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Wear study of field worn clutch actuators and evaluation of a model test

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ABSTRACT

Pneumatic clutch actuators, employed in trucks, have been investigated. The surfaces of the inside of the anodised aluminium cylinders, of the lip seals and of the guiding rings have been studied by SEM and optical microscopy. For most of the actuators no significant wear was revealed. However, one actuator, with leakage problems, was severely worn. An extensive amount of scratches was found on the cylinder surface, the thickness of the guiding ring had decreased and large parts were missing from the lip seal. A possible explanation is that particles have entered the system thus altering the contact conditions. A test setup was developed to investigate how particles present in the system affect the wear. A part of the piston, with lip seal and guiding ring, slides against a part of the anodised aluminium cylinder in a back- and forward motion. Pure silicone grease lubricated tests resulted in no wear. Tests with added dust particles resulted in distinct scratches on the aluminium surface and embedded particles in the guiding ring and the lip seal. These tests provide results in good agreement with the wear revealed in the investigations of used actuators and support the theory that wear is caused by particles.

1. Introduction

In automotive vehicles a clutch allows connecting and disconnecting the engine from the transmission. It can be either self-actuated or, as in the case of friction clutches, actuated by an actuator. The driver applies a force on the clutch pedal to disengage the clutch. The actuator then converts this force into a different travel and force acting on the release bearing of the clutch [1].

A type of clutch actuator widely used is based on pneumatic cylinders. It consists of a cylinder housing of cast aluminium in which an aluminium piston slides in an axial back- and forward motion with an amplitude of some tens of millimetres and superimposed vibrations originating from engine and driveline. Mounted on the piston are a rubber lip seal and a guiding ring of PTFE. These slide against the inner surface of the cylinder housing. The system is lubricated with silicone grease before assembly. To increase the corrosion protection and the wear resistance of the cylinder housing, it is anodised after casting and machining [2].

Clutch actuators are guaranteed to withstand a minimum of 3 million cycles but the demands on their service life are increasing. Used actuators most often function almost as well as at assembly but sometimes have severe leakage problems. Two such extremes would imply that an extraordinary event has occurred, resulting in the catastrophic leakage. One possibility is that particles have entered the system, changing the contact situation.

To investigate the probability of this hypothesis a new laboratory test method has been developed. It simulates the sliding contact between the anodised aluminium surface, and the rubber lip seal and the PTFE guiding ring. Tests with and without particles have been performed. To verify that the wear occurring in the tests resembles that of the real contact situation, pneumatic clutch actuators, used in trucks, have been investigated.

2. Experimental

2.1. Clutch actuators from field

2.1.1. Materials and history

The investigated aluminium cylinders were produced by permanent mould casting. The chemical composition of the foundry alloy is included in Table 1. The casting was followed by machining and anodising of the cylinders. The anodising parameters are displayed in Table 2. The lip seal of the actuator is made of HNBR rubber with shore hardness of 75 (HNBR75) and the guiding ring is made of PTFE.

The four actuators investigated in this study have been employed in trucks. Three of them were fully functional when removed and had been subjected to various amounts of strokes, between 100 000 and 1 million. The fourth actuator had been subjected to a greater number of strokes, between 3 million and 4.5 million, i.e. more than the guaranteed service life. It was removed from the truck because of leakage problems.

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Table 1
Nominal chemical composition (wt%) of the aluminium cylinders.

Alloy	Si	Fe	Mg	Ti	Sb	Others	Al
$AlSi_7Mg$	6.7	0.13	0.43	0.12	0.13	<0.01	Rest

Table 2
Anodising parameters.

Parameter	
Electrolyte	H_2SO_4 with a concentration of 160–170 g/l
Temperature	Max 20 °C
Concentration of Al ions in bath	<15 g/l
Voltage	20 V
Current density	1.5 A/dm^2

2.1.2. Analysis of surfaces

After assembly the piston is situated approximately in the middle of the cylinder and slides towards the clutch when actuated. The sliding distance is some tens of millimetres. As the clutch is gradually worn the starting position of the piston moves towards the clutch. To facilitate the presentation of the results of the analysis, the cylinder is divided into four zones, see Fig. 1. In practice, zone 1 will normally never be in contact with the piston, and the piston starting position will continuously move from zone 2 to zone 3 and finally to zone 4 during the use of the system.

Parts, cut out of the aluminium cylinders removed from trucks, were cleaned in an ultrasonic cleaner, first with white spirit and then ethanol. The surfaces were examined by scanning electron microscopy (SEM).

