STUDIES ON THE DEVELOPMENT OF A RELIABILITY DIAGNOSIS FOR AGRICULTURAL TRACTORS GEARBOXES

/

STUDII PRIVIND DEZVOLTAREA UNUI DIAGNOSTIC DE MENTENANȚĂ LA CUTIILE DE VITEZE A TRACTOARELOR AGRICOLE

Alexandru-Vlad HELLER *); Nicolae FILIP; Teodora DEAC
Technical University of Cluj-Napoca, Department of Road Vehicles and Transport,
Bd. Muncii, Nr. 103-105, cod 400641, Cluj-Napoca / Romania;
Tel: +40264401779; E-mail: teodora.deac@auto.utcluj.ro

DOI: https://doi.org/10.35633/inmateh-71-75

Keywords: *reliability diagnosis, agricultural tractors, gearboxes, reliability indicators*

ABSTRACT

Faults and failures analysis involve a wide variety of engineering areas, so concepts and reliability indicators help us to determine the types of faults easier, their appearance in functioning and the mathematical relations for determining different failures. In this context, test stands help us to identify accelerated noises, vibrations and serious malfunctions that occur during operation and can lead to major equipment failure, thus helping engineers to quickly find optimal solutions in most cases. The current methods used to determine the reliability of the agricultural tractors gearboxes are those in open energy flow, as they best simulate the real operating conditions. An agricultural tractor gearbox test stand was designed to perform rapid noise and vibration diagnostics and reliability tests. Considering the working conditions of the gearbox and its possible failures, the stand was equipped with transducers and a data acquisition system for data collection.

REZUMAT

Defectele și analiza defectelor implică o mare varietate de domenii ale tehnicii, astfel conceptele și indicatorii de fiabilitate ne ajută să determinăm mai ușor diferitele tipuri de defecțiuni, apariția acestora în funcționare și relațiile matematice pentru determinarea diferitelor defecțiuni. În acest context, standurile de testare ne ajută să identificăm zgomotele accelerate, vibrațiile și defecțiunile grave care apar în timpul funcționării și pot duce la defectarea majoră a echipamentelor, ajutând astfel inginerii să găsească rapid soluțiile optime în majoritatea cazurilor. Metodele curente utilizate pentru determinarea fiabilității cutiilor de viteze ale tractoarelor Agricole, sunt cele în flux de energie deschis, acestea simulând cel mai bine condițiile reale de funcționare. Am proiectat un stand de testare a cutiilor de viteze ale tractoarelor agricole pentru realizarea de diagnostic și teste rapide de fiabilitate a zgomotului și vibrațiilor. Având în vedere condițiile de lucru ale cutiei de viteze și posibilele defecțiuni ale acesteia, standul a fost echipat cu traductoare și un sistem de achiziție de date pentru colectarea datelor.

INTRODUCTION

Reliability is an important part of the process of identifying safety problems that occur in the operation of equipment, devices and components. Reliability discipline is training top engineers in maintaining the technical condition of automotive equipment. The operation of a product is limited by the occurrence of a reduction in operating efficiency or a failure. Reliability is the ability of a product to function without failure. Mathematically, it is possible to estimate, with some degree of certainty, the behaviour of a product under certain conditions of use (*Filip, 2010*). Reliability is linked directly to the notion of quality of a product. To a certain extent, the notion of quality can be considered as the statistical learning of the operating conditions at a given time, while the notion of reliability is the dynamic learning of the operating conditions. (*Bosch, 2022*).

Reliability has a new role in engineering, in accordance with international standards: it forces the designers to learn to design in the new conditions of the quantitative specification of reliability from the conception phase. Reliability concerns also have the effect of eliminating the causes of systematic failure and reducing the probability of the occurrence of other defects, thus leading to "reliability improvement".

Experimental or laboratory reliability requires, in addition to special installations for reliability tests, the establishment of a correct test program to represent the conditions of use. This is difficult to achieve and in general the tests are carried out under conventionally established conditions. In this case, the problem arises of establishing the equivalence of the laboratory tests with that of the actual behaviour in use. (*Bonnick et al, 2005*).

