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TYPICAL FAILURES OF GEAR PUMPS. DEFECTS CLASSIFICATION

Paweł Pietkiewicz

Chair of Mechanics and Machine Design
University of Warmia and Mazury in Olsztyn

K e y w o r d s: gear pumps, symptom, defect, diagnostic relations.

A b s t r a c t

The paper comprises research results of the gear pump typical failures and their connection with symptoms observed during the pump working. Worked out criteria and their boundary values allowed the defect classes creation and the defect-symptom diagnostics relation building.

TYPOWE USZKODZENIA POMP ZĘBATYCH. KLASYFIKACJA DEFEKTÓW

Paweł Pietkiewicz

Katedra Mechanizacji i Podstaw Konstrukcji Maszyn
Uniwersytet Warmińsko-Mazurski w Olsztynie

S ł o w a k l u c z o w e: pompa zębata, symptom, defekt, relacje diagnostyczne.

A b s t r a k t

Artykuł zawiera wyniki badań nad typowymi uszkodzeniami pomp zębatych oraz ich powiązaniami z symptomami obserwowanymi w czasie pracy pomp. Opracowane kryteria oraz ich wartości graniczne pozwoliły na stworzenie klas defektów i budowę relacji diagnostycznych symptom-defekt.

Introduction

Transfluent liquid energy utilization is very common nowadays. Despite of passing time and new technical solutions, which are still rising in many fields, hydraulic and pneumatic systems are the most preferable systems for the machinery drive. A pump, that acts as the pressure and flow rate generator is the basic unit of the hydraulic system. The main job of the pump is the high working pressure generation with as high efficiency as possible. Since the higher the working pressure is, the greater the stream density of the transported energy is, so the higher is the efficiency of the whole system.

Present science endeavours do not focus on the new appliances designing, but on making a study of changes occurring in the existing elements and whole systems during their exploitation. For various reasons one aims at the prediction of the failure states generation, which the most often are preceded by every part or sub-assembly wear symptom occurrence. Possibility of the breakdown occurrence prevention is connected with the correct interpretation of the wear diagnostic. Necessary requirement of such possibility is the knowledge of the most often occurring device defects and definition of the relations between symptoms and defects of each device and whole systems. Symptom-defect relation definition, that occur in the technical object allows construction of the model, which by the modern inference methods application, for example heuristic methods, enables the break-down anticipation, that were not found as yet.

This work is dedicated to the defects, that occur in one of the basic pump types, which the gear pump with the external gear is (Fig. 1). Gear pumps are used for all liquids of a little contamination (ICKIEWICZ 1995a, 1995b, KOLLEK 1996), and the high work pressure generation possibility is their advantage.

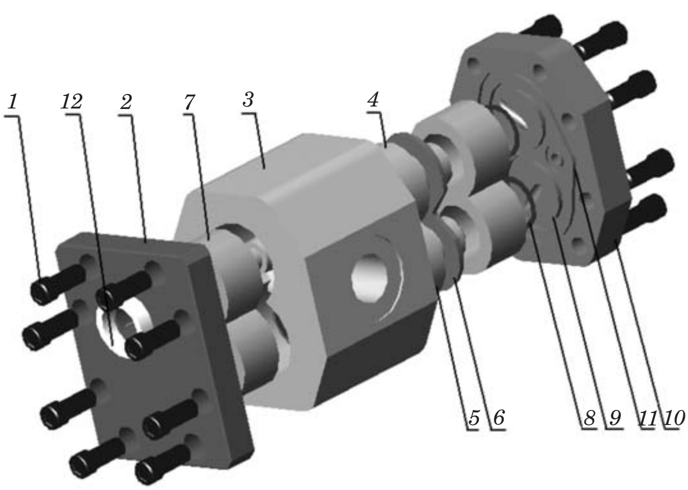

Fig. 1. Demonstrative drawing of the PZ2 type gear pump structure: *1* – bolts, *2* – front end plate, *3* – casing, *4* – driving wheel (drive gear), *5* – driven wheel (idler gear), *6* – resistance filler (compensation), *7* – bearing sleeve, *8* – thrust ring, *9* – seal under the driven wheel, *10* – rear end plate, *11* – large seal (stadium), *12* – Shaft end seal

Source: own study.

In the pump casing 3 two identical gear wheels: driving 4 and driven 5, are rotating. The gear pump functioning is based on the working liquid transportation along the wheel circumference and forcing out the certain liquid batch from the suction space to the pressure space owing to the gear wheels rotation. Considering the finite volume of the pressure chamber, under the influence of the generated pressure, the liquid surplus is forced out through the outlet plot, into the fed hydraulic system.

