i=1}^{n} P_i$.

2. Events of the “tree” connected by the logical condition “or” are combined according to the principle of logical addition, and their respective parameters form the following dependence:

$P = 1-(1-P_1)(1-P_2)...(1-P_n) = 1-\prod_{i=1}^{n}(1-P_i)$, which in particular, for example, for $n=3$ and $n=2$, takes the form: $P_{i=2} = P_1 + P_2 - P_1 \cdot P_2$;

$$P_{i=3} = P_1 + P_2 + P_3 - P_1 \cdot P_3 - P_2 \cdot P_3 - P_3 \cdot P_1 + P_1 \cdot P_2 \cdot P_3.$$

3. Transformations and simplifications of structural functions are carried out in compliance with the basic rules of Boolean algebra. In accordance with the law of absorption, for example, the following identities are true: $A \cdot (A \cdot B) = A \cdot B$; $A + (A + B) = A$.

4. With the well-known structural fault-free schemes of technical systems and the operation safety, they can easily be turned into an “event tree”. At the same time, their parallel-connected elements correspond to the logical operation “and”, and series-connected elements to the logical operation “or”.

Analysis by the “fault tree” method allows one to identify combinations of equipment failures (malfunctions), personnel errors (objective and subjective) and external (man-caused, natural) influences leading to the main event (emergency). This method is used to analyze the occurrence of an emergency and calculate the probability of failure based on establishing the probability values of the initial events [1, 3].

Reliability assessment of technical systems should be performed for the most dangerous of them. From a preliminary analysis of the types of injuries and generally negative consequences for the human body when operating the forging equipment, it is clear that these may be: main and auxiliary equipment; local ventilation with an aspiration system, the which failure can result in an abrupt increase of the harmful substances concentration in the air of the production room;

pneumatic or hydraulic systems of the manipulator for loading and unloading workpieces into a heating furnace and their rotation during forging; conveyor system for transporting workpieces to workplaces, etc.

When constructing "trees", certain symbolics are used when the state of elements or initial events that cannot be subdivided is represented in the form of circles, and the consequences in the form of rectangles. First you need to make a list of failures (events) of a particular technical system and determine their reliability. For example, for a pneumatic-actuated arm, the fault recount includes events listed in the table.

But, at the same time, it must be borne in mind that the first and second events from the ones listed in the table can arise not only due to manifestations of known harmful and dangerous production factors, but also related to such reasons as technical, organizational, sanitary and hygienic psychophysiological ones.

Tab. 1. The probability of an emergency during the operation of the pneumatic system of the manipulator

№	Event	Probability P(t)
1	Security breach	$5 \cdot 10^{-4}$
2	Performing equipment repair during operation	$4 \cdot 10^{-5}$
3	Search for controls and the implementation of a given control action	$3{,}9 \cdot 10^{-2}$
4	Signal Detection and Decision Making	$6{,}2 \cdot 10^{-2}$
5	Button pressing	$1{,}5 \cdot 10^{-3}$
6	Turn on the toggle switch	$1 \cdot 10^{-3}$
7	Issuing or accepting a voice command	$2 \cdot 10^{-4}$
8	Cable Connection Action	$1{,}4 \cdot 10^{-3}$
9	Cable Disconnect Action	$5 \cdot 10^{-4}$
10	Hose Connection Action	$4{,}5 \cdot 10^{-3}$
11	Seal Installation Action	$9 \cdot 10^{-3}$
12	Moving a person on an assembly site	$1 \cdot 10^{-3}$
13	Moving a person on temporary decking	$6 \cdot 10^{-3}$
14	Use of protective equipment for removable guards	$2{,}5 \cdot 10^{-1}$
15	Mechanical damage to the cylinder reducer	$3 \cdot 10^{-5}$
16	Mechanical damage to the pneumatic system piping	$5 \cdot 10^{-5}$
17	Mechanical damage to the pneumatic system pipeline gearbox	$5 \cdot 10^{-5}$
18	Gearbox nut failure	$2 \cdot 10^{-6}$
19	Gearbox gasket failure	$4 \cdot 10^{-4}$
20	Overpressure in the cylinder	$4 \cdot 10^{-6}$
21	Faulty cylinder operation	$2 \cdot 10^{-5}$
22	Operation of a failed compressor unit	$2 \cdot 10^{-5}$
23	Fuse failure	$3 \cdot 10^{-6}$
24	Motor Bearing Failure	$2 \cdot 10^{-6}$

25	Motor impeller failure	$1{,}1 \cdot 10^{-7}$
26	Limit switch failure	$3 \cdot 10^{-6}$
27	Gland wear	$3 \cdot 10^{-6}$
28	Compressor shaft bearing failure	$2 \cdot 10^{-6}$
29	Clutch wear	$2{,}5 \cdot 10^{-6}$

If set up that the time between failures of the pneumatic system is, for example, more than 16,000 hours, but it can be different though, then the calculation of the probability values of failure-free operation of its individual elements can be performed according to the failure rate (table) and the “fault tree” (Fig. 1, 2) considering the period of normal operation, when $\lambda = const$.

