ADVANCES IN ANGULAR CONTACT BALL BEARINGS TESTING MACHINE DESIGN

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Abstract: Angular contact ball bearings are machine parts used to sustain the rotating shafts of various mechanisms and their failure may conduct to catastrophic crash of the entire machine. To obtain an extended operating time, it is very important to assure an optimum preload of the bearings working in tandem (X - face to face- arrangement for short spindles, and O – back to back- tandem for long spindles and significant thermal expansions). A proper bearings design includes adaptive systems able to maintain the axial preload as a function of the running parameters (speed, load, and lubricant type) and environmental conditions (temperature). In this paper, a new testing device based on preload system of shape memory alloy springs and some preliminary experimental results are presented.
Key words: ball bearings, axial preload, shape memory alloys, test rig, mechanical design.

1. INTRODUCTION

The concept of innovation can be synthetically defined as developing new processes and procedures in various fields of activity. The actions that serve this purpose are the result of man's permanent concern for discovering and introducing new technologies which in turn, represents the main elements that determines mankind's evolution over the course of its history. The importance and size of these activities have grown exponentially as society evolved.
Over the last decades, a remarkable increase in studying and innovation was noted as a way to achieve a solid economic growth. The opening towards innovation and the ever increasingly fast pace of change are visible in the day by day life. Innovation is necessary to achieve a constant technological progress and to improve the quality of life.
The innovation in machines' field comprises also rolling bearings. Rolling bearings are included in over 90 % of existing rotating machines, being used to sustain the rotating shafts. Studies on rolling bearings started over one hundred years ago [1]. A unified treatment of rolling bearing theory was presented in [2]. Regarding the friction torque in rolling bearings, the developed theory was validated by experimental results [3-9]. Olaru [3] designed a new test rig for friction torque and temperature measurement of angular contact ball bearings. Cretu et al. [4], Prisacaru et al. [5], and Bercea et al. [6] proposed new testing machines for heavy loaded tapered and cylindrical roller bearings. Paleu et al. [7], Bujoreanu et al. [8], and Damian et al. [9] carried out tests on angular contact ball bearings at high speed and pure axial load, and moderate speed and combined radial-axial load.
As a part of the innovation process, this study presents a preloading solution for angular contact ball bearings used in various machinery and equipment, bearings that require a certain preload in order to increase the operational reliability of these machines. In this case, the preloading is accomplished by using disc springs manufactured from a special shape memory alloy [10]. Using shape memory alloys in engineering, can solve some of the current problems encountered by engineers while designing industrial machinery and equipment by surpassing specific limitations that were noticed while operating certain types of machinery. In order to apply preload to the angular contact ball bearings we developed a device that can measure the preloading as well as the behavior of the tested bearings under certain conditions. According to conducted tests, this device confirmed that shape memory alloy disc springs modified and increased the preload [10]. The data collected during the operation of the first variant of the preload testing device, shows that the expected preloading was achieved with the use of the disc springs manufactured from a shape memory alloy. This shows that the shape memory alloys springs can be used in bearings preload systems. Also, by further processing the collected data, the behavior of this type of shape memory alloys can be observed.

2. ROLLING BEARINGS PRELOAD

The bearing's internal clearance can be reduced or eliminated by proper preloading. Usually, ball bearings are designed and built with small spaces or clearances between their components, in order to allow them to move freely. If that clearance isn't reduced or eliminated by preload, can cause the bearing's rolling elements to skid instead of rolling as they should do, and can also cause misalignment in the bearing races. Preloading with elastic systems is made possible with the help of elastic elements, like helical springs, disc springs and other specific elastic elements. Bearings are complex machine parts used to support rotating or oscillating shafts of different machines and devices. Ball bearings are a class of rolling element bearing that uses spherical balls to maintain the separation of the bearing races. Ball bearings are usually used to support machine parts that rotate or oscillate; these parts include: gears, machine cable guides and pulleys, spindles, rotating lifts and tables, etc. Some of the advantages of using ball bearings are: axially smaller dimensions, the possibility of increasing the accuracy of spindles through the use of preloading, relatively simple to lubricate and the possibility to starve the bearings of any lubrication for a short period of time. An application for the preload of ball bearing can be found in the machines that use ball bearings subjected to negligible loads and high speeds; in these cases, the rolling elements skid, damaging the machines that they are used in. This can be avoided by mounting the ball bearing correctly and by applying preload.

