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The effect of lubrication on the friction performance in pneumatic clutch actuators

F. Riddar*, Å. Kassman Rudolphi

Tribomaterials Group, Uppsala University, Ångström Laboratory, Box 534, SE-751 21 Uppsala, Sweden

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ABSTRACT

Pneumatic clutch actuators in trucks transform the force applied on the clutch pedal into the force acting on the clutch. The actuator consists of an anodised aluminium cylinder in which a piston, with a rubber lip seal and a PTFE guiding ring mounted on it, slides. The system is lubricated with silicone grease before assembly. Wear of the lip seal will lead to a deteriorated sealing capacity, and ultimately failure.

A test setup is used to evaluate the effect of silicone grease amount on friction performance, PTFE transfer and rubber lip seal wear. Reciprocating sliding and vibration tests were performed. The surfaces of cylinders, guiding rings and lip seals were studied by SEM and ESCA.

The friction level is highly dependent on the amount of grease in the contact area. During sliding, grease is pushed out from or dragged into the contact area, resulting in a fluctuating friction. Furthermore, even with grease lubrication, PTFE transfer to the aluminium surface occurs. A triple transfer from guiding ring, to aluminium surface, to lip seal, to another part of the aluminium surface was observed. Finally, although the unstable lubricating effect, it was found that the grease protects the lip seal from wear.

1. Introduction

To disengage the clutch in a vehicle, with a manual gearbox, the force applied by the driver on the clutch pedal must be transformed into the force acting on the release bearing on the clutch [1]. One possible way to achieve this is to use a pneumatic clutch actuator. The studied actuator consists of an anodised aluminium cylinder inside of which a piston, with a rubber lip seal mounted on it, slides. The motion of the piston is controlled by the air pressure, and typically it slides, back and forward, some tens of millimetres. Between clutch actuations, the piston may be subjected to vibrations originating from the system of engine and driveline. Furthermore, a PTFE guiding ring is also mounted on the piston. Its function is to guide the piston and absorb transverse forces. At the same time it prevents contact between the metal piston and the cylinder inner surface. Silicone grease, that is applied once, before assembly, is used as a lubricant and as an aid to the sealing. It also facilitates the assembly of the actuator.

A special test setup has been designed in order to perform simplified lab tests simulating the contact situation in a clutch actuator (the sliding or vibrating contact of an anodised aluminium surface against a rubber lip seal and a PTFE guiding ring). In a previous study by the present authors, friction and wear mechanisms during reciprocating sliding at different contact loads and temperatures were studied [2]. Some interesting findings were that: (i) during sliding the anodised aluminium oxide layer may crack and small oxide fragments may come loose, (ii) such oxide fragments, or other added particles, may become embedded into the PTFE guiding ring and abrade the anodised aluminium surface, (iii) during some test conditions thick layers of adhered material form on the rubber seal lip, and (iv) the coefficient of friction fluctuates a great deal and spans between approximately 0.05 and 0.25.

In this paper, the tribological system of a clutch actuator is further studied. Both reciprocating (as in the previous study [2]) and vibration sliding tests are performed. When in use, during the time between actuating the clutch, the piston is vibrating at a more or less fixed position. Thus, both tests are relevant, simulating different motions of the piston.

PTFE is a material known for giving low friction in dry sliding. This is due to material transfer to the counter surface, i.e. in reciprocating contact the sliding occurs between two PTFE surfaces. The development of PTFE surface films and the influence of operating conditions have been discussed elsewhere [3]. However, in the pneumatic clutch actuator a large amount of silicone grease is used, and therefore it may not be possible to achieve the required material transfer. Another interesting issue is the influence of the silicone grease on friction and wear. It is not obvious

* Corresponding author. Tel.: +46 18 4717241; fax: +46 18 4713572.
E-mail address: frida.riddar@gmail.com (F. Riddar).

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that silicone grease lubrication reduces the friction. It is important though to protect the rubber lip seal from wear, if it becomes heavily worn it will lead to leakage and ultimately failure of the actuator. Therefore, in this study the influence of type of test and of amounts of lubrication, on the friction performance, PTFE transfer, and rubber lip seal wear are studied.

2. Experimental

2.1. Experimental setup

A reciprocating sliding test rig was used. To simulate the contact in a clutch actuator, parts of a lip seal and a guiding ring are mounted on a segment of a cylindrical piston and slide against the inner surface of a part (10 mm wide segment) of an aluminium cylinder. A schematic of the contact setup is shown in Fig. 1, while the test equipment is more thoroughly described in [4]. Because of the contact geometry the area in contact on the aluminium sample depends on the amplitude of the sliding movement. When the peak-to-peak amplitude is larger than approximately 5 mm, the contact area on the aluminium sample is divided into three areas; one area only sliding against the guiding ring (A), one area only sliding against the lip seal (B), and between these an area in alternating contact with both the guiding ring and the lip seal (C).

