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Matrix FMEA analysis with cause-effect diagram for selected fluid power component

Macierzowa analzia FMEA z wykorzystaniem diagramu przyczynowo-skutkowego wybranego elementu hydrauliki siłowej

Abstract

This paper presents an application of matrix FMEA analysis and cause-effect diagram for a double acting hydraulic cylinder. A decomposition of the investigated cylinder has been made and main functions and potential failures for the pair-function relation have been identified. Elements with the greatest probability of failure and cause-effect relationship have been determined.

Keywords: FMEA, cause and effect diagram

Streszczenie

W artykule przedstawiono macierzową analizę FMEA siłownika hydraulicznego dwustronnego działania. Dokonano dekompozycji, zidentyfikowano podstawowe funkcje i potencjalne wady dla relacji para–funkcja. Określono elementy, które charakteryzują się największym prawdopodobieństwem wystąpienia wad i wyznaczono związki przyczynowo-skutkowe.

Słowa kluczowe: FMEA, diagram przyczynowo-skutkowy, hydraulika

1. Introduction

Hydraulic power systems are widely used in many applications due to their versatility and possibility of power transmission. However, more and more demands are put on hydraulic systems to ensure their reliability in extreme environmental conditions. Therefore, the ability of identifying potential defects during the design and manufacturing processes has a great importance. More than a half of all defects arise during the design and manufacturing, but they are detected mostly during operation. Therefore, new methods, tools and techniques that can be used for the assessment of product quality at the design and manufacturing stage have been developed in the last years. Qualitative methods, among which the FMEA (Failure Mode and Effects Analysis) can be distinguished, are examples of such methods. The FMEA is used to identify potential faults and their causes that may arise during the design and manufacturing processes [1]. The method allows for the qualitative assessment of reliability in order to evaluate the risks and consequences of any defects that may have occurred. Because of the possibilities of identification of potential defects at the early stages and relatively simple integration with computer aided and expert systems, the FMEA seems to be an effective tool which may have a great impact on the quality and reliability of hydraulic power systems.

2. The FMEA principles

The FMEA was developed in 1949 for the needs of the US Army and has been described in MIL-P1629 standard "Procedures for Performing a Failure Mode, Effects and Criticality Analysis". The aim of application of this method was the evaluation of the degree of risk of military missions, taking into account command systems, equipment and human resources. Currently, the FMEA is used wherever the product/process, for reasons of people's safety and the environment, is required to meet the "zero defects" principle. Therefore, the FMEA includes not only the manufacturers of final products, but also suppliers, for whom the use of this method is a condition of establishing cooperation. The FMEA procedure is included in the ISO/TS 16949 specification, which integrates qualitative systems in the automotive industry and in EN 60812: 2006 (U) "Analysis techniques for system reliability. Procedure for failure mode and effects analysis (FMEA)" standard as well. The FMEA method which depends on the way potential defects are identified and presented may be divided into classical and matrix methods. Classical FMEA evaluates the Risk Priority Number (RPN), while matrix FMEA determines the function-failure relationship. The matrix FMEA (xFMEA) shows the relationship between investigated components, their functions and identified failures.

3. The xFMEA analysis of hydraulic cylinder

Matrix FMEA analysis was conducted for a typical double acting hydraulic cylinder which is widely used in hydraulic drive systems. The analysis was conducted at three stages. The first one was a decomposition of a hydraulic cylinder structure, identification of the basic functions of components and identification of potential defects. The second stage was to determine three diagrams of dependence. The EP matrix shows the relationship between the pairs of cooperating components (P) and their functions (E). The PF matrix is the relationship between failures (F) and pairs (P). The dependencies were described using a binary evaluation system. The value of 0 is assigned if there is no dependence, while value 1 if a dependency exists. The third matrix (EF) is a function – potential failures relation, which arose as a result of the multiplication of (EP) and (PF) matrixes.

