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IDENTIFICATION OF POTENTIAL FAILURES OF THE TEST STAND FOR TESTING HYDRAULIC PUMPS USING FMEA METHOD

WYKRYWANIE POTENCJALNYCH WAD DLA STANOWISKA DO BADANIA POMP HYDRAULICZNYCH METODĄ FMEA

A b s t r a c t

This paper shows FMEA analysis using "function-failure" approach to define potential failures of a system, its grouping and classification. The paper shows criteria according to which FMEA analysis was conducted for the test stand for testing of electronically controlled hydraulic pumps. The results of analysis will be used for improvement of the investigated test stand.

Keywords: FMEA, "function-failure" approach, hydraulic system, failures

S t r e s z c z e n i e

W artykule przedstawiono analizę FMEA wykorzystującą podejście „funkcja-wada" do określania potencjalnych wad wyrobu, ich grupowania i klasyfikacji. Przedstawiono kryteria, według których analiza FMEA została przeprowadzona dla nowo budowanego stanowiska do badania pomp hydraulicznych sterowanych elektronicznie. Zaprezentowane w referacie wyniki analizy zostaną wykorzystane do ulepszenia projektowanego stanowiska.

Słowa kluczowe: FMEA, podejście „funkcja-wada", układ hydrauliczny, wady

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1. Introduction

The process of creation of new machines and devices might be divided into 6 basic stages: preparation of technical and operational requirements, design requirements, initial design, a prototype and its test and a pilot series. Each of these stages is important from the designer's point of view. However, taking into account the influence of individual stages on functionality and reliability of machines and devices during their operations it might be noticed that design stage has a great influence in this range. Therefore, it is important to analyze potential failures of product at the design stage and on the basis of this information make modifications of the project. One of the ways to identify probable failures is using qualities methods. Failure Mode and Effects Analysis (FMEA) is one of such methods. This method is very popular over the last years.

Failure Mode and Effects Analysis using "function- failures" approach is presented in the paper. This analysis was used for a test stand for testing of new generation of electronically controlled, variable delivery hydraulic pumps.

2. The object of research

Fig. 1 shows the diagram of investigated test stand for testing of electronically controlled, variable delivery hydraulic pumps.

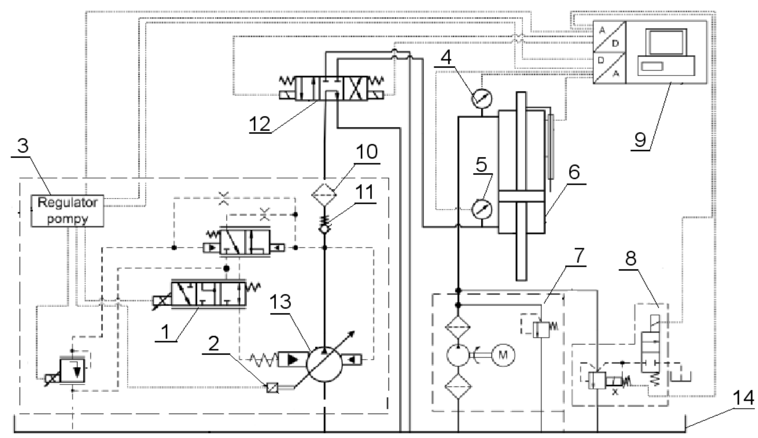

Fig. 1. Diagram of analyzed test stand

Rys. 1. Schemat analizowanego stanowiska

The test stand consists of: overflow valve (1), positioning system of stator ring transducer (2), control system (3), pressure transducers (4, 5), double acting – double piston rod hydraulic cylinder (6), load supply system (7), proportional valve for controlling load pressure (8), data acquisition and control unit (9), filter (10), return valve (11), 4-port 3-+position directional control valve (12), variable displacement vane pump (13), hydraulic fluid tank (14).

