Measurement and Evaluation of the Test Bench with an Open Flow of Mechanical Power for Gearboxes Testing

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Abstract. The article deals with assembly, measurement and evaluation of the gearboxes test bench with open flow of mechanical power. The article describes building a bench with tested gearboxes and its connection to a Ward-Leonard system. Subsequently, the procedure for connecting the bench to the electric network is described and also the connection of individual measuring sensors and their location in the bench. Furthermore, the article describes the connection of individual sensors with the measuring instruments recording the measurement and the evaluation of the experimental measurement. The conclusion summarizes the measurement results and the determination of the efficiency with the energy balance of the test bench with open power flow. The test bench can be used for any type of gearboxes including the planetary gearboxes as presented in the article. The work presented in this article was done at the Department of Design and Machine Elements of Faculty of Mechanical Engineering, University of Zilina.

Keywords: Test Bench · Gearbox · Energy Balance · Ward-Leonard System

1 Introduction

Nowadays, there are sophisticated simulation programs for simulating and analyzing of gearboxes and transmissions [1, 2] and also their particular elements, e.g. bearings [3–6] or their accessories [7] and their particular characteristics [8–10]. Simulations and analyses are mostly performed in programs under ideal conditions with the addition of boundary conditions to replace the real state. However, these results may not correspond to the reality [11, 12]. Therefore, testing of designed gearboxes and transmission systems on real test benches are still important. In real-life testing of gear systems on test benches, the parameters that cannot be determined in simulation programs are determined and verified, and these parameters significantly affect the functionality and life of the gearbox [13]. Therefore, the main objective of the article is to present a built test bench for gearboxes and transmission systems and to evaluate the energy balance of the test bench. It is a test bench with an open flow of mechanical power, which is connected to the Ward-Leonard system. The measurement of the energy balance is based on determining the effectiveness of the whole test bench and thus assessing economic indicators.

J. Homišin et al. (Eds.): ICMD 2020, AHE 17, pp. 365–370, 2023.
https://doi.org/10.2991/978-94-6463-182-1_38

2 Materials and Methods

2.1 Design of the Test Bench

By the assembling of a test bench with an open flow of mechanical power, the knowledge of gear system testing was applied. It was also based on the tests that were carried out at the testing laboratory at the University of Zilina.

The block diagram in Fig. 1 illustrates the wiring and deployment of components for assembling a test bench with open flow of the mechanical power for gearboxes and transmission testing.

As shown in Fig. 1, the entire test bench is composed of a drive system, which is a 132 kW two-pole asynchronous electric motor (EM) controlled by a phase converter and the tested two-stages planetary gearbox units (GB 1 and GB 2) type A 2000, which are connected in series, but mirror-turned, to give a final gear ratio $i = 1$. Subsequently, at the end of the test bench, the Ward-Leonard system (W-L S) is used to recuperate and convert mechanical energy into electrical power, which is then returned to the electric grid. Furthermore, there are electrical power sensors (S1 and S4) and mechanical power sensors (S2 and S3) in the circuit. These sensors are connected to a Yokogawa WT 1800 (YKGV) measuring device. The test bench prepared for measurement is shown in Fig. 2.

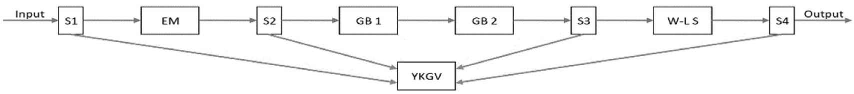

Fig. 1. Block scheme of the proposed test bench: S1 - electric power sensor; EM - electric motor; S2 - mechanical power sensor (torque meter); GB 1 and GB 2 - planetary gearbox A 2000; S3 - mechanical power sensor (torque meter); W-L S - Ward-Leonard system (dynamometer); S4 - power sensor; YKGV - measuring device Yokogawa WT 1800.

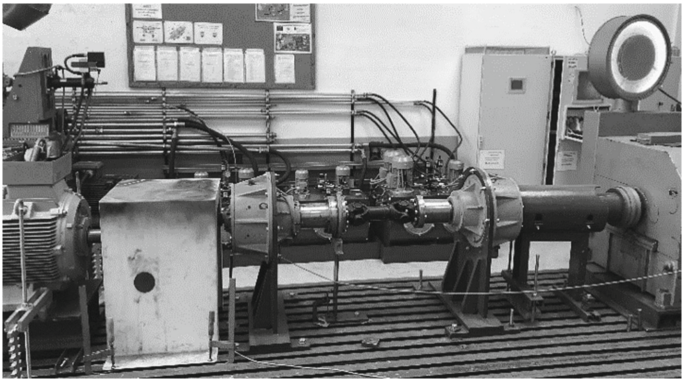

Fig. 2. Photograph of a test bench with open flow of mechanical power in the laboratory of the University of Zilina.

2.2 Connecting of the Test Bench

The test bench was connected in two phases:

1. In the initial phase, the circuit was mechanically coupled. The electric motor was coupled with the tested gearboxes and the group was connected to the Ward-Leonard system. All mechanical joints were realized using cardan shafts to compensate the different heights of the devices in the test circuit;
2. In the second phase, the circuit was electrically connected. The drive electric motor was connected to the phase changer to allow regulation according to the measurement requirements [14, 15].

After connecting of the electric motor, the individual sensors were connected to the test places. Since it was necessary to measure more parameters simultaneously and the Yokogava WT 1800 does not have such a large number of sensor connection slots, a reliable system connection was sought.

