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Prediction of potential failures in hydraulic gear pumps

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Abstract

Hydraulic gear pumps are used in many machines and devices. In hydraulic systems of machines gear pumps are main component of supply unit or perform auxiliary function. Gear pumps opposite to vane pumps are less complicated. They consists of such components as: housing, gear wheels, bearings, shaft, seal for rotation motion which are not very sensitive for damage and that is why they are using very often. However, gear pumps are break down from time to time. Usually damage of pump cause shutting down of machines and devices. One of the way for identifying potential failures and foreseeing their effects is a quality method. On the basis of these methods a preventing action might be undertaken before failure appear. In this paper potential failures and damages of a gear pump were presented by the usage of matrix FMEA analysis.

Keywords: fmea matrix method, gear pump, function, component, failures

1. Introduction

Hydraulic drive system is one of the typical drive system of machines like hydraulic excavators, loaders, jib cranes, etc. Therefore it has important influence on working characteristics of such machines. Sudden failures of hydraulic system may cause machine shut down or oil leakage and in consequence contamination of environment. Therefore it is very important looking for methods for identification of potential failures and their causes. The advantageous of quality methods are being noticed more often last years in preventing potential failures. It might be found application of such methods for accessing cast components [1, 2, 3, 4]. And also elements of hydraulic pumps such as housing and covers are made of cast iron or aluminum in cast process. It lead to taking an attempt of assessing usability of quality methods in determination of potential failures of gear pumps. On the basis of available literatures [5, 6] a using of various kinds of quality methods for similar products to gear pumps was initially determined. FMEA matrix method was used due to possibilities of integration with computer aided systems and expert systems.

2. Object of analysis

The object of analysis is gear pump PZ type. Figure 1 shows the section view of the pump.

Analyzed pump is a device which works under high working pressure and with high rotational speed. That is why pump components such as: seal of rotational elements, static seal, bearing and quality of pump housing have very important meaning. Analyzed pump contains only a few components but for purposes of quality analysis it is necessary to decompose the pump to single parts. The following components were specified: housing, cover, drive shaft, sealing ring at drive shaft, sealing ring, plain bearing, drive gear, idler gear and screw were assigned.

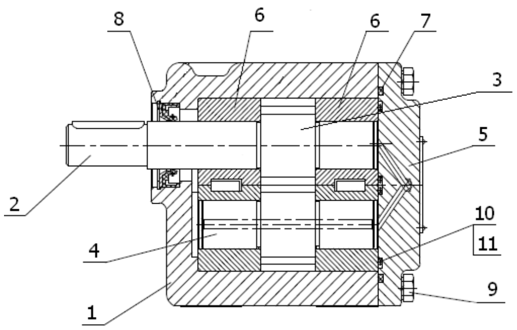

Fig. 1. Gear pump PZ type: 1-pump housing, 2-drive shaft, 3-drive gear , 4-idler gear, 5-cover, 6-plain bearing, 7,10,11-sealing rings, 8-shaft sealing ring, 9-screw

For each of these parts functions they are performing in analyzed pump were defined.

3. FMEA analysis

During using FMEA matrix method two matrixes EC (function-component) and CF (component-failure) are created [7, 8]. When matrixes EC and CF are formed than EC matrix is multiplied by CF matrix. The EF matrix is a result of this multiplication:

$$EF = ECxCF \tag{1}$$

The EC matrix is formed by assignment functions for each analyzed parts. Five functions were defined. They are: Secure (E_1), Position (E_2), Stabilisation (E_3), Transfer (E_4) and Prevent (E_5). In the EC matrix columns define components whereas rows their functions. For each EC_{ij} element value 0 or 1 was assigned. If component does not have a given function than value 0 is used. When component have a given function than value 1 is used. The EC matrix with forty elements was created (tab. 1).

