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APPLICATION OF ENERGY DISSIPATION ANALYSIS FOR IDENTIFICATION OF MACHINE COMPONENT CONDITION

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Abstract

Energy transformation in power transmission systems of machines is accompanied by occurrence of a series of processes which cause energy losses. Analysis of the phenomena occurring in the process of energy transformation and energy transmission and the methods used for determination of its dissipation paths is the major task of this study. Structural components of a three-axle vehicle with all-axle drive were used for a description and analysis of degradation mechanisms involved in energy dissipation. Practical aspects of the proposed methodology allow to define precisely the sites and the major factors affecting occurrence of losses in the power transmission systems of vehicles. Demand for methods and means enabling effective insight into the causes and effects of energy losses in machine components are issues that need to be addressed using available means and in a possibly short time.

Key words: *energy dissipation, efficiency, energy losses , power transmission system*

1. INTRODUCTION

Energy distribution in a power transmission system of machines is directly connected with factors such as: the object technical condition, mechanical efficiency of particular subassemblies, maintenance, strategy of operation, environment of operation, behavior of the operator and many others. All these factors contribute to rational, effective and safe operation of machines and is reflected by different factors affecting a machine state including energy losses in its particular subassemblies.

A machine is referred to as a mechanism or set of mechanisms, powered by a stimulus induced or applied by a human, designed to perform the assigned work connected with the process of production, energy transformation. The main part of a machine is the operating component which is directly involved in energy transformation, power transmission, transformation of movements, transfer of loads [12]. The power transmission system of machine is an example of such an operating component which transforms and transfers energy onto other components making up a set of mechanisms connected with each other.

Members of this system take part in transforming and transferring energy from drive links onto passive ones, that is, loaded by resistant forces. However, not the whole work of active forces is utilized for the intended useful goals. Part of the energy is used to overcome friction resistance accompanying movements, and dissipates into the environment in the form of heat while a portion of the energy accumulates in the mechanism as kinetic energy and sometimes as potential energy [8]. The aim of this study is: analysis of the phenomena occurring in the process of energy transformation and transfer and presentation of the method for identification of its dissipation on the basis of tests carried out with the use of an off-road truck.

2. DEGRADATION OF THE MACHINE ACCORDING TO ENERGY BASED APPROACH

Degradation of a mechanical system involves loss of structural and functional properties of their structural components, and in effect of the whole system. This loss will result in change in mechanical or geometrical properties of the system exceeding the specified tolerances. These changes appear in effect of functioning in a given environment and external and internal energetic interactions [2].

According to the general theory of systems, operating systems are open systems characterized by mass, energy and information flow. Thus, they are systems transforming energy with its inseparable external and internal dissipation, which is presented in figure 1. Hence, the input mass flow (material), energy and information are transformed into two output flows, useful energy in its other desired form or a product being the designed target of a given object. The other flow includes energy dissipated, partly exported into the environment or the system meta, and partly accumulated in the object in effect of different wear processes occurring during a machine operation [2,13].