The tight separation of the suction chamber from the pressure one is the condition of the proper functioning of that device. Pumping assembly leak-tightness is an important factor in the correct pump and the whole system functioning. It is acquired by the resistance fillers 6 application (Fig. 1). The axial compensation, that increases the pump efficiency by the internal leak-tightness improvement, is their principal task. The radial clearance compensation is the complement of the axial compensation and is rarely applied at the present time (KOLLEK 1996).

Domain of research

Research, comprising observations and failures measurements, that occur in the tested pump pieces, were conducted in the Chair of Mechanics and Basis of Machinery Design of the University of Warmia and Mazury in Olsztyn. They referred to the selected components, the wear of which have a very distinct influence on the pump functioning and their output parameters.

In case of the **seals** applied in such type pumps, the subjects to assessment were:

– outer seal – so-called stadium – responsible for the external tightness of the pump from the side of its rear end plate,
– gear wheel seals – responsible for the proper axial forces compensation, that exist during the pump working,
– rubber-spring seal on/of the pump shaft – responsible for the external tightness from the side of the power drive feed to the pump.

The mechanical or thermal damage degree was estimated in all mentioned seal components, distinguishing the following seal wear states:

– new seal – soft material, section according to the design,
– worn out seal – hard inflexible material, flattened section,
– damaged seal -the seal continuity break off, the surface defect, melting in consequence of too high working temperature.

In case of the resistance (compensation) fillers – responsible for the proper axial forces compensation, which occur during the pump working and reduction of the differential pressure on the suction and pressure sides of the pump beyond the oil transport zone – the following quantities were estimated:

- R_{max} of the compensation filler from the side, which cooperates with the end face of the gear wheel,
- compensation filler deflection,
- percentage part of the seized or torn off from the compensatory filler surface,
- filler scorch traces occurrence.

During the tests and measurements realization it was found, that some quantities measurements would be encumbered with an error, which would not allow conclude properly upon the element wear relations as well as on the pump output parameters change. Quantities, which do not have a direct influence on the pump working parameters, were not submitted to the precise measurements.

- trace of the material acquired from the inner casing surface, which mates with the gear wheels,
- wear out scale/ratio/rate attrition rate of the needle bearings races,
- the noise generated by the working device.

Research results

Defects observed together with the pumps number weight, in which failures have been observed with reference to the overall number of tested pumps, are placed in Table 1. Specified failures have created a defects set S (failure states) of elements $\{s_1, s_2, ..., s_n\}$.

Table 1

Failures occurring in the tested pumps. Elements of the defects set S (failure states)

Id	Defect	Part in test
s_{01}	Resistance filler scratches over 16 μm	74.0%
s_{02}	Resistance filler flexure over 0.1 mm	67.7%
s_{03}	Resistance filler scorch	45.2%
s_{04}	Copper resistance filler surface defect	32.3%
s_{05}	Torn gear wheel seal off /broken	32.3%
s_{06}	Regular seals wear	29.0%
s_{07}	Resistance filler scratches 16 μm and below	26.0%
s_{08}	Resistance filler flexure up to 0.1 mm	26.0%
s_{09}	Gear wheel sealing rings fusion	22.6%
s_{10}	Seized surface of the resistance filler	19.4%
s_{11}	Lack/failure of the shaft end seal	9.7%
s_{12}	Resistance filler surface tear off/break	6.5%
s_{13}	Torn off/broken big seal „stadium”	6.5%
s_{14}	Incorrect/abnormal shaft end seal assembly	3.2%
s_{15}	Case crack	3.2%

Element s_{15} was recognized as accidentally occurring. During the research it was found, that the pump specimen, which was characterized by the failure state s_{15}, did not show the distinct wear symptoms related to the stated failure. In this consequence the s_{15} element was not taken into consideration in the subsequent research results analysis. Exemplary pictures of the selected seal failures and resistance fillers in the tested pumps, are shown in Figs. 2÷3.

Fig. 2. Gear pump seal failures: *a* – torn gear wheel seal off, *b* – fused sealing rings, *c* – torn big seal on the rear end plate ("stadium")

Source: own research.

