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Adaptive and adequate lubrication for highest component-lifetimes in feed drive axes with ball screws

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Abstract

This paper presents an approach to raise the resource-efficiency of machines with ball screw based feed axes over their whole life cycle. Core of the approach is the usage of adaptive lubrication, which supplies optimal amounts of lubricant to the ball screw. This leads to increased lifetimes, reduced friction torques and more sustainability due to less consumption of lubricant. Therefore the resource-efficiency of feed axes is significantly enhanced. With a test rig the adaptive lubrication was validated by performed lifetime tests. Within the tests conventional non-adaptive lubrication was compared to adaptive lubrication. Results are lubricant savings and significant increases in component-lifetimes of approximately 70 %.

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Keywords: Resource efficiency; ball screw; adaptive lubrication;

1. Introduction

One of the objectives in Life Cycle Engineering is to save precious resources. Improvement potentials to save those resources can be found in all life cycle phases from pre-manufacturing to final disposal. By recommendation of [1] an effective strategy during the phase of product-use, where this paper focuses on, is the design for maintenance to achieve high product-lifetimes. Especially in manufacturing industries maintenance can be a significant factor in an organization´s profitability [2]. To reduce maintenance to the essential, it is expedient to focus on components with a high risk of failure. [3] showed within a study that in machine tools, which build the core of modern manufacturing industries, feed axes have the highest risk of failure caused by wear.

Core of this paper is the demonstration of an adaptive lubrication method for feed axes with ball screws based on the consideration of the parameters friction torque and temperature. Objectives are to achieve increased component-lifetimes and more sustainability of feed axes due to less consumption of lubricant and reduced energy consumption due to less friction.

In feed axes ball screws are a widespread element for transforming rotary motion into translatory motion. During this transformation a friction torque arises which results in wear. Wear is inherent in the ball screw but can be minimized by an optimized lubrication strategy. To raise the resource-efficiency of machines with ball screw based feed axes it is important to supply optimal amounts of lubricant over their whole life cycle, what can be enabled by the usage of adaptive lubrication [4].

[5] describes adaptive lubrication as a system that allows to adapt, change, or modify the lubrication mechanism as conditions change to provide the optimal lubrication and wear protection best suited to the system's current needs. A lubrication system that regards the ball screw´s friction and temperature is more beneficial when compared to a system that uses manual or non-adaptive automated lubrication which have high risks of over- or under-lubricating the component.

To understand the importance of the correct amount of lubricant for ball screws, Fig. 1 visualizes the influence of over- and under-supply. Under-supply results in too less lubricant in the contact-zone of spindle, balls and ball screw nut and therefore in increased contact-friction which in turn

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results in increased wear [6]. However, even an over-supply with lubricant reduces the achievable lifetimes of the component because of churning losses and an increased resistance against the motion of the balls [7]. This increased resistance results in high friction-torques and finally lower lifetimes. [8] analyzed the influence of friction on achievable lifetimes of ball screws and emphasized, that wear resulting from rolling and drilling motion friction can only be minimized by an adaptive procedure of relubrication.

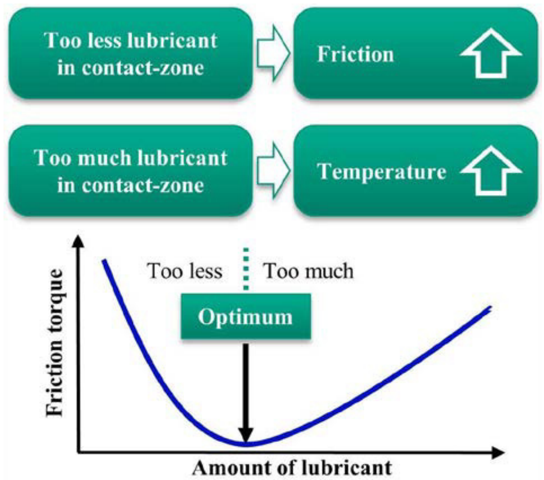

Fig. 1. Influence of over- and under-supply with lubricant.

