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DEVELOPING TEST EQUIPMENT SUITABLE FOR TESTING TORQUE TRANSFER SYSTEMS USED IN AGRICULTURE

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Abstract: It is a very common machine design task for engineers to create high-efficiency energy transfer, for which a standardized calculation methods as well as design factors determined by empirical and laboratory experiments are used. Contrary to general technical practice, these design factors are not always available for scaling the machine elements operating in agricultural and food industry equipment. Without this, we can only rely on the results of our own costly lifetime tests. Our aim is to create such a laboratory test bench with which the operation of the machine elements involved in the drive can be tested under working conditions.

Key words*: test bench, drives, transmission, infrared thermal analysis, efficiency, slow motion, active support, bearing*

INTRODUCTION

The defined research tasks can be solved by experimental methods, relying on their results. "During the experiment, the phenomenon being tested is artificially produced in a strictly controllable situation the conditions of which can be modified and reproduced [1]". A specially designed test bench was created to reproduce the working load and conditions of the machine elements making up the torque transfer systems used in agriculture and the food industry. Machinery operating on the arable field and food industry equipment is exposed to specific environmental impacts and stresses, unlike the

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common conditions in general engineering. In the following, four factors are highlighted:

Stochastic load. The load and stress of agricultural machinery occurs due to the interaction with materials having specific physical-mechanical and other properties (plants, fruit, soil, manure, animals, etc.). As a result, the testing of organic materials as a "workpiece" is particularly important [3]. Not only do the material properties but also other characteristics (stock density, dimensions, maturity, moisture content, etc.) of the agricultural materials and plant stock to be treated vary within a wide range, which results in a dynamic load of the machines, i.e. the acting forces are random. These dynamic stresses have an adverse effect on the components of the machines, but at the same time the phenomenon can be used, for example, for the energy-saving shredding of fiber feed. Via the stochastic description of the load process the straw cutting drum can be optimized and thus the edgewise vibrations of the straw cutting blades, which greatly reduces cutting energy [4,5].

Climatic and arable land relations. Agricultural machines working on arable land generally operate in extreme weather conditions and an environment contaminated with dust, leaf and stem residues, which has an impact on the operation and lifetime of the entire structure. Primarily, polymeric components are sensitive to environmental influences (temperature, humidity, abrasive materials, etc.), which greatly modify the material and friction properties [7]. For example, the components of harvesters may reach extremely high temperatures during the summer harvest, depending on how far they are situated away from the engine room. Machine elements often operate between a temperature range of 80 to 110°C under the plate cover. Extremely low temperatures often occur in the food industry. In the case of refrigerators or the equipment of cooled rooms, it is common to have an environment of -18°C [6]. Field machines are not only affected by climatic impacts, but large volumes of stirred dust (solid, mineral particles, small particles), leaf and stem residues also appear as contaminants and cause the abrasive wear of the parts. The dust particles adhere to the active surface of the machine elements, which depends on the moisture content of the air, the hygroscopicity of the particles, the electrostatic properties of the granules, and the shape of the particles, thus affecting the friction and wear processes [2].

Geometric machine setup errors on field machines. The agricultural harvesting machines are large plate-body self-propelled structures on which the power supply of the (threshing, cleaning, moving, etc.) machine units handling the crop is realized via mechanical drives. The distance and angular misalignment of the shafts involved in the drive may vary widely, which may arise from the uncertainty of mounting - deriving from the plate construction - and from the deformation of the frame structure occurring during operation. In such cases, by selecting a suitable drive the power transfer can be assured, but the additional loads of the set-up errors result in reduction in efficiency and service life.

Process medium. In the case of agricultural machines, the presence of dry matter loads is very common and high, and in the case of food processing machines, operating areas with humid and liquid medium can be mentioned. Among the machinery units used in technical life it can be mentioned regarding rolling element bearings that the use of widely used metal rolling bearings in a process medium is only possible if the serious sealing problems are solved. Process fluids (water, alkali or acid fluids, apple juice, wine, milk, etc.) have an adverse effect on the operation of bearings. In these cases, on the one hand the occurring corrosive effects must be expected as well as the inadequate lubrication of bearings. By now, due to the large development of materials science and manufacturing processes bearings with plastic outer and inner race and some kind of aseptic rolling element (e.g. glass, acid-resistant steel or ceramic) have appeared in the areas of rolling bearings, however, their behaviour against process media is still unclear.

MATERIAL AND METHODS

Construction of the test bench. The test bench basically consists of a bench, two motor units, accessory elements as well as an electrical and measuring system (Fig. 1). The stand structure is made up of two independent grooved tables that can be assembled in any position. The set-up of the drive parameters and data collection is facilitated by the manual control panel and the touch screen display.

