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Testing the Effect of Bending Moment on Wheel Bearing Heating

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Leading manufacturers and sellers of products in the field of rolling bearings for the automotive industry guarantee their quality. Extensive product testing is required to guarantee quality. When testing wheel bearings, bending fatigue test stations are used, among other things, to verify the strength of components. The content of the presented work is the analysis of the effect of bending moment on the temperature of a newly wound wheel bearing of the 3rd generation, based on experimental measurements. These are dynamic tests of the strength of wheel bearing components at a resonant test station. This verification is very important and has the effect of preventing the start of mass production of components that do not meet the basic safety requirements.

Keywords: bending moment; temperature; wheel bearing

1 Introduction

Issues relating to environment, safety, and energy savings are being widely raised as technological trends for automobiles [1]. In order for the automotive industry to meet all the required standards, all subcontractors must constantly produce products of the appropriate quality. As with all car chassis components, there are requirements for the strength of this component throughout its life with the wheel bearing. The reason for the ever-increasing requirements for wheel bearings in the construction of the vehicle is their constant development. [2-5]. The variables influencing this development are, for example: an increase in engine power, weight, an advanced production process, simplification of assembly, up to new materials. But also the deformation behavior of the inner ring, because the deformation of the inner ring has a direct effect on the bearing play and the clamping force [6-9].

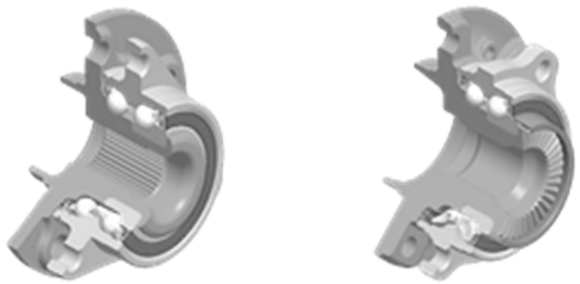

Fig. 1 *3rd generation wheel bearings*

The product range of production includes wheel units for cars and trucks in various designs, for driven and non-driven axles. The wheel bearing (Figure 1) withstands static as well as dynamic forces, while guaranteeing wheel rotation. Other requirements include high bearing stiffness, low friction, easier assembly and maintenance-free operation.

The average wheel bearing will make around 100 million revolutions over its lifetime. In addition, of course, it carries part of the car's weight and with each pass of any unevenness, change of direction, braking or acceleration, it must withstand the forces that increase its weight. So one day, every car will have a time when it will need to be replaced. The most prominent symptom of the bearing at the end of its service life is humming, a low-frequency booming sound, which intensifies or weakens according to the driving situation. Wheel bearings do not need to be changed often, but their failure can be unpleasant and even dangerous. [10-12]

The bearings also react very sensitively to elevated temperatures. The aim of this paper is to specify the influence of the bending moment when loading a newly wound wheel bearing on its warming, so that they are not damaged during operation.

In one of the specifications, according to which wheel bearings are examined by bending tests, there is a requirement to measure the temperature of the bearing during the test. If the temperature exceeds 80°C, the test should be interrupted.

2 Current status

The wheel bearing is essentially a very complex component, in particular in the 3rd generation the bearing consists of a wheel flange, an outer ring, one inner ring (the other inner ring is already integrated in the type described), a cage and thirty balls, Figure 2.

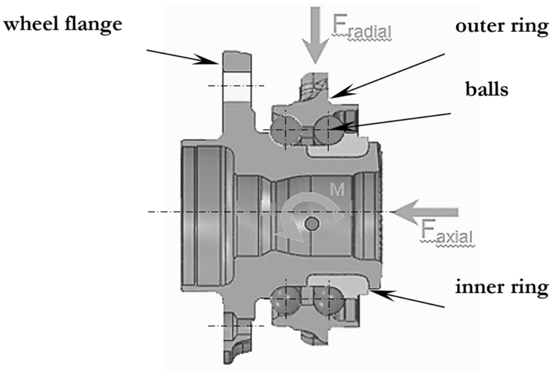

Fig. 2 3rd generation bearing model

The responsibility of the manufacturers in all versions of wheel bearings lies primarily in the guarantee of tilting strength, ie. no fatigue in contact with the rolling parts during the required service life, ensuring tightness, as well as guaranteeing the strength of individual components, ie. no fracture failure at the wheel-bearing connection.

The forces acting on the wheel bearing consist of longitudinal, transverse and vertical forces. These forces are influenced by the weight of the vehicle in connection with cushioning the speed in the curves and the acceleration, resp. vehicle deceleration. The result of these effects are axial and radial loads, as well as the resulting tilting moment in the wheel unit.