Table 1.
Function-Component matrix (EC)

	C1	C2	C3	C4	C5	C6	C7	C8
E1	1	0	0	0	0	0	0	0
E2	1	1	0	0	0	0	0	0
E3	1	0	0	0	0	0	0	1
E4	0	0	1	1	1	0	0	0
E5	0	0	0	0	0	1	1	0

Elements of CF_{ij} matrix were created on the basis of eight components of pump which were analyzed. They are: pump housing, cover, drive shaft, drive gear, idler gear, sealing ring at shaft, sealing ring, plain bearing. For each component their features were defined (tab. 3). These features might provide to component failures such as: buckling (F_1), bending deformation (F_2), impact fracture (F_3), ductile fracture (F_4), contact fatigue (F_5), fretting corrosion (F_6), abrasive wear (F_7), adhesive wear (F_8), pitting corrosion (F_9), extrusion (F_{10}), cavitation corrosion (F_{11}), galling (F_{12}), thermal fatigue (F_{13}), corrosive fatigue (F_{14}), fretting wear (F_{15}), brinelling (F_{16}), erosion (F_{17}), blistering (F_{18}), plasma degradation (F_{19}), fretting fatigue (F_{20}). For each CF_{ij} element value 0 or 1 was assigned depending on situation: 1 - probability that failure has influence on component, 0 – failure has not influence on component. Table 2 presents a part of CF matrix which contains 160 elements. Forty eight elements of this matrix have value 1.

Table 2.
Component-Failure matrix (CF)

	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
C_1	0	0	1	0	0	0	1	0	1	0
C_2	0	0	1	0	0	0	1	0	1	0
C_3	1	1	1	1	1	1	1	1	0	0
C_4	0	1	1	0	0	0	1	1	1	0
C_5	0	1	1	0	0	0	1	1	1	0
C_6	0	0	0	0	0	0	1	0	0	1
C_7	0	0	0	0	0	0	1	0	0	1
C_8	0	0	0	0	1	0	1	0	1	0

Table 3.
Features of components

Component (C)	Feature
Pump housing (C_1)	Thread
Cover (C_2)	-
Drive shaft (C_3)	Key
Drive gear (C_4)	Teeth, hole
Idler gear (C_5)	Teeth, hole
Shaft sealing ring (C_6)	-
Sealing ring (C_7)	-
Plain bearing (C_8)	-

The EF matrix contains 100 elements with information about potential failures. In this matrix to above sixty six elements were assigned value 0 and for four elements was assigned value 3. Value of EF_{ij} matrix element defines the probability of failure for analyzed functions in range from 0 to 3. Value 0 in intersection of point ij means that failure has no influence on function. Value 3, in intersection of point ij defines the highest probability of failure j for function i. Table 4 shows EF matrix.

Table 4.
Function-Failure matrix (EF)

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
E1	0	0	1	0	0	0	1	0	1	0
E2	0	0	2	0	0	0	2	0	2	0
E3	0	0	1	0	1	0	2	0	2	0
E4	1	3	3	1	1	1	3	3	2	0
E5	0	0	0	0	0	0	2	0	0	2

	F 11	F 12	F 13	F 14	F 15	F 16	F 17	F 18	F 19	F 20
E1	1	0	0	0	0	0	0	0	0	0
E2	2	0	0	0	0	0	0	0	0	1
E3	2	1	1	1	1	1	0	0	0	0
E4	2	0	0	0	0	0	2	0	0	0
E5	0	0	0	0	0	0	0	2	2	0

Using similarity method (λ) which is presented in paper [7] and described by equation:

$$\lambda = CF^T xCF \qquad (2)$$

potential failures might be grouped and classified. Using equation (2) λ matrix was created. Table 5 shows a part of λ matrix.

Table 5.
Similarity matrix (λ)

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
F1	1	1	1	1	1	1	1	1	0	0
F2	1	3	3	1	1	1	3	3	2	0
F3	1	3	5	1	1	1	5	3	4	0
F4	1	1	1	1	1	1	1	1	0	0
F5	1	1	1	1	2	1	2	1	1	0
F6	1	1	1	1	1	1	1	1	0	0
F7	1	3	5	1	2	1	8	3	5	2
F8	1	3	3	1	1	1	3	3	2	0
F9	0	2	4	0	1	0	5	2	5	0
F10	0	0	0	0	0	0	2	0	0	2

In this matrix columns and rows present potential failures. Value of λ_{ij} element means the potential possibility of failure. In the λ matrix the λ_{ij} element has assigned value from 1 to 8. Values for point i=j is criterion for grouping potential failures according to the highest probability of appearance. On the basis of assumed criterion, 20 identified failures were grouped in 5 groups. Table 6 presents groups of failures.