3. Principles of the FMEA method

For the determination of relations describing influence of potential failures on functions realized by the investigated system, the FMEA analysis with “function-failure” approach was used. The data included in knowledge database, formed on the basis of previous analyses could be a source of information about the potential failures for analysis functions for such an approach. FMEA analysis using “function-failure” approach is realized in 3 steps: preparation stage, analysis and conclusions. In the preparation stage of the analysis, information about analyzed system should be found. For this purpose, analyzed system should be divided into components and the list of components (C) should be created. For each component, potential failures (F) are defined and realized functions (E) as well. Therefore, it is important to be familiar with operation of all components of the system before conducting the FMEA analysis. Thanks to that, given function will be adequately assigned to proper components. In the next step of FMEA, relations among the following: components (C), failures (F) and functions (E) are analyzed. When failure appears in CF relation or function appears in EC relation, than this fact is described by binary number or a real number. Binary system is used if the designer does not have enough information about analyzed system. Value 1 is used when failure exists whereas value 0 when it does not exist. Works focused on developing method of valuation are currently conducted. One of the methods that is considered to be applied is the computer graphics system. Works on such way of valuation are carried out at Cracow University of Technology. When CF relation and EC relation are created than probability of failure which might happened for components functions are defined. For that purpose EF relation is formed as the result of valuation between CF relation and EC relation [4]. In the second stage of analysis, the obtained failures are grouped and classified for the sake of their frequency of appearance in analyzed system. The similarity method “component – failure” which is described in [1] with equation presented below, may be used for that purpose:

$$\Lambda = CF^T \times CF \quad (1)$$

where:

- Λ – relation which is use to separate the group of failures,
- CF – “Component – Failure” relation,
- CF^T – “Component – Failure” transpose of a relation.

In the next step of analysis the groups of failures are classified in three levels (I, II and III). Classification is made according to the selected criterion. The following criteria were created: level I includes group of single failures which appears at analyzed system most often, level II contains group of two or three failures whereas level III contains groups of failures which include more than three failures (failures with the lowest probability of appearance). When all the groups of failures are classified, failures appeared for given function of analyzed system are described. On the last stage of analysis failures which have negative influence for function are identified. The identification is realized according to the “three steps” [1]. In the first step of analysis is assumed the principle that each failure of level I should always be considered at the design stage for new projects. In the second step of analysis, functions which will be analyzed in detail should be selected. For each of these functions a failure with the highest probability of appearance is defined. This information might be obtained from "function – failure" relation (EF) presented in table 1 and table 2. In the third step, failures which have the highest probability of appearance for given function have to be grouped and classified to proper level: I, II or III. If failure belongs to the first level it is always analyzed by designer. If failure belongs to the second level, all group of failures belonging to this level are to be analyzed, whereas when failure belongs to level III than the influence of the whole level on function realized by the system it is not considered but only this failure which has influence on functions analyzed by designer. The analysis results in the set of failures for analyzed system which should be analyzed on the design stage by designer. This set might be marked as "A".

If make an assumption that besides the set A there also exists the set B containing all possible failures defined on the basis of previous analyses for similar systems, than it might be assumed that the set A is contained in the set B. This relation might be described in symbolic form (2).

$$A \subset B \tag{2}$$

where:

A – set of failures which were identified during analysis of the system,

B – set of all possible failures.

During analysis, sometimes not all of possible failures for analyzed system will be identified. Than besides the set A also the set C exists, which describes set of failures not identified during analysis. Therefore notation (2) could be have a form presented below:

$$(A \cup C) \subset B \tag{3}$$

where:

C – set of failures not identified during analysis.

4. The FMEA analysis

Analysis started from decomposition of the test stand. The 20 components were selected for the analysis. For each component functions realized in the system were defined (sum of 6 functions) and possible failures (sum of 19 failures). In the next step, relation among components, functions and failures were defined. On the basis of this data "function – failure" relation for the whole system was obtained. This relation is presented in table 1 and table 2.

In the next stage of analysis, on the basis of EF relation, "component – failures" influence of identified failures on analyzed system was defined using similarity method (Table 3). Relation presented in the table 3 (marked as Λ) is the base for grouping failures and their classification according to criteria "close values of appeared failures" (for example: fracture (7) – galling (6)). Other ways of failure grouping might be also considered. One of them is grouping of failures for the sake of their tendency for common action on analyzed system or situation in which existing failure cause another failure.