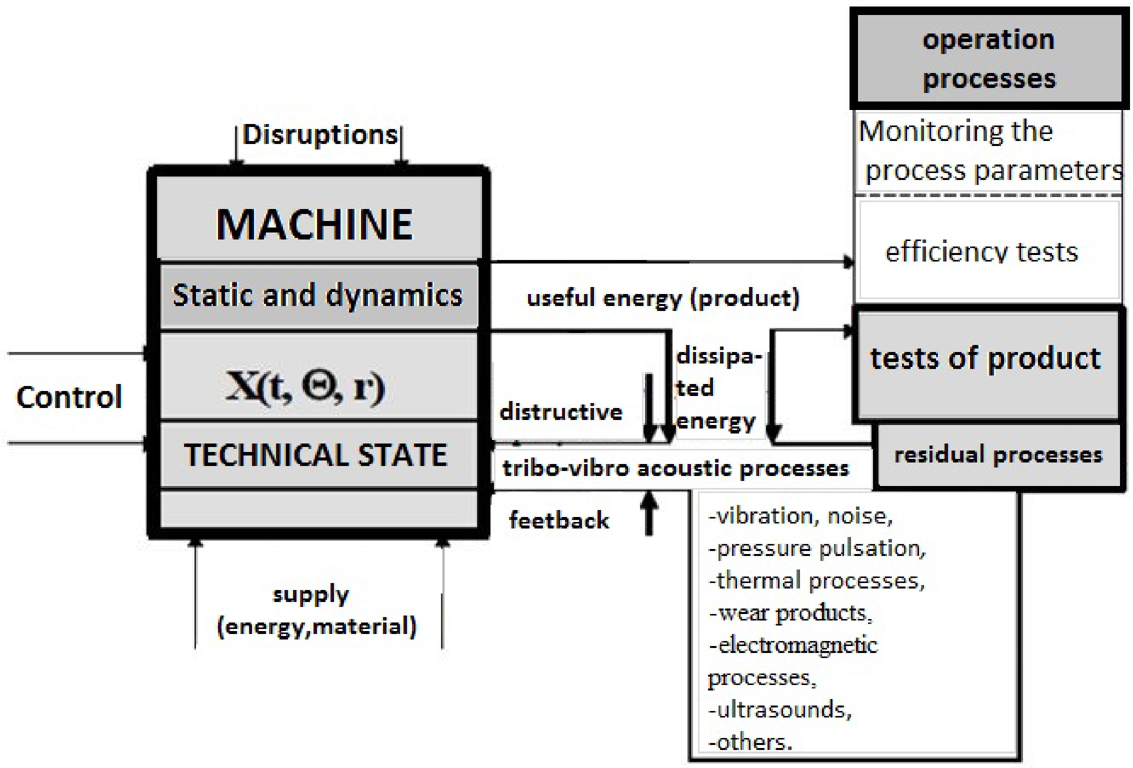

Fig.1. Machine as a system of energy transformation and its diagnostics possibilities

All possibilities of diagnosing can be classified into three basic groups, one that accounts for advisability of research on assessment of the quality of condition or the product.

The first of them involves diagnosing through observation of operational processes by monitoring their parameters in a continuous manner, or at special stands carrying out tests of machine efficiency (power, torque, speed, pressure, etc,) Tests of this kind have a future due to sensors, microprocessors etc. increasingly used in machines, which requires to be familiar with the model of the object functioning.

The second method of machine diagnostics includes the product quality tests, consistence of dimensions, joints, fittings etc. as the better the machine technical condition is the higher its production quality.

The third possibility of diagnostics involves observation of residual processes, using different physicochemical processes included in the machine output processes, and being the source of many attractive machine diagnosis methods [13].

Damage is one the most significant events that occur in the process of machine use, determining its reliability, efficiency, the process of maintenance and the needs for technical diagnostics.

Most generally speaking, the concept of machine damage can be defined as an event involving transition of a machine (system, component) from the state of usability to the state of being unusable. The state of usability is referred to as such a state in which a machine can perform the functions specified in its technical documentation. Whereas, the state of being unusable is understood as such that makes it impossible to perform one of the functions specified in the technical documentation.

Due to the environmental impact and performance of the assigned tasks the object initial properties can undergo change, which will result in a change of initial measurable values of the object properties and possibly in a change of its immeasurable properties.

Machine damage during operation and maintenance can occur:

- in effect of slow, irreversible aging and wear processes , occurring in a machine;
- in effect of reversible processes of variable intensity, caused by temporal exceeding permissible values of one or more forcing factors;
- in a step-like manner, involving discontinuous transition of one or more properties beyond the boundaries accepted as permissible for a given machine [12,13].

3. ENERGY DISSIPATION IN THE POWER TRANSMISSION SYSTEM

Energy dissipation is directly connected with such issues as: energy balance, mechanical efficiency of the discussed object, energy consumption and energy losses. It plays the role of quantitative presentation of energy transmitted and lost in particular components of the power transmission system.

The energy contained in fuel in a chemical form called supply which is transformed into mechanical energy is accepted to be the system feed energy. The amount of energy obtained in result of mechanical energy transformation depends on the engine efficiency and ranges from 35 to 55% of the whole energy supplied. It is further transmitted by the power transmission system, being then limited by the quantity of losses connected with energy transfer to wheels. Mechanisms used for transmission of this energy are called power transmission mechanisms and the whole system is referred to as a power transmission system. Torque is applied to the axles of powered wheels in effect of which a tangent reaction of the surface occurs and the vehicle starts moving. The stream of power flowing to the engine is at some point divided into smaller streams flowing to particular wheels [1,4,5].

The power stream diminishes while flowing through each mechanism of the power transmission system which is caused by occurring resistances, which is presented in fig. 2.

The analyzed energy losses can be described by mechanical efficiency of particular components of the power transmission system as well as by overall efficiency of the power transmission system.