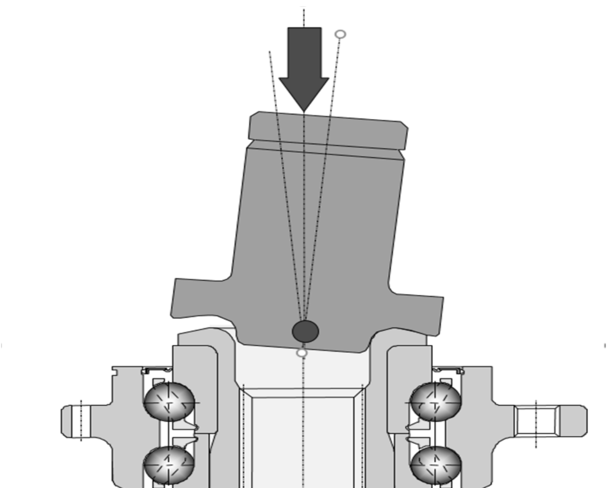

Fig. 3 Schematic representation of the resonance test process

When the vehicle is stationary, this tilting moment acts statically on the bearing (wheel hub). During dynamic driving, the bending moment in the hub is created when the wheel rotates. This moment acts cyclically so that one cycle is performed each time the wheel is turned. In order for wheel units to comply with safety regulations, they are tested on test equipment, whether for new products, structural changes, as well as for series production verification. To verify the strength of components, so-called resonant test stations are used, Figure 3. These stations are subject to regular maintenance and inspection of safety elements.

In particular, components that are in the area of the wheel-bearing connection, such as a wheel bearing flange, including a screw connection, are tested. The bearings are cyclically loaded with a bending moment. Here it is necessary to mention the difference in stress on the wheel and transmission side of the bearing. When the vehicle passes a "Z-curve", one bending cycle acts on the rotating part of the wheel unit each time the wheel is turned by one revolution, ie. innumerable load cycles during cornering. In contrast, only one bending cycle acts on the transmission part (non-rotating - connection of the bearing with the wheel carrier) during the passage.

The stress on the bearing is imitated in the laboratory by a station with an unbalanced mass, which mimics the dynamic driving of the vehicle. The advantage of such a system is low energy consumption, high frequency of load cycles, low maintenance costs, as well as accurate and automatic detection of cracks or fractures of the wheel unit or its components. Rotary test stations for bending fatigue tests have been developed for determining the strength of wheel bearings of passenger cars, in particular for wheel bearings with an orbital shaped head. This test can indirectly reveal hidden problems after this operation.

With rotating bearings and static loads, the bearing wears out very quickly and the test is no longer possible. At resonant test stations, the cyclic bending moment when the bearing is stationary prevents fatigue in the orbits and thus makes it possible to determine the strength of the parts.

3 Experiment

In the past, wheel bearing components were made of carbon steels, which had a higher carbon content. Due to the required hardness and low critical cooling rate, these components were cooled into water. However, this created inner tensions. These reasons resulted in a susceptibility to cracking, dimensional instability and deformation. Carbon steels have therefore been replaced by case hardening steel. The advantages are small volume changes after hardening and low hardness in the annealed state. This allows not only better machinability during chip machining, but also cold pressing. The disadvantage is the lower strength of the core. This results in deformation of the orbit, assuming high pressures and a small cementation layer [13].

At present, the development has stabilized on an alloy steel with a composition of 1% C and 0.4 to 1.6% Cr, intended for direct hardening. They are characterized by better wear resistance. During hardening, they cool the most into the oil, where there is less risk of deformation and cracks [14].

The result of hardening is a hardening image (Figure 4). The hardening image is affected by the inductor, technological conditions of hardening, spindle operation and arrangement of fixtures. The inductor mainly affects the width of the hardening image. Technological conditions affect the hardness, structure of the material.

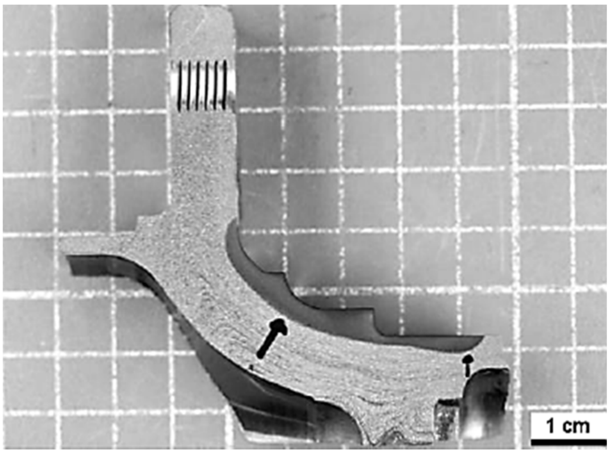

Fig. 4 *Hardening image of the wheel bearing flange*

After the production of the wheel bearing components, their heat treatment and assembly into blocks, the bearings are tested on a test station SO33, which can detect possible hardening errors, residual austenite in the wheel bearing flange and errors in the bearing head rolling process. The test is performed by the action of cyclic loading and the result is an increased temperature or deformation cracking.