Table 1

The main cases of reliability

Different concepts of reliability	Content
Forecast reliability (preliminary, predictive)	Is the reliability predetermined by calculation, by any previous trials. It is specific to the design stage of a product.
Experimental reliability (laboratory)	Reliability obtained through determinative tests in the laboratory on special stands, based on product samples. It is called: a) observed (estimated) - if it refers to the stage observed in the laboratory; b) extrapolation - if based on information from laboratory to make estimates by extrapolation of the length;
Operational reliability (exploitation)	Reliability determined based on the processing of operational information.
Rating reliability	The reliability prescribed in the technical documentation (standards, norms, contracts, etc.).
Intrinsic reliability	Determined based on the link between the applied stress and the stress resistance of the considered element.
Extrinsic reliability	Determined on the basis of sampling or analytical data processing with the help of reliability indicators.

Economic analysis of constructive solutions often shows that instead of a single product with a high reliability, high life and without need of maintenance or repair, it is more economical to use two or three products with a shorter life span and possibly repairable.

Basically, the automotive industry is able to produce a product with a high reliability, but unacceptable in terms of cost.

Analysing variations in cost depending on reliability and maintenance (Fig. 1.), it is found that there is an optimal economic zone (minimal cost) which corresponds to the optimum reliability (Ropt).

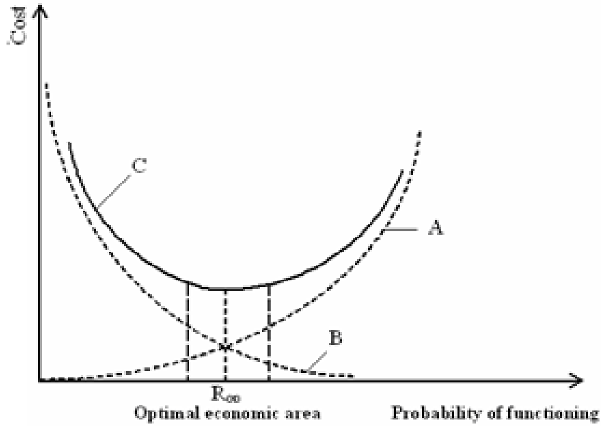


Fig. 1 – The relation between cost and reliability of a product

For a reliable R > Ropt, the investment cost is large in relation to the intended use. In many cases it should also be taken into account the damages caused by the lack of reliability.

In general, the value of Ropt is lower than the possible technical reliability. Therefore, a number of defects, not negligible, should be expected in order to ensure the most economical cost of operation. Thus, it is necessary to carefully schedule the appropriate maintenance.

In the end, the reliability which was adopted by the design solution represents a trade-off between reliability and maintenance cost.

The level of optimum reliability, Ropt, is different from one stage to another and from one use to another, depending on the effects and consequences.

Faults and failures is a vast domain of engineering. Quality control is not interested in the technical concept of defect, but "compliance" or "non-compliance" in relation to a set of circumstances. Later, at another level, the non-compliance found out is interpreted and treated as a defect in a technical sense, tracing the defects back to the conception phase.

Failure means the physico-chemical processes of degradation which has effect on malfunctioning. The defect is the event that occurs as a result of a failure. An item (simple element, component, entity, product, etc.), is not only an elementary part or component of a system, but also any product whose reliability is studied independently of the reliability of its components.

The item is characterized by a specific function that it has to fulfil.

During functioning, the component supports a certain stress that produces a cumulative deterioration, causing, after a random amount of time, the occurrence of an expected defect. This defect disrupts the functioning of the component (*Bertsche, 2008*).

The reliability of the component can be determined in two ways (*Cordos et al, 2000; Filip et al, 2020*):

a) The method is based on the assumption of a sample analysis. The general relations of reliability are determined considering a sample of elements working in the same conditions.