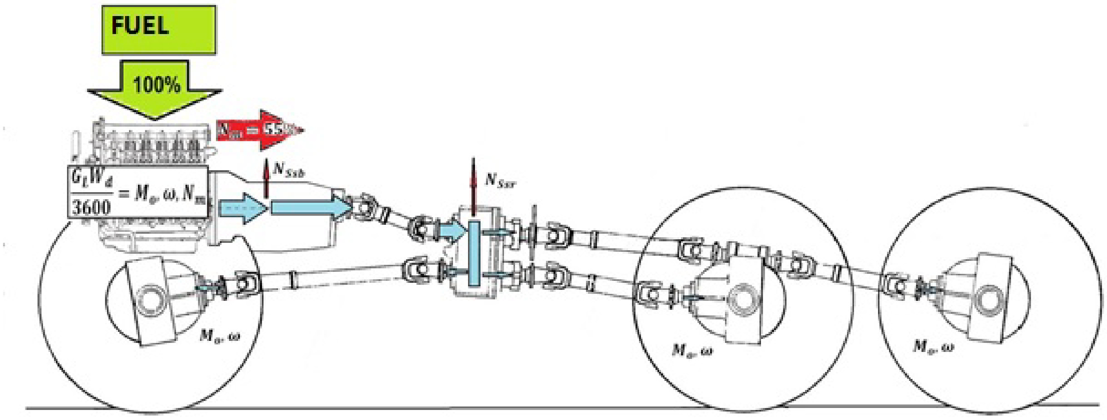

Fig. 2. Energy transformations in power transmission system [own research]

Mechanical efficiency is referred to as the ratio of utilized energy to the energy supplied in the same time. Improving efficiency involves decreasing energy use. A method for determination of energy dissipation in the power transmission system is dependent on the way particular structural components are joined. [4,9,12]. If machine is composed of n mechanisms series connected, this is useful work L_U of each proceeding mechanism work L_D supplied to the next mechanism [3,6,8,9,11], is expressed by dependence (1):

$$\eta_1 = \frac{L_{U1}}{L_D}; \eta_2 = \frac{L_{U2}}{L_{U1}} ... \eta_n = \frac{L_{Un}}{L_{U(n-1)}} \quad (1)$$

After transformation of the above formula we obtain:

$$\eta = \eta_1 \cdot \eta_2 \cdot ... \eta_n \quad (2)$$

In the below figure 3 there are schemes of series connected machine components:

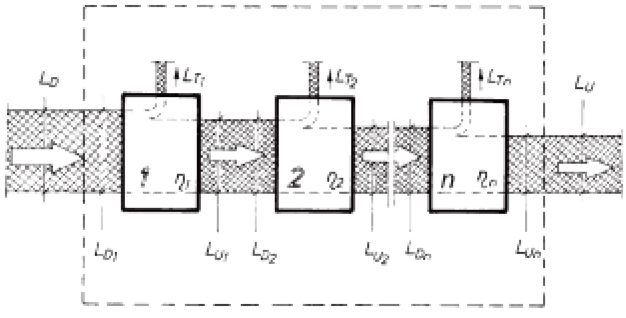

Fig. 3. Series connected machine components [8,9]

In the case of a parallel connection of n machine components, the largest influence on the system efficiency is on the part of the energy stream division itself, we obtain the following formula defining efficiency:

$$\eta = \frac{L_U}{L_D} = \frac{L_D \cdot \sum k_i \cdot \eta_i}{L_D} \tag{3}$$

where:
k_i – coefficient of power dissipation.

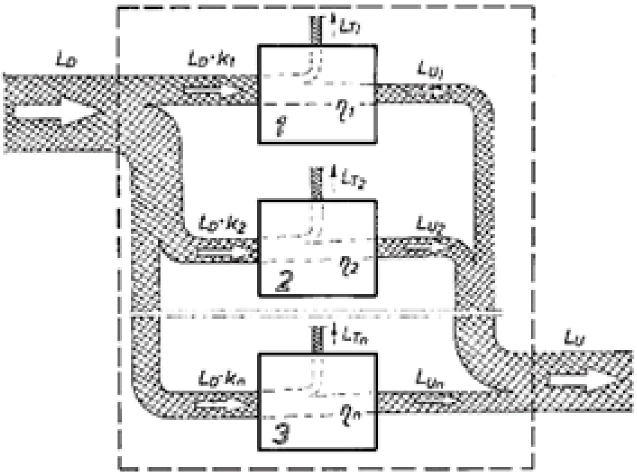

Fig. 4. Parallel connection of machine components [8,9]

The above presented dependence 3 and figure 4 prove that the overall efficiency of a machine with parallel connection of mechanisms largely depends on the energy stream division in the machine [8,9]. It should be mentioned that the presented case of parallel connection of mechanisms is hardly ever used in machines and most commonly mixed connections are used.