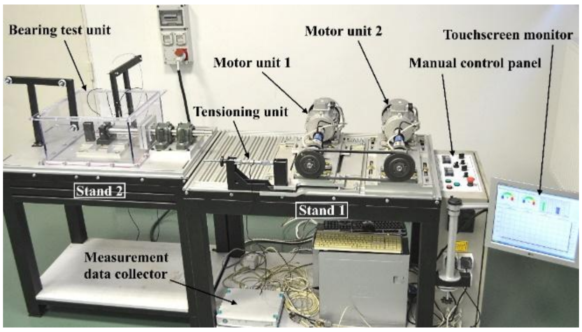

Figure 1. The construction of the test bench

Either of the two motor units is capable of fulfilling the drive or braking function, thus the transmission direction can be changed in a fixed arrangement. When testing the torque transfer components, one of the motors dedicated as the drive generates the performance to be transferred, the other one converts it into electric power as a generator and feeds the generated current back to the system, so only the losses must be compensated from the mains. With this solution, long-term lifetime experiments can be economically realized. The revolution of the three-phase asynchronous motors with forced cooling (NERIMOTORI IEC 34-1, 1.5 kW) and the braking torque can be adjusted manually using two Fuji Electric 5E1S-7E inverters (Variable Frequency Drives (VFDs)). In addition, the drive characteristics can be controlled by a programmable logic controller (PLC) produced by Moeller and the unique load function of the machine elements to be tested can be created. During the measurements it is possible to fix all the drive parameters and to precisely measure them with the help of an 8-channel HBM Spider 8 type data acquisition system. The torque values are supplied by NCTE 2200-17,5 torque transducers (measuring range: 0 to 17.5 Nm; accuracy class 1). The revolutions, the angular speed fluctuations, the angular accelerations, the angular deviations and sliding of the shafts can be measured using Hengstler 0538633 RI76TD/5000ED incremental encoders with a resolution of 5000 pulses per revolution. The diagram of the electric and metering system of the test bench is shown in Fig. 2.

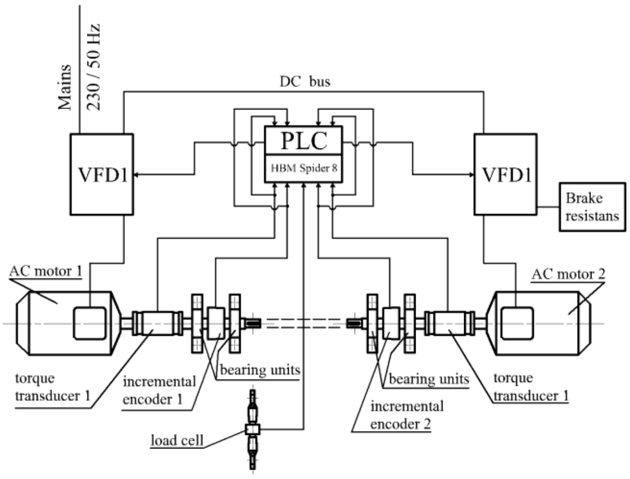

Figure 2. Schematic diagram of the electrical and measuring system

Test arrangement of belt drives. For the testing of the belt drives the drive unit is fixed to a tensioning mechanism guided by a linear bearing. The pretensioning of the belt can be set with an adjusting spindle and a load cell (HBM U9B 10kN) connected in series with it, whose line of action coincides with that of the shaft pulling force (F_H). In this way the pre-tensioning force can be measured directly. The construction of the universal test bench assembled for the belt drive tests is shown in Fig. 3.

