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JOANNA FABIŚ-DOMAGAŁA*

FMEA ANALYSIS OF A HYDRAULIC CYLINDER USING ARTIFICAL NEURAL NETWORK

ANALIZA FMEA SIŁOWNIKA HYDRAULICZNEGO Z ZASTOSOWANIEM SZTUCZNYCH SIECI NEURONOWYCH

A b s t r a c t

This paper presents Failure Mode and Effects Analysis (FMEA) on the hydraulic cylinder using matrix analysis and artificial neural network. Functions for each cylinder components were identified. Also relationships between pairs for interacting components and their potential failures where identified. Training and testing of an artificial neural network was conducted in MATLAB software environment.

Keywords: *FMEA, analysis, failure, neural network*

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

W artykule przedstawiono analizę przyczyn i skutków powstawania potencjalnych wad (FMEA) siłownika hydraulicznego przy wykorzystaniu analizy macierzowej oraz sztucznej sieci neuronowej. Określono funkcje, jakie pełnią poszczególne części siłownika. Zidentyfikowano zależności zachodzące pomiędzy parami współdziałających elementów oraz ich potencjalne wady. Trenowanie i testowanie sztucznej sieci neuronowej przeprowadzono w środowisku programowym MATLAB.

Słowa kluczowe: *FMEA, analiza, wada, sieć neuronowa*

* M.Sc. Joanna Fabiś-Domagała, Institute of Applied Informatics, Faculty of Mechanical Engineering, Cracow University of Technology.

1. Introduction

Hydraulic cylinders are one of the most important components of the drive operating mechanisms. These mechanisms and hydraulic cylinders are exposed to external environmental factors such as: dust, variable temperature and dynamic loads. Although the hydraulic cylinders belong to a group of devices with relatively uncomplicated structure they are susceptible to damage and failure. Therefore, the identification of failures in the early stages of its formation allows to undertake an appropriate preventive action, to not allow to extend their influence to other components of the system. According to a study presented in work [1] approx. 75% of all failures is formed during the preparation of manufacturing process but theirs identification at this stage is very negligible. The moment the failures are identified is the production stage. More than 80% occurring failures are removed during the final inspection and during operation, therefore the cost of its elimination is much higher than elimination of defect on the stage when it arises. It is also important to undertake preventive actions even at the design stage of the product. This allows to reduce the costs due to “poor quality” and such actions are in accordance with “the principle of continuous improvement”, E. Deming. Therefore, the methods which allows to detect potential failures and their causes are still developed. In case of hydraulic components the analysis of available literature [3, 4] and qualitative methods shows that using the matrix analysis (FMEA) may be very effective. Such methods may also be easily integrated with computer systems, particularly with expert systems and allows to identify failures on early stages.

The paper presents a matrix FMEA analysis for hydraulic cylinder using selected artificial neural network.

2. The object of analysis

The object of the research is the double action hydraulic cylinder with swivel bearing [1]. The structure of the cylinder is shown in Figure [1], where: 1 – cylinder body, 2 – piston rod 3 – gland, 4 – piston sleeve, 5 – nut, 6 – self aligned bearing, 7 – cylinder end with self aligned bearing, 8 – piston seal, 9, 11, 12 – sealing ring, 10 – wiper ring, 13 – guide ring.

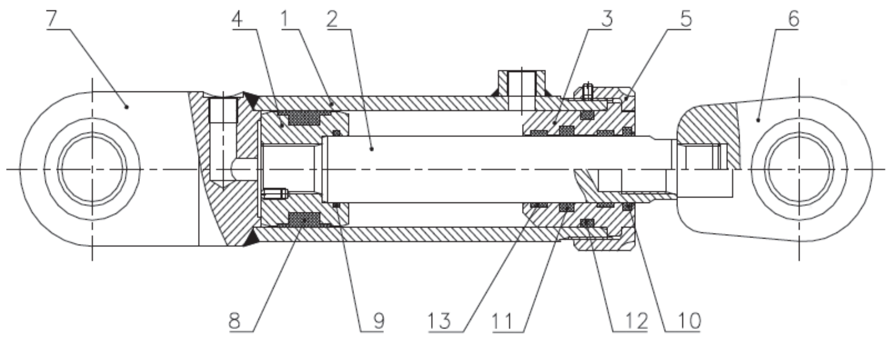

Fig. 1. Scheme of hydraulic cylinder

In order to identify potential failures on a matrix FMEA analysis the hydraulic cylinder structure was decomposed into ten components (*c*) which may cause improper operation. These are: cylinder body (c_1), piston sleeve (c_2), piston rod (c_3), sealing ring (c_4), piston seal (c_5), wiper ring (c_6), ring (c_7), gland (c_8), nut (c_9) and self aligned bearing (c_{10}).