Table 1

The influence of failures on functions realized in the hydraulic system (EF)

	Fracture F1	Galling F2	Corrosion F3	Wear F4	Damage F5	Abrasion F6	Overheating F7	Leak F8	Aeration F9	Tightness loss F10
Safety	2	1	2	2	6	0	0	0	0	0
Stabilization	2	2	1	2	0	1	1	1	1	0
Position	1	1	1	0	0	0	0	0	0	0
Separation	2	1	0	6	2	0	0	1	1	0
Transformer	1	2	1	2	4	1	1	0	0	0
Control	0	1	1	2	8	0	0	0	0	0
Accumulation	0	0	0	0	0	0	0	1	1	0
Connector	1	0	0	0	0	0	0	0	0	1
Transport	1	1	0	2	2	0	0	0	0	0
Regulation	0	0	0	0	2	0	0	0	0	0

Table 2

The influence of failures on functions realized in the hydraulic system (EF) cont.

	Bend F11	Chemical contamination F12	Silting-up F13	Pollution F14	Oxidation F15	Ageing F17	Emulsification F18	Shearing F19	Maladjustment F20
Safety	0	1	1	2	1	1	1	1	0
Stabilization	0	0	0	0	0	0	0	0	0
Position	0	0	0	0	0	0	0	0	0
Separation	0	0	0	2	1	1	1	1	0
Transformer	0	0	0	0	0	0	0	0	0
Control	0	0	0	0	0	0	0	0	2
Accumulatio n	0	0	0	0	0	0	0	0	0
Connector	1	1	0	0	0	1	0	0	0
Transport	0	0	0	2	1	1	1	1	0
Regulation	0	0	0	0	0	0	0	0	0

Table 3

Relation of the influence of failure on investigated hydraulic system (Λ)

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19
F1	7	4	1	8	6	1	1	0	0	1	1	0	0	0	0	0	0	0	0
F2	4	6	2	6	4	2	2	0	0	0	0	0	0	0	0	0	0	0	0
F3	1	2	3	0	2	1	1	0	0	0	0	0	0	0	0	0	0	0	0
F4	8	6	0	28	16	2	2	0	0	0	0	2	2	0	0	0	0	0	0
F5	6	4	2	16	44	0	0	0	0	0	0	2	2	0	0	0	0	0	4
F6	1	2	1	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
F7	1	2	1	2	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0
F8	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
F9	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0
F10	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
F11	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
F12	0	0	0	2	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0
F13	0	0	0	2	2	0	0	0	0	0	0	1	1	0	0	0	0	0	0
F14	0	0	0	0	0	0	0	0	0	0	0	0	0	4	2	2	2	2	0
F15	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	0
F16	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	0
F17	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	0
F18	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	1	1	1	0
F19	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	4

As an example of this type of failures: "high cycle fatigue" and "cracking". On the basis of accepted criteria, 19 identified failures were grouped in 5 groups and next they were classified in three levels: I, II and III. The way of grouping failures and their classification is presented in table 4.

Table 4

Groups of failures identified in investigated hydraulic system

<table>
<tr><th>Number of group</th><th>Failures</th><th>Values from table 3</th><th>Level of classification</th></tr>
<tr><td>1</td><td>Damage</td><td>44</td><td rowspan="2">I</td></tr>
<tr><td>2</td><td>Wear</td><td>28</td></tr>
<tr><td rowspan="2">3</td><td>Fracture</td><td rowspan="2">7–6</td><td rowspan="5">II</td></tr>
<tr><td>Galling</td></tr>
<tr><td rowspan="3">4</td><td>Corrosion</td><td rowspan="3">4–3</td></tr>
<tr><td>Pollution</td></tr>
<tr><td>Maladjustment</td></tr>
<tr><td rowspan="11">5</td><td>Abrasion</td><td rowspan="11">2–1</td><td rowspan="11">III</td></tr>
<tr><td>Overheating</td></tr>
<tr><td>Leak</td></tr>
<tr><td>Aeration</td></tr>
<tr><td>Tightness loss</td></tr>
<tr><td>Bend</td></tr>
<tr><td>Chemical contamination</td></tr>
<tr><td>Silting-up</td></tr>
<tr><td>Oxidation</td></tr>
<tr><td>Emulsification</td></tr>
<tr><td>Shearing</td></tr>
</table>

