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An attempt to use FMEA method for an approximate reliability assessment of machinery

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Abstract. The paper presents a modified FMEA (Failure Mode and Effect Analysis) method to assess reliability of the components that make up a wrench type 2145: MAX Impactol TM Driver Ingersoll Rand Company. This case concerns the analysis of reliability in conditions, when full service data is not known. The aim of the study is to determine the weakest element in the design of the tool.

1 Introduction

Reliability is an ability of devices to fulfil specific functions. It is characterised by models of the functions of reliability distribution that are time-based. These models are associated with a function that determines the intensity of damage occurring during operation. These are statistical dependencies relating to a certain population of devices used under certain conditions. Reliability of devices is shaped by factors which can be attributed to groups related to:

• Construction,
• Use of materials and production technologies,
• Conditions of use.

When deciding on use of devices for specific tasks, conformity of their operating conditions with operating conditions intended by the equipment producer [1] should be determined. It is often necessary to use devices that are designed to operate under conditions not anticipated by the producer. There is also a scenario of determining suitability of the device for use in conditions that have not been tested to improve the construction of the device.

In practice, equipment acceptance tests are used. They involve adoption of certain number of failures and an assumption of significance level for which they are determined and then the probable time of use between consecutive failures. Unfortunately, these tests do not meet expectations regarding the probability of failure of individual parts of the device.

In order to determine reliability of the equipment, it is necessary to carry out extensive tests in a form of statistical dependence for specific conditions. It is a laborious and costly task.

In this work, an attempt was made to use the FMEA method to estimate reliability of an Ingersoll Rand Company 2145 MAX Impact™ wrench dedicated for the automotive industry and used in the mining industry.

2 Characteristics of the device and its conditions of use

The view of the device is presented in Fig. 1.

Fig. 1. A view of the wrench type 2145: MAX Impactol TM ¾" Driver produced by Ingersoll Rand Company (images taken from http://www.ingersollrandproducts.com).

Basic technical parameters of the impact wrench:

• Impact rate: 1 150 BPM.
• Max speed: 7 000 RPM.
• Average speed: 6 300 RPM.
• Noise level: 91.1 dB.
• Average air consumption: 241 L/min.
• Max air consumption: 906 L/min.

According to the producer, the impact wrench is designed for mounting and dismantling screw connections. This task is accomplished by generating a specific torque of impulsive force. Impact wrenches ensure that the maximum torsional moments are not exceeded during the screwing cycle, thus, ensuring repetitive tensile stresses in the bolts and preventing

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damage to the joints. Reliability and durability during assembly and disassembly of screw connections in service conditions of keys is a decisive feature of their usefulness [2]. This feature is supported by easy control, easy torque change and activation (switch on/off).

These types of pneumatic impact wrenches are designed for various types of assembly and repair works. In particular, they are widely used in the automotive industry, and less often in heavy works e.g. in mining. In hard coal mining, pneumatic wrenches are used during assembly and dismantling of mining enclosures, and therefore, used in significantly less favourable conditions. The operation of pneumatic impact wrenches in the mining industry is characterised by very difficult conditions, different from other applications. They include:

- High level of dustiness,
- High humidity, or even drowning a device in muddy waters,
- Haste in work,
- Difficult, frequently improper conditions of device storage (during brakes).

The minimum time required to use keys in their stand-by mode should ensure that all work, including the assembly of the mining enclosure, is performed in the full and exclude the risk of losses due to damage and loss of required functions.

An important problem is the serviceability of the device (wrench), understood as the ability to maintain or reconstruct a functional state after failure, to fulfil the intended tasks [3-4]. This problem is directly related to the construction of three main functional units: pneumatic motor, impactor and compressed air control unit. The pneumatic motor accelerates the inertia element, which periodically hits the projections of the wrench operating shaft. The outer mass, which is driven by the pneumatic motor, transmits through the resilient combination of energy colliding elements to the inertia element. By the stiffness of the seat-screw system (spring mechanism), the inertia element transfers energy to the screw, which in the model is treated as a substrate. During operation, the inertial element periodically collides with a very rigid screw-socket system and, as a result, a sudden (in-step) fall in inertial velocity occurs. The jumping drop and increase in inertial velocity, in turn, results in the generation of torque applied to a short impulse with a significant peak value. The double oscillation system used in impact wrenches enables very efficient transfer of energy from the impactor to the screw. The individual wrench solutions [8-11] differ in the construction of the inertial element and the coupling mechanism and in the inertia element.

In the present case, the system of pneumatic drive consists of 9 elements, the drive control system also consists of 9 elements, while the impactor consists of 8 elements.