3.1 Testing using resonance test station

Resonant test stations are systems capable of oscillating motion and damping capability. The system works by exciting the oscillating motion of the system at its own frequency by means of an oscillating force. The oscillating properties are determined by the parameters of unbalanced mass, spring stiffness and damping. Large acting forces, resp. moments are then achieved by very low excitation forces. In principle, the natural frequency with the highest resonant amplification is used. The magnitude of this resonant amplification depends mainly on the damping. Components made of metallic materials normally have very low damping, so they are tested very well at resonant test stations.

In the described machines, such as SO33 (Figure 5.), the excitation is performed by means of an unbalanced mass. The excitation force depends on the speed of the rotating mass. The change in speed affects the sample load. Load regulation is performed according to the rising resonance curve.

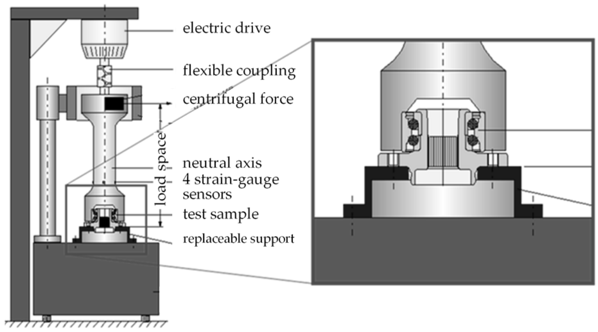

Fig. 5 *Construction of test equipment SO33*

The SO33 test station is a computer-controlled, resonant test station with an electric motor drive with a bending arm, in which is an excenter. Its purpose is to determine the strength of wheel bearings of passenger cars, especially bearings with an orbital shaped head. It consists of two oscillating systems. The tested bearing is shown by the spring c_1, the heavy table is represented by the weight m_1 and the unbalanced mass m_2. The rotating unbalanced mass around the neutral axis creates a bending stress on the tested bearing.

In case of damage in the form of cracks is reduced resonance frequency, thus the system becomes "softer". The regulation responds to the change in resonant frequency and this at a certain frequency change can be used as switch-off criterion. The stiffness of the bearing is not the same around the entire circumference. On the neutral axis, several DMS sensors (strain gauges) are used in four planes. They have the task of measuring the magnitude of the bending moment amplitude in real time. The station control selects the maximum torque on the sample and uses it to control the entire system.

The control system consists of several components located in the control cabinet. The regulation itself is performed on a computer with Emotion II software. The measured signals travel through the amplifier and are processed in the PC using A/D cards.

From the result, the software reads the signal for setting the motor frequency and it is then sent via CAN-BUS to the frequency converter. The frequency converter then sets the motor speed and thus the rotational frequency of the unbalanced mass is regulated

The software allows us to set various parameters, such as running-in time, tripping criteria, amplitude size, number of cycles, offset, graphical representation of wheel bearing stiffness, functional dependencies (e.g. amplitudes and time) and much more. The whole system is very sensitive, it is important to mention that every time the system is changed (replacement of PC, motor, flexible coupling, etc.) a subsequent calibration of the station is necessary. This is important in terms of the results achieved. Preview of measurement outputs Figure 6.