There are two main bearing preloading methods:

1. Position preload;
2. Constant pressure preload.

According to application and used bearing type, preloading can be either radial or axial. For example, cylindrical roller bearings can only be radially preloaded because of the way they are designed. On the other hand, cylindrical roller thrust bearings and thrust ball bearings allow only an axial preload. In order to achieve a correct axial preload, tapered roller bearings and single row angular contact ball bearings are mounted in pairs, in one of the following configurations:

-back - to - back: in this case, the load placed on bearings diverges;

-face - to - face: the applied load converges.

In certain applications, precise bearing preloading might be required. If high rigidity or positional control is needed, then, preloading is in order. On the other hand, if the external loads are minimum or missing, when the bearings are in operation, preloading is needed to ensure a small load. The application of preload is determined by measuring a force, a distance / path or a frictional torque. Applications that require bearing arrangements with negative operating clearances, include: automotive components such as gearboxes and differentials, machine tool spindles, electric motors, etc. In these cases, preload improves the rigidity or the accuracy of the shaft positioning.

By axially preloading deep grove ball bearings, the radial internal clearance is increased resulting nonzero contact angle.

The angular contact ball bearings and the tapered roller bearings mounted in back - to - back configurations will have a longer distance between the pressure centers than bearings mounted in face – to - face configurations. When the distance between the bearing centers is shorter, the bearings mounted in the back – to – back configuration will be able to withstand increased tilting moments.

Usually, when mounting bearings, the preload is applied at the ambient temperature. This can affect the machine in which the bearings were installed in, when the shaft's temperature is higher than the casing, by decreasing or increasing the preload. When the outer ring of the bearing thermally expands radially, the preload increases. If the bearings are mounted in the face – to – face configuration, the preload increases as the thermal expansion is in the axial direction. For the back – to – back bearings configuration, if the coefficient for the thermal expansion and the distance between the bearings are of certain values, the radial and axial thermal expansion can be reduced, leaving the preload unchanged.

In order to determine the optimal preload for a system, the value should be calculated taking into consideration the bearings types and sizes, the loading parameters, the starting and running torque of the system and the rigidity that is required. The effects of incorrectly applied preload can conduct to an increase in friction torque and temperature in bearings.

In order to apply proper preload in a system, the elastic spring preload or fixed preload can be used. In order to accomplish a solid or fixed preload if required, locking mechanisms or spacers are needed to have the inner and outer rings of the bearings fixed while concomitantly applying an axial load. The main advantage of using a solid or fixed preload is that the system becomes more rigid, making it easier to design such systems. The disadvantage of using this method is given by the fact that the system is influenced by the temperature; the system reacts to temperature changes that occur in its components, thus, changing the value of the preload.

One of the most common bearing preload applying methods is by using compression springs. The spring preload method is simpler to implement and easier to use because it allows thermal expansion and contraction of the elements in the system and slight misalignments. The spring preload method can be

used to apply preload to angular contact ball bearings of machine spindles rotating at high speeds, although this method is not recommended for applications that require a high degree of rigidity, when the direction of the axial load can change or when unexpected loads that are higher than the normal ones occur.
The main advantages of preloading bearings, are:
- Extending the service life of the bearings;
- Preloading compensates for the wear and settling in the bearings;
- Improves the rigidity and stiffness of the system;
- Improves the shaft guidance systems;
- Reduces the vibrations and noise in the system;
- Maintains the exact position of the bearings and the running accuracy of the shaft radially and axially;
- Prevents sliding between the rolling bearing elements and raceways.