3 FMEA method and its use

FMEA method (Failure Mode and Effect Analysis) does not use experimental data as standard, but it involves a methodical analysis of the future design. For this reason, the results of this analysis can be used to eliminate defects in future products or future processes [12]. Improvement in construction is obtained by identifying the causes of potential defects, analysing the possibility of failure, applying effective preventive measures and avoiding the occurrence of identified hazards in new products or processes. This is achieved with knowledge and experience from previous experiments and similar works.

The FMEA was developed in the 1960s for the needs of the American space program Apollo-Saturn. It is a current standard [12] in various industries, where the product is required to be particularly reliable for its safety. The method allows to verify the design, remove sources of product defects inherent in its design and build the production process. This saves a lot of money to cover the so-called "bad quality costs". As a result, cheaper and better-quality products can be produced; thus, a manufacturer gets a better competitive position.

The method works in a variety of conditions: in serial and unit production – wherever a defect in a product can expose the manufacturer to serious financial losses. Its use is consistent with the principle: it is better to prevent than repair.

Another important feature of the FMEA is that the project can undergo further analyses, introducing improvements that are increasingly effective in eliminating sources of product defects. Project analyses can provide new ideas to improve the properties of the product. In this way, the FMEA method is entered in the Deming Wheel Cycle: P-D-C-A (Plan-Do-Check-Act). It makes it very useful both in ISO 9001 quality assurance systems, as well as in TQM-compliant systems [13].

This method consists in assigning a numerical indicator to all components of the device, and then in ordering the part according to the likelihood of failure.

The FMEA does not specify, for example, the average time between failures or reliability function, but it can be used to describe a type, effect, cause and severity of damage to the functional units of a device that are globally defined by the so-called risk priority number. A high value of this number, referring to specific construction elements, indicates the appropriateness of using preventive measures to improve the reliability of the device.

Figure 2 shows the structure of the modified FMEA method. The introduced change consists in adapting this method to the analysis of an existing structure, rather than those being designed and used in the criteria determining the risk of failure in MTBF time. The method is limited to numerical determination of three characteristic elements of every construction:

- Probability of the event occurring (LPW),
- Severity of the event (LPZ),
- Detection of the event (LPO).

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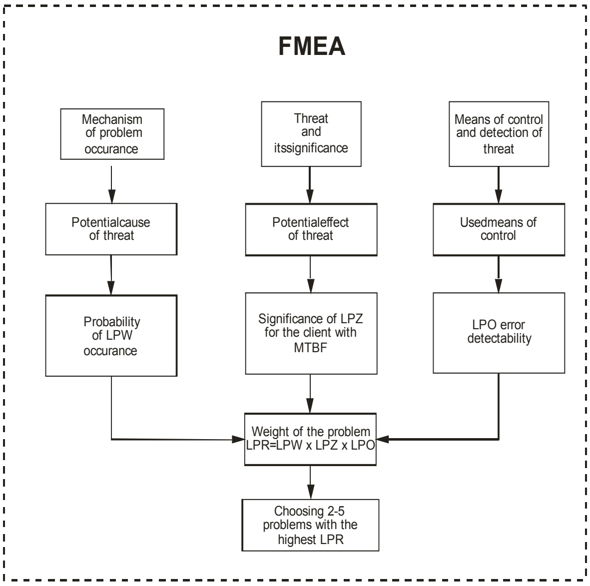

Fig. 2. The structure of a modified FMEA.

For each failure, one should calculate the LPR, which is an index of event priority (the weight of the problem), which is the product of the values of the indicators: LPW, LPZ, LPO. A high value of the LPR indicates a high importance of the part in the design of the device, with the high probability of failure of that part and the high severity of the failure for the user.

4 Practical example

A practical use of the FMEA method was demonstrated in the example of the impact wrench 2145: MAX Impactol. The basic element of FMEA analysis is the method of evaluating the value of three basic indicators (LPW, LPZ, LPO). They are necessary to prioritise the threat and are defined in Table 1. For each element of the structure, numerical weights of the problem are assigned. They were identified by answering the following questions:

1. What is the probability of a failure in each element (defining LPW)?
2. If the failure occurs, what is its severity for the user (defining LPZ)?
3. If the failure occurs, what is the probability of detecting this even by the user (defining LPO)?

For each of the questions listed, consider the values in Table 1 referenced for each element of the structure. The values were expressed by numbers of the answers to the individual questions. This value will be used to rank the "importance of events".

Additionally, to determine the LPW, LPZ and LPO values, MTBFs (Mean Time Between Failures) were estimated based on data provided by the service.

Mean time between failures of a given device is calculated from the formula [5-7]:

$$MTBF = \frac{t_e \cdot 100}{r} \tag{1}$$

Where:
r – number of failure of a given element per 100 failures,
t_e – time of constant use (in this case c.a. 2480 hours).