The number of defects that occur during functioning determines the variation in reliability over time. Reliability is defined on the basis of sample hypothesis and may also refer in this case to "intrinsic reliability" because the product is considered as a "black box" without considering the internal mechanism of the defect, and the reliability results from the behaviour of the item viewed from the exterior.

b) The method is based on physical mechanism of the degradation processes. It consists in the analysis of physical-chemical mechanism of the degradation process, the appearance of the defect and stochastic modelling. The forces applied and the stress resistance depending on operational time are considered random variables.

Stochastic modelling of the degradation process leads to the definition of the probability of occurrence of the faulty element and therefore to the definition of predictive reliability. This method of determination is based on the description of the internal mechanism of the defect.

MATERIALS AND METHODS

Considering the construction and operation mode of mechanical gearbox, with the variation of transmission ratio in steps, when testing them, the pursued objectives are: efficiency and power losses at different loads and speeds; the size, nature and position of the teeth footprint gears at the working under load; characteristic temperature (temperature regime of operation at different loads); noise and vibrations produced during operation; resistance to static request; durability of ball bearings; wear resistance of main parts; synchronizers quality and reliability; operation of the gearshift actuator; the reliability of a conventional gearbox expressed through the duration of operation until the first breakdown of the testing process or mechanism.

The project and the components of a stand intended for testing the reliability of a gearbox must ensure the possibility of reproducing the load regimes and operating speeds, which should be as close as possible to the operational operating conditions. This condition is necessary so that the obtained results come as close as possible, or coincide with the results obtained under real operating conditions. (Fig.2).

The measuring stand is designed to simulate, as faithfully as possible, the operation of the gearbox under working conditions (Fig.2).

The drive system is provided by a three-phase motor (*1*) with a power of 4 kw, which has an output shaft speed of 1500 rpm. The transmission of the moment from the drive motor to the gearbox is carried out by the planetary coupling (*2*). The gearbox (*3*) is fixed to the frame by an elastic coupling (4), thus it is isolated from unwanted vibrations during measurements. The transmission of the moment from the gearbox to the dynamic brake is accomplished with a planetary coupling (*5*) equipped with an elastic bush (*6*) and a low-frequency vibration attenuator (*7*). The dynamic brake (*8*) is a direct current motor, with a power of 4 kW, 220 V, used as a generator, which ensures the conversion of mechanical work into electrical energy, thus, making it possible to determine the power losses in the gearbox (*9*) (*Golgot et al., 2021*).

The working principle is the following: electrical energy is converted into mechanical work which is then converted back into electrical energy. This captured energy is used to charge the gearbox, by using high power resistors (*Heller et al., 2016; Mocanu, 2006*).