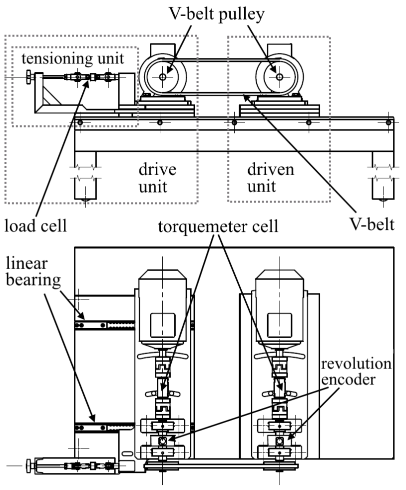

Figure 3. Test bench assembled for belt drive tests

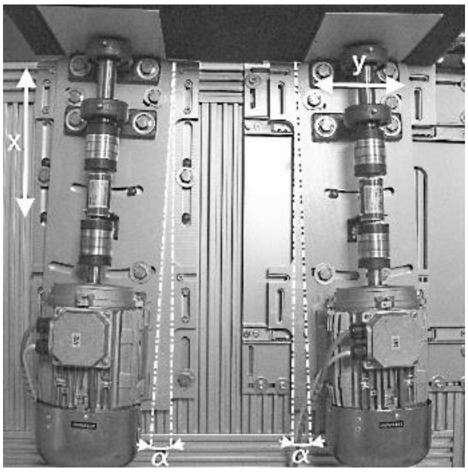

Figure 4. Setting the geometric error on the test bench

Such a locking mechanism has been created to fix the drive and braking motor units to the stand which allows a variety of machine setting errors to be realized on the drive to be tested (Fig. 4).

The shaft end of the motor units can be adjusted angularly and axially to accurately create and repeat the parallel and angular errors of the drive shafts.

Experimental layout to test the active supports. During the bearing tests, one motor unit was fixed to one grooved table and the other table contained a set of structural elements required for the bearing tests. The conceptual structure is shown in Fig. 5.

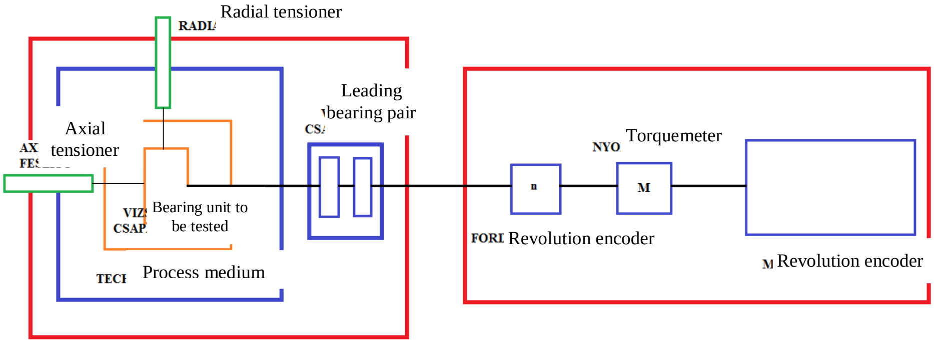

Figure 5. Block diagram of the bearing test bench

Basically, there are three main bearing rolling parameters to be modified. In addition to the radial and axial loads, it is necessary to realize the change of the rotation according to different needs. The introduction of the drive shaft into a polycarbonate cabin was realized by means of two specially designed and manufactured seal cases attached to each other by bolt connection. In order to avoid possible leakage between the seal case and the cabin, the cases are connected to the side of the cabin with an endless, foamed, silicone O-ring, ensuring complete sealing. The sealing next to the shaft is provided by two spring sealing rings (Fig. 6).

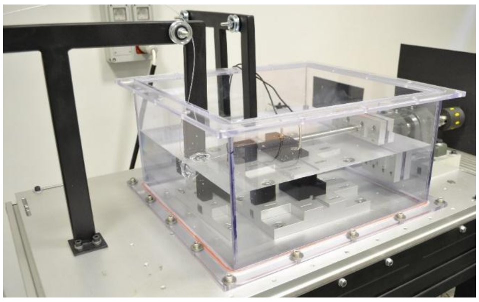

Figure 6. The medium retention conditioning cabin

The load system ensures the constant load of the bearings by weight force. Thus, in this case, the bearing block is not fixed during the measurement runs, it acts as a floating bearing housing, which can move both radially and axially. In order to test the torque-transmitting elements in the process medium it was necessary to provide a medium-retention solution with which the machine element to be tested can be separated from the outside environment so it is only affected by the effects of the process medium. For this purpose a polycarbonate conditioning cabin was designed and manufactured.

Test Methods. During the experiments not only the values measured by the test bench $(n_1; n_2; M_1;\ M_2; \omega_1;\ \omega_2; F_i; T_i; s)$ can provide a test parameter, but other measuring instruments can be incorporated into the experimental arrangement too. It is also possible to measure the temperature, temperature distribution or change (such as loss intensity) of machine elements operated under artificially created conditions by means of a thermal camera. In addition, a high-speed camera can be fitted into the experimental arrangement, with which the fast processes occurring among realistic motion relationships can be analysed.

The temperature is measured with an infra camera type NEC H2640. Its infrared detector has a high resolution (640 x 480), a sensitivity of 0.03°C and a temperature measurement range from -40°C to + 500°C. The thermal camera images can be recorded at a frequency of 0.25 - 30 Hz, through which the process of warming can be observed.