3. Input data for FMEA analysis

The qualitative analysis of the hydraulic cylinder by matrix FMEA method requires to create two matrix EC (function-component) and CF (component-failure) [3, 4]. Using decomposition of the hydraulic cylinder (defined in Section 2) a seventeen pairs of interacting components have been identified. Pairs (*p*) are shown by the matrix diagram where sign (+) means the relationship between the analyzed elements, sign (–) means no dependence, and sign (*x*) means the relationship between the same components.

Table 1

Diagram of relations between the interacting components of hydraulic cylinder (p)

	c_1	c_2	c_3	c_4	c_5	c_6	c_7	c_8	c_9	c_{10}
c_1	x	+	–	+	+	–	–	+	+	–
c_2	+	x	+	+	+	–	–	–	–	–
c_3	–	+	x	+	–	+	+	+	–	+
c_4	–	+	+	x	–	–	–	+	–	–
c_5	–	+	–	–	x	–	–	–	–	–
c_6	–	–	+	–	–	x	–	+	–	–
c_7	–	–	+	–	–	–	x	+	–	–
c_8	–	–	+	+	–	+	+	x	+	–
c_9	–	–	–	–	–	–	–	+	x	–
c_{10}	–	–	+	–	–	–	–	–	–	x

Then, for all the interacting components (Table 1) functions (e) which perform in the hydraulic cylinder have been specified (Table 2).

Based on the identified functions and the analysis of the literature [5] ten failures (*f*) have been identified for interacting pairs of hydraulic cylinder. These are: abrasive wear (f_1), crevice corrosion (f_2), fretting corrosion (f_3), seizure (f_4), fatigue friction (f_5), pitting (f_6), thermal fatigue (f_7), adhesive wear (f_8),oxidation wear (f_9), buckling (f_{10}).

Table 2

Description of functions

Function	Description
fixing (e_1)	the correct position of the hydraulic cylinder components, alignment of the hydraulic cylinder
converting (e_2)	converting fluid pressure energy into mechanical motion straight-back, the main function of hydraulic cylinder
preventing (e_3)	prevents against of dust, dirt, grains of sand, removes impurities
protecting (e_4)	preventing oil leakage, seal cylinder, piston and piston rod guided in the cylinder, the lateral loads and vibration resistance

4. FMEA matrix analysis

The FMEA analysis includes creating two diagrams of dependence. The first one (Table 3) shows the relationship between the pairs of interacting components (p_j) and performed functions (e_i). For each element of the matrix e_ip_j value of 0 or 1 was assigned. If a pair does not perform assigned function than value is 0, if the function is performed than the value is 1. The resulting diagram is size [4 × 17] and contains 68 elements.

Table 3

Diagram of the relationship between functions and pairs (EP)

	p_1	p_2	p_3	p_4	p_5	p_6	p_7	p_8	p_9	p_{10}	p_{11}	p_{12}	p_{13}	p_{14}	p_{15}	p_{16}	p_{17}
e_1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	1
e_2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
e_3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0
e_4	0	1	1	1	0	0	1	1	1	0	1	1	0	1	1	1	0

The second diagram of dependencies (Table 4) shows the relationships between interacting components (p_i) and theirs potential failures (f_j). For each pair of matrix pifj a value of 0 or 1 have been assigned. A value of 0 is assigned if the defect does not occur for the pair. The value of 1 if the defect occurs. The resulting matrix PF has dimension [17 × 10] and has 170 elements. Fragment of PF matrix [8 × 8] is shown below.