4. METHOD FOR MEASURERING EFFICIENCY OF A SUBASSEMBLY

Energy flowing through the system of power transmission is torque and rotational speed obtained in effect of processes occurring in an internal combustion engine and connected with transformation of energy contained in the chemical form in fuel into mechanical energy. In result of measuring and comparison of energy obtained on the output to the energy used to supply a given subassembly we obtain its efficiency coefficient defining the size of energy losses. For quantitative determination of losses, a method for determination of the system efficiency involving determination of the value of transmitted torque in particular points of the power transmission system, has been proposed. Measurements of the transmitted torque were performed in a non-contact manner in service conditions, without a necessity of structural changes in the power transmission system, on the basis of shaft strain, by means of resistant tensometry [7,10]. The measurement method is based on voltage value measurement on the tensometric bridge output, and proportional to the strain occurred on the drive shaft due being loaded by torque on the basis of dependence 4 and 5.

$$\varepsilon = \frac{2\Delta U}{akU_o} \tag{4}$$

where:

ΔU – voltage increase (measured voltage) [V]
a – signal enhancement
U_o – tensometer induced voltage [V]
k – tensomeer constant [mV/V]

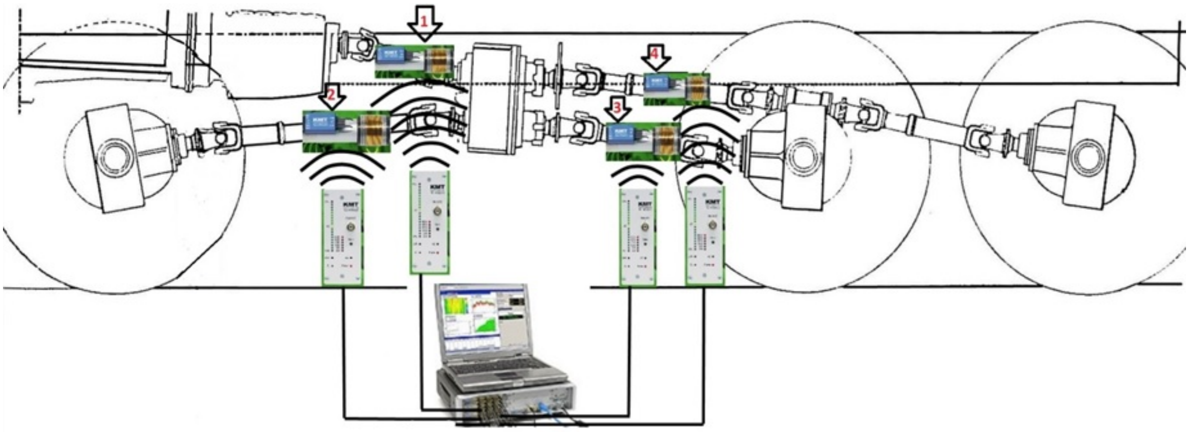

Fig. 5. Measurement points in the power transmission system with measuring equipment [own research]

$$M_o = \frac{1}{8} \cdot \varepsilon \cdot G \cdot \pi \cdot (D^3 - d^3) \quad (5)$$

where:
π – pi number
G – Kirchoff module [Pa]
ε – shaft deformation (measured)
D – shaft external diameter [m]
d – shaft internal diameter [m]

The chosen localization of measurement points aims at minimal intervention into the structures of power transmission system and simultaneously providing the possibility of verification of the measurement signal from particular sections of the studied system which is presented in figure 5. Measurement equipment with telemetric measurement signal transmission enabling wireless measurement of torque with acquisition of measurement data in the form of voltage signal.

5. RESEARCH

The research object of the performed experiment was a drive system of an off-road truck Star model 266M2, presented in figure 6. The vehicle was modernized in 2012 in AUTOBOX Starachowice from version 266 to 266M2.

The basic changes involved the process of modernization connected with the power transmission system included:

- montage of IVECO type F4AE0481 with power 125 kW (170KM) and maximal torque 560 Nm [date obtained from producer].
- montage of 6 –gear Eaton gear box,
- all the assemblies (including drive axle, transfer case, drive shafts) were overhauled.

Fig. 6. Research object [own research]

Preparation of the object for tests

Preparation of the object for tests involved preparing the surface of drive shafts for tensometers to be glued , for this purpose the paint had to be removed from the shafts.