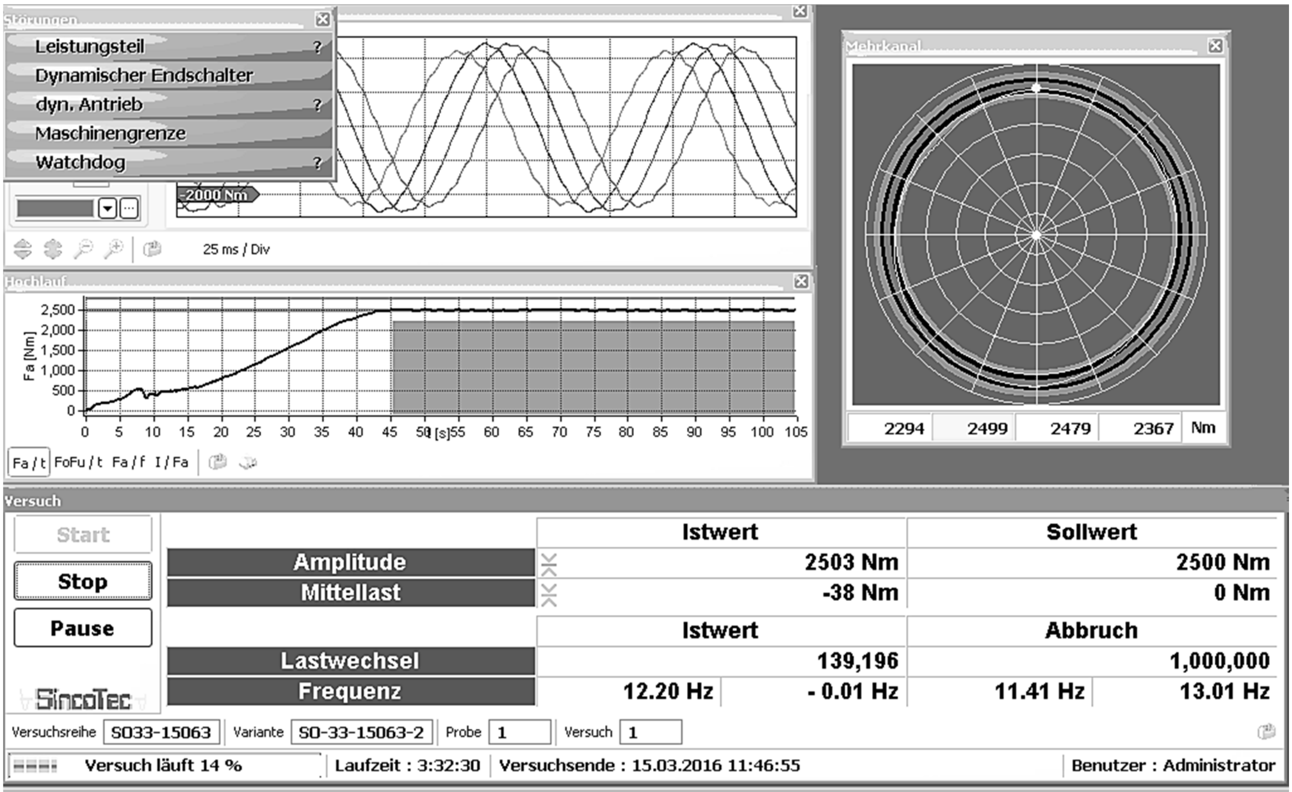

Fig. 6 *View of the measurement software output*

3.2 FEM analysis

For a better idea of the load zones and the most accurate placement of thermocouples in the most loaded zones, an FEM simulation of the bearing was created, on which a thermal analysis was performed. FEM simulation shows us the stresses that act on the bearing, respectively on bearing components. Similar analyses are created to give a better idea of stresses, deformations or natural frequencies, heat flow, etc. [15,16].

It is a numerical method that allows us to create a physical model of a part. It is used to control the structure, but also to optimize it. The principle is that multiple models are created and after recalculating and simulating the operating conditions, a model is preferred that not only meets customer requirements, such as component life, but also meets the criteria of operational strength and production costs.

The presented FEM analysis shows a variant of the structural design of the bearing, for the idea of elastic deformations. Input parameters for analysis processing, such as bending moment, motor frequency, bending moment amplitude and material data and the design of the bearing are identical to those used in real resonance tests.

From the point of view of deformation, the flange (Figures 7 and 8) is the most stressed part of the wheel bearing. This part is not quenched in its entire volume, and therefore plastic deformations predominate in it during operation.

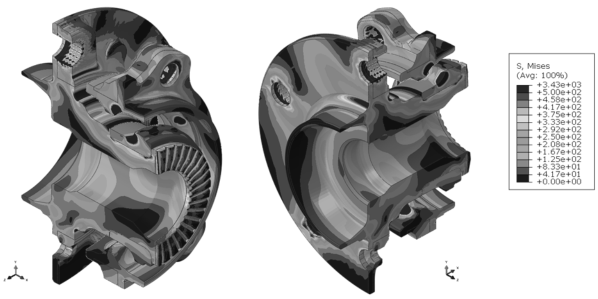

Fig. 7 *FEM analysis of bearing F-577714.05*

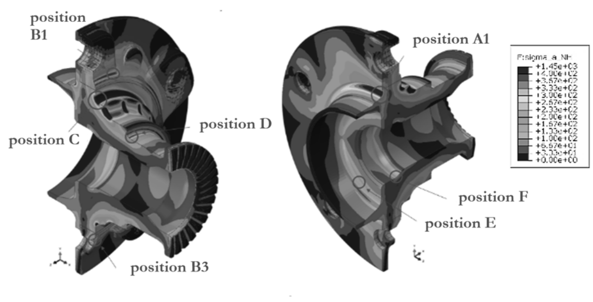

Fig. 8 *Detail of wheel flange, a - part from gearbox, b - part from wheel*

The analysis shown below shows the tested wheel bearing, representing the most modern angular contact wheel bearing so far. It is dimensioned for a bending moment of 4000 Nm.