At the last stage the FMEA matrix analysis use the principle of multiplication of the matrix presented at work [4]:

$$\mathbf{EP} \times \mathbf{PF} = \mathbf{EF} \quad (1)$$

Table 4

Diagram of the relationship between the pair and their potential failures (PF)

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
p_1	1	0	1	1	0	1	1	1
p_2	1	0	0	1	0	0	0	0
p_3	1	0	0	0	0	0	0	0
p_4	1	0	0	1	1	0	0	0
p_5	1	1	0	0	0	0	0	0
p_6	1	1	0	0	1	1	0	0
p_7	1	0	0	1	0	0	0	1
p_8	1	0	0	0	0	0	0	0

A diagram showing the probability of failures (f) has been built, for pairs of interacting components (p) due to the function (e) performed by the pair in the hydraulic cylinder. Table 5 shows the probability of occurrence of failures in the range of 0 to 11. Value 11 indicates the highest probability of failure for a given function.

Table 5

Diagram function – failure (EF)

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
e_1	4	3	1	2	0	1	1	1
e_2	1	1	0	0	1	1	0	0
e_3	2	2	0	1	0	0	0	0
e_4	11	3	1	9	2	0	1	1

For analyzed hydraulic cylinder the highest probability is for failure: abrasive wear (f_1) for pairs of realizing the protecting function (e_4). These are the following pairs: p_2, p_3, p_4, p_7, p_8, p_9, p_{11}, p_{12}, p_{14}, p_{15} and p_{16} which includes the seal. These components are more sensitive for failures than others of the hydraulic cylinder because:

- the working liquid is contaminated: present in the liquid particles damage the surfaces of the piston, the piston rod and the O-rings,
- aggressive chemical agents: some working fluids react with seals,
- leaks are caused by high pressure,
- extreme working conditions – when the temperature exceeds the operating limits of the use for sealing materials than seals harden, crack and crumble.

5. Analysis of hydraulic cylinder failures using artificial neural network

The artificial neural network is a mathematical relations which imitating the structure and signal processing in the central nervous system of living organisms. Neural networks are the adaptive systems which are capable of pattern recognition due to the learning process. Constant values defining the significance of the inputs (network weights) are determined based on experience (learning examples). By machine learning process we can obtain a situation in which the output data (network response) is close to the actual value. This kind of learning is called supervised learning with the teacher which is most commonly used [7].

Artificial neural networks are characterized by many advantages among which the most important are:

– the ability to learn and generalize the acquired knowledge. Artificial neural networks allow to find regularities in the conditions of a large number of variables of different nature. Such relationships often require the use of complex mathematical operations or are undetectable using mathematical methods,
– the network is resistant to errors in the input data (the noise) and errors appearing in some weights or incorrectly set constant in the model,
– networks enables fast processing of information, often available at the real time.

The most frequently used neural networks are:

– regression or otherwise approximation of unknown functions of several variables (most common), on the basis of experimental observations,
– prediction – predicting the future behavior of the system based on the values of the past within the continuous adjustment of network weights,
– detection of patterns which allows to group signals having similar characteristics (Kohonen networks). This is an unsupervised learning which do not require the training set.

This paper is an attempt to use predictive neural network to identify potential failures at the hydraulic cylinders using the data contained in the FMEA matrix analysis. On the basis of FMEA analysis the three input parameters for the test network and one output parameter were defined. Inputs are the pairs of cooperating components and their functions. The output is a potential failures. The input layer have 24 inputs while the output layer has 9 outputs. The input layer includes 3 cases for learning the network. The first case using 5 neurons, the second case 10 neurons and the third case 20 neurons. The results of the neural network analysis have been developed using the Matlab environment.

I case: 24-5-9: a part of network response of five neurons in the input layer are presented in Table 6.

II case: 24-10-9: a part of network response of ten neurons in the input layer are presented in Table 7.

III case: 24-20-9: a part of network response of twenty neurons in the input layer are presented in Table 8.

The artificial neural networks provide information similar to the information contained in the diagram relationship pair-failure obtained in the FMEA. Therefore, in the next step of the analysis for each considered ANN network the errors of potential failures were identified to select a network with the smallest error. The accuracy of ANN was evaluated by using the of root mean square (RMS). The results are shown in Fig. 2.

