RESEARCH WORK ABOUT THE TROUBLE-FREE OPERATION OF A ROBOTIC CELL FOR THE WELDING OF THE BOGIE FRAME ON A FREIGHT WAGON

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Abstract: *This research work presents the results of the monitoring on a robotic cell operation for welding the bogie frame on a freight wagon for two months. The structure of the robotic welding cell is revealed and a register of the occurred failures was formed. A statistical processing of the received information has been made and an analytical expression about the trouble-free operation has been determined. Recommendations for increasing trouble-free operation are suggested.*
Keywords: RELIABILITY, ROBOTIC WELDING CELL, FAILURE, TROUBLE-FREE OPERATION PROBABILITY

1. Introduction

The trouble-operation of a technical system is determined by one of the private properties of reliability – faultless work. Quantitative reliability has been assessed by criteria: probability of faultless work, probability of failure, flow refusals parameter, etc. The realistic design standardization is especially important because it participates in the determination of the project performance and at the production stage is demonstrated the prognosis of probability.

A robotic welding cell (RWC) on the frame of the bogie on freight wagon is part of a robotic complex where the frame components have been welded.

In RWC industrial robot Motoman-6 HP welds the frame components (Fig. 1) that consists of two longitudinal beams (1), connected in the middle by centralbolt beam (2), and ends with two transverse beams (3). To this frame construction four axel jaws (4) are aggregated for the suspension of the frame to the axles and a number of strips for mounting the braking system elements. The components of the frame have been set manually before entering the RWC, where the set frame have been put in two coordinate devices. The program cycle duration of the frame components welding is 82 min [2].

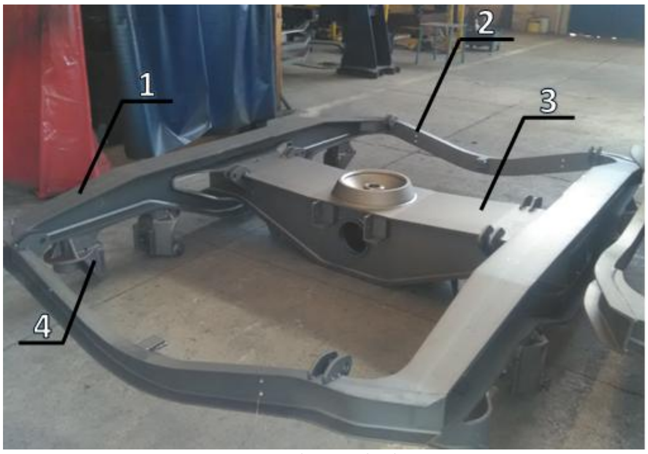

Fig. 1. *The bogie frame of a freight wagon*

During operation, faults arise of different physical nature that disrupt the normal functioning of RWC and reduce its performance. Both internal and external factors are influencing the working capacity.

The purpose of this study is to discover emerging failures, their physical nature and their distribution law.

2. Structure of the robotic welding cell

The Fig. 2 schematically presents the structure of RWC.

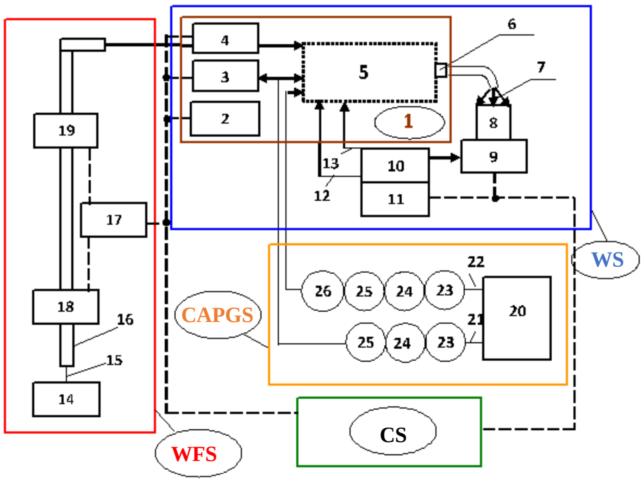

Fig. 2. *Block-diagram of the robotic welding cell*

The following set systems and their components are distinguished based on a functional principle in the RWC:

Workflow System (WS) – welding robot (1), welding machine control unit (2), cleaning station (3), main wire feeder (4), hose (5), welding burner (6), welding arc (7), welded part (8), adjusting device (9), welding machine (10), welding machine control unit (11).

Wire Feeder System (WFS) – a roller with additional wire (14), additional wire (15), core (16), wire feeder blocks control (17), wire feed units (18, 19).

Compressed Air and Protective Gas System (CAPGS) – factory trunk line (20), shut-off valve (23), filter (24), pressure gauge (25), flowmeter (26).

Computer system (CS).

The welding burner (Fig. 3) and the welding machine are the main functional elements of the work process. The relationship between them is made by means of a hose that secures the bulk cable (13), the cooling piping (12) and the elements of the compressed air systems (21), protective gas (22) and wire feeding. The elements of the welding burner work under extreme conditions and have a short technical resource. They are defined as consumables and are always spare parts for quick removal of related faults. For the same purpose are a spare burner and a spare hose have been provided.