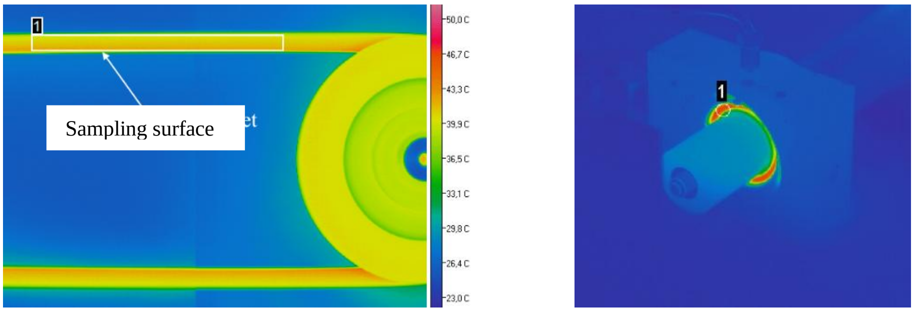

Figure 7. Thermal camera imaging and the sampling surface

Temperature data is obtained from the thermal image taken of the surface of the tested machine element by using the evaluation software Image Processor Pro II (Fig. 7). From the infrared camera images the temperature of the sampling surface marked on the measured object gives the temperature rise of the machine element. This temperature rise is described by the Baule-Mitscherlich saturation function (Fig. 8), in which the measured parameters change along a decreasing gradient towards the maximum of saturation.

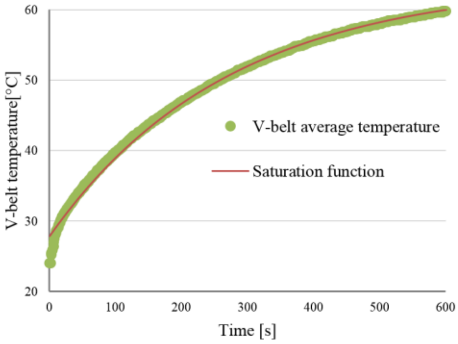

Figure 8. The measurement data and the saturation function

Different stable (saturation) temperature and heat generation rates belong to each experimental setting so the duration of the measurement is also dependent on the setting. With the help of the mentioned mathematical model the steady-state operating temperature can be determined and during the experiments it is not necessary to reach it, so the duration of the measurements can be the same regardless of whether or not the temperature of the machine element has stabilized under the circumstances. The temperature change can be determined from the difference of the starting and the saturation temperature, which means the power loss between the two steady states - between the workshop and the stabilized state of the operating temperature.

The general equation of the function of saturation:

$$Y = A \cdot \left(1 - e^{z + c \cdot X}\right) \tag{1}$$

The test arrangement with the high-speed camera is shown in Fig. 9, where an Olympus i-SPEED TR camera is used to make an image of the torque transfer element. The components to be tested are provided with measuring points whose path of motion describes the movement of the machine elements. For high-speed camera application a special DC powered light source has to be utilized to avoid periodic variation of illumination and provide sufficient light intensity. The image sensor (CMOS) is set parallel to the plane of motion to avoid a parallax error. The operation of the unit is supported by the central control unit, which displays a real-time image.

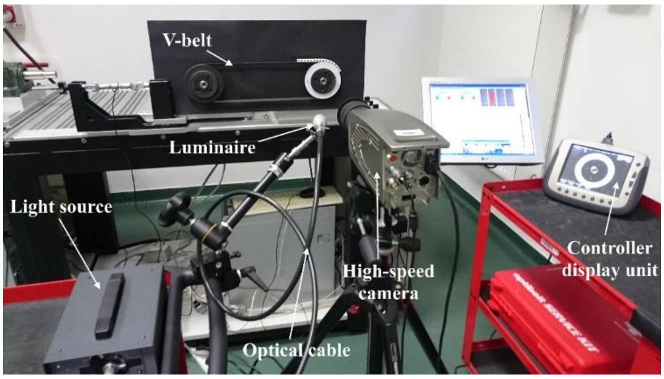

Figure 9. Experimental arrangement of relative motion tests

The motion path described by the measuring points is determined by the i-SPEED Control Pro imaging software belonging to the camera. To retrieve the selected object, it is necessary to correct the recorded images, during which the color images are converted to grayscale first. Then in order to highlight the tested marks two-color black and white frames are created from the grayscale images to separate the test points (pixel sets) from the background without losing information. In the following image analysis step the size of the object in the image is calibrated and a general coordinate system is given. The built-in algorithm of the software creates the coordinates of the manually selected object at the selected length of the image and then the coordinate data are processed using an Excel spreadsheet program.