If there is a three-conductor or four-conductor system, which is balanced, the two-watt meter method can be used to measure the power (the Aaron method). This method is particularly suitable for a three-wire system, since it is always balanced, even if it is incoherent [16–18].

It was proved, that the three-phase power in the three-wire system and the balanced four-wire system can be measured with the Yokogawa WT 1800. Based on these facts, the sensors were connected in more steps:

1. The first sensor was connected to the input from the electrical network to know the electricity consumption;
2. The second sensor was connected behind the phase converter to determine its efficiency for the individual values as it is required for the measurement;
3. The first torque meter for the electric motor was joined to measure the efficiency of the electric motor;
4. The second torque meter was connected behind the tested gearboxes to determine the efficiency and the power loss in the connected gearboxes;
5. The last sensor was placed behind the Ward-Leonard's system to determine, how much power is consumed for its own operation and how much is consumed in the test bench and also to find out the proportion of consumed power to the recuperated power, which is returned to the electric network.

2.3 Measuring of the Test Bench

The measurement parameters were designed to reflect the test bench properties and to avoid areas, where the Ward-Leonard system has its own frequencies in order to do not impair the measured data and also do not damage the test bench components. The critical frequency zones were around 800 rpm and 1 200 rpm.

The input parameter, that was controlled by the phase converter, was the engine speed. It acquired the values of 700 rpm; 900 rpm; 1 100 rpm, 1,300 rpm and 1 500 rpm. On the output (Dynamometer), the load was increased from 100 Nm to 550 Nm. The load values were changed in steps of 50 Nm. Subsequently, the system was allowed to stabilize at a given load value before the measurement was started. At each steady state,

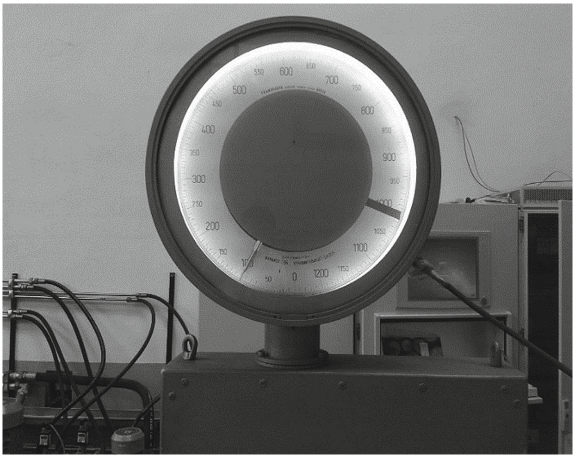

Fig. 3. Dynamometer indicator at the speed 1 300 rpm and the load 100 Nm.

ten measurements were made. For example, the speed 1 300 rpm and the load of 100 Nm was set and 10 measurements were triggered (Fig. 3); this was done for each speed and load configuration. There were over 500 measurements obtained and subsequently evaluated.

3 Results and discussing

After the measurement was completed, all the collected values were processed into a large table. After processing the values, the resulting graph was obtained (Fig. 4).

It shows the dependence of the test bench efficiency by variable input power. The highest efficiency achieved the value 63.4% by the input power of 100 kW, which

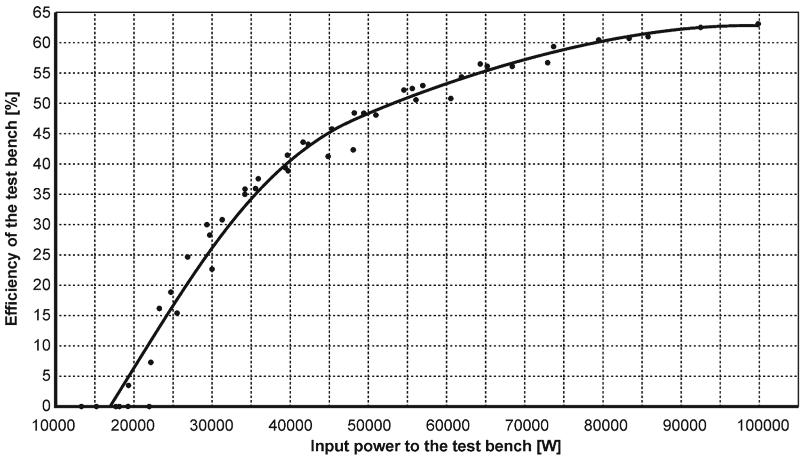

Fig. 4. Dependence of the efficiency from the input power.

represents the output power of 63.4 kW. The remaining 36.6% of the energy (36.6 kW) represents the heat loss at the test bench.

It should be mentioned that the results of the performed measurement was not only the above-mentioned graph, but also the efficiency of all test bench components such as:

- the progress of the phase inverter efficiency for each input power;
- the progress of the electric motor efficiency;
- the progress of the Ward-Leonard system efficiency.

4 Conclusions

The above-mentioned results show that the test bench with an open flow of mechanical power connected with Ward-Leonard system is not suitable for long-term testing of transmission systems and gearboxes. It is evident, that in the long-term testing, the power loss of less than 40% is quite high and it is economically inefficient. However, the advantage of such a circuit is the ability dynamically to change the load and speed, making it more attractive for short-term transmission and gearbox testing.

Acknowledgement. The research was supported by the Cultural and Educational Grant Agency of the Ministry of Education, Science, Research and Sport of the Slovak Republic under the project No. 045ŽU-4/2021 Approximation of the content of a group of project-oriented subjects based on the requirements of practice.

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