The large size of the work area necessitated the construction of an additional wire feeder system to support the main feeder block mounted on the welding robot. Its structure is shown in Fig. 4. Supplementary wire feed units (18 and 19) include quick couplers (4), electric motor (1), gearbox (2) and friction rollers (3). The positions in brackets correspond to the positions in Fig.2.

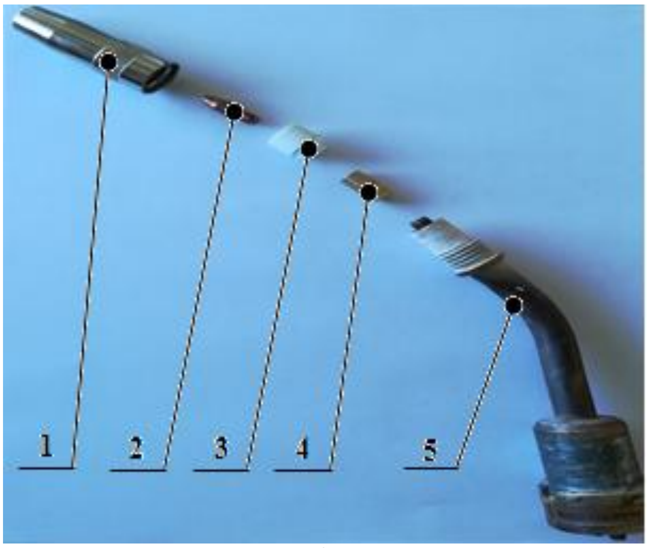

Fig. 3. *Elements of the welding burner*
1 - gas nozzle; 2 - current nozzle; 3 - insulator sleeve;
4 - gas distributor; 5 - body;

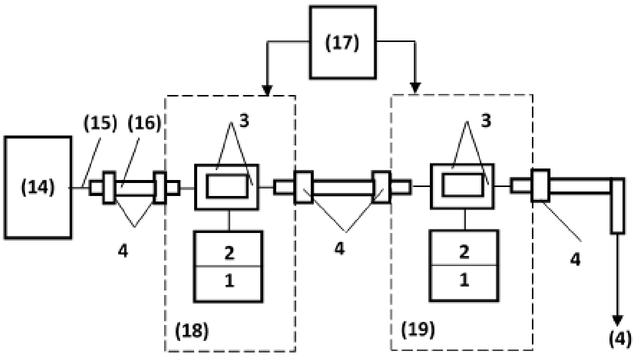

Fig. 4. *Flowchart of the supplementary feeder system*

The cleaning station removes stuck metal and slag particles on the inside of the gas nozzle, which reduce the diameter of the orifice and reduce the effectiveness of weld seam protection. At present, the cleaning station is not functioning and the operators performs its functions (limited in scope).

3. Statistical study of the robotic welding cell operation

The monitoring on the RWC's operation continued for two months (40 working days) under two-shift mode. During this period, 167 program cycles (articles) were completed and 66 failures were registered, the type of which is given in Table 1.

When collecting the necessary statistical information, the method of the observed operation is applied – the information in an advance prepared forms for each working day is filled by the instructed operators of the welding robot. As a result of their processing, a register of failures was formed, which clearly shows the type and the moment of the origin of the failures, the minimum and maximum duration of the periods of the trouble-free operation, etc.

An excerpt from the failure log is given in Fig. 5.

Failures occurred by reasons outside of RWC, such as lack of protective gas and or compressed air in the factory trunk line; damaged crane, blocked transport system.

4 . Processing of monitoring results

The subsequent processing of the obtained statistical information is related with the determining of the statistical function of the trouble-free operation of the RWC and finding an analytical expression for its presentation. Using the Sturges formula [3] the width (***t***) of the intervals is determined at which the trouble-free cycles taken from the failure register have been grouped.

Table 1. *Types of failures*

Code	Type of failure
1	Movement without welding with wire feed
2	Current Nozzle Failure
3	Refusal to gas nozzle
4	Insulator bushing failure
5	Gas distributor failure
6	Impossible welding start
7	Holding the torch in the milling cutter
8	A group of pores in a welded joint
9	Weld seam cut
10	Large protrusion of weld
11	Restart of the welding machine
12	Lack of search
13	Lack of protective gas
14	Charging with extra wire
15	Absence of compressed air
16	Hose leakage
17	Break the fast connection
18	Blocked transport system

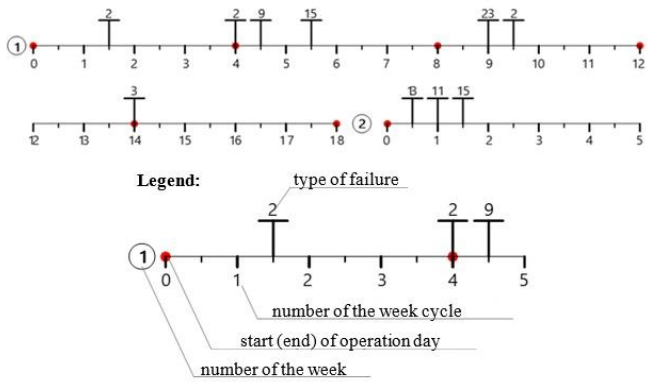

Fig. 5. *Excerpt from the register of failures*

(1) $$\boldsymbol{t} = \frac{x_{max} - x_{min}}{1 + 3{,}322 \log N} = \frac{7{,}5 - 0{,}5}{1 + 3{,}322 \log 167} = \mathbf{0{,}99} \text{ cycles}$$

x – maximum (minimum) number of cycles of trouble-free operation;
N – total number of failures.

