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THE DEFECTS ANALYSIS OF MECHANICAL TRANSMISSIONS

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Abstract: This study aims to present the defects that can occur in mechanical transmissions and their classification. Mechanical transmissions are a set of mechanical elements kinematically linked to each other, having strictly determined movements. Each machine part can be designed and executed separately, but within the assembly, its operation is influenced by the behaviour of the other machine parts that are part of the transmission. In the context in which the geometric and kinematic parameters required to be achieved by a mechanical transmission are increasingly high and the operation at these parameters must be achieved without accidental stops, a more accurate knowledge of all the defects that may occur is required. Knowing the faults of the transmissions and identifying the causes that generate these faults will enable the measures that must be taken to eliminate them.
Keywords: classification, defects, transmission, stationary, parameters

1. THE MOTIVATION FOR THE RESEARCH – RESEARCH PLAN

The research starts from the identification of the problems which occur in the different industrial sectors in Romania. Thus, whether we are talking about the metallurgical, chemical or cement industry, the problems related to predictive maintenance and the automatic identification of mechanical transmission defects are the same.

If we add to this the increasingly poor training of human resources, we have a clear picture of the importance of automatic identification and classification of defects.

The research aims to create an optimal system for the automatic detection of defects in a mechanical transmission.

In order to carry out this work, we will follow a theoretical and experimental research route. We will start with the study of mechanical transmissions, the study of the defects of mechanical transmissions, the study of sensors and systems used mainly in industry for measurement of the parameters and we will establish the criteria according to which we will classify the defects of mechanical transmissions.

2. MECHANICAL TRANSMISSIONS – OVERVIEW

Mechanical transmissions are a set of mechanical elements kinematically connected to each other, having strictly determined movements.

Each machine part can be designed and executed separately, but within the assembly, its functioning is influenced by the functioning of the other machine parts from the component of the mechanical transmission. In the context in which the geometric and kinematic parameters required to be achieved by a mechanical transmission are increasingly high and the operation at these parameters must be achieved without accidental stops, a more accurate knowledge of all the defects that may occur is required.

A mechanical transmission is considered to be defective when it no longer performs the functions for which the transmission was designed.

The automatic classification of these defects that can occur in mechanical transmissions will allow the rapid identification of transmission components that no longer work at normal parameters, significantly reducing the downtime required to restore the transmission to the parameters for which it was designed.

The classification of defects that can occur in a mechanical transmission implies the diagnosis of the defects.

In order to perform a complete diagnosis, it is necessary to determine the type and size of the defect, to identify the moment in which it appeared and how the transmission will be influenced as a whole by this defect.

3. TYPES OF DEFECTS FOUND IN MECHANICAL TRANSMISSIONS

Defect classification criteria

A) According to consequences of the defects [1]:

- critical – It is the defect that no longer allows the transmission to accomplish its function for which it was designed. The appearance of this type of defect involves significant costs for bringing the transmission to the initial parameters for which it was designed;
- major – Reduces the ability to use the transmission. The lack of measures to eliminate this type of defect can turn it into a critical defect;
- minor – It can be considered as a deviation from the standards according to which, parts of the transmission are designed and executed. This type of defect will not affect the capacity of the transmission.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

B) According to wear process:
— total;
— partial.
C) According to loading:
— admissible loading;
— inadmissible loading;
— according to defect evolution;
— in leaps;
— without any special statistical law;
— according to some statistical laws.
D) After the failure rate:
— randomly;
— systematic;
— premature.

Defects of mechanical transmissions bearings

Bearings are one of the most important components of mechanical transmissions and that is why they are the most studied elements in industrial applications. Moreover, a large part of the bearing manufacturers provide the industrial sectors with systems that allow monitoring their operation. For example, the manufacturer of Schaffler bearings has developed the Optime sensor, a sensor that allows monitoring of the vibrations and the temperatures of the bearings. It is an automatic analysis system, based on the expertise in the field of the manufacturer Schaffler.