The investigated hydraulic cylinder consists of a cylinder with its bottom and a nut. The cylinder has a piston with a seal and gland. The piston is connected to a self-aligned bearing by the piston rod. There is a wiper ring, two guiding rings and three sealing rings in the gland. The cylinder and its bottom were considered as one component. The piston sealing system was considered as one sealing set. Finally, the FMEA analysis included a cylinder (c1), piston (c2), piston rod (c3), gland (c4), cap (c5), sealing system (c6) and a self-aligned bearing (c7). Subsequently, eleven pairs of cooperating components were determined (p): p1 (c1, c2), p2 (c1, c6), p3 (c1, c4), p4 (c1, c5), p5 (c2, c3), p6 (c2, c6), p7 (c3, c6), p8 (c3, c4), p9 (c3, c7), p10 (c4, c6), p11 (c4, c5). Each pair has an individual function in the cylinder (EP matrix). Four functions have been found:

- fixing (e1): ensures correct position of the components and their alignment: p1, p4, p9, p11,
- converting (e2): energy conversion of working fluid pressure into mechanical energy, energy transfer: p5,
- preventing (e3): prevents against dust, dirt, grains of sand; removes contaminations: p7, p10,
- protecting (e4): secures leakage of hydraulic fluid, sealing the piston and the piston rod, absorbs mechanical vibrations and side load: p2, p3, p6, p7, p8, p10.

In the next step on the basis of available references [2, 3, 8] and identified functions, ten potential failures were determined, which were classified into 5 categories in a similarity matrix. Those are: wear (f1), corrosion (f2), seizure (f3), fatigue (f4) and buckling (f5). In Table 1 each failure (f) a pair (p) in which failure may occur was assigned (PF matrix).

Table 1. Similarities matrix for identified failures for investigated components

Potential failure	Type of failures (f)	Pair (p)
abrasive wear, adhesive wear	wear (f1)	p1, p2, p3, p4, p5, p6, p7, p8, p9, p10, p11
oxidation wear, pitting		
crevice corrosion, fretting corrosion	corrosion (f2)	p1, p4, p5, p7, p8, p9, p10, p11
seizure	seizure (f3)	p1, p2, p3, p6, p7, p8, p10, p11
fatigue friction, thermal fatigue	fatigue (f4)	p1, p3, p5, p8
buckling	buckling (f5)	p9

The matrixes PF and EP were used to create EF matrix of the relationships between the potential failures (f) and functions (e) performed by the individual pairs (p). Table 2 shows the probability of failure in the range from 0 to 6. The value of 6 is the greatest probability of failure occurrence for a given function. The key failures for the investigated hydraulic cylinder are wear (f1) and seizure (f3) for pair implementing function protective (e4). These pairs are: p2, p3, p6, p7, p8, p10 which includes the sealing system. This is the key system that has an impact on the design, operation and durability of the hydraulic cylinder. It is also a most common cause of a cylinder failure. Therefore, the causes and consequences of failures of sealing systems in hydraulic cylinders need to be recognized. For this purpose, the matrix FMEA can be supplemented with the tool of quality improvement, which in this case was the cause and effect diagram.

Table 2. Function-failure matrix

		Potential failure (f)				
		1	2	3	4	5
Function (e)	1	4	4	2	1	1
	2	1	1	0	1	0
	3	2	2	2	0	0
	4	6	3	6	2	0

4. Cause and effect diagram

The diagram of cause and effect is also known as a fishbone diagram due to appearance of a fish-like graph. For the first time this method was used in Japan at Sumitomo Electric. Its purpose is a graphical representation of the relationships between effects and causes [5]. The procedure for solving the problem (effect) consists of four stages:

- determining the effect (of the problem),
- identifying possible categories of causes,
- determining the possible causes for each category,
- selecting the main cause.

For the investigated hydraulic cylinder the sealing failure was found as the main problem. Then six major reasons of causes were selected: I-repair, II-exploitation, III-cooperating components, IV-working fluid, V-design, VI-storage. For each category, possible causes affecting the sealing failure of the hydraulic cylinder were determined. In total, over twenty reasons were selected and three main ones among them. They have the biggest impact on the considered "sealing defects" problem. These are the causes of categories II, III and IV, which are:

- seizure and worn out components,
- poor quality of the working fluid,
- inadequate working conditions.

Graphical presentation of the cause and effect relationship diagram for sealing of the hydraulic cylinder is shown in Fig. 1.

