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The use of the FMEA method for the evaluation of failures in crawler cranes

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Abstract. The use and operation of crawler cranes in the Czech Republic is dependent on the availability of several major producers (Liebherr, Caterpillar, Volvo, Sennebogen, etc.) and Czech producers (Unex Uničov with its successor ND LOR Uničov, Tatra and others). The authors of this article explain the problems of operation, repairs and risks of failures in specific types of crawler cranes supplied by Liebherr during their operation in the steelmaking company Třinecké železárny, a.s. and Trilet Ground Services, a.s., the company specialized in renting machines that are used for foundations of buildings. The article proceeds from the evaluation of the operational data of both delivered and repaired machines and the data obtained from the repair company needed for the commissioning of the serviced machine, as well as the frequency of repairs during the specified hours of work within the course of operation of the machines. The processed data serves as a basis for the evaluation of risk of possible failures when using machines. Risks are evaluated using the FMEA method.

1 Introduction

The range of use of crawler cranes in practise is quite extensive. Their performance and scope of work cover many areas of human activities. The machines are often used in various and very poor external conditions; for instance in the Czech Republic they are used in Třinecké železárny under extreme conditions (high temperatures, great dustiness, cyclic operation in foundries, operation in high temperatures). The work of crawler cranes consists in breaking a solidified slag in a large tank in order for the slag to be reused it in the foundry process. In construction industry machines are used for the foundation of buildings (ramming the piles into the ground and thus anchoring the foundations). It means that external climatic conditions (heat, cold, rain, snow) have a great impact on the operation of the machinery. However, the machines are only operated seasonally from spring to autumn. In winter constructions are not initiated due to climatic conditions in Central Europe.

The design of crawler cranes is dealt with in a work [1] while damage to wire ropes, during operation of machines, is solved in the works by authors [2, 3]. The operation of wire ropes and their failures are addressed in [4].

In particular, the focus of this article is on the collection and evaluation of data from the operation of machinery using the FMEA risk analysis method for detecting the failures in individual units, and the subsequent evaluation of the highest probability of failure with a proposal for its elimination.

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2 Operation of machinery

Třinecké železárny is a Czech steel works with the largest domestic capital that produces the major share of steel in the Czech Republic. Two crawler cranes are permanently used there to ensure the continuous running of the iron foundry for the breaking of deposited slag in the steel tank in order for the slag to be reused in the next foundry process. The machines are operated in a very challenging environment; the temperature is very high in the foundry (in excess of 50° C, the humidity of the air is also high due to the cooling of slag with water and there is also a lot of dust, which affects the operation of the machinery). The machines are used in a three-shift operation, however, their operation is irregular based on demand, which is influenced by the tapping of the furnace and the supply of slag, and therefore, the machines are not operated for the whole 8 hour shift.

Table 1. Description, machine numbers and operation. Source: Internal company materials, adjusted. Source: [5]

Machine number	Date of commissioning	Total number of failures / service	Total number of hours of work
HS8040-HD-182522	10 January 2017	3	484
HS 8030-HD-182914	29 January 2018	1	63

Table 2. Evaluation of repairs Source: Internal company materials, adjusted. Source: [5]

Machine number	Repair 1	Repair 2	Repair 3	Maintenance
HS8040-HD-182522	Replacing a display – electronics	Defective lift limit switch of the wire rope	Defective plate on a boom (defective cabling)	-
Number of hours of work	129 hr	277 hr	395 hr	484 hr
HS 8030-HD-182914	Assembly	Adding the fire protection – lifting piston rods, winch protection holders	-	-
Number of hours of work	0	63 hr	-	-

Trilet Ground Services, a.s.

Trilet Ground Services, a.s. was founded 21 years ago in Prague. The company's purpose of business is rental and leasing of construction machinery and equipment, information technology activities, rental and leasing of products for personal use, especially for households, and it is also specialized in six other areas, for example foundation of buildings, bridges and hydraulic structures.

Table 3. Description, machine numbers and operation. Source: adjusted [5]

Machine number	Date of commissioning	Total number of failures	Total number of hours of work
HS 855 - HD827 - 184617	10/2007	3	10,824
HS 8030 – HD827 -182914	12/2008	5	15,936

Table 4. Evaluation of repairs. Source: Internal company materials, adjusted [5]

Machine number	Repair 1	Repair 2	Repair 3	Repair 4
HS 855 - HD827 - 184617	High fuel pressure – replacement of a pressure sensor on a diesel engine	Clogged fuel lines	Defective high pressure fuel pump of a diesel engine	
Number of hours of work	9,820	10,318	10,824	Increased smokiness of an engine
HS 8030 – HD827 - 182914	Defective diesel particulate filter	Defective winch	Defective water pump in a diesel engine	7,547
Number of hours of work	1,373	3,591	5,611	
Machine number	Repair 5	Repair 6		
HS 855 - HD827 - 184617				
Number of hours of work				
HS 8030 – HD827 - 182914	Replacing the motor wiring due to heat damage	Replacement of a boom after it fell		
Number of hours of work	14,494	15,936		

The machinery is operated outdoors for about 8 months of the year; it is not operated during wintertime because of frost and snow. The machinery is used in a two-shift operation with approximately 2,000 hours of work, which means that the machines need to be serviced by an external company four times a year.