The main defects found at the bearings are [2]:
— abrasive wear;
— pitting on the raceways;
— grooving;
— contamination;
— corrosion;
— incorrect lubrication;
— fatigue;
— incorrect alignment;
— burns caused by the electric current.

Abrasive wear is perhaps the most common cause that leads to the destruction of bearings. The penetration of foreign particles, such as the very fine shavings resulting from the turning operations of cast iron and bronze parts or metal particles resulting from the grinding of the parts or abrasive particles detached from grinding stones will lead to premature wear of the bearing rings

Pitting on the raceways can be caused by the penetration of hard materials inside the bearings. These hard particles can lead to the appearance of burns on the surfaces of the raceways, burns that can represent micro–crack primers. These micro–cracks, under the action of the cooling–lubricating oil, will lead to the appearance of pitting. Improper lubrication of the bearing, can also lead to the appearance of burns on the surfaces of the raceways and to the premature appearance of pitting

Grooving is caused by the penetration of hard objects inside the bearing. These objects remain stuck in the material from which the bearing cage is made and cause grooves on the bearing raceways.

Contamination is caused by the penetration of dirt, sand, etc. inside the hydraulic lubrication systems. Along with abrasive wear, they are the most common causes that lead to the premature destruction of bearings. Failure by the transmission user to comply with the recommendations made by the manufacturer of mechanical transmissions regarding the time intervals at which the oil filters must be changed, respectively of the lubricating cooling oil, leads most often to the appearance of contamination of the oil and at the premature destruction of the bearings.

Incorrect alignment is mainly caused by:

Incorrect processing of the casing bores – lack of parallelism and concentricity between the casing bores or deformation of the shaft as a result of its incorrect processing

Burns caused by the electric current – the cause is the incorrect realization of the grounding of the machine.

Defects of mechanical transmissions gears

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

The main defects that can occur in mechanical transmission gears are:
— pitting;
— breaking or cracking.

Pitting – has as its cause the fatigue that appears in the superficial layers of the active flanks. Pitting appears in the form of micro cracks in the active flanks. The oil penetrates these micro cracks and so a hydrostatic pressure is created that will lead to the enlargement of the micro cracks and finally to the detaching of the material

The breaking or cracking of the teeth occurs as a result of the bending fatigue.

During engagement, the teeth are subjected to dynamic stresses so that the static efforts are increased by the following coefficients [4]:
— **KA** – transverse load factor;
— **KFβ** – face load distribution factor at tooth root;
— **KV** – dynamic load factor;
— **KFα** – transverse load factor at tooth root.

Tooth breakage as a result of bending fatigue stress is due to tensile stresses that occur at the tooth root. According to [3] the tooth root stress is:

$$\sigma F = \sigma F0 \cdot KA \cdot KV \cdot KF\beta \cdot KF\alpha \quad (1)$$

where: **σF0** – the nominal stress at tooth root under static conditions.

Considering that [3]:

$$\sigma F0 = Ft/(b \cdot mn) \cdot yF \cdot yS \cdot y\beta \cdot yB \cdot yDT \quad (2)$$

result [3]:

$$\sigma F = Ft/(b \cdot mn) \cdot yF \cdot yS \cdot y\beta \cdot yB \cdot yDT \cdot KA \cdot KV \cdot KF\beta \cdot KF\alpha \quad (3)$$

where: **yF** – Tooth form factor; **yS** – Stress correction factor; **yβ** – Helix angle factor; **yB** – Rim thickness factor; **yDT** – Deep tooth factor; **Ft** – Nominal circumferential Force at pitch circle; **b** – Face width; **mn** – Normal module.