Moreover, the probability of failure-free operation of each element is determined by the formula $P(t) = e^{-\int_0^1 \lambda(t)dt}$ or $P(t) = e^{-\lambda t}$ for a given t, and accordingly, failure probability for each element will correspond to the value obtained from the equation $P(t) + Q(t) = 1$.

Probability calculation on failure-free operation of equipment without taking into account the human factor.

Calculation of the probability of failure-free operation of the pneumatic system manipulator (Figure 1).

1. $P'_A = P_B + P_C - P_D \cdot P_C$; 2. $P_B = P_1 + P_2 - P_1 \cdot P_2$;

3. $P_C = P_D + P_I + P_F + P_G - P_D \cdot P_I - P_I \cdot P_F - P_F \cdot P_G - P_D \cdot P_I \cdot P_F \cdot P_G$;

4. $P_D = P_{15} + P_{16} + P_{19} - P_{15} \cdot P_{16} \cdot P_{17}$; 5. $P_I = P_{18} + P_{19} - P_{18} \cdot P_{19}$;

6. $P_F = P_{20} + P_{21} + P_{22} - P_{20} \cdot P_{21} \cdot P_{22}$;

7. $P_G = P_{23} + P_{24} + P_{25} + P_{26} + P_{27} + P_{28} + P_{29} - P_{23} \cdot P_{24} \cdot P_{25} \cdot P_{26} \cdot P_{27} \cdot P_{28} \cdot P_{29}$;

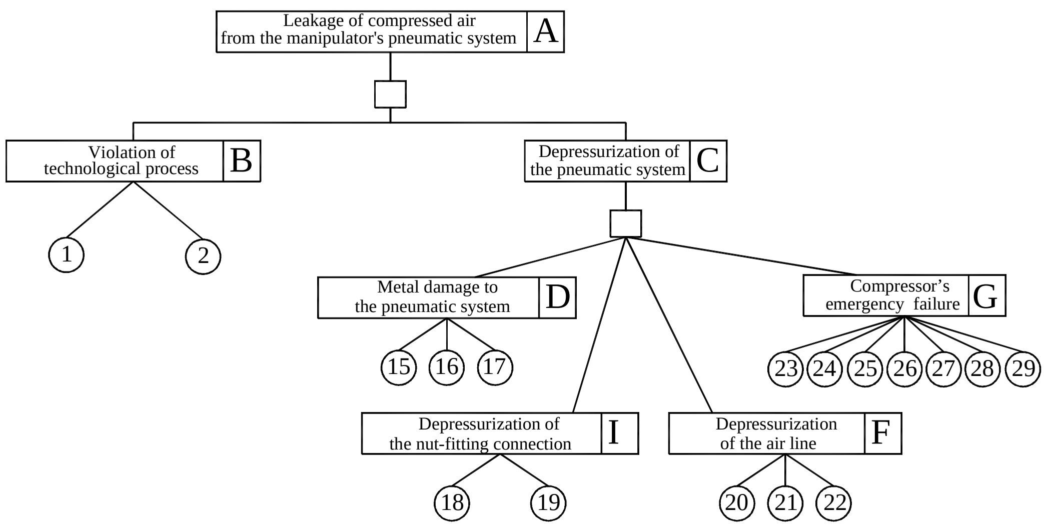

Fig. 1. The probability of an emergency when a compressed air leak from the pneumatic system of a manipulator

After substituting the values of P (t) obtain:

The probability of equipment failure $P'_A = 1{,}135 \cdot 10^{-3}$

Probability calculation on failure-free operation of equipment considering the human factor.

Probability calculation of failure-free operation during operation of the pneumatic system of a manipulator (Figure 2).

1. $P''_A = P_B + P_C - P_B \cdot P_C$;

2. $P_B = P_1 + P_2 + P_3 + P_4 + P_5 + P_6 + P_7 + P_8 + P_9 + P_{10} + P_{11} + P_{12} + P_{13} + P_{14} -$
$- P_1 \cdot P_2 \cdot P_3 \cdot P_4 \cdot P_5 \cdot P_6 \times P_7 \cdot P_8 \cdot P_9 \cdot P_{10} \cdot P_{11} \cdot P_{12} \cdot P_{13} \cdot P_{14}$;

3. $P_C = P_D + P_I + P_F + P_G - P_D \cdot P_I - P_I \cdot P_F - P_F \cdot P_G - P_D \cdot P_I \cdot P_F \cdot P_G$;

4. $P_D = P_{15} + P_{16} + P_{19} - P_{15} \cdot P_{16} \cdot P_{17}$; 5. $P_I = P_{18} + P_{19} - P_{18} \cdot P_{19}$;

6. $P_F = P_{20} + P_{21} + P_{22} - P_{20} \cdot P_{21} \cdot P_{22}$;

7. $P_G = P_{23} + P_{24} + P_{25} + P_{26} + P_{27} + P_{28} + P_{29} - P_{23} \cdot P_{24} \cdot P_{25} \cdot P_{26} \cdot P_{27} \cdot P_{28} \cdot P_{29}$.