The skidding and wear of ball and races contact surfaces within a bearing leads to clearances that can be compensated by elastic preloading.

When the preload is set according to the specifications, the operational reliability can be increased, because the loads are better distributed in the bearings.

3. TESTING DEVICE

The test rig used in this research was completely presented in [10]. The testing device presented in this paper is designed to test the preloading of angular contact ball bearings using disc springs made from shape memory alloys.

The main body of the device constitutes a metal cylinder that was precisely machined and balanced. The inside surface was carefully machined in order to reduce friction and to make it easier to assemble.

The current iteration of the preloading test device carries over a few design elements from the previous version. One such element is the disc springs assembly that is used to induce preloading in the ball bearings. It consists of a part that is similar to a piston; it is used to compress the disc springs that are held in place by the rod of the piston. The rod is used to center the disc springs and the washers.

The cylinder that houses the piston and the springs engages a part that pushes against the outer ring of one of the two ball bearings used in the device which in turn induces the preload. The surfaces of the cylinder and the piston are machined in order to reduce friction and to provide a smooth movement of the disc springs when the preloading the ball bearings.

With the device assembled, the piston rests against the bottom cover of the device. This cover has a center threaded hole for the load cell as well three small holes for the rods that are used to transfer the preloading to the piston. When the load cell is tightened the three rods are being pushed against by a disc; this ensures that the three rods are pressed with the same amount of force.

Initially, we used a standardized load cell that was pre - calibrated from the factory. In order to check the calibration for the load cell, we designed a set of components that we used to check the specifications to make sure that our tests will be accurate.

The top cover of the preload testing device is used along with the bottom cover to secure the device's components and to form a compact unit. The main components of the preload testing device are held together with six stud bolts. For the stud bolts as well as for the other components, a finite element analysis (FEA) was performed before manufacturing the required parts.

The components of this current iteration of the preloading test device were manufactured with strict tolerances and thoroughly checked as we prepared it for the final assembly. We took extra safety measures in order to be able to start and conduct the tests safely as the shaft of this iteration of the device will rotate at speeds in excess.

A general view of the testing device is given in Figure 1.

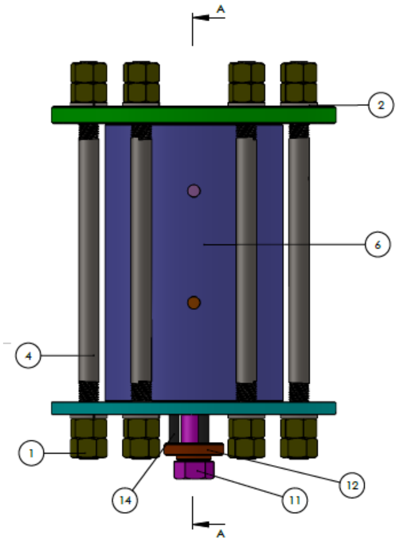

Fig. 1. General view of testing device

The components of the preload testing device are numbered in the picture above:
1. Lock nuts;
2. Washers;
4. Stud Bolts;
6. The main body of the device;
11. Load cell;
12. Thaler;
14. Pressure rod.

A section view of the testing device is presented in Figure 2. The components of testing device are numbered as follows:
1. Lock nuts;
2. Washers;
3. Top cover;

4. Stud bolts;
5. Angular contact ball bearing;
6. The main body of the device;
7. Device shaft;
8. Bearings press;
9. Piston cylinder;
10. Piston;
11. Load cell;
12. Thaler;
13. Bottom cover;
14. Pressure rod;
15. Disc springs.