A width of one-cycle intervals was adopted, resulting in eight intervals (see Table 2).

Formula (2) [1] determines the average number of trouble-free cycles.

(2) $$\boldsymbol{t_{cf}} = \frac{\sum_1^n f_i t_i}{\sum f_i} = \mathbf{2{,}5} \text{ cycles}$$

According to the data in Table 2 and the dependence (3) [5] the values of the statistical function for trouble-free operation have been determined (see Table 2) and its graphical interpretation is shown in Fig. 6.

(3) $$\boldsymbol{P^*(t_i)} = \frac{(N - \sum_1^i f_i)}{N}$$

The hypothesis for an exponential law of the probability of the failure-free operation of the RWC has been put forward, which at $\boldsymbol{t_{cf}} = \mathbf{2,5}$ cycles yields the form (4) [4]:

(4) $$\boldsymbol{P(t)} = \mathrm{e}^{-\frac{t}{2,5}}$$

Table 2. *Results of the statistical processing of the monitoring data on the work of the RWC*

№		1	2	3	4	5	6	7	8
Link intervals		0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Middle intervals, t_i		0,5	1,5	2,5	3,5	4,5	5,5	6,5	7,5
Frequency of refusals	**Statistic f_i^***	21	13	9	8	5	5	3	2
	Theoretical f_i	22	17	13	9	7	5	4	3
Probability of trouble-free operation	**Statistic $P_i^*(t)$**	68,2	48,5	34,8	22,7	15,2	7,6	3,0	0
	Theoretical $P_i(t)$	67,0	44,9	30,1	20,2	13,5	9,1	6,1	4,1
Cumulative failure rate	**Statistic $\sum f_i^*$**	21	34	43	51	56	61	64	66
	Theoretical $\sum f_i$	22	37	47	54	59	62	64	66
Difference between cumulative frequencies $\lvert\sum f_i^* - \sum f_i\rvert$		1	3	3	3	3	1	-	-

The probability values for the failure-free operation are shown in Table 2 and Fig. 6.

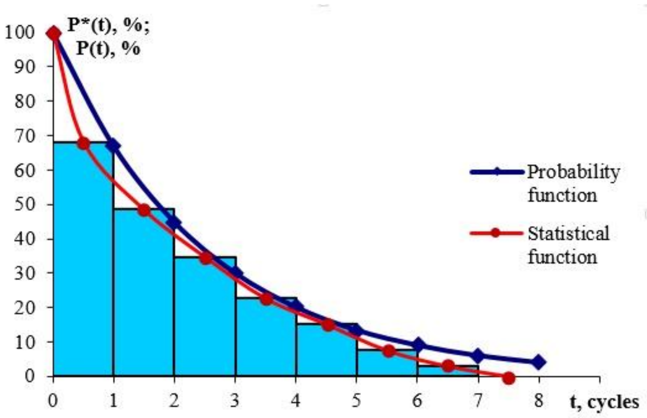

Fig. 6. *Theoretical and statistical functions of reliability*

Statistical verification of the hypothesis of an exponential probability distribution law for failure-free operation was performed according to Kolmogorov's criterion [3]:

(5) $$\boldsymbol{\lambda = D/\sqrt{N}}$$

D – maximum difference between the cumulative frequencies of the statistical and theoretical distributions.

Ehen there is a maximum difference between cumulative frequencies $D = 4$ is obtained $\lambda = 0{,}492$ and the probability $P(\lambda) = 0{,}96998$. Therefore, it can be assumed that the exponential distribution is an adequate statistical model.

The conducted statistical observation and analysis of the obtained results allow us to formulate the following recommendations for trouble-free operation of RWC:

- ✓ Welded parts must be regularly cleaned of corrosion and grease stains to reduce the number of failures with codes 2, 3, 6 and especially 8.
- ✓ It is necessary to repair the cleaning station in order to eliminate: the breach of the technology for cleaning the elements of the welding burner; the increasing probability of part of the failures; loss of time from manual lubrication of the gas nozzle; increased operator workload.
- ✓ The timing of the change of wire must be strictly observed in order to prevent prolonged stays of the RWC.
- ✓ The nomenclature and the quantity of spare parts, as well as the inventory of purchased items, should be optimized to reduce the duration of RWC stay.

5. Conclusions

- The physical nature of emerging failures in the RWC has been discovered and analyzed to formulate sound recommendations for increasing trouble-free operation.
- An analytical term has been found describing the true work of the RWC to develop a mathematical model for the investigation of the reliability of the RWC.
- An exponential distribution of the probability of failure-free operation has been proven to create the opportunity to conduct adequate simulation studies of RWC.

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