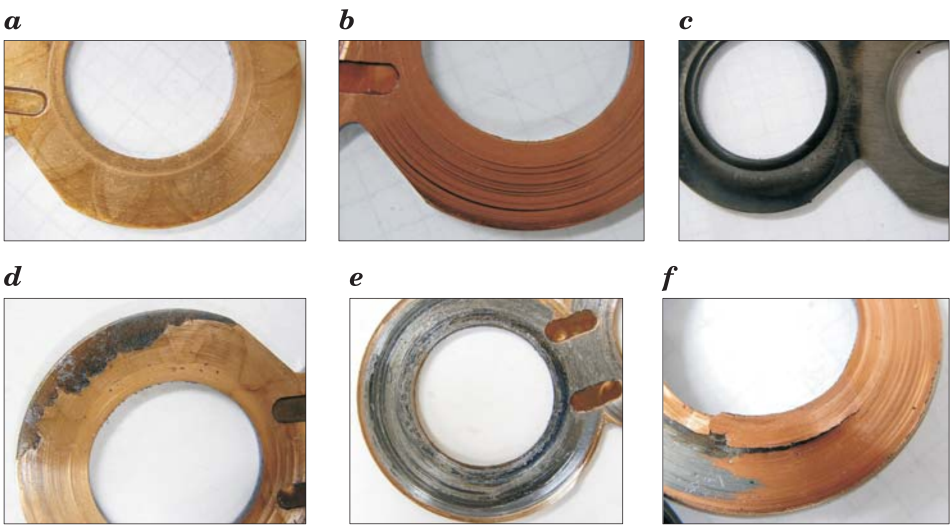

Fig. 3. Resistance filler seals failures: *a* – resistance filler scratches under 16 μm, *b* – scratches over 16 μm, *c* – resistance filler scorch, *d* – torn filler surface off, *e* – seized surface of the resistance filler, *f* – copper coating defect

Source: own study.

Relation of the occurring failure states and observed symptoms

The gear pump failure states, that occurred most often, were identified in chapter 3. Criterial quantities providing the wear symptoms identification of tested pumps, were separated during the pump characteristics empirically obtained analysis.
– maximum pump working pressure $\Delta p_{\max}$ at the minimum and nominal rotational speed,
– maximum pump total efficiency in the working point at the minimum and nominal rotational speed,
– slope of a flow characteristic at the nominal rotational speed.

The symptom groups were formed and presented in Table 2.

Table 2

Elements specification of the set of gear pump wear symptoms *A*

Id	Verbal description of the symptom	Criterial quantities boundary values
a_1	Pump efficiency reduction from several to over a dozen per cent compared to a new device of the same type. Acquired maximum working pressure equal to the nominal in the whole rotational speed range. Slightly decreasing flow characteristic towards the increasing working pressure.	$\Delta p_{\max} = \Delta p_{\mathrm{nom}}$ (160 at) $0.74 < \eta \le 1.00$ $10^{-7} \le \mathrm{tg}\ \theta \le 4 \cdot 10^{-6}$
a_2	A device total efficiency exceeding 74%. Maximum forcing pressure varying according to the rotational speed, not lower than a half nominal value at the nominal rotational speed. Flow characteristic considerably sloped in the direction of the pressure increase.	$0.5\ \Delta p_{\mathrm{nom}} < \Delta p_{\max} \le \Delta p_{\mathrm{nom}}$ $0.50 < \eta \le 0.73$ $4 \cdot 10^{-6} \le \mathrm{tg}\ \theta \le 10^{-5}$
a_3	A device total efficiency exceeding 50%. Maximum forcing pressure up to 50% of the nominal value at the nominal rotational speed, at the lower speeds the lower pressure value. Flow characteristic considerably and very sloped.	$\Delta p_{\max} \le 0.5\ \Delta p_{\mathrm{nom}}$ $0.00 < \eta \le 0.50$ $\mathrm{tg}\ \theta \ge 10^{-5}$
a_4	A device efficiency equal to zero. Pump load inability, slope coefficient/factor of the flow characteristic determination impossibility. Very abundant outflow of the working medium through the device shaft sealing.	$\Delta p_{\max} = 0$ $\eta = 0$ tg θ value determination impossibility

The attempt to find a relation among them was undertaken in the subsequent order (CEMPEL, TOMASZEWSKI 1992, PIETKIEWICZ 2004a, 2004b, RZADKOWSKA, PIETKIEWICZ 2004, PIETKIEWICZ, RZADKOWSKA 2004). For that purpose the trial to compose a binary symptom-defect diagnostic matrix was taken up. The received binary matrix (Tab. 3) defines, if there is any relation between specific symptoms and defect, which were noticed during tests.

Table 3

Binary symptom-defect diagnostic matrix

a_i	Failure state s_j													
	s_{01}	s_{02}	s_{03}	s_{04}	s_{05}	s_{06}	s_{07}	s_{08}	s_{09}	s_{10}	s_{11}	s_{12}	s_{13}	s_{14}
a_1	1	1	0	0	0	1	1	1	0	0	0	0	0	0
a_2	1	1	1	1	1	1	0	1	0	1	0	1	1	0
a_3	1	1	1	1	1	1	1	1	1	1	0	1	1	1
a_4	1	1	1	1	1	1	0	1	1	1	1	0	0	0

Analyzing values of the matrix placed in the form of the Table 3, one can notice, that the majority of symptoms are likely to be generated by a number of specific failures. The symptom a_4 can be an example as well as the failure states s_{01}, s_{03} and s_{11}. It means, that one symptom may be caused by different defects. Further probability analysis of the failure occurrence in the tested unit trial indicated a high probability of such cases.