The critical stress areas in Figure 8 are represented by positions B1, B3, C, D. Between positions C and D there are other places with higher stress, but from our point of view these are not critical areas. Upon closer examination, we find that this is the stress that is created between the balls and the orbit on the flange. These are elastic deformations. The balls as well as the orbit are heat-treated to the prescribed hardness. Positions B1, C and B3 represent the greatest risk of fatigue fracture. According to statistics, the sample is most disturbed in position C. It is at position C that the largest stress amplitudes occur. At this point, we can assume the largest plastic deformation during the loading of the sample. The second critical point is position D. It is here that fatigue fracture occurs on 2nd generation bearings.

We did not want to obtain specific values from the above FEM analysis, as due to the complexity of the deposit it is not possible to determine exactly the boundary conditions and all input parameters as they are in real life. With this analysis, we only obtained the locations with the assumption of the highest stresses, so that we could correctly position the strain gauges during the experimental measurements.

3.3 Wheel bearing temperature measurement

As follows from the above, the task of experimental measurements is the effect of bending moment on the temperature of the test sample, during the test - bending fatigue test at the resonant station SO33.

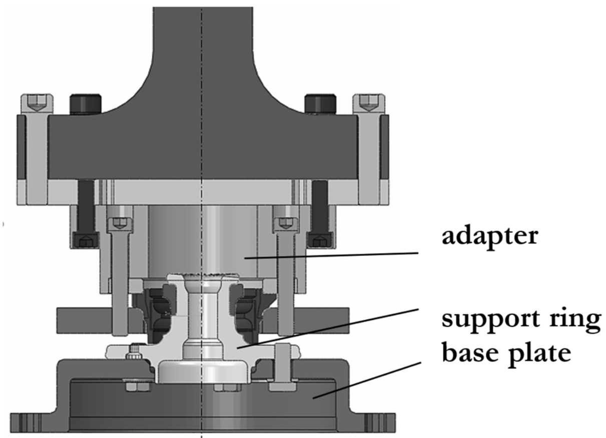

Fig. 9 *Model of test equipment and test sample*

Figure 9 shows the situation of a mounted sample on a test equipment. Due to the construction and the way the sample is placed on the equipment, the sample was not scanned by a thermal imager, which would allow a better idea of the temperature development on the sample.

For this reason, the bearing temperature was measured using thermocouples during the test. A thermocouple or thermocouple probe converts the temperature difference to a stress due to a thermoelectric effect (Seebeck effect). The stress is created at the joint of two different metals

The magnitude of the stress is proportional to the temperature difference and also varies according to the type of thermocouple. Thermometers that measure temperature using a thermocouple measure this stress and convert it to temperature. A great advantage of thermocouples is the possibility to create a very small probe with a fast response or to shape the sensing part according to the surface. This proved to be very suitable during the preparation of the sample for the experiment.

The temperature at the bearings during the test was measured using two thermocouples which were placed as close as possible to the zones with the largest deformation. The placement of thermocouples directly in the areas of plastic deformation was not possible from the constructional point of view and the method of placing the sample on the testing machine. As the plastic deformation in these places is the largest, it is assumed that these will be the places that will produce the most thermal energy. Figure 10 shows the areas of plastic deformations of the wheel flange. It is also one of the results of the FEM analysis. Red markers indicate thermocouple placement positions.

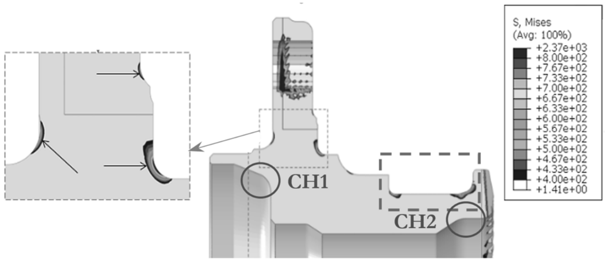

Fig. 10 *Plastic deformation areas and thermocouple locations*

When measuring the temperature during the test, the sample vibrates. To ensure contact between the analyzed surface and the thermocouple, Loctite 5450 liquid metal was used for the connection (Figures 11, 12). Thanks to metal additives, it conducts thermal energy very well. After curing, it can be processed as metal.