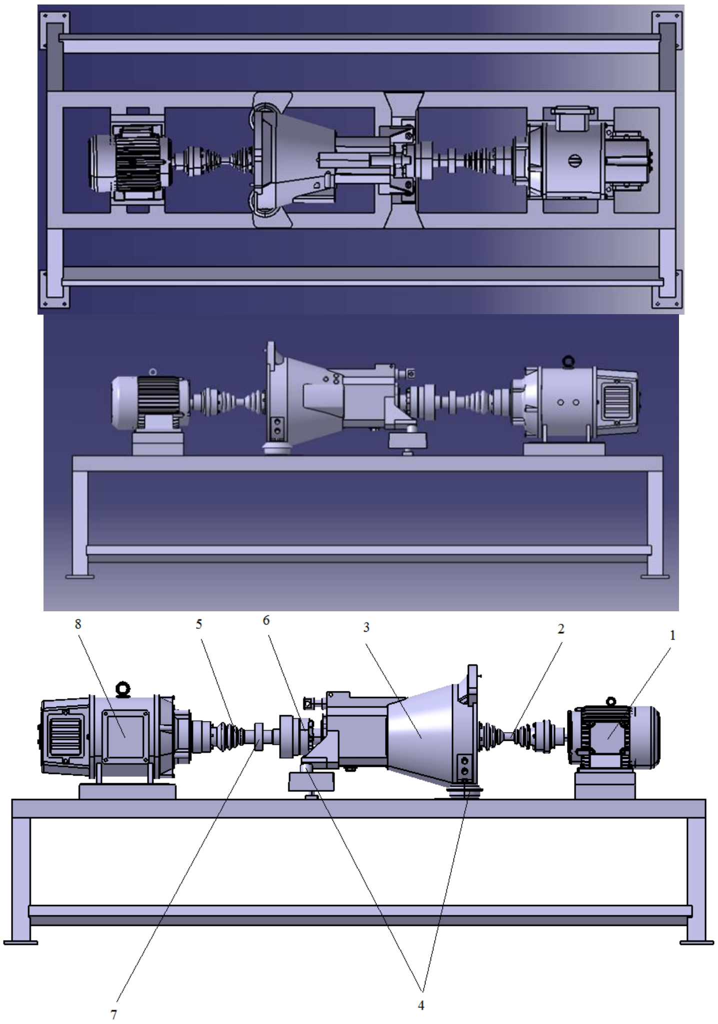


Fig. 2 - Gearbox test bench

1. Electric engine drive; 2. Planetary coupling; 3. Gearbox; 4. Elastic couplings; 5. Planetary coupling; 6. Elastic rubber flange; 7. Low- frequency vibration damper; 8. Brake dynamics

Method of testing in open energy flow

The method used for the gearbox's bench testing in the present paper is the method of testing in open energy flow (*Denton, 2006*). The testing bench must satisfy the following conditions:

- nominal power of the engine drive, must be at least equal to the power that the gearbox transmits during the operating conditions of the vehicle.
- the speed of the drive motor, must be at least equal to the nominal speed of the motor vehicle and can be changed continuously.
- the equipment should allow the measurement of torsion moment at the primary and secondary shafts using transducers (resistive or inductive);
- the brakes must be sized in terms of time and speed resulting from secondary shaft of gearbox, so they can absorb the power transmitted from the gearbox at all its ratios.

To measure the load applied to the gearbox, a Pico Ta009 direct current clamp meter (Fig.2) was used, a device that allowed precise monitoring of the current absorbed by the external consumers. Knowing the two parameters, the voltage and the intensity of the electric current, the degree of loading of the generator can be determined.

The adjustable rheostat was replaced by two light bulb panels, composed of 28 100 W (2800 W) light bulbs, 220 V supply voltage, each with a switch. This way, the amplitude of the signal was tracked by applying a progressive load to the gearbox.

For each position, three measurements were taken at three points, arranged at 90 degrees to each other. In each gear (3rd, 4th and 5th gear) 72 measurements were made at different loads and speeds. The determinations were made at the characteristic speeds (894 – 1482 revolutions per minute) with a load from 0% to 90% to be able to identify the proper vibration mode of the gearbox.

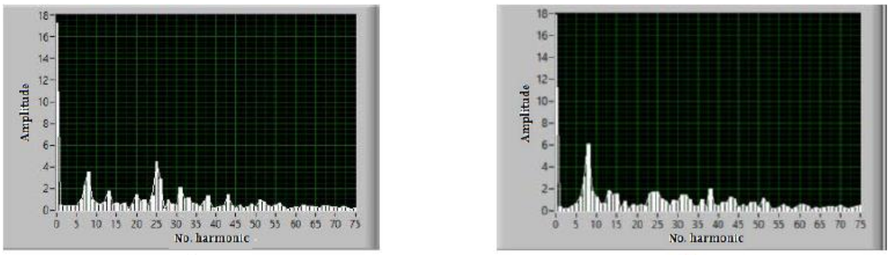
To perform the three measurements in three points arranged at 90 degrees to each other, the following procedure was followed: the piezoelectric sensor ai0 recorded the values in the vertical position of the three sections; the piezoelectric sensor ai1 recorded the values in the horizontal position of the three sections, by moving the position from point 1 to point 2. Each section was composed of two measurements at 90º, ai0(fixed)+ai1(left) A1, B1, C1 and ai0(fixed)+ai1(right) A2, B2, C2. Later, in the experimental data processing, these were extracted and compared in bands and frequency range.

RESULTS

After data collection, their processing consisted in the simultaneous determination of vibrations in three measuring points and for three sections. The results obtained after data processing are displayed in a wave chart, which is an interface component dedicated to displaying one or more graphical representations simultaneously, for which the variation over time is followed.