Table 6

Response of ANN for 5 neurons

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
p_1	1	6.2e-08	0.9	1	3.7e-05	0.9	1	1
p_2	1	4e-05	6.8e-05	0.7	0	2.6e-07	1.5e-06	1.5e-05
p_3	1	1e-08	9.5e-04	0	1.4e-09	0	0	1.1e-04
p_4	1	8e-06	4.5e-07	0.8	0.83	1.4e-06	4.6e-06	5.5e-05
p_5	1	0.9	1e-07	1.3e-08	0	2.4e-07	1.3e-06	1.2e-05
p_6	1	0.8	2.4e-06	1.5e-07	1	1	2.7e-06	1.9e-08
p_7	1	8.4e-05	1.5e-06	0.9	1.8e-05	9.8e-07	1.3e-06	0.8
p_8	1	0	0	0	5e-10	0	2e-04	3.3e-06

Table 7

Response of ANN for 10 neurons

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
p_1	1	0.1	0.1	0.98	1.2e-15	1	0.9	0.9
p_2	1	1.1e-04	2.5e-09	0.62	0	0	0.1	0
p_3	1	2e-04	0	1.1e-09	0	0	0.2	0
p_4	1	0	0	0.2	0	0	0	0
p_5	1	0.9	0.4	3.1e-11	0	1e-04	0	0
p_6	1	0.8	5.5e-09	1e-10	0	0.4	0	1e-07
p_7	1	0	1	0.4	2.2e-16	6.3e-05	0	0.5
p_8	1	0	0	1.8e-11	0	3e-04	0	0

Table 8

Response of ANN for 20 neurons

	f_1	f_2	f_3	f_4	f_5	f_6	f_7	f_8
p_1	1	1	0,92	0	0	8,5e-12	0	1
p_2	1	1	1,3e-05	1	0	8,3e-12	0	0
p_3	1	1	1,7e-05	0	0	1,4e-11	0	0
p_4	1	1	1,4e-05	0.4	0	8,8e-12	0	0
p_5	1	1	1,3e-05	0	0	8,3e-12	0	0
p_6	1	1	1,3e-05	0	1	7e-12	0	0
p_7	1	1	5,1e-06	0.5	3,9e-05	2,2e-10	0	1
p_8	1	1	3,8e-06	0	0	5,1e-11	3,4e-07	0

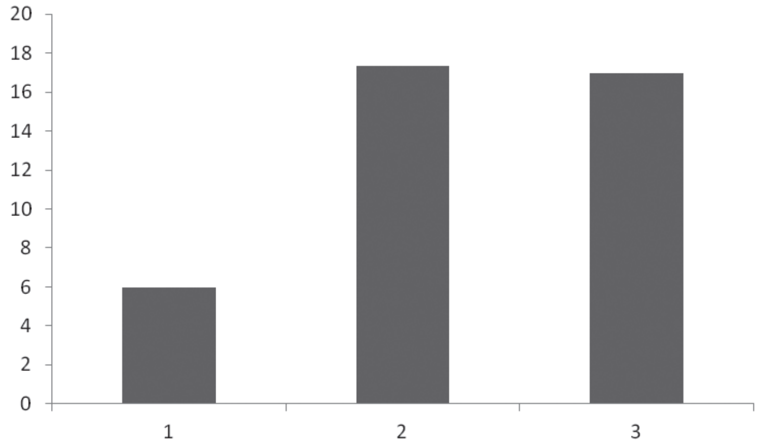

Fig. 2. The RMS value for ANN: 1-network 24-5-9 is 5.97, 2-network 24-10-9 is 17.36, 3-network 24-20-9 is 16.99

As it arise from the graph a network 24-5-9 gives the smallest error so on networks with fewer neurons in the input layer .

5. Conclusions

The presented work was an attempt of using neural network in identification of potential failures of hydraulic cylinder. As a learning process of neural network were used data obtained for matrix FMEA analysis. Obtained data shows that the neural network are able properly identify potential failures which may occur in hydraulic cylinder and may be used as an effective tool for FMEA analysis.

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