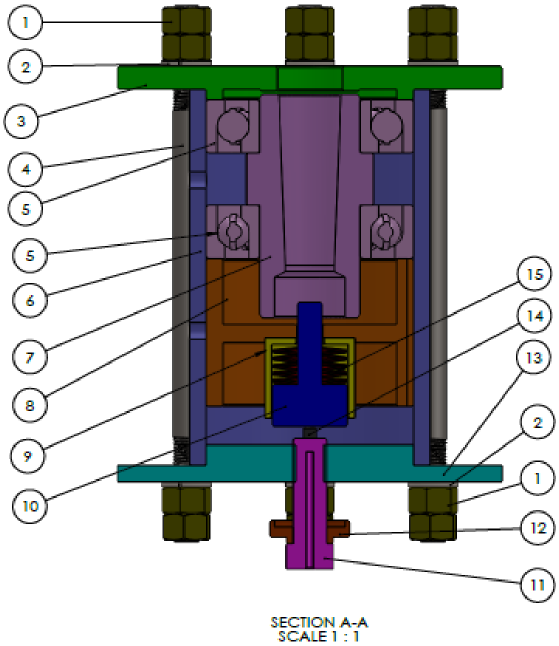

Fig. 2. Section view of testing device

Figure 3 gives a detailed section view of the device.

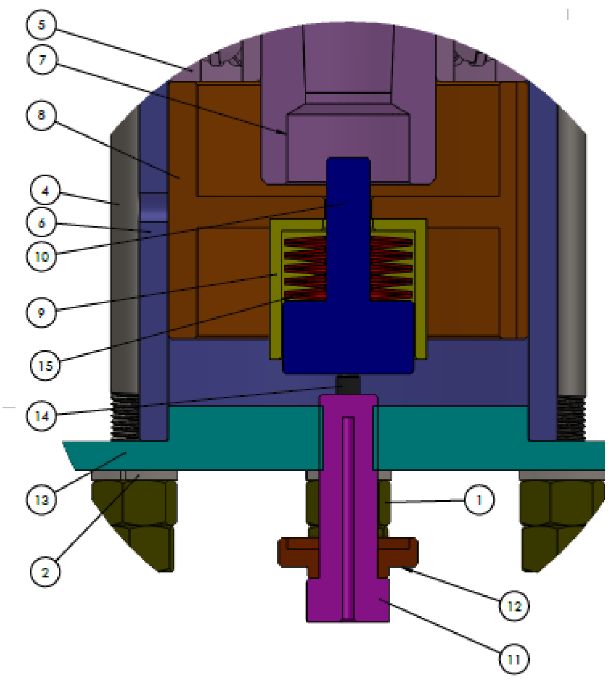

Fig. 3. Detailed section view of testing device

A picture of the shape memory alloy springs used in this paper is given in Figure 4.

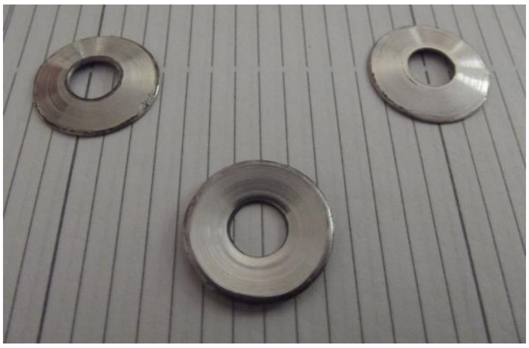

Fig. 4. Shape memory alloy disc springs used in the device

Patents were issued with details concerning the material used for these disc springs, their properties [11] and manufacturing technology [12] and for this reason these aspects shall not be discussed here being beyond the scope of present paper.

4. RESULTS AND DISCUSSION

The testing bearings are from 7206C series, tandems of two bearings being mounted in face-to-face arrangement. Testing started at lower speeds and no separating washers between the shape memory alloy disc springs.

The disc springs were positioned inside the device in pairs. Seen from a section view, the positioning of the springs is similar to an ellipse. As we were testing the device and experimenting with different values of the preload, we noticed that the temperature inside the device was slightly higher than the room temperature. As expected, the temperature grew if the values of the preload were higher.

