The influence of initial commutator surface roughness on wear of the starter motor commutation system

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Keywords: wear, roughness, surface, electric motor

Abstract. One way to improve the run-in period of the commutation system of an electrical motor is the modification of the commutator’s roughness. The reduction of the run-in period affects the wear during the motor life time. Therefore, within this paper the influence of the initial commutator roughness on the run-in period and the electromechanical wear is investigated. The research is done with a special starter components test rig. During the tests the wear is analyzed while the applied electromechanical and mechanical load is varied in order to enforce different wear behaviors. It is expected that with an optimal initial surface roughness the amount of wear is reduced until the steady state has been reached. However, the results revealed that there is no significant influence of the initial surface roughness on the examined electromechanical tribological system. It was found, that the mechanical wear of the commutator and the brushes is similar to the electromechanical wear during the run-in period. The run-in period of the mechanical load tests is shorter compared to the other experiments.

Introduction

The approach to reduce environmental key factors such as CO₂-emission or fuel consumption forces automotive suppliers, such as the Robert Bosch GmbH, to continuously improve their products towards efficiency [1]. Nowadays, more and more cars are equipped with start-stop starter motor systems, which automatically stop the combustion engine when the car is idling, e.g. when waiting at a red traffic light. This requires more start-stop cycles during the starter motor’s life time compared to standard systems, which directly affects the wear of the starter motor components. Therefore, the starter manufacturers focus on improving the bearings, planetary gear, stronger pinion-engagement mechanism and the commutator [2].

Firstly, during the start of a combustion engine the commutation system of the starter motor sustains electromechanical wear until the ignition of the engine, followed by mechanical wear when the starter armature runs down disengaged from the combustion engine to a standstill. Until now, knowledge regarding the influence of the surface roughness on the electromechanical wear behavior of a starter motor commutation system is missing.

According to Möckel et al. the factors mechanical wear and electromechanical wear have an optimum, depending on the contact pressure between brush and commutator [3]. The pure electronic wear amount cannot be measured. Here, the mechanical wear amount could be used to indicate the mount of electrical wear by subtracting the mechanical wear from the electromechanical wear. In this way both wear mechanisms can be identified.

All tribological systems have three different stages of progressing wear: a run-in period with increased wear, a steady state and a high wear progress at the end leading to a sudden component failure [4, 5]. The transition time from the first to the second stage is related to motor life time,
since a short run-in period would go along with less brush wear in the beginning and therefore a longer steady state.

After the run-in period the components surfaces get a steady state roughness due to sliding friction effects. This roughness state is independent from the initial commutator’s surface roughness. Though the material properties, the load spectrum, temperature as well as the contact pressure affect the steady state roughness. A mechanical tribological system has less wear during the run-in period when the initial roughness is close to the surface roughness in the steady state called steady state roughness [6]. The company Schunk GmbH indicates that humidity affects the wear of the commutation system [5, 7]. Hence, the absolute humidity should be considered during the tests.

The first aim of this research is to investigate the wear rate of the commutation system until the steady state is reached, focusing separately on electromechanical and mechanical wear to indicate the electric wear amount. Furthermore, the influence of the initial roughness on the electromechanical wear will be investigated. The mechanical wear theory of Kragelski et al. [5, 6] will be proofed for an electromechanical load system. The theory describes that for a mechanical tribological system a faster run-in period will be performed, when the initial roughness is as close as possible to the steady state roughness.

This research contributes to a better understanding of the commutation system and its wear mechanism. The overall objective is to enhance the starter motor life time to realize a change of mind start stop function.

**Experimental set up**

**Test rig.** The wear test rig is designed for starter motor components tests. That means, that only the armature, brush holder, pole housing and end shield are original parts of the starter motor that are used for the testing. The overrunning clutch and the planetary gear are not implemented; therefore mechanical influences caused by these components are eliminated. The structure of the test rig is shown in Fig 1. The power unit is connected with a safety clutch to torque transducers; the torque measuring shaft is joined with a clutch. On the opposite side of the clutch an adapter is installed fixing the armature shaft permanently with the power unit through a cogging. The armature is supported by two bearings. One is integrated into the end shield, the other is mounted in a cylindrical element, which ensures the radial alignment of the starter components to the other test rig parts.

