A NEW TEST RIG FOR THE INVESTIGATION OF ROLLING BEARINGS IN THE CENTRIFUGAL FIELD

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INTRODUCTION
Applications for bearings, which are exposed to centrifugal load, are, for example, connecting rod bearings of internal combustion engines or planetary wheel supports of planetary gears. At the current stage, however, there are only a few studies of the behavior of rolling bearings in the centrifugal force field. Although connecting rods supported by rolling bearings were of great interest for the early engine manufacturing already at the beginning of the 20th century. Research activities by TIEMANN [1] show clearly the high potential of crank shafts supported by rolling bearings and estimate consumption savings in the NEDC up to 5.4 %. But, especially in the application as planetary gear bearings, rolling bearings exposed to centrifugal load afford a significant contribution to the total friction losses in planetary gears such as the 8HP automatic transmission from ZF. One reason for this is the high number of bearings in these transmissions. Such an enormous saving potential in the two mentioned applications may not be ignored, especially concerning CO₂ reduction and downsizing. Therefore, the phenomena of rolling bearings exposed to centrifugal load must be investigated accurately.

A NEW TEST RIG – REQUIREMENTS AND FEATURES
The requirements of planetary wheel supports are basically similar to those of connecting rod bearings but not completely identical. For this reason and with respect to a basic, application-independent experimental research of the friction influencing processes in rolling bearings under centrifugal load a new test rig should be developed at FAU. This test rig has to be independent of the kinematics of the specific application. At the same time, it has to measure the friction torque of the test object, which is located in the centrifugal force field. It must be ensured that only the friction torque of the test object itself is measured. Furthermore, the temperature and the axial thrust of the rolling bearings have to be measured. Therefore, a new test rig the so called "Wälzlagerschleuderprüfstand" – furthermore assigned as WSP – was developed, designed and manufactured, see Figure 1. WSP stands in a separate bunker, has a total mass of 16 tons and a total test space of 22 square meters. The test unit is completely encapsulated by a thick steel cover.

Figure 1: WSP: a) from the outside; b) from the inside; c) oil supply system
It is possible with WSP to apply a centripetal acceleration up to 3000 times gravity to the test objects, which are predominantly needle roller cages. Relative rotational speeds up to 9 000 min\(^{-1}\) can be adjusted independently. The test objects can be supplied with lubricating oil by lubricating ducts in a range from 0.05 l/min to 4.00 l/min. The lubricating oil may also be varied in a temperature range from 30 °C to 120 °C.

**FUNCTIONAL PRINCIPLE**

The functional principle of WSP is based on an open planetary gear, see Figure 2. When the sun gear, located at the center, is driven, the outer planet gears and thus the test bearings rotate around their axes. If additionally the planet carrier, the connection of the two planets, rotates around its axis, the planets describe together with the test bearings a circular movement, which induces a centripetal acceleration in the test objects. As the sun gear and the planet carrier are driven independently, there are no fixed kinematic bonds between the two movements.

In order to make the functional principle applicable for experimental procedures and to integrate the measuring technology as near as possible to the test objects, it is not possible to use a simple planetary gear as the design of the test rig. Furthermore, a simple exchange of the test objects and a continuous and steady supply of lubricating oil have to be guaranteed. A design sketch is shown in Figure 3.

![Figure 2: functional principle of WSP](image)

![Figure 3: WSP design sketch](image)

Main shaft (1) and hub (2), which are fixed to each other, carry the two cartridges (3) with the test objects (4). The two cartridges have an offset of 180°. Main shaft (1) combined with hub (2) are thus equivalent to the planet carrier. Motor 1, which drives the main shaft via pulley (10), determines the speed of the circular movement of the test objects and thus the centrifugal load. In order to realize a relative rotational speed of the test objects (4), the shaft, connected to the specimens, is coupled to planet gears (5). These are engaged with the sun gears (6).

The sun gear wheels (6) are mounted on the sun shafts (7). These are driven by motor 2 via pulley (8) and belt (9). Since the motors 1 and 2 can be driven independently from each other, the relative rotational speed and the centrifugal load applied to the test objects can be adjusted independently. A kinematic forced coupling of the two variables does not exist. The cartridges (3) are connected via bolts to the hub (2), so that the test objects can be changed easily.
MEASUREMENT METHODS

All measurement data can be measured directly on the test object itself. WSP measures the bearing friction torque, the bearing temperature in the load zone and shifted by 180° and the possibly occurring axial thrust, see Figure 4.

![Figure 4: measurement method: a) axial thrust; b) temperature; c) friction torque](image)

The design of WSP allows that the bearing outer ring can rotate freely, so if bearing friction torque occurs, the bearing outer ring is rotated. This rotation of the outer ring is taken up by a bending spring, which is applied with strain gauges and thus the present bearing friction torque is measured, see Figure 4 c).

In addition to the friction torque the temperature of the test object is taken. The temperature is taken by temperature sensors in the bearing outer ring. The recording of the temperature ensures that measurements are only performed during steady-states.

The outer ring is not only free to rotate, but also free to move axial. Through this axial degree of freedom of the bearing outer ring, it will move in axial direction, if axial thrust occurs. The resulting axial forces are measured by bending springs, according to Figure 4 a).

Another approach to examine friction of centrifugally loaded bearings was published by Tiemann [1]. In this work the complete crankshaft of a car was supported by roller bearings and the savings were investigated. However, this holistic approach provides no information about how much of the savings are caused by the crankshaft main bearing and how much is generated by the connecting rod bearing. There is another approach presented by von Hollen [2]. He examines the friction torque of a crankshaft of a dragged single cylinder engine. The crankshaft is completely supported by roller bearings. Based on reference tests he determines the friction torque of the crankshaft main bearings. By the difference between the two coefficients he concludes to the friction torque of the connecting rod bearing. None of these approaches is able to measure the friction torque of rolling bearings exposed to centrifugal load itself.

CONCLUSION

By WSP it is possible measuring the bearing friction torque, the bearing temperature and the axial thrust of rolling bearings exposed to centrifugal load directly while varying different influencing parameters such as rotational speed, centrifugal load, oil quantity, etc. So WSP contributes to the development of a better understanding of the phenomena occurring in rolling bearings exposed to centrifugal load.

REFERENCES


KEYWORDS

rolling element bearings, test rig, centrifugal load