While operating the device at a higher speeds and preloads, we noted a sudden drop in the preload force. This was because of the temperature rise inside the device and the fact that the disc springs interfered with each other. This behavior was countered by inserting washers between the disc springs. The surfaces of the washers that came into contact with the disc springs were carefully machined so that the roughness won’t affect the device’s accuracy.

Once we confirmed the initial results, the washers were inserted between the disc springs and the speed of the device was increased gradually. The future experiments will aim an increase in the rotation speed of the shaft and the time cycles as well as a preload increase in order to check the behavior of the tested shape memory alloy disc springs.

In [10] the authors emphasized the ability of shape memory alloy springs to maintain constant preload during higher periods of about 2 hours.

It is very well known the real problem of rolling bearings arrangements [13-15], which tends to modify

during time, even for constant running parameters. The proper choose of the preload of a rolling bearings arrangement of a spindle influences the reliability of the entire mechanism. For example, in machine tools the variation of the bearing preload of the spindle affects the quality of the machined surfaces.
In Figure 5, the variation of friction torque within the tested bearings versus preload and speed is indicated. The friction torque firmly increases with respect to load, but increasing the speed seems to favorize the formation of better lubrication conditions, a slight decrease of torque being observed. This is assumed to be due to increased surfaces asperity contacts at light load. These rapid tests were carried out during about 2 minutes each of them.

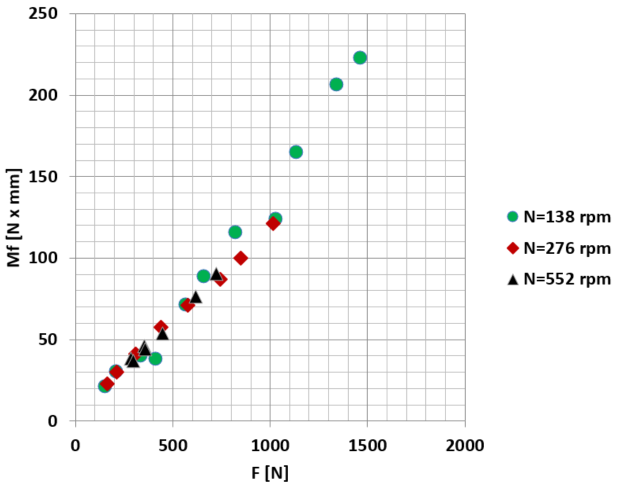

Fig. 5. Torque versus preload and speed

The effect of temperature activation of shape memory alloy springs is emphasized in Figure 6 and Figure 7.

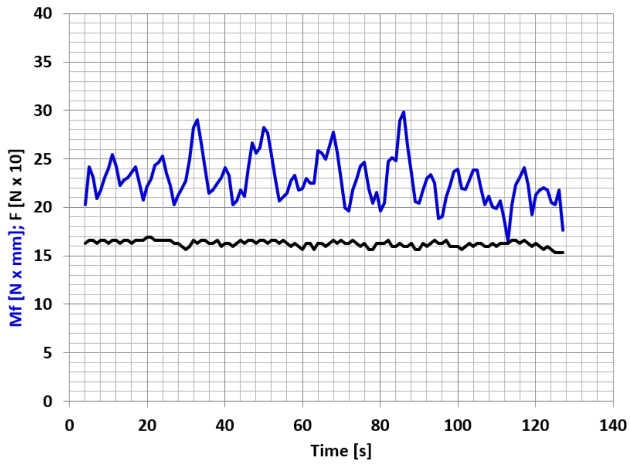

Fig. 6. Load and torque versus time – speed: 276 rpm ; preload: 170 N

At slow speed of 276 rpm, the bearings assembly had not enough time to develop a suited temperature of activation for the shape memory alloy springs, the friction torque varying while the preload is kept constant. According to equation (1), the total friction torque of bearings T, can be divided in friction due to applied load (T_1), and viscous friction due to lubricant viscosity and speed (T_2).