The test rig is torque controlled for the mechanical wear tests. The torque profile simulates the real load during a start of a combustion engine. After the nominal torque load cycle of the power unit is reached the control stops and the system runs out by itself. The revolutions per minute are measured for several cycles at the steady wear state and the average speed profile is calculated. This speed profile is used to control the power unit in order to identify the wear of pure mechanical sliding. In this case, no current flows through the commutation system. During the electromechanical and mechanical test cycles the system runs out by itself, only inertia and friction forces of bearings and brushes acting on the system.

In the following the main measurements will be described. The brush wear is measured tactile with a position sensor. The wear of the commutator is measured inside the pole housing with a contactless measuring system. The current and voltage which flow through the commutation system are measured for identifying the accrued patina of the tribological system. The patina is an interface layer which consists of the wear debris of the commutator and the brushes and their oxides. Furthermore, the maximum rotational speed and the run-down time to standstill are recorded. The temperature and relative humidity is measured inside the test rig to investigate the influence from the environment. The absolute humidity can be calculated from these data [8].


**Specimens.** All tested starter motor components are from the same type. Only the surface topographies of the commutators were modified to different surface characteristics, manufactured with different turning tools and process parameters. The characterization is done perpendicular to the sliding direction by tactile surface measurement. At first, the steady state roughness is identified during the steady wear state, several cycles after the run-in period. The mean roughness depth $R_z$ value is selected as key value, due to the knowledge to calculate $R_z$ easily for turning processes. Afterwards three different surfaces were manufactured: The first surface was machined with a mean roughness depth at 50\% of the steady state roughness. The second is manufactured with the identical $R_z$ value of the steady state roughness and a third surface with 250\% of the steady state $R_z$ value (Fig. 2). The mechanical wear tests are conducted with the smoothest surface, to compare the mechanical wear of the system with the electromechanical wear, as well as to identify total mechanical and electrical wear amount. Each surface characteristic is tested three times for the electromechanical load and two times for the mechanical wear tests.

![Figure 1: Structure and components of the wear test rig](image1)

![Figure 2: Surface profile of the specimens and balance roughness](image2)
Results

Run-in period of the electromechanical friction system. Fig. 3 presents the wear behavior and the system performance during the run-in period indicated by the brush and commutator wear, the current and voltage flow, the revolutions per minute of the armature and the actual run time to a standstill. All electromechanical experiments show in average the same results. During the first load cycles up to 700 cycles the wear of brush and commutator are increasing, the wear rate is on a higher level compared to the wear during the steady stage. The progressing brush and commutator wear shows closely the same course. However, the amount of brush wear (0.5 mm) is about 8-times larger than the amount of commutator wear (0.06 mm), due to softer brush material in comparison to the copper material of the commutator. The radius of the brush is bigger than the radius of the commutator at the new condition so that only a line contact exists between these two components. After the first 200 start-stop cycles the progressing wear causes a close-fitting contact between the sliding surfaces, which enables the transport of high current. That results in lower voltage due to a constant power supply and furthermore higher revolutions per minute, since more electrical power without a system change leads to higher mechanical power. The results presented in Fig. 3 show a switchover from the run-in period to the steady stage between 700 and 900 start-stop cycles. At that stage the brush and commutator wear reaches the steady wear level. The other factors current and voltage flow, the revolutions per minute of the armature and the run time to standstill change significantly at that stage. This characteristic was also found out by Czichos [4], who investigated that the wear rates of the sliding components, e.g. brushes and commutator, decrease after the run-in period. The reduction of the maximum current indicates the existence of an interface layer, called patina. The patina causes an increased contact resistance and less friction between the brushes and the commutator. Hence, the maximum speed decreases due to a smaller current flow which is caused by an increasing contact resistance. The run time to standstill increases because friction is reduced due to the up-building patina.