Within the evaluation of operation, it is possible to monitor the reliability of operation and to evaluate the frequency of failures and dependence of failures on the total number of hours of work.

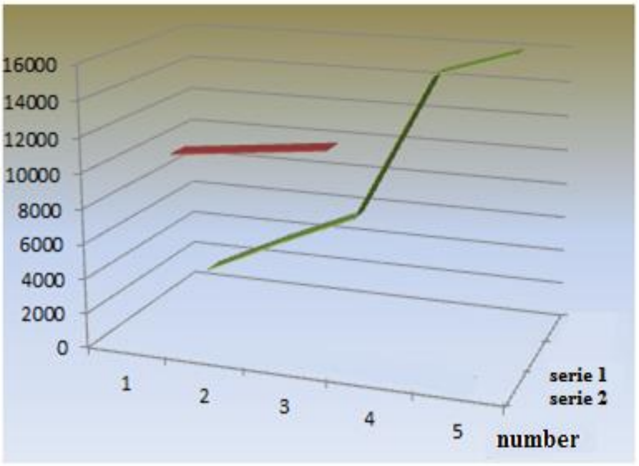

Fig. 1. Defects depending on hours of work. Source: Own processed data

The graph shows that there is no linear dependence against hours of work and defects occurred. After a running-in period between 3rd and 4th failures (Series 3) the increase in hours of work is very high (failure-free operation); with increasing age and wear of the machinery the time of occurrence of the next failure shortens even if the technical conditions of operation and regular servicing of the machinery is observed in accordance with the technical regulations. The evaluation of operation of the machinery (Series 2) shows that among the first and the second failure and among the second and third failure the numbers of hours of work are almost identical [6].

3 Risk assessment using the FMEA method

The Failure and Mode Effect Analysis was used to assess the risks. This method is suitable for assessing the different stages of the life cycle of the system / product and for various cases, each having a different scope of focus [7-10]. In the said case, the FMEA method was used in the existing process to ensure a reduction of failures in the analysed system, taking into consideration the influence of the environment and location of the existing process.

The following tables (Table 1, Table 2 and Table 3) define the general assessment criteria for the significance, occurrence and possibility of detecting failures. Simultaneously, the level of risk of analysed failures are assessed in Tab. 4, the FMEA form. Using the FMEA form the failures, which actually emerged during operation, have been analysed, and they will have to be addressed in the future in order to avoid their recurrence. Crawler cranes, which are the subject of this work, operate in extreme heat and dusty conditions. Their operation is not continuous, which is the reason for the occurrence of typical failures resulting from the working environment as well as typical failures related to diesel engines.

Table 5. The significance of the failure consequences according. Source: own processed data [7, 8]

Significance of the failure consequences	Customer related level	Production related level	Grade
Dangerous – no warning	A very high grade; a potential failure affects the safety of the machine without warning and/or does not comply with the statutory rules.	or a machine or its assembly may endanger the operator without warning	10
Dangerous – with a warning	A very high grade; a potential failure affects the safety of the machine with a warning and/or does not comply with the statutory rules.	or a machine or its assembly may endanger the operator with a warning	9
Very high	The product / system is inoperative (loss of basic properties).	or 100 % of the product must be scrapped or remade and repaired with a repair time of more than one hour.	8
High	The product / system is operating but its performance is reduced, the customer is unsatisfied.	or the product needs to be segregated and a part of it (less than 100 %) is scrapped or remade and repaired with a repair time of half an hour to one hour.	7
Medium	The product / system is functional but the operating comfort is reduced. The customer is unsatisfied.	or a part is remade and repaired in less than half an hour without the need to segregate the product (less than 100 % is to be scrapped).	6
Low	The machine operates at a partially reduced performance and comfort.	or 100 % of the product has to be remade or repaired	5
Very low	Failure spotted by the majority of customers (more than 75 %)	or it is possible to segregate the product and its part (less than 100 %) must be remade	4
Of a little significance	Failure spotted by 50 % of customers.	or a part (less than 100 %) must be remade (cannot be performed on the spot)	3
Insignificant	Failure spotted by selective customers (25 %).	or a part (less than 100 %) must be remade (can be performed on the spot)	2
No significance	No significance	or a minor difficulty in performance or in the operator's control or without significance	1