$$T = T_1 \text{ (load)} + T_2 \text{ (viscosity, speed)} \qquad (1)$$

In light preload of the ball bearings, in the beginning of the running-in period, the T_1 contributes to the increase of friction torque, till the ball and races contact surfaces become smoother [16]. At the end of the test, the main contribution to the friction torque is due to the fluid friction between the grease layers separating almost entirely the mating surfaces, T_2. [10]. Increasing two times the speed conducted to the activation of the shape memory ally springs, and to a sudden augmentation of the friction torque and preload. At this stage, the shape memory alloy springs recall their initial shape, before the moment of preloading and their elastic deformation. It seems that the operators must study more the behavior of such shape memory alloy springs and to use the priory obtained calibration results [10].

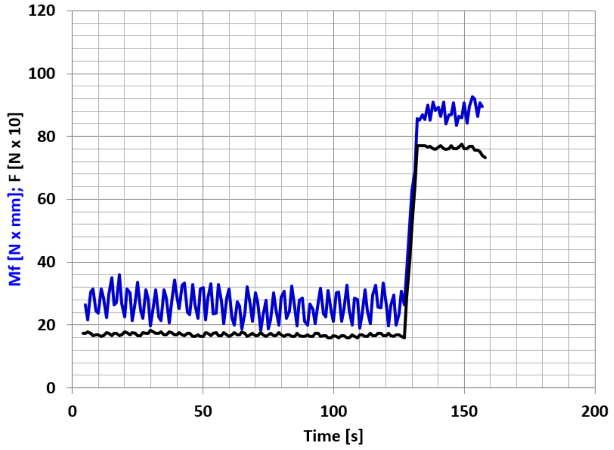

Fig. 7. Load and torque versus time – speed: 552 rpm; preload: 170 N

It must be highlighted that the arrangement of an even number of disc springs with shape memory (4 springs, Figure 8), assured a constant load during tests, recommending these springs for axial bearing preloads.

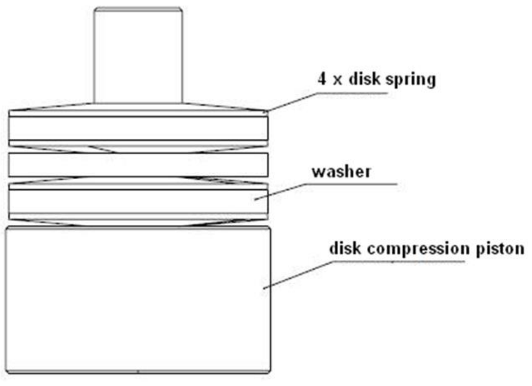

Fig. 8. The 4 memory shape disks in bearing preload arrangement

More aspects on the effect of temperature augmentation on the shape memory alloy springs were presented at large in [10]. The tests will be continued in different configurations of the preloading springs, in an effort to replicate as accurately as possible the operation conditions of the preloaded angular contact ball bearings in existing applications.

5. CONCLUSIONS

A proper bearing design includes adaptive systems able to maintain the axial preload as a function of the running parameters (speed, load, and lubricating regime) and environmental conditions (temperature). The precise preload of rolling bearings is imposed to avoid skidding, friction, temperature increase, and consequently their premature failure.

In this paper, a new testing device based on preload system of shape memory alloy springs and some preliminary experimental results are presented.

Shape memory alloy springs have the property to reach the initial shape if thermally activated, allowing to maintain the initial preload of rolling bearings at desired value, even their friction torque and temperature increase.

The first part of the paper analyzed the preloading methods of rolling bearings. The second part presented a new testing device and the results of preliminary test.

In order to set and to control the preload of rolling bearings at desired values, calibration results of shape memory alloy springs [10] must be used.

Further tests must focus on higher speeds and on highlighting the effect of speed and preload on the time required to activate the shape memory alloy springs.

The results could prove that this preloading method is effective, opening the possibility to be used with other types of bearings operating in machines located in different environments that require precise preloading.

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