![Figure 3: Wear behavior and system performance during the run-in period](image)
For the following research, the point of minimal gradient in the current graph defines the run-in cycle, which describes the end of the run-in period. The wear of brush and commutator is identified after 1,400 start-stop cycles within the steady stage to compare the wear amount of these trials. The absolute humidity is measured during the last cycle of the run-in period.

**Influence of initial roughness on electromechanical wear.** The results regarding the influence of the initial roughness on the electromechanical wear are illustrated in Fig. 4. It can be seen that the initial roughness does not significantly influence the run-in cycle number. Equally the commutator wear and the surface wear indicate independence from the initial roughness. The absolute humidity has small variations during the experiments, but the measured data are within the optimum values between 8 and 15 g/m$^3$ proposed by Schunk [7]. Nevertheless it is possible, that other environmental impacts influence the run-in period. Summarized the theory of Kragelski [6] cannot be confirmed for the investigated electromechanical sliding friction system.

![Figure 4: Run-in behavior and wear amount depending on the initial roughness](image)

**Mechanical wear compared to electromechanical wear.** Fig. 5 presents the mechanical compared to the electromechanical tribological system. During the first 200 cycles the brush and commutator wear is similar for the mechanical and electromechanical friction system. However, the number of start-stop cycles for the mechanical run-in period is about 25 % of the electromechanical wear amount. After 200 cycles the wear rate is reduced and the wear system reaches the steady wear stage with less progressing wear. Until 200 cycles the run time to standstill proceeds the same way for both load collectives. The mechanical and electromechanical tribological systems keep the same revolution per minute after the run-in period and an initial time to standstill. However, after the run-in period of both systems the time to standstill is reduced when no current flows. This effect may result from a higher friction coefficient between brush and commutator, because the other friction coefficients of the tribological system (e.g. of the power unit bearings) are constant after the run-in period. Only initially the temperature of all bearings increases thus the friction coefficients decrease.
Conclusions and Outlook

The influence of the initial roughness on the electromechanical wear and this wear compared to the mechanical wear were investigated. This investigation illustrates, that the initial roughness of a commutator surface does not considerably influence the number of run-in cycles and the total amount of component wear in an electromechanical tribological system. The mechanical wear theory of Kragelski et al. [5, 6] could not be verified for an electromechanical load system.

The measurements of the test rig show clearly the switchover from the run-in period to steady wear stage. The progress of the current flow within the experiments confirms the existence of an interlayer, the patina, which causes an increased run time to standstill for the electromechanical tests.

The mechanical friction system requires less run-in start-stop cycles compared to the electromechanical system until the steady wear stage is reached. This affects the total wear amount, which is about 30 % smaller compared to the electromechanical wear amount.

The mechanical wear mechanism is the dominate effect during the first start-stop cycles caused by the development of the close-fitting contact between brush and commutator. The wear of the mechanical and the electromechanical load system are equal during this process. The mechanical surface fitting could outbalance the influence of the initial roughness and the current flow.

The influence of the absolute humidity could not be fully investigated with this research. Since the test rig is not located within an air-conditioned measuring room, the present humidity is related to environmental impacts, such as the weather. A randomized absolute humidity exists during the trials, but all single values were within the optimum values proposed by Schunk [7].

Nevertheless, the initial roughness may affect the wear behavior, but the interaction between the humidity and the initial roughness prevents a significant identification of effects. In further investigations the influence of the humidity on the electromechanical wear system will be investigated to validate the values proposed by Schunk [7].
Furthermore, the influence of the initial roughness should be examined with only mechanical load to investigate theory of Kragelski et al. [5, 6] for this researched tribological system. That may clarify whether the initial roughness does not affect the wear amount with electromechanical load which is caused by the current flow.

Acknowledgements

This project is sponsored by the Robert Bosch GmbH business unit Starter Motors and Generator. The armature specimens are manufactured at Bosch plant Hildesheim, Germany. The armature surfaces are machined by the Competence Center E-Machine Industrialization under the leadership of Dr. Engler. The support of the Robert Bosch GmbH is appreciated.

References


[2] Robert Bosch GmbH Starter Motor and Generator: Start/Stop technology reduces CO2 emissions and saves fuel, company brochure, 292000P0K6, 2013, p. 4