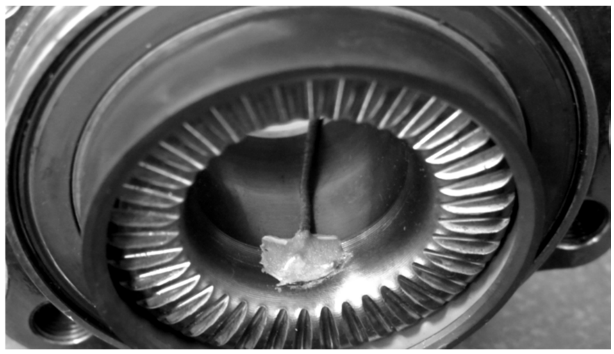

Fig. 11 *Fixed thermocouple - gearbox side*

Fig. 12 *Fixed thermocouple - wheel side*

3.4 Application to the load arm of the test station

Strain gauges (hereinafter referred to as DMS) are used to be able to record changes (relative elongation / relative compression) of the surface of components. They allow experimental determination of the mechanical stresses that is stresses of the material. This is especially important in cases where these stresses cannot be determined quite accurately by calculation.

16 DMS sensors of the HBM 3/120 XY 11 type with a double measuring network are applied on the arm of the presented test station. To protect against corrosion and dirt, the measuring bridges are coated with a special varnish. To prevent mechanical damage, the sensors are hidden under an aluminum sleeve (not shown).

The layout of DMS is circumferentially divided into four planes at 45° angles. With this layout, we get four measuring circuits, with four complete bridges. In this way, the moments under static as well as under dynamic load are sensed.

Due to variations in the tightening torques of the screws during installation and the asymmetry of the bearing flange or installation parts, the bending moment around the bearing circumference is not constant. For this reason, in order to determine the maximum bending moment, it is necessary to use several measuring circuits when measuring.

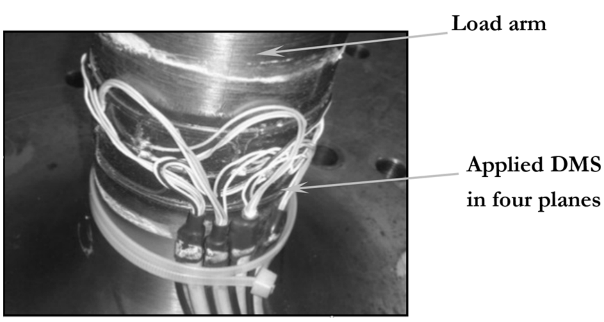

Fig. 13 *Tensometer sensing elements on the load arm*

Figure 13 shows the distribution of the sensing planes. The load arm of the SO33 station does not rotate around its axis. Only the oscillating movement acts on the sample after running-in. This allows the software to determine and display the load moment separately for each plane when the bending moment is reached.

3.5 Evaluation of measurements

The evaluation included the results of the measurements performed at different bending moments, namely at 2500 Nm, 3000 Nm, 3500 Nm, 4000 Nm and 4500 Nm.

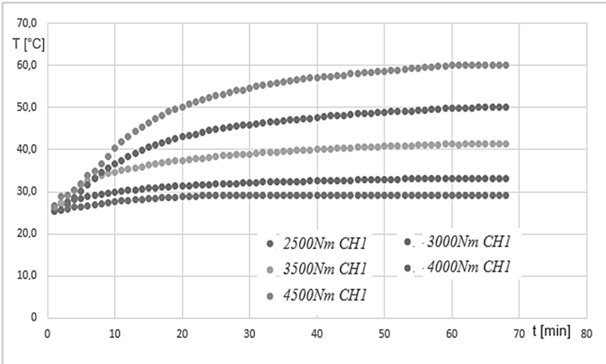

Fig. 14 *Graphical evaluation of the temperature on the rolled head*

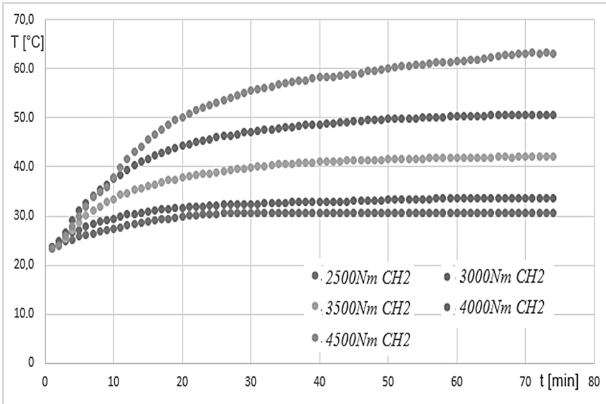

Fig. 15 *Graphical evaluation of the temperature on the bearing flange*

Figure 14 and 15 are graphical evaluations of the temperature evolution of sample of wheel bearing at different bending moments. The graphs represent the function of the temperature over time. The temperature was measured for at least 60 minutes. This time was set as a limit because it was this time period that was sufficient to saturate the temperature.