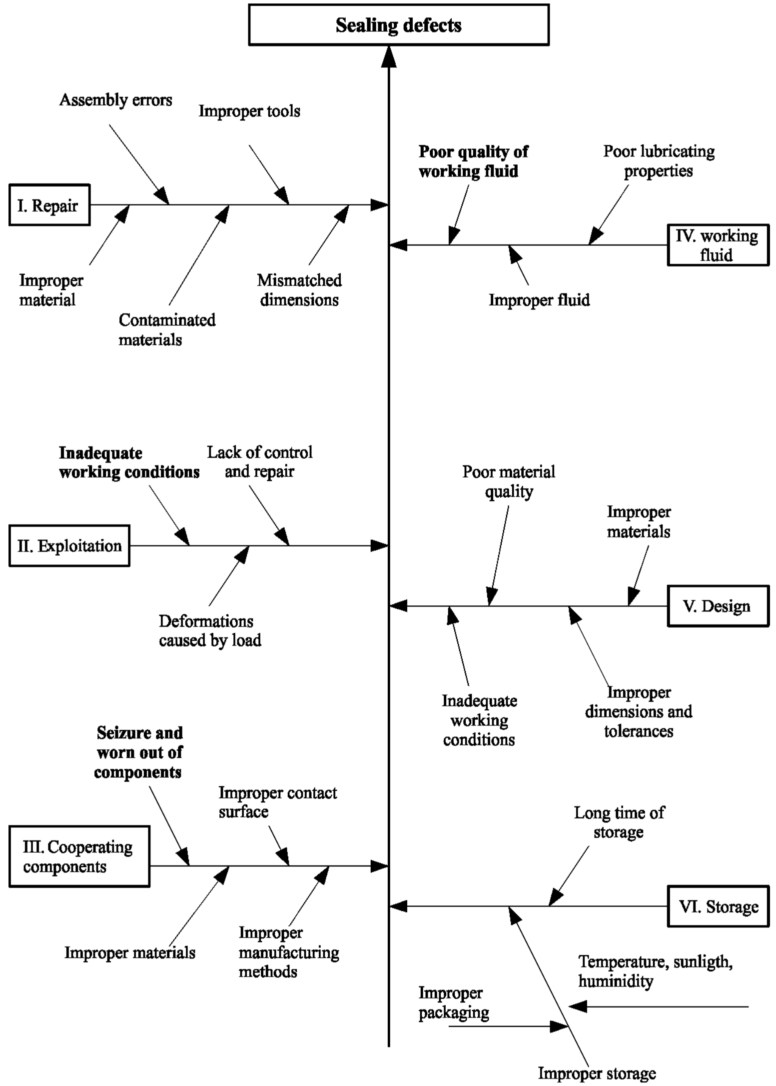

Fig. 1. Cause and effect relationship diagram for sealing system

Within the analysis of cause-effect diagram a hierarchic structure of primary cause has been created which takes into account the probability of its occurrence during cylinder operation:

- poor quality of the working fluid,
- seizure and worn out components,
- inadequate working conditions.

Table 3 shows the main reason along with the description [3, 6].

Table 3. Causes of seal damages

Failure	Description
Poor quality of the working fluid	Solid particles cause seizure of the surface of seals and guiding rings. Air bubbles cause seizure on the inner area of sealing rings on the high pressure area and breaking lip seals.
Seize and worn out components	Improper cylinder selection for operating conditions. Non axial load
inadequate working conditions:	
Extreme temperatures	Seals exposed to high temperature out of the range of working conditions becomes harder may cracks and crumbles.
Aggressive chemical agent	Some working fluids react with seals. Seals becomes sticky, stretched, dried or cracked.
High pressure	The seal may be damaged or deformed over the entire inner surface, leaks may appear.

5. Summary

The matrix FMEA analysis with the use of cause and effect diagram seems to be an effective tool for the identification of potential failures of hydraulic components. It allows to identify the main problem along with main causes which have influence on the problem appearance. As a consequence, preventive measures can be undertaken in time to eliminate the problem, and if the failure already occurred, an improvement plan prepared.

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