Table 6. The probability of occurrence of failure according. Source: own processed data [7, 8]

PROBABILITY of failure	Frequency of failure	Grade
Very high: Failure is almost inevitable	>= 100 out of 1,000 pcs	10
Very high: Failure is almost inevitable	50 out of 1,000 pcs	9
High: Reoccurring failures	20 out of 1,000 pcs	8
High: Reoccurring failures	10 out of 1,000 pcs	7
Average: Occasional failures	5 out of 1,000 pcs	6
Average: Occasional failures	2 out of 1,000 pcs	5
Average: Occasional failures	1 out of 1,000 pcs	4
Low: Relatively small number of failures	0.5 out of 1,000 pcs	3
Low: Relatively small number of failures	0.1 out of 1,000 pcs	2
Very low: Failure is unlikely	<= 0.01 out of 1,000 pcs	1

Table 7. The probability of detection of failure according. Source: own processed data [7, 8]

Probability of detection of failure	Criteria	Grade
Almost impossible	Absolutely undetectable	10
Very difficult	Probably undetectable by inspection	9
Difficult	Low chance of detection by inspection	8
Very low	Low chance of detection by inspection	7
Low	Possible detection by inspection	6
Medium	Possible detection by inspection	5
Medium high	A good chance of detecting by inspection	4
High	A good chance of detecting by inspection	3
Very high	Almost certainly detected by inspection	2
Almost certain	Certainly detected by inspection	1

Table 8. Own FMEA form. Source: own processed data

Title FMFA					Date of the FMEA		
Subject of the FMEA					FMEA Team		
Crawler crane							
Possible failure	Possible consequence	Cause	Significance	Occurrence	Detection	Possible risk	Recommended precautions
failure of electronics	broken display	short circuit	8	5	6	240	inspection
		manufacturing defect	8	3	3	72	inspection
defective contact	defective lift limit switch of the wire rope	wear and tear	7	8	3	162	inspection
		manufacturing defect	7	2	9	126	inspection
defective cabling	defective plate on the boom	material wear	9	8	5	360	inspection of material
		manufacturing defect	9	3	7	189	inspection
defective diesel particulate filter	higher fuel consumption, the engine does not have the thrust, the exhaust system could be damaged	clogging by soot and micro particles	9	8	2	144	cleaning
		clogging by contaminated fuel	9	6	4	216	selecting good quality fuel with a suitable additive
defective winch	the rope does not wind	wear and tear	9	7	2	126	maintenance
		insufficient power supply	9	4	4	144	inspection
defective water pump in a diesel engine	overflowing	damaged material	7	4	3	84	inspection
	incorrect pressure	leakage	7	6	4	168	inspection

incorrect combustion of the engine	increased smokiness of the engine	pump adjusted incorrectly	9	5	2	90	inspection
		ignition advance incorrectly set	9	6	2	108	inspection
high fuel pressure	damaged pressure sensor	injection incorrectly adjusted	8	3	2	48	inspection
clogged fuel lines	the engine is difficult to start or will stop soon, the engine cannot be started	impurities from the lines	8	6	2	96	observance of hours of work
		clogging by contaminated fuel	7	3	2	**42**	selecting good quality fuel with a suitable additive
incorrect pressure in the fuel pump	defective high pressure fuel pump	sediments	8	6	2	**96**	observance of hours of work
		incorrect adjustment	8	3	2	**48**	inspection
damaged engine wiring	engine wiring replacement	exposure to extreme heat	6	5	4	**120**	measures to protect against heat
deformation of the boom	boom replacement	fall	10	3	1	**30**	observance of working procedures

4 Suggestions and recommendations

On the basis of the results of the FMEA, the following results can be evaluated:

- the highest probability of the failure during operation of the machinery concerns the electrical parts – damage to the wiring, short-circuit and wear of the material;
- another area of possible damage is the hydraulic system of the machines;
- with increasing environmental protection from the perspective of emissions the risk of frequent failures in the fuel and exhaust system of the engine also increase.

In order to eliminate defects in the operation of the machinery and to prevent the occurrence of failures, it is necessary to carry out regular maintenance in specified operating cycles; also, operators of the machines should be trained in the basic knowledge of the machine structure. In addition, checking the condition of the machine upon completion of work should be included in the operators' work duties; any minor defects should be reported and eliminated by means of maintenance to prevent damage in the event of an accident or machine breakdown.

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