The analysis of the experimental results consisted in the development of the analysis in the frequency spectrum for the tests carried out *(Kloeden, 2008)*.

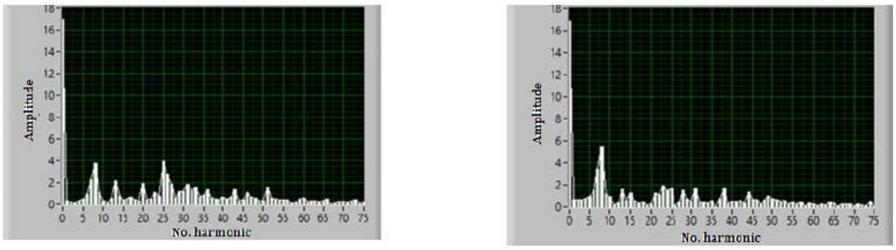
Figures 3a – 8a show the graph of the frequency bands of the measurements made at point A1, A2, B1, B2, C1, C2 at 0% load, and figures 3b – 8b show the graph of the frequency bands of the measurements made at the same points A1, A2, B1, B2, C1, C2 at the same load 0, the difference being that in the graphs marked with b the results are different due to the buffer that simulates the gearbox failure. From the analysis of the two graphs, in each analysed case it can be observed that the first harmonic F0 is approximately equal in both variants. The 8th harmonic is significantly higher in the case of the graph representing the measurements performed with a weakened buffer, i.e. figures 3b – 8b. The 25th harmonic is significantly higher in the case of the first graph, i.e. figures 3a – 8a representing the measurements performed with a tight buffer (*Upadhyay, 2020*).



a b

Fig. 3 - The graph of the frequency bands of the measurements made at point A1 at 0 % loading

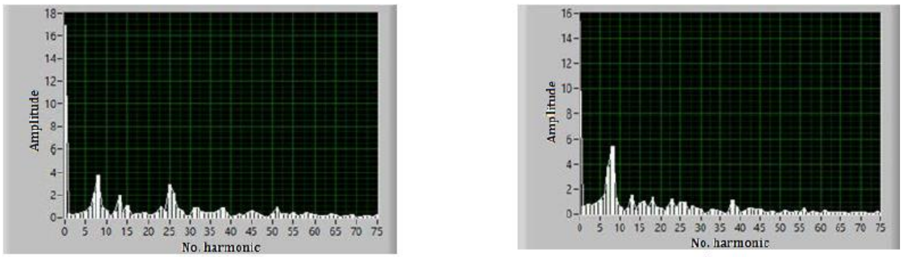
a. T3 tight buffer A1 S0, b. T3 loose buffer A1 S0



a b

Fig. 4 - The graph of the frequency bands of the measurements made at point A2 at 0 % loading

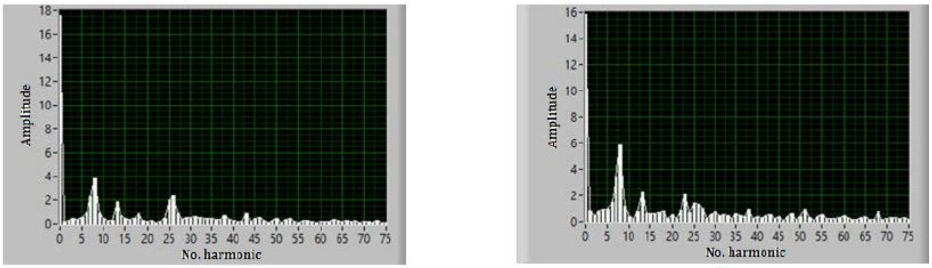
a. T3 tight buffer A2 S0, b. T3 loose buffer A2 S0



a b

Fig. 5 - The graph of the frequency bands of the measurements made at point B1 at 0 % loading