Classification of the occurring failures. Defects classification

The diagnostic matrix, placed in chapter 4, presents the relations between the observed gear pumps wear symptoms and their specific defects. Once the structure and gear pump principle of operation is known, an attempt at the failure states groups creation, also called as the defects classes, was made. Failures of the gear pump structure pieces, which are the members of the defects set (failure states) S with $\{s_1, s_2, ..., s_n\}$ elements, were grouped into the defects classes, thus making a set of defects classes K with $\{k_1, k_2, ..., k_n\}$elements.

The defects classes description and information on which failure states were assigned to a particular defects classes, were placed in table 4. The failure classes were created as sets of defects, which in a different manner perturb the gear pump functionality.

Defects, which arise during the regular gear pumps exploitation by loading some elements of their structure, are contained in k_1 class.

Defects generating a total loss of axial compensation are included among the k_2 class. The loss of this property by the gear pump is a ground to a large maximum pressure reduction, which the pump is likely to generate. Defects numbered among the k_2 class most often arise in consequence of the system overloading, its overheating and as the result of the compensation fillers damage and often by tearing the gear wheel seals off.

Table 4

Defects classes created on the basis of the carried gear pump research out

k_l	Class description	s_j
k_1	Exploitation wear of sealing and responsible for the axial compensation elements	s_{06} s_{07} s_{08}
k_2	Total loss of axial compensation	s_{05} s_{09}
k_3	Total loss of pump leak-tightness	s_{11}
k_4	Pump leak-tightness reduction/failure	s_{13} s_{14}
k_5	Axial compensation failure – excessive elements wear responsible for the axial compensation	s_{01} s_{02} s_{03} s_{04} s_{10} s_{12}

In case of the defect denoted as s_{11} the separate defect class k_3, which consists of only one failure, was created. The rubber-spring seal on the pump shaft destruction as well as its absence results in the total loss of pump leak-tightness. An oil; led to the device; flows outside through the gap at the driving shaft very often even before the pump start-up.

The defects class k_4 contains failure states related to the pump outer seals failure, which however do not generate the entire hold-up of the hydraulic system. The reason of this class failure arising, may be a considerable pump overloading or an irregular sealing assembly.

The most numerous class of the failure states is the k_5 class, to which defects considerably reducing the axial compensation effectiveness of the forces related to the working medium pressure, were included. Failures related to the frequent device overload, incorrect working medium application, its high impurity or else foreign matters getting inside the pump, belong to them.

Table 5

Binary symptom-defect class diagnostic matrix for the tested pumps sample

a_i	Defects classes k_l				
	k_1	k_2	k_3	k_4	k_5
a_1	1	0	0	0	1
a_2	1	1	0	1	1
a_3	1	1	0	1	1
a_4	1	1	1	0	1

Creation of the failure states classification, which occur in a pump, enabled to define a relation between the observed symptoms and defect classes (Cempel, Tomaszewski 1992, Pietkiewicz, 2004b, Pietkiewicz, Rzadkowska 2004) in the form of the symptom-defect class matrix (Tab. 5).

Based on the table 5 it is possible to conclude about the interrelation existence between the observed wear symptoms of the tested devices and the defects classes, which may come out in the particular specimen.

Summary

The research, conducted for the gear pumps, allowed to establish failures occurring the most often and their relation to the observed wear symptoms. Similar research may be conducted for any technical device or machine. In case of the complex mechanical systems such experiment may be hard to carry out. Therefore, before the research project of the whole system is constructed, tests of each element entering into its composition should be executed. Gear pump always is a part of more complex hydraulic system, which drives a material system, and is the example of this. The failure states of the whole hydraulic system may be the results of subsystems failure states or of its elements (i.e. the pump). Therefore the observed symptoms may be very ambiguous and may signal failure states of different elements of the entire system.

Diagnostic matrices, which arose as a result of the research and exhibit symptoms to the occurring diagnostic states relation, allow the technical devices models to be constructed. The proper symptom-defect relations structure may be helpful in the break down anticipation of the simple material systems as well as the complex machines. The diagnostic models construction requires the precise identification concerning probable failure states. This is not always possible in case of complex material systems.

One may make an attempt at the models construction of machines and systems based on heuristic inference algorithms, owing to an adequate unification methods application and analysis of the obtained results. Unlike the classic algorithms, which require the knowledge of all variables, heuristics allows a continuous adaptation of the inference algorithms to arisen situation. In case of new, not encountered before symptoms or failure states occurrence, heuristic models partially based on the “experiment”, make additions to a base of knowledge on the analysing object, simultaneously developing or aiding the development of new procedures when the failure not observed up to now occurs.

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