2.1.3. Analysis of particles

When the actuator, subjected to the greater number of strokes and leakage problems, was disassembled some of the silicone grease was collected. It was diluted with white spirit and placed in an ultrasonic cleaner for about an hour. When removed from the cleaner the particles in the solution sank to the bottom of the beaker. After a while the solution could be decanted and the process repeated. After a few repetitions moderately clean particles, together with white spirit, could be gathered at the bottom of the beaker using a pipette. This solution was then placed onto a silicone wafer where, after evaporation, the particles were studied with SEM and their chemical composition was analysed with energy dispersive X-ray spectroscopy (EDS).

2.2. Laboratory test method

2.2.1. Experimental setup

A new method for testing the tribological contact between the surface of the aluminium cylinder, and the rubber lip seal and the PTFE guiding ring, has been developed, see Fig. 2. The aim was to enable testing of different materials and lubrications, as well as environmental conditions. For a good resemblance of the real contact, parts of the actual cylinder and piston were used. Part of the aluminium cylinder is placed in a lower sample holder. The upper holder consists of a part of the piston, with a part of the lip seal as well as a part of the guiding ring mounted on it. In a real actuator the lip of the lip seal is kept in contact with the aluminium surface due to the pneumatic pressure pushing it. In the test setup this was accomplished by a small part of rubber, precisely fitted into the gap in the lip seal, thus keeping the lip in contact with the aluminium surface.

A spring is used to keep the upper and the lower samples in contact with a contact force of 15 N over the 10 mm wide segment of the cylinder. In the real case the contact force depends on the air pressure. The experimental contact force is chosen to be within the typical range of the contact force in the actuator.

The lower sample holder moves in a back- and forward motion allowing the aluminium part to slide against the lip seal and the guiding ring in a movement similar to that of the actual actuator. The amplitude and the frequency can be varied to simulate both the longer strokes of the piston when disengaging the clutch, and the smaller vibrations that affect the actuator when the clutch is engaged.

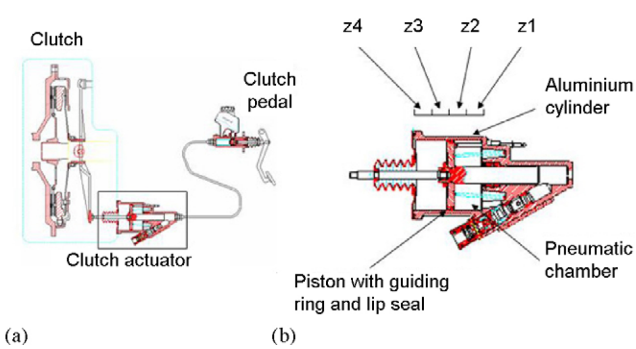
2.2.2. Experimental test parameters

In this study tests, with 10 000, 50 000 and 100 000 strokes were performed with an amplitude of 7 mm and a frequency of 3 Hz. 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 sliding distance in a clutch actuator is some tens of millimetres. All the tests were performed at 20 ± 2 °C and approximately 20% relative humidity.

Because of the contact geometry the area in contact on the aluminium cylinder is divided into three areas; one area only in contact with the guiding ring, one area only sliding against the lip seal, and between these an area in contact with both the guiding ring and the lip seal.

All tests were lubricated with the same silicone grease as that used in the actuators removed from trucks. The grease was applied with a finger onto the aluminium sample.

For some tests, dust was used to study the effect of foreign particles in the actuator. Dust was applied onto the film of silicone grease and then flattened out evenly across the surface. Two types of standard dust developed for vehicle testing, ISO 12103-1, A2 Fine Test Dust and ISO 12103-1, A1 Ultra Fine Test Dust, were used. They both have the same chemical composition, see Table 3, and their distribution in size is 0–80 μm and 0–10 μm, respectively. With the fine dust additional tests were performed with 10 and 100 strokes.



(a) (b)

Fig. 1. (a) System including clutch, clutch actuator and pedal. (b) In this study the results of the analysis is presented for four zones, z1–z4, of the aluminium cylinder of the clutch actuator.

Table 3
Chemical composition (wt%) of the test dust.

Chemical	SiO_2	Al_2O_3	Fe_2O_3	Na_2O	CaO	MgO	TiO_2	K_2O
Wt%	68–76	10–15	2–5	2–4	2–5	1–2	0.5–1.0	2–5

3. Results

3.1. Actuators from field

3.1.1. Anodised aluminium surfaces of functional actuators

After casting and machining, the cylinders display a rather smooth surface except for lines perpendicular to the piston sliding direction. These are due to the machining and they are still visible