The significance of MTBF for shaping the criteria LPW, LPZ AND LPO are presented in Table 1.

The LPW, LPO values (Table 1) were determined by estimation, based on work experience. On the other hand, LPZ (Table 1) was adopted using an additional criterion (MTBF) not part of FMEA analysis as defined in standard [12].

Table 1. Numerical evaluation of risk priority number (PRN).

Probability	LPW	Severity	LPZ	Detection	LPO
Failure occurrence within 2 years: 0<n<30.	3	MTBF >6000 hours.	1	Failure grows slowly and is easy to observe in exploitation.	2
		MTBF 4000÷6000 hours.	2	Failure grows slowly and is difficult to observe.	5
Failure occurrence within 2 years: 30<n<120.	6	Failures grow in an observable manner and lead to small limitation of performing element's function MTBF is 2000÷4000 hours.	4	Failure grows fast and is observable.	7
		For failures grow in an observable manner and lead to limitation of performing element's function MTBF is 1000÷2000 hours.	5-6		
Failure occurrence within 2 years: n>120.	10	For failures grow in a step manner and lead to significant limitation of performing element's function MTBF is 500÷1000 hours.	7-8	Failure grows fast and is not possible to observe.	10
		For failures that cause malfunctioning of the element and generate losses for the client MTBF<500 hours.	9-10		

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The numerical results of LPW, LPZ, LPO and numerical result of FMEA analysis in a form of LPR were calculated by multiplying LPW, LPZ and LPO values for individual parts of the wrench are presented in Table 2.

Table 2. Event priority number (PRN) was calculated according to FMEA methodology.

Name of system	Element	LPW	LPZ	LPO	LPR
Pneumatic drive	Rotor front bearing	10	10	1	100
	Rotor rear bearing	10	10	1	100
	Cylinder	10	3	10	**300**
	Casing	6	10	2	120
	Blade package	6	3	7	126
	Rear bearing distance of the rotor	6	3	2	36
	Engine washer	6	3	2	36
	Rotor	6	5	7	210
	Front plate	6	3	10	**180**
Drive control	**Buttons set**	10	10	10	**1000**
	Rotary valve assembly	10	5	5	250
	Trigger assembly	10	5	2	100
	Spacer inlet sleeve spacer	10	3	5	150
	Set of inlet assembly	6	3	5	90
	Filter of inlet sleeve	3	3	7	63
	Power control knob	3	5	2	30
	Rotary knob	3	5	2	30
	Inlet band sleeve	3	10	10	**300**
Impactor	Impactor chamber screw	10	3	2	60
	Impactor chamber sleeve	6	5	2	60
	Impactor chamber washer	6	3	2	36
	Hammer frame assembly	6	3	10	180
	Impactor hammer	6	5	2	60
	Impact chamber assembly	6	10	10	**600**
	Pin	6	10	2	120
	Hammer stroke	6	10	2	120

The results presented in table 2 are based on three functional assemblies consisting of the wrench construction. For each team, two parts with the highest LPR value were selected. These are important parts in the design of the device, with the high probability of failure of this part and high severity of the failure for the user. In the next step for these parts, a program of actions to improve the construction and the program of actions preventing the occurrence of the failure have been developed.

5 Conclusions

FMEA analysis can be used for a rapid, descriptive assessment of reliability of products construction for use in industry. The illustrated example of a practical use of the method shows that the FMEA method can be modified in a simple and fast way for specific needs, e.g. by considering other additional factors such as MTBF.

Because of the analysis for the Ingersoll Rand impact wrench Type 2145 MAX Impactol TM ¾ that the most likely damage was found in:

• Pneumatic motor assembly: cylinder and front plate,
• The control unit: the set of buttons and the sleeve of the intake assembly,
• Impact assembly: the impact chamber assembly.

The results obtained have been confirmed by the complex reliability analyses carried out by the wrench service company.

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References

1. M. Klank, Przegląd Górniczy. **12** (2013)
2. S. Szymaniec, Napędy i sterowanie. **18,** 66-72 (2016)
3. P. Fuchs, J. Zajicek, Maint. Rel. **15**. (2013)
4. W. Zhigang et al., SAE International Journal of Materials and Manufacturing. **9**, 303-314 (2016)
5. M. Morelli, Reliability and Maintainability Symposium (RAMS), 2016 Annual. IEEE (2016)
6. L. Xiaolei,. Revista de la Facultad de Ingeniería, **31.7** (2016)
7. R. Langlois-Berthelot, *Trwałość niezawodność funkcjonalność wyrobów przemysłowych* (WNT, Warszawa, 1972)
8. US 6.186 332 B1
9. US 6.889.778 B1
10. US 8.074.732
11. WO 2012/138721
12. IEC 812
13. PN-EN ISO 14121-1:2008