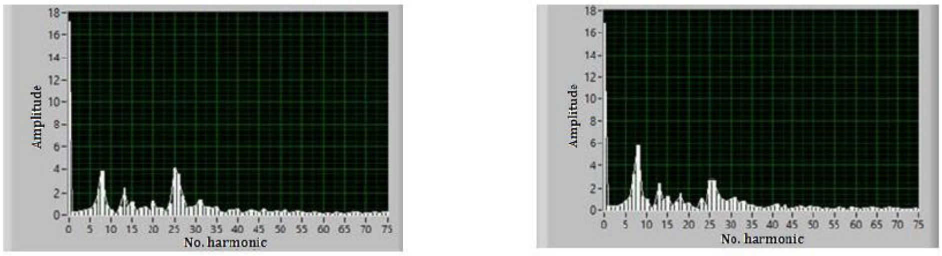
a. T3 tight buffer B1 S0, b. T3 loose buffer B1 S0



a b

Fig. 6 - The graph of the frequency bands of the measurements made at point B2 at 0 % loading

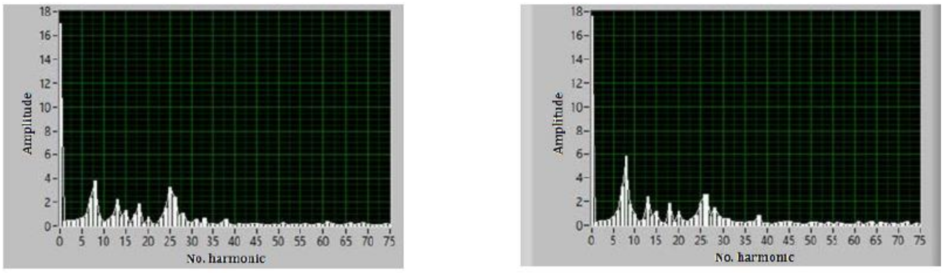
T3 tight buffer B2 S0, b. T3 loose buffer B2 S0



a b

Fig. 7 - The graph of the frequency bands of the measurements made at point C1 at 0 % loading

a. T3 tight buffer C1 S0, b. T3 loose buffer C1 S0



a b

Fig. 8 - The graph of the frequency bands of the measurements made at point C2 at 0 % loading

a. T3 tight buffer C2 S0, b. T3 loose buffer C2 S0

Similarly, the graphs of the frequency bands related to each measurement point without load and under load at 30%, 60%, 90% were made (*Dobre, 2018; Cardei et al., 2023*). The ratios of the dominant frequencies according to the load are presented in Table 1, and in Figs. 9-12. The dominant frequencies are represented according to the applied load.

Table 1

The ratio of the dominant frequencies as a function of the applied load

Loading [%]	**Harmonic no.**	**Operating frequency f_a [Hz]**	**Dominant frequency f_d [Hz]**	**Ratio f_d / f_a**					
				A1	**A2**	**B1**	**B2**	**C1**	**C2**
0	F7	24.78	13.58	0.547					
	F8		15.52	0.626					
	F25		48.5	1.956					
30	F7	24.73	13.58	0.549					
	F8		15.52	0.627					
	F25		48.5	1.961					
60	F7	24.55	13.58	0.553					
	F8		15.52	0.632					
	F25		48.5	1.975					
90	F7	24.45	13.58	0.555					
	F8		15.52	0.634					
	F25		48.5	1.983					