4. MATERIALS & METHODS USED – THE DESIGN OF THE TEST STAND

Experimental research and data collection will be carried out on the test stand shown in the following figure [6]:

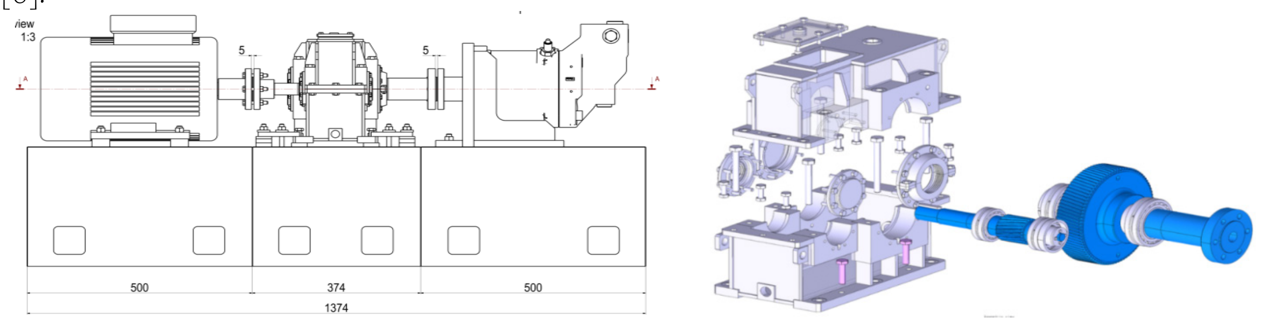

Figure 1. Test stand

The test stand will be made using a type A gearbox, with one–stage and with the transmission ratio i=4 and with the main dimensions shown in the figure below [6]:

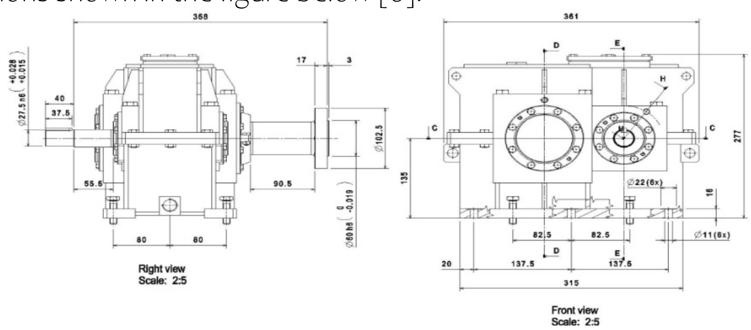

Figure 2. The main dimension of the gearbox

The lubrication system of the gearbox will be external and will be made with a hydraulic group shown in the diagram below, where: 1–gear pump (Kracht), 2–electric motor, 3–sequenc valve, 4–oil filter, 5–pressure switch, 6–pressure gauge, 7–8–pressure switch, 9–bearing, 10–level switch.

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

5. SIMULATION OF DEFECTS – MONITORING AND CONTROL EQUIPMENT

Will be simulate the defects that can occur in the mechanical transmissions:
- bearing defects;
- gear defects;
- improper motor–reducer alignment;
- improper fixing of the reducer on the foundation;
- defects of the hydraulic lubrication system;
- improper lubrication;
- high temperature of the lubricating oil;
- clogged filter system.

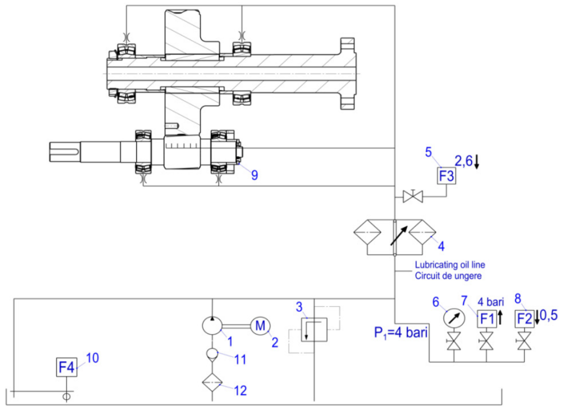

Figure 4. Lubrication system

Simulation of bearing defects

We will materialize the defects of the bearings by making small indentations on the raceways. We will simulate the appearance of the pitting on the raceways and will perform vibration measurements using an accelerometer type MEMS IEPE with the following characteristics: sensitivity–100mV/g;; frequency response–0.5–15000Hz; dynamic range–80g.