Table 6.
Groups of failures

Group number	Value form table 5	Failures
1	8	abrasive wear (F_7)
2	5	impact fracture (F_3), pitting corrosion (F_9), cavitation corrosion (F_{11})
3	3	bending deformation (F_2), adhesive wear (F_8)
4	2	contact fatigue (F_5), extrusion (F_{10}), erosion (F_{17}), blistering (F_{18}), plasma degradation (F_{19})
5	1	buckling (F_1), ductile fracture (F_4), fretting corrosion (F_6), galling (F_{12}), thermal fatigue (F_{13}), corrosive fatigue (F_{14}), fretting wear (F_{15}), brinelling (F_{16}), fretting fatigue (F_{20})

Groups of failures were classified in three levels (I, II, III) according to the rule:

- single failures which appears most often,
- two or three failures,
- more than three failures with the lowest probability of appearance.

Table 7 presents three level for five groups of failures.

Table 7.
Classification groups of failures

Group number	Quantity of failures	Level
1	1	I
2	3	II
3	2	II
4	5	III
5	9	III

On the basis of grouped and classified failures and EF matrix a set of potential failures which might be analyzed at the design stage or during pump modification was defined. For that purpose a rule of "three steps" [7] was used. At the first step failures for the pump which should always be taken into account at the design stage or during its modification were defined. This failure is „abrasive wear (F_7)" which belongs to the first level. At the second step on the basis of EF matrix (table 4) failures which have high probability of appearance were defined for Transfer function (E_4). According to EF matrix for E_4 function exists the highest probability of bending deformation, impact fracture, abrasive wear and adhesive wear. Fig. 2 presents appearance of potential failures for function "Transfer" (E_4) in graphical form. On x coordinate potential failures for function E_4 are presented, y coordinate describes potential possibility of failures.

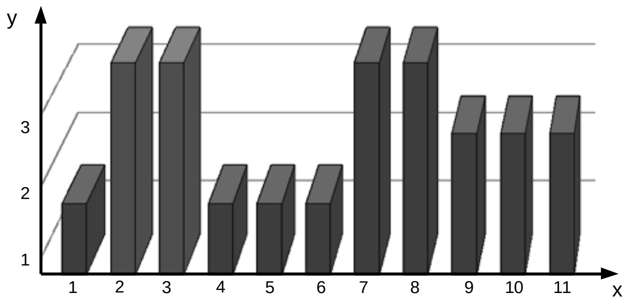

Fig. 2. Potential probability of failures appearance for function "Transfer", where:1-buckling, 2-bending deformation, 3-impact fracture, 4-ductile fracture, 5-contact fatigue, 6-fretting corrosion, 7-abrasive wear, 8-adhesive wear, 9-pitting corrosion, 10-cavitation corrosion, 11-erosion

At the third step a level of classification for failures bending deformation, impact fracture, abrasive wear and adhesive wear obtained at second step was defined. In case of first level the identified failure should always be taken into account at design stage for new pump or during pump design modifications. In case of second level all failures which belong to this level should be taken into account at the design stage or during pump design modification whereas for the third level only the identified failure should be taken into account at the design stage of a new pump. According to above rules:

- failure abrasive wear belongs to the first level that is why it should always be analyzed by designer at design stage for new pump or during its modification,
- failures bending deformation, impact fracture and adhesive wear

belong to the second level that is why all failures of this level should be analyzed by designer.

The result of analysis of the gear pump is the set of potential failures which should be taken into account by designer for function "Transfer". They are bending deformation (F_2), impact fracture (F_3), abrasive wear (F_7), adhesive wear (F_8), pitting corrosion (F_9) and cavitation corrosion (F_{11}). These failures might cause such faults as: scratched, abraded, corroded, seized, grooved and fractured, pitted, cracks of surface, dented, loose, bent, extruded.

4. Conclusions

In this paper using of FMEA matrix method for identification of potential failures for hydraulic gear pump was proposed. Analyzed pump was decomposed by reason of component functions (EC) and potential failures (CF). For gear pump five functions was defined: Secure (E_1), Position (E_2), Stabilisation (E_3), Transfer (E_4) and Prevent (E_5). Twenty potential failures were identified. FMEA analysis was conducted and probability of potential failures for analyzed function were defined. On the basis of "failure-failure" similarity method failures were grouped. The analysis results allowed for classification of failures which were defined on three level of significance. Decomposition of pump on functions and failures allowed to define probability of appearance potential failures for analyzed functions. This information allow to define a set of potential failures which designer or user may use to improve product. This analysis confirmed that FMEA method presented for hydraulic gear pumps is useful tool which might be used for creating knowledge base of potential failures.

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