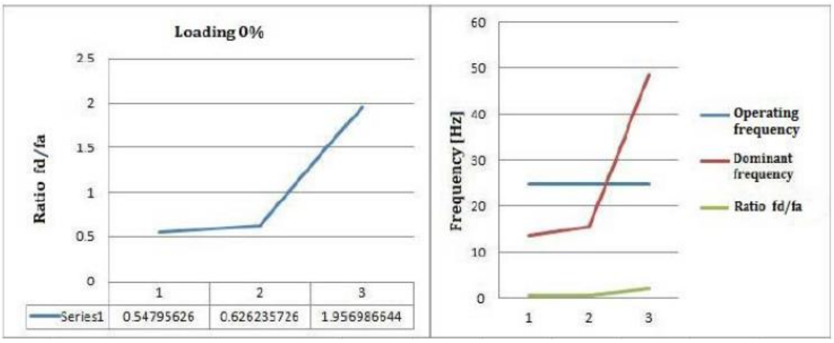


Fig. 9 - Dominant frequencies at 0 % loading

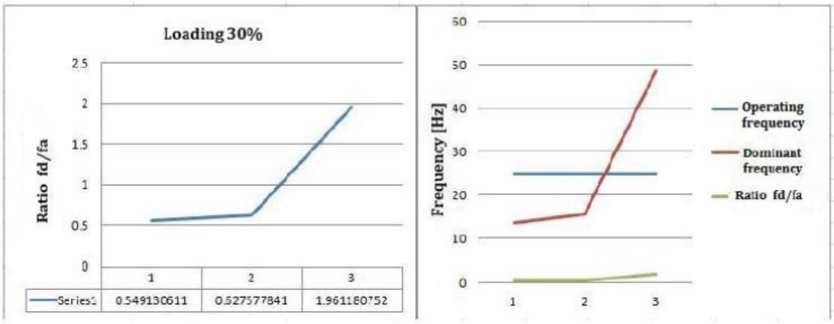


Fig. 10 - Dominant frequencies at 30 % loading

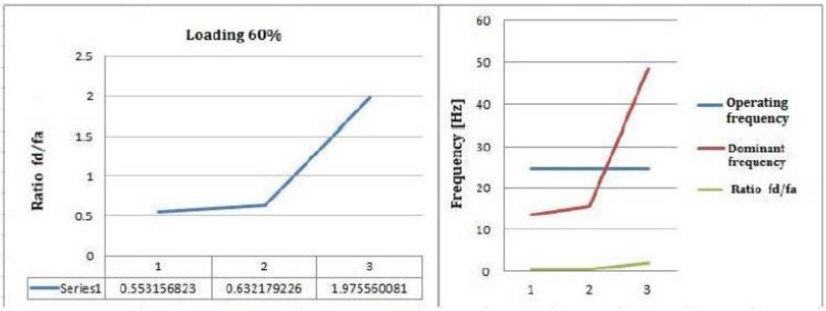


Fig. 11 - Dominant frequencies at 60 % loading

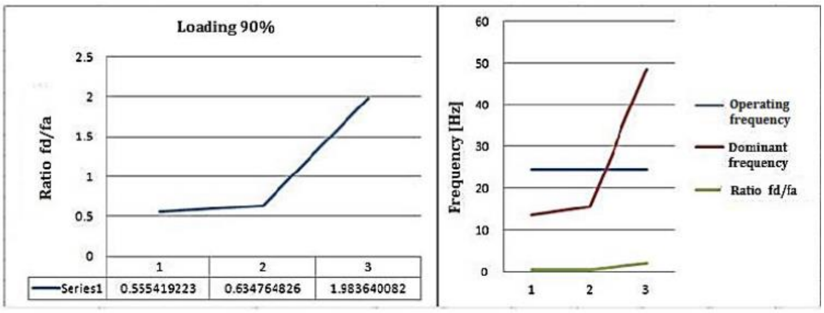


Fig. 12 - Dominant frequencies at 90 % loading

Following the analysis of the obtained experimental data, it was determined that although at 0% load the amplitudes of harmonics and automatic gearbox vibrations were approximately equal for both types of measurements with and without a buffer, with increasing load the value of the amplitude starts to increase in the case of measurements made with a buffer, reaching a significantly higher value (*Zhang et al., 2021*).

The functional parameters of gearboxes do not remain the same during their lifetime. This is explained by the fact that the parts that make up the gearbox wear out over time. The nature of parts wear is of two types: mechanical wear and chemical wear. Whatever the nature of the wear, it has the effect of altering the geometric shapes of the parts, which is finally reflected in the change of the dynamic parameters (gear noise, power losses, more pronounced heating of the components).

CONCLUSIONS

The study of vibration applied to reliability has the goal to improve gear ratio at different speeds to avoid critical resonance thresholds and can be applied for agricultural tractors.

Amplifying vibrations leads to rapid removal from operation of the elements (e.g., fatigue breaking shaft). Reducing vibrations extends the life cycle of the components of the gearbox.