Table 1 shows the maximum temperatures that were reached during the measurement.

Tab. 1 *Maximum achieved temperatures, CH1 - bearing head, CH2 - bearing flange*

Moment	Position	Max. T [°C]
2500 Nm	CH1	29.2
	CH2	30.7
3000 Nm	CH1	33.2
	CH2	33.7
3500 Nm	CH1	41.7
	CH2	42.2
4000 Nm	CH1	50.1
	CH2	50.7
4500 Nm	CH1	61.1
	CH2	63.2

From all the values measured during the analysis, averages were generated and on the basis of them a graph of the dependence of the sample temperature on the bending moment with which the sample was stressed was created, Figure 16.

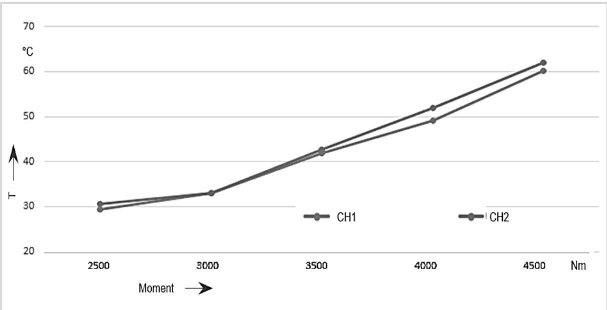

Fig. 16 *Graph of the dependence of the temperature and moment of the wheel bearing on the resonant test station SO33*

In the framework of the presented analysis, another case was tested, namely the breaking of the screw that clamps the wheel flange and the base plate of the installation parts. This effect often occurs during routine testing of samples. The screws are subjected to cyclic loading similarly to the samples. The reason for this simulation was to verify the question of whether such damage would not significantly change the thermal characteristics of the course of the test. Figure 17 shows the course.

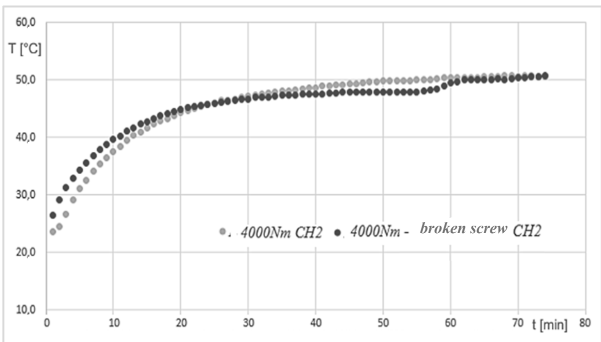

Fig. 17 *Temperature comparison of the test with a damaged screw*

As can be seen from the figure, a broken screw and the associated reduction in load frequency do not affect a significant change in temperature. The ramp of the sample temperature rise shows only small deviations. The temperature stabilized again on the value that represented the state without damage to the screws.

Figures 18 - 21 below show the most common sample defects encountered in the SO33 test station.