RESULTS AND DISCUSSION

The universal test bench is a tool used both in the research program and educational work of the Szent István University, Faculty of Mechanical Engineering, Institute of Mechanics and Machinery. The research results obtained with the test equipment are shown below, which can be discussed in two main directions.

Testing of installation and machine setting of torque transfer systems. During the tests related to bearings performed so far a conclusion was drawn regarding the changes in physical and geometrical parameters impacting the operation of bearings, due to the effect of process fluids. In connection with this, an installation technology recommendation was developed to help decide what shaft or nest fittings are necessary in the case of the given non-metal rolling bearing for ideal bearing use. The recommendation takes into account the operating temperature of the bearing, the type of process medium, or the special material properties coming from the relaxation process.

Manufacturers prescribe such a small size interval for the geometry setting of V-belts that cannot be maintained in agricultural equipment. The impact of machine setting defects on V-belt drive was tested by experimenting on the test bench. During the experiments the heat loss of the belt drives and the lost motion were taken into account together. An error limit was determined, where V-belt drives were still working at adequate efficiency. Furthermore, it was found that in addition to the magnitude of the differences between the pulleys, the nature of the fault also affects the loss of performance.

Testing the operating characteristics of torque transfer systems. For the technical world using roller bearings, the relationship between radial and axial loads in the case of some bearing types is not new. In the case of conventional metal base bearings, the equivalent static load can be calculated from the radial and axial components of the static load. This is the load (radial with radial bearings, axial with axial bearings) that would cause the same maximum rolling load in the bearings as the actual loads. In the case of non-metallic bearings, such a relationship between axial and radial loads has not been available for technical life so far. As a result of the research work, a ratio has been established, which helps to interpret the relationship between the two main directions of load. Within the framework of the research program, it was important to establish and prove the assumption what function is described by the temperature change parameters in the case of changing the three main parameters affecting the operation of the bearings. After describing these functions, the maximum operating temperature of the non-metal rolling bearing can also be calculated with different setting parameters. The significance of the result is that based on them in most cases it will be possible to avoid bearing damage due to bearing overheating.

It was justified in the scope of the major characteristics affecting the power loss of V-belt drives that by ideally selecting the parameters of the V-belt drive, power loss can be measurably reduced. Based on the heat generation of the V-belts, the mathematical model for loss of performance was established, where it was determined by the variance analysis of variables that the size (or reciprocal) of the diameter of the disc influences the heating-up of the belt to the greatest extent. The effect of the bending frequency and the pulling-through rate is nearly identical, but at the same time this effect is more than an order of magnitude less than that of the pulley diameter.

CONCLUSIONS

Using the test bench developed by the authors, through laboratory experiments, the torque transfer systems operating in different agricultural and food industry conditions can be tested, the result of which is indispensable in the sizing, operation and product development of machine elements. The test equipment is suitable for testing the operation, lifetime and efficiency of drives and other rotating machine elements (different belt drives, gear drives, clutches, active supports, etc.) operating under the mentioned conditions.

The development and implementation of the test bench suitable for examining the machine elements presented in this article is currently in the state described above. The current state makes it possible to examine torque transfer systems with different settings in the cabin flooded with the process medium. In the future, there might be an opportunity for closing the cabin and for the programmed adjustment of the indoor environment. The long-term goal of the development is to create the controlled inner medium. According to the current concept, PLC controlling will allow the cabin temperature, humidity and the internal atmosphere to be controlled.

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RAZVOJ OPREME ZA TESTIRANJE SISTEMA PRENOSA MOMENTA SILE KOJI SE KORISTE U POLJOPRIVREDI

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Sažetak: Veoma uobičajen zadatak za inženjere konstruktore mašina je konstrukcija visoko efikasnog prenosnika pogona, za koju se koriste standardizovane metode proračuna, kao i faktori koji određeni empirijskim i laboratorijskim ogledima. Nasuprot opštoj tehničkoj praksi, ovi elementi konstrukcije nisu uvek dostupni za kapacitet mašinskih elemenata primenjenih u opremi za poljoprivredu i prehrambenu industriju. Bez ovoga možemo da se oslonimo samo na rezultate dostupne rezultate sopstvenih ispitivanja. Naš cilj je da konstrušemo takav laboratorijski sto za testiranje na kome ćemo moći da ispitujemo rad mašinskih elemenata ugrađenih u prenosnik pogona u radnim uslovima.

Ključne reči: *sto za testiranje, pogoni, transmisija, infracrvena termalna analiza, efikasnost, usporeni snimak, aktivna podrška, ležaj*

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