The tensometer was glued by means of cyanogen acrylic glue and next it was dried in higher temperature.

Fig. 7. Measuremnt system while being mounted on the drive shaft [own research]

Encoder was secured together with an antenna by a ferromagnetic tape eliminating interference of the measurement signal, the montage way is presented in figure 7. As the measurement system was provided with additional power source, the distance between the transmission and reception antennas was increased from 50 to 150 mm. It allowed to perform measurements under service conditions of the power transmission system and suspension system.

Tests conditions

The tests were carried out outdoor on a surface strengthened with hexagonal concrete slabs of Trylinka type. During the test the air temperature was 21C°, with the air relative humidity 88%. Atmospheric pressure: 1-14hPa. Speed of wind: 2km/h. The tests were performed for a fixed rotational speed of the engine in the amount of 1512 rev/min and in third gear which corresponds to gear box ratio 1:2.80.

Processing of measurement data

The measurements were performed during six tests on a straight section of a road which provided the values of voltage. The sampling frequency was established at the level of 41Hz. He results were recorded and reduced to 1 Hz in result of equalization of measurement blocks. On the basis the presented mathematical dependencies, the strain of shafts was determined, according
to dependence (4), for which the following data was accepted:

ΔU – voltage increase (voltage was measured) [V]
a – signal increase 8000
U_o – voltage of tensometer excitation 4V
k – tensometer constant 2,075

Next, the provided values of strain were used in dependence (5) determining torque, basing on:
shape deformability module of Kirchoff module – 80 [GPa],
external diameter – 70 [mm]
internal diameter - 64 [mm]

In result of calculations, the values of torque were provided in established measurement points. These values are included in figure 8 showing the torque time history.

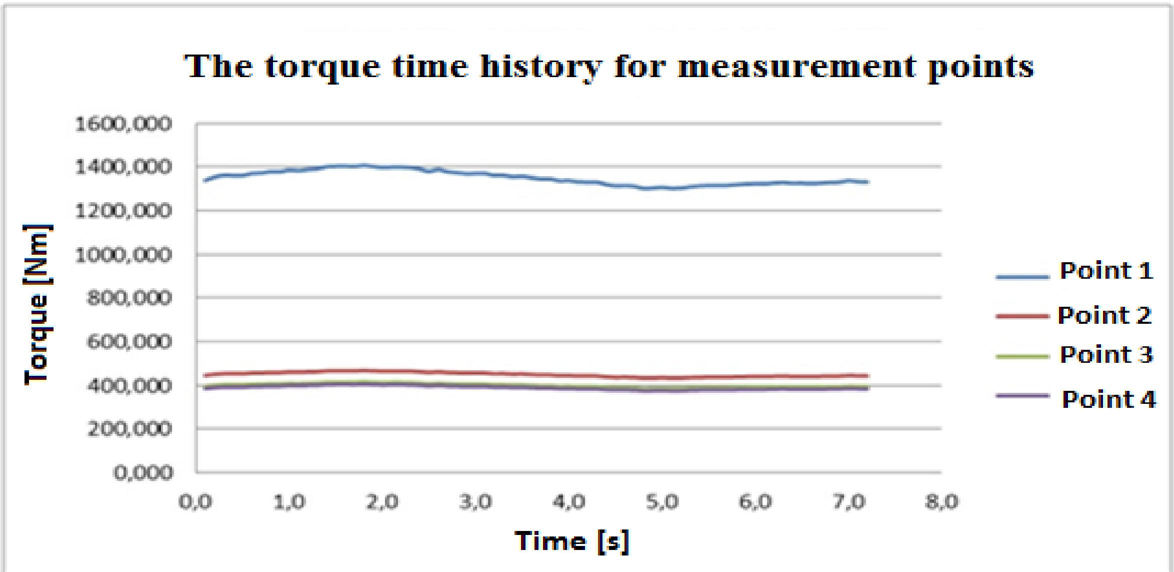

Fig. 8. Torque time history for measurement points [own research]

6. CONCLUSIONS

Analysis of the phenomena occurring in the process of energy transformation and transfer and the method for identification of its dissipation paths, enable determination of the efficiency of particular subassemblies of the power transmission system. In result of the carried out experiment a torque of the transfer box reduced by the value of energy losses was reported, which enabled determination of the subassembly efficiency. On the basis of the provided measurement data it was found that the transfer box efficiency was 91.6%. The proposed method can find application in the process of machine condition identification, using data from machine efficiency tests (power, torque, peed, etc.) carried out during its operation and maintenance.

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