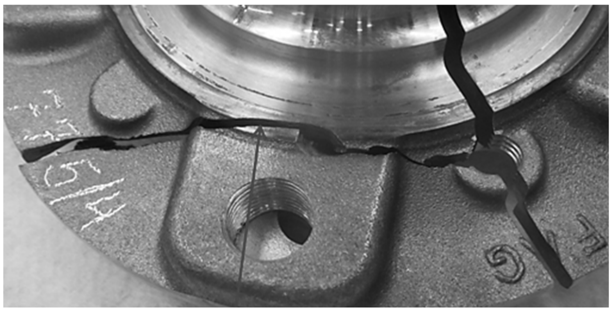

Fig. 18 *Bearing flange damage – 775 000 cycles*

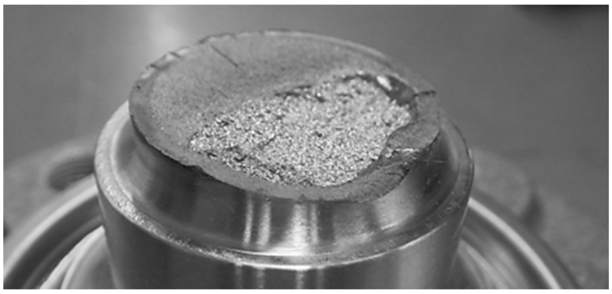

Fig. 19 *Bearing flange damage 445 586 cycles*

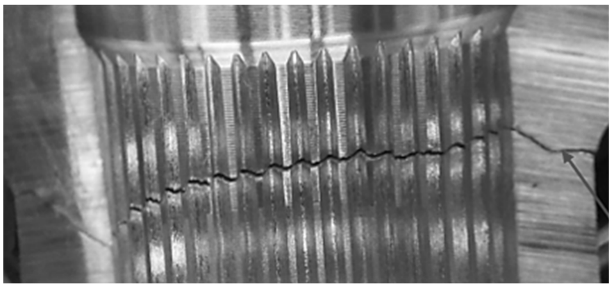

Fig. 20 *Bearing flange damage 956 500 cycles*

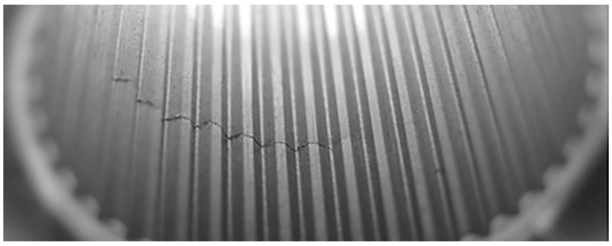

***Fig. 21** Bearing flange damage 569 841 cycles*

As can be seen from the figure, a broken screw and the associated reduction in load frequency do not affect a significant change in temperature. The ramp of the sample temperature rise shows only small deviations. The temperature stabilized again on the value that represented the state without damage to the screws.

4 Conclusion and benefits

The performed experimental verifications were dedicated to testing the wheel bearing on the SO33 resonant station. These were bending fatigue tests and heat development during testing. The manufacturing company deals with this issue whenever it develops a new type of wheel bearing or structurally modifies the manufactured wheel bearing at the customer's request. There are various modules which, on the basis of input information such as plastic deformation, stress tensors, modulus of elasticity, etc., would be able to calculate the amount of thermal energy if all the necessary data on the production material used were available. One such module is Solid226 from the firm Ansys. The problem remains, however, that the result is only an estimate of the thermal energy generated. Much of the supplied mechanical energy is stored in the material as the energy of internal faults, phase changes and other permanent microstructural changes.

The mathematical calculation is again extremely demanding, because the bearing is a complex component. In addition, its parts are heat-treated differently. Another problem is the variety of bearing types that go into series production and thus into the testing process. The structure of the bearing depends on the customer's requirements and its robustness. With the change in structure and requirements, changes also come in the load zones in the entire volume of the bearing.

In addition, friction between the individual parts of the installation enters the process of thermal energy development during testing at the SO33 test station, which also causes the temperature to rise. The calculation would also have to take into account the large heat transfer by coding between the sample and the testing machine. Assembly and manufacturing errors can be another factor. Even very small deviations from the structure can cause a change in the deformation characteristics of the component. Based on these facts, it is more cost-effective to obtain the sample temperature empirically.

The problem described in the introduction with interrupting the test if the sample exceeds a temperature of 80 °C can be solved using a programmable regulator. An example is the JUMO dTRON 300, which has various analog-to-digital inputs and outputs. With the help of a thermocouple and this regulator, a simple chain can be created that would communicate with the station software. Exceeding the default value would interrupt the test run.

But this was not necessary, since the maximum temperature when measuring all samples did not exceed 64 °C, while the maximum moment did not exceed 4600 Nm. Although the test station is calibrated to 4950 Nm, loads above 4600 Nm have not yet been used. Therefore, the moment of 4600 Nm was determined as the maximum value during this analysis.

The generation of heat in a wheel bearing is not only related to quality, but the bearing life is also affected by other factors, especially the operating environment, professional installation and proper maintenance. The bearing design must be such that during installation and operation no additional loads are created due to impermissible mutual tilting of the bearing rings, axial clamping (overloading) of the bearings during installation and the effect of shaft and body expansion during operation. Therefore, even at the design must take care to ensure the misalignment storage places for adequate stiffness of connecting components and their dimensions. Of course, the machines must be kept in good working order. In addition to ensuring the necessary "coaxiality" of the bearing, it is necessary to protect the bearings from extreme temperatures, humidity and pollution. The correct assembly procedure and the selection of a suitable tool must be chosen so that the bearings are not damaged during assembly. Observance of lubrication and maintenance plans, control of operating conditions is an important prerequisite for maximum bearing life.

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