Ball screws can be lubricated with oil or grease. Benefit of grease-lubrication is on the one hand the higher interval of relubrication-cycles and on the other hand a lower emission of pollutants to the machines as well as the environment. These reasons suit grease-lubrication from an economic and an environmental point of view.

In the following sections an adaptive lubrication method for ball screws is presented, which is based on the consideration and monitoring of the target parameters friction torque and temperature. Therefore the detection of an occurring demand for lubricant is essential, what can be enabled by a monitoring system combining metrology and simulation. Furthermore the results of performed lifetime tests, where conventional lubrication is compared to the new method, are presented.

2. Detection of demand for lubricant in ball screws

To lubricate ball screws with the optimal amount of grease at the right time it is important to detect and interpret an occurring demand for lubricant correctly. Therefore an adaptive lubrication system was developed, which detects occurring demands based on the deviation of the target parameters friction and temperature. Initially the detection of the ball screw´s specific ideal friction torque is presented. For a comparison between simulated values and actual values additionally a measurement system is necessary. Both systems were finally combined in a reliable lubrication algorithm.

2.1. Detection of ideal friction torque

In preliminary work a simulation model for ball screw based feed axes was developed, whose fundamentals were published in [4] and [9]. The model allows the simulation of a friction torque based on the ball screw´s temperature, load and revolution for constant operating conditions. According to Balys theory for calculating the friction torque in angular contact ball bearings [10], the simulation regards the tribological components of irreversible deformation work, hydrodynamic rolling friction and the part from drilling motion of the balls. With respect to the specific kinematics in ball screws the alternation between 2- and 4-point contact loads and changing angular velocities of the balls can be considered. The simulation submits the calculation of friction torques for ball screws in wear-free condition.

In consequence of deviations in production, assembly and primal lubrication at the manufacturer the friction torque of structurally identical and equally strained ball screws differs over their whole lifecycle. This issue makes every ball screw individual, what has to be considered in the calculation of an ideal friction torque as well as the lubrication method.

Fig. 2. illustrates the measured friction torques of eight ball screws of size 40x20 for 7 000 cycles (1 400 mm each) at the beginning of their lifetime. The feed axes were constantly loaded with 50 % of their maximal admissible dynamic load and driven with 800 rpm. The measured values show, that on one hand the friction torques deviate till 55 % (Minimum = 4.5 Nm, Maximum = 7 Nm) and on the other hand the friction torque of ball screws has a tendency to decrease during start-up phase. This decrease can be attributed to the continuous distribution of balls and lubricant in the ball screw nut as well as the initial wear of the sealings. As illustrated in Fig. 2. the friction torque of ball screws tends to decrease during the start-up phase till it settles at a constant value, which differs for every individual ball screw and is strongly dependent from load and revolution. This value of the friction torque is selected as the ideal friction torque for a specific ball screw for specific operating conditions in further analysis.

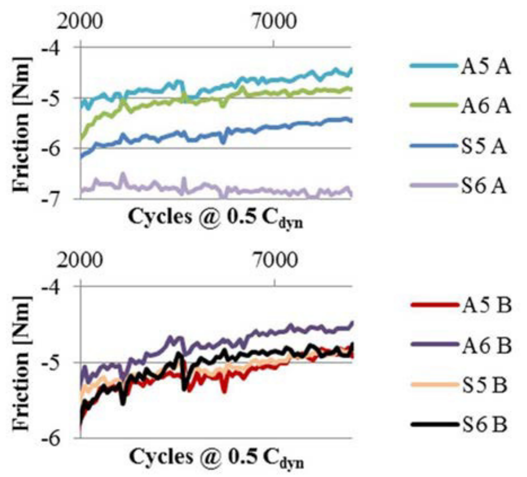

Fig. 2. Measured friction torques of eight ball screws at start-up phase of lifetime and individual, ideal friction torques at end of start-up phase.