The proposed stand can be used in practice in reliability tests. The stand has been designed to develop reliability testing based on acoustic and vibration measurements.

The vibro-acoustic analysis of the vibration mode of the gearbox is an effective way of evaluating its components. This type of analysis has the following advantages:

- the ability to quickly obtain information on failure mode and possible defects in agricultural tractors before gearbox failure.
- the investigation of the defect can be carried out without the need to dismantle the gearbox.
- the vibro-acoustic analysis technique is currently used in specialized centres around the world, but it is not yet used in our country.

The processing of the experimental results represented the analysis of 1024 values for each measurement point at the imposed speeds and load regime. The harmonics representing the contribution of the gearbox mounting pads to the vibration spectrum have been identified.

The developed stand can be used for the maintenance diagnosis of gearboxes of agricultural tractors. Thus, using the stand and the techniques of vibro-acoustic analysis, the defects in the gearbox components of agricultural tractors can be diagnosed, which leads to the extension of their life span.

REFERENCES

[1] Bertsche, B. (2008). *Reliability in automotive and mechanical engineering*. Springer, Berlin.

[2] Bonnick, A., Newbold, D., A. (2005). *Practical Approach to motor Vehicle Engineering and Maintenance*, Second Edition, Ed. Elsevier, Burlington.

[3] Cardei, P. et al. (2023). Superior inferential statistics of the experimental data of a complex experimental cultivator, *INMATEH Agricultural Engineering*, 71(3), 147-163, https://doi.org/10.35633/inmateh-71-12.

[4] Cordos, N., Filip N. (2000). *Reliability of Motor Vehicles (Fiabilitatea Autovehiculelor)*, Todesco Publishing House, Cluj-Napoca.

[5] Crișan, H., G., Heller, A., V. (2015). The graphical modeling, simulation and realization of an equipment with opto - reflective sensors for the management of urban public transport passengers, *Journal of Industrial Design & Engineering Graphics*, Special Issue, (10).

[6] Denton, T. (2006). *Advanced Automotive Fault Diagnosis*, Second Edition, Ed. Elsevier, United Kingdom.

[7] Dobre, A. (2018). The simulation of the dynamic behaviour for an elastic mechanical transmission of passenger car, *Automotive engineering (Ingineria automobilului),* 48, 23-25.

[8] Filip, N. (2010). *Road traffic engineering (Ingineria traficului rutier)*, Mediamira Publishing House, Cluj-Napoca.

[9] Filip, N., Popescu, G. (2020). *Reliability and maintainability with applications in vehicle and transport engineering (Fiabilitatea si mentenabilitatea cu aplicatii in ingineria autovehiculelor si trasporturilor),* UT PRESS Publishing House, Cluj-Napoca.

[10] Golgot, C., Filip, N. (2021). Exhaust noise analysis research for a single-cylinder diesel engine and evaluation of noise filtration by simulation, *INMATEH Agricultural Engineering*, 65(3), 203-2012, https://doi.org/10.35633/inmateh-65-21.

[11] Heller, A., V., Filip, N. (2016). The development of an experimental test stand for diagnosis of gearbox reliability, *Romanian Journal of Automotive Engineering*, RoJAE vol. 22(3)

[12] Kloeden, P., Platen, E. (2008). *Numerical solution of Stochastic Differential Equations*, Springer, Sydney

[13] Mocanu, F. (2006). *Material resistance (Rezistenta Materialelor)*. Vol. I, Tehnopress Publishing House, Iasi.

[14] Robert, Bosch, Gmbh. (2022). *Automotive Handbook*. 11th Edition, Wiley Publishing House, BRT9781119911906.

[15] Upadhyay, K. (2020). *Basics of Vibration and Condition Analysis*, Notion Press Publishing House, ISBN 9781648999635.

[16] Zhang, M. et al. (2021). Experimental study on air flow field characteristics of suction metering device, *INMATEH Agricultural Engineering*, 65(3), 57-66, https://doi.org/10.35633/inmateh-65-06.