Reciprocating sliding tests were performed for 100,000 cycles at a frequency of 3 Hz, corresponding to a test duration of approximately 9 h 16 min. With this frequency the maximum sliding speed for the test setup will be similar to that of the piston in an actual clutch actuator. The peak-to-peak amplitude was approximately 7 mm. The sliding distance in a clutch actuator is some tens of millimetres.

Vibration tests were performed at a frequency of 100 Hz and peak-to-peak amplitude of approximately 100 μm. (The sample holder of the aluminium sample was vibrated with the set amplitude, but the true relative amplitudes between the aluminium surface and guiding ring and lip seal cannot be measured.) Two different vibration tests were performed: *continuous vibration* and *interrupted vibration*. Both tests were performed during 10 h, corresponding to 3.6×10^6 vibration cycles. During the interrupted test, one 1 Hz sliding cycle of approximately 5 mm peak-to-peak amplitude was applied every 30 min, i.e. every 1.8×10^5 cycle. The continuous vibration test simulates the vibrations stemming from engine and driveline, that affect a clutch actuator between actuations. In the interrupted vibration test the longer sliding motion simulates the actuation of the clutch.

In all tests the contact load was 15 N, and applied by a spring, resulting in a contact pressure corresponding to the real application (calculations based on pneumatic pressure). The friction force was measured with strain gauges.

Since the lip seal is not required to seal against any air pressure, as is the case for the real actuator, the sealing capacity is not monitored in this test setup. In the real application the pneumatic pressure keeps the lip of the lip seal in contact with the counter surface. To ensure a contact situation similar to the real conditions, silicone caulk is precisely fitted into the gap of the lip seal, thus keeping the lip in contact with the aluminium surface. Previous work by the authors has shown that neither the lip seal nor the guiding ring carries all of the load [2]. However, it has not been verified that the load ratio is comparable to the contact situation in the real application.

In a reciprocating sliding rig misalignment is usually a risk factor. For this test setup the contact situation was measured with pressure sensitive film and the misalignment was considered small enough to not affect the tests.

The working temperature of a clutch actuator is approximately 80 °C. The tests were therefore performed at an aluminium sample temperature of 80 °C. This was achieved using two thermo elements mounted inside the lower sample holder. The test samples were prepared and mounted and the contact load was applied. After that, the heating was started and after 15 min, when the aluminium sample had reached the set temperature, the test was started. After testing the samples were cooled down before disassembly.

Three conditions of lubrication were tested. For each of these, two reciprocating sliding, one continuous vibration, and two interrupted vibration tests were performed.

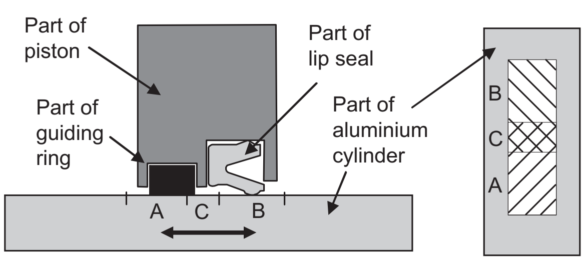

Fig. 1. Schematic of the test setup and particularly the contact geometry. Area A slides only against the guiding ring, B only against the lip seal and C against both guiding ring and lip seal.

3. Materials and lubrication

The aluminium cylinders were produced by permanent mould casting and the aluminium foundry alloy was AlSi7Mg. The cylinders were machined and anodised according to standard procedures for commercial clutch actuators [5]. In addition, the tested lip seal, guiding ring and silicone grease are typical for commercial clutch actuators. The lip seal is made of NBR rubber (Shore A hardness of 75) and the guiding ring of PTFE with 25% graphite.

Three conditions of silicone grease lubrication were tested: *no lubrication*, *high lubrication*, and *low lubrication*. The lubricant was always evenly applied onto a set area, 15 mm × 10 mm, of the anodised aluminium sample. For the high lubrication tests, 10 ± 1 mg of silicone grease was evenly applied. For the low lubrication tests, 2 ± 1 mg was used. These amounts correspond to approximately 70 and 15 μm initial grease film thicknesses. The set area was larger than the tested sliding area.

3.1. Surface analysis

The surfaces were investigated with scanning electron microscopy (SEM). Chemical analysis was performed with electron spectroscopy for chemical analysis (ESCA, also known as XPS) using a PHI Quantum 2000 spectrometer with monochromatic AlKα radiation (1486 eV). The X-ray analysis spot diameter was 200 μm. Mapping was performed using a scanning X-ray spot of 10 μm diameter. Surface neutralisation was used for all ESCA-analyses.

The test samples had to be carefully cleaned from the silicone grease in order to be analysed using these vacuum techniques. Therefore, they were ultrasonically cleaned, first in white spirit and then in ethanol.

The test samples were all made of electrically insulating materials (lip seal and guiding ring) or had an insulating surface (oxide layer of aluminium cylinder). Therefore, a thin layer of a gold alloy had to be evaporated on the surfaces in order to make SEM imaging possible.