In accordance with measured values, we will be able to automatically place the transmission in one of the classes specified in the ISO 10816–1 standard. According to the ISO 10816–1, machines (mechanical transmissions) are classified according to figure 5 into four classes [5]:
- Class I: Individual parts of engines or machines integrally connected to the whole machine in its normal operating condition. (electric motors up to 15 kW are typical examples for machines in this category);
- Class II: Medium–sized machines (typically electric motors with power between 15 and 75 kW), without special foundations, rigidly mounted internal combustion engines or machines (up to 300 kW) on special foundations;
- Class III: Motor machines and other machines with rotating masses mounted on rigid and heavy foundations which are relatively rigid in the direction of vibration measurement;
- Class IV: Motor machines and other machines with rotating masses, mounted on relatively weak foundations in the direction of vibration measurement (for example: turbo–generators and gas turbines with output powers greater than 10 MW).

Gear failure simulation

As in the case of bearings, we will simulate the appearance of pitting on the tooth flanks of the gears by making small alveoli on the flanks of the pinion teeth and the toothed wheel. We will measure vibrations and temperatures both before and after performing the alveoli. Depending on the measured values, we will place the transmission in one of the classes provided in the ISO 10816 standard.

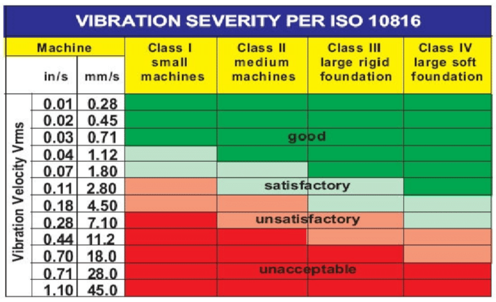

Figure 5. Vibration severity

Simulation of hydraulic lubrication system faults

The hydraulic lubrication system is designed to operate in accordance with the parameters presented in the following table:

Table 1. The hydraulic parameters of the lubrication system

	Contactors and transmitters	Pos. no	Adjustment–functioning		Normal operation / Possible defects
1.	Min. lubrication pressure	F1 (7)	4 bar–up	Maine engine start	Normal operation
2.	Low lubrication pressure	F2 (8)	0.5 bar–down	ALARM	Defect pump drive motor Defect hydraulic lubrication pump Pump suction filter clogged Blocked pressure regulating valve Oil losses on the lubrication flow
3.	High pressure difference on the oil filter	F3 (5)	2.6 bar–up	ALARM	Filter element clogged
4.	Low lubricating oil level	F4 (10)		ALARM	Oil losses on the lubrication flow
5.	Lubricating oil temperature high	F1 (11)	65°–up	ALARM	Lack of lubricating oil in the tank

During the tests on the stand, we will simulate all the defects that can occur in the hydraulic lubrication system

ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665

6. CONCLUSIONS

Simulating defects that can occur in mechanical transmissions, bearing defects, gear defects, hydraulic lubrication system defects and then developing a system that automatically identifies these defects, will represent an important step towards predictive maintenance.

In this way, the downtime of mechanical transmissions, due to accidental defects, will be significantly reduced and the costs generated by these downtimes will be reduced.

Note: This paper was presented at International Conference on Applied Sciences – ICAS2023, organized by University Politehnica Timisoara, Faculty of Engineering Hunedoara (ROMANIA) and University of Banja Luka, Faculty of Mechanical Engineering Banja Luka (BOSNIA & HERZEGOVINA), in May 24–27, 2023, in Hunedoara (ROMANIA).

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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN–L 1584 – 2665