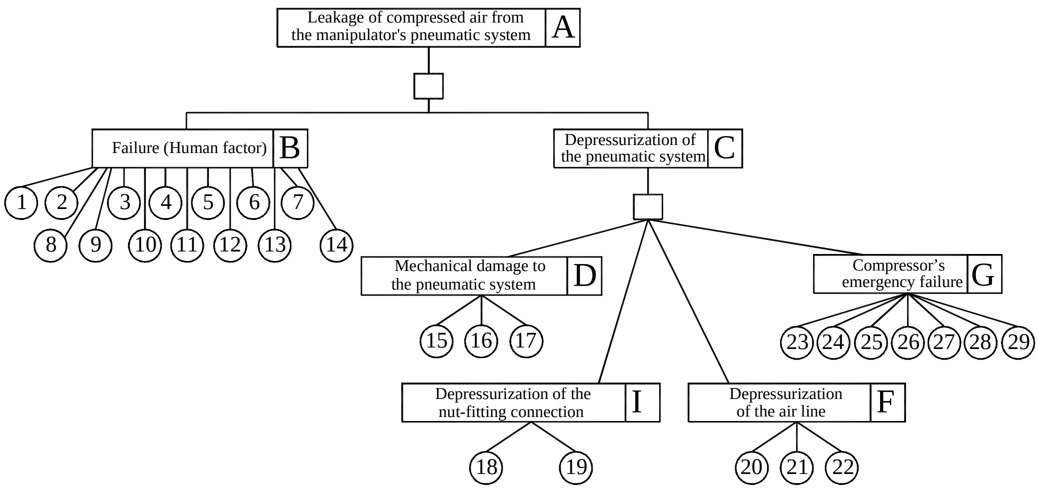

Fig. 2. The probability of an emergency when a compressed air leaks from the pneumatic system of a manipulator considering the human factor

After substitution of values $P(t)$ obtain:

$$P''_A = 0,375 + 5,95 \cdot 10^{-4} - 0,375 \cdot 5,95 \cdot 10^{-4} = 0,375.$$

Obtained value P''_A (the probability of failure-free operation of the equipment considering the human factor), as you can see, the reliability has sharply decreased.

We will calculate how much the reliability of the equipment has decreased. To do this, we determine the probability of failure for two cases.

$$Q' = 1 - P'_A = 1 - 1{,}135 \cdot 10^{-3} = 0{,}998865;\ Q'' = 1 - P''_A = 1 - 0,375 = 0{,}625.$$

We determine how much the human factor reduces the reliability of equipment: $Q = Q' - Q'' = 0{,}998865 - 0{,}625 = 0{,}373865$.

Equipment reliability decreased by 37% reckon in the human factor.

References

1. Vishnevskiy D.A. Reliability calculation for metallurgical equipment and production risk // Bullein of Scientific Papers of DonSTU. Alchevsk, SEI HPE LPR DonSTU. 2017. Issue 7 (50). P. 139-146.
2. Korchagin A.B. Reliability of technical systems and man-made risk: st. guide in 2 parts. P. 2: practice / A.B. Korchagin, V.S. Serdyuk, A.I. Bokarev. – Omsk: OmSTU, 2011. – 140 p.
3. Vishnevskiy D.A. Impoving the reliability of metallurgical equipment through the introduction of Realtime Location Systems technologies and Internet of Things / D.A. Vishnevskiy, B.A. Sakharov // Journal of Advanced Research in Technical Science. – 2018. – Issue 12. – P. 74-77.

Список литературы

1. Вишневский Д.А. Расчет надежности металлургического оборудования и производственного риска // Сборник научных трудов ДонГТУ. Алчевск, ГОУ ВПО ЛНР ДонГТУ. 2017.. Вып 7 (50). С. 139-146.
2. Корчагин А.Б. Надежность технических систем и техногенный риск: уч. пособие в 2-х ч. Ч.2: практикум / А.Б. Корчагин, В.С. Сердюк, А.И. Бокарев. – Омск : Изд-во ОмГТУ, 2011. – 140 с.
3. Vishnevskiy D.A. Impoving the reliability of metallurgical equipment through the introduction of Realtime Location Systems technologies and Internet of Things / D.A. Vishnevskiy, B.A. Sakharov // Journal of Advanced Research in Technical Science. – 2018. – Issue 12. – P. 74-77.

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