In the last stage of analysis, failures which have negative influence on function realized by the test stand were analyzed using method of three steps. The procedure on this stage of analysis was presented for “position” function. In the first step groups of failures for the first level of classification were defined. There are groups “one” and “two” presented in table 4, where group “one” represent failure “damage” and group “two” failure “wear”. These failures should be always analyzed at the design stage of the system or during conceptual modification. In the second step on the basis of EF relation (table 1 and table 2) failures with the highest probability of appearance were defined for analyzed function “position”. There were functions: fracture (F1), galling (F2) and corrosion (F3). On this stage of analysis it is necessary to answer the question: are these failures causing others failures in the analyzed system? If answer is “yes” than a type of failures and their influence on analyzed system should be defined. In the third step of analysis it has to be defined which group of failures contain failures appeared in the previous step. Acoocrding to table 4, failures “fracture” and “galling” belong to third group of failures whereas failure “corrosion” belongs to the fourth group. Both of these groups are classified as level II. Therefore, according to rules on all failures from groups 3 and 4 should be analyzed at the design stage. As the consequence of analysis, the set A containing failures which must be analyzed at the design stage is obtained. It contains following failures: damage F1, wear F2, fracture F3, galling F4, corrosion F5, pollution F6 and maladjustment F7. As it arises from CF relation (Table 5) set A influences defective action or damage on 19 out of 20 analyzed components.

Table 5

Relation component – failures

		F1	F2	F3	F4	F5	F6	F7
Component	Housing	1	1	1	0	0	0	0
	Sealing ring	0	0	0	2	0	0	0
	Vent valve	0	0	0	0	2	0	0
	Seal	1	0	0	2	0	0	0
	Ring	1	0	0	0	2	0	0
	Rotor	0	1	1	0	0	0	0
	Blades	1	1	0	2	2	0	0
	Slide bearing	1	1	0	2	0	0	0
	Stator ring	0	0	1	0	2	0	0
	Control plates	0	0	0	0	2	0	0
	Position plungers	0	1	0	0	0	0	0
	Return valve	0	0	0	0	2	0	0
	Double acting – double piston rod hydraulic cylinder	1	1	0	2	2	0	0
	Lines	1	0	0	0	0	0	0
	Directional control valve	0	0	0	2	2	0	0
	Filter	0	0	0	2	2	0	0
	Overflow valve	0	0	0	0	2	0	0
	Hydraulic fluid	0	0	0	0	0	2	0
	Positioning system of stator ring	0	0	0	0	2	0	2

Failures possible to occur were generally formulated during analysis because the author of this paper wanted to show the procedure for “function-failure” approach. However, in analysis prepared at the design stage it is necessary to precise failures possible to occur in analyzed system, for example: if we identify failure “wear” for analyzed component, than a type of wear should be defined. An exemplary way of identification types of failures is presented in Table 6.

Table 6

Identification of failure types

Failure	Type of failure	Definition
Wear	Abrasive	Wear due to hard particles or hard protuberances forced against and moving along a solid surface [2].
	Adhesive	Wear due to localized bonding between contacting solid surfaces leading to material transfer between the two surfaces or the loss from either surface [2].
	Corrosive	Corrosive wear occurs when the sliding surfaces are in a corrosive environment [3].

5. Conclusions

In this paper the FMEA analysis was conducted for the test stand for the new generation of electronically controlled, variable delivery hydraulic pumps. The analysis was carried out for 20 components of investigated system. For each component, possible failures and realized functions were defined. On the basis of “function-failure” relation and “component-failure” relation failures were grouped and classified according to the assumed criteria. Possible failures of analyzed test stand which should be analyzed at the design stage were defined. The way of identification of failure types for hydraulic systems was proposed.

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