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Re-design of a guide bearing for pneumatic actuators and life tests comparison

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ABSTRACT

The re-design at the front-head/guide-bearing interface of a linear pneumatic actuator is proposed in this paper. Design changes were performed by means of finite element analyses. Contact pressure and its redistribution at the rod-guide interface were assumed to be the "leading parameter" in this process to promote improvements of tribological behaviour, viz., reduction of guide-bearing wear and increase of cylinder life. Wear measurements and life tests made possible a comparison of pneumatic actuator life: these were modified on the basis of the various re-design solutions proposed. Therefore, a validation of the model's predicted conditions was possible.

1. Introduction

Friction, wear and lubrication definitely contribute to enhance the performance and durability of mechanical components and systems. These include pneumatic cylinders, which are extensively used in industrial applications for a variety of actuation purposes. The external load applied at the end of the piston rod is responsible for contact pressure, stress and wear on the guiding system elements. The front guide bearing is particularly involved in this process: the correct behaviour of this mechanical component affects the effectiveness of the sealing system and therefore the operative life of the whole pneumatic cylinder, its efficiency and durability.

The importance given to the durability and reliability of pneumatic cylinders is demonstrated by standards, manufacturers' and research centre studies. In particular, Ref. [1] specifies the procedure for carrying out standard life tests on commercial pneumatic cylinders with a radial load applied to the rod; data processing using a Weibull statistics approach is defined to compute cylinder life. Following this standard, many other approaches have been proposed; they also consider more severe test conditions, viz., high radial load or reduced greasing of internal components. In this way accelerated life tests have been defined. The method proposed in [2,3] by Belforte et al. allowed evaluation of the effects of radial load extents and greasing conditions on cylinder operative life. Rod guide wear resistance has been found to be fundamental and main wear mechanisms and damages have been identified. In [4] Chen et al. defined and performed accelerated life tests on cylinders for the pneumatic industry and a way to shorten test time to arrive at a reliable evaluation of pneumatic cylinders was described. Accelerated tests were performed by properly choosing test conditions and identifying the main stress parameters affecting cylinder life from the result. Various kinds of tests according to both non-accelerated and stress-accelerated testing were carried out in [5] by Chen et al.; according to a failure mechanism analysis, wear and tear accumulating failure was identified. In particular, the importance of frequency and temperature stresses were analysed. Great interest has also been devoted to the experimental investigation of individual sliding elements. Friction and wear in the piston-barrel contact of a cylinder of a diesel engine was studied by Blau et al. in [6]; tests were performed on a standard tribometer using a segment of piston ring and a flat sample for the barrel. Findings provided important indications on how friction and wear are affected by normal load, lubricant type and temperature. Temperature effects and contact pressure were also found to be important parameters by Lee et al. in [7]; in particular, FE (finite elements) analysis and experiments on contact pressure were shown to be viable tools in the design evaluation of a sliding lip seal. Experiments and FE analyses performed by Belforte et al. in [8,9] used contact pressure as the main parameter both in comparing seals design performances and optimising an existing seal design. Other studies have concerned the development of mathematical models for

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simulating wear progress of sliding elements and guide bearings to optimise their tribological behaviour. In [10] Hegadekatte et al. developed a wear model, implemented in a FE-based wear simulation tool to predict loss of material and life-span of a micro tribosystem. The model was then improved by Hegadekatte et al. [11] and used to simulate wear in a pin-on-disc tribometer; Archard's wear model was demonstrated to be valid, especially when materials are stiff and wear prediction is in good agreement with experimental results. In [12,13] Shen et al. proposed a method for solving a sliding wear process based on an Archard model by applying a series of discrete quasi-static actions. The proposed method that combines a FE model and a wear simulation programme, can be a practical tool for predicting wear problems for engineering. A simplified analytical approach to estimate material loss and wear in a sliding guide bearing for a pneumatic cylinder was proposed by Belforte et al. in [14]; the thickness of removed material, and therefore cylinder life, can be predicted on the basis of a classic Reye–Archard model and rigid mating surfaces of the tribological couple. The analysis of contact pressure distribution at the rod-guide bearing interface of a pneumatic actuator was developed by Manuello et al. in [15]; experimental tests, using pressure-sensitive film and finite element results were found to be in close agreement. Preliminary re-designing of bearing-seat mating areas was proposed to distribute contact pressure at the bearing-rod interface more advantageously along the bearing's axial length.

On the basis of the latter work the authors present here a new study on the rod-guide of pneumatic cylinders subjected to a radial load. The aim was to enhance and increase the cylinders' service life. The analysis was carried out with a finite element model and a specifically designed experimental setup. The model of the whole cylinder was here developed; it allowed investigation of the contact at the interface of the tribological pair, taking into account current geometric and working conditions. The contact pressure distribution was assumed as the optimising factor in the redesign process of the bearing-seat interface. Various redesigned bearing-seat interfaces were proposed to prevent contact pressure peaks on restricted areas and therefore achieve advantages from the standpoint of wear and durability. The proposed solutions were manufactured and experimentally tested by means of life tests on pneumatic cylinders. Test results proved the effectiveness of the proposed design solutions, since a substantial increase in life was observed with respect to the reference configuration represented by the commercial assembly.

2. Cylinder under test and test setup

A scheme of the cylinder under study is shown in Fig. 1.

The cylinder is an ISO 15552 series unit, working pressure 0 to 12 bar, $\varnothing = 50$ mm bore, $s = 250$ mm stroke, $d = 20$ mm rod diameter. The moving piston-rod group (1, 2) operates inside the cylinder barrel (3); piston (1) is provided with two lip seals (4) which isolate the two cylinder chambers. Stroke is limited by the cylinder front (5) and rear head (6) secured to the barrel (3). Seal (7) isolates the front chamber from the outside environment. Slide ring (8) and bearing (9) guide the linear motion of the piston-rod group. Lubricated-for-life polyurethane lip seals are employed. The sliding fit between the rod and the guide bearing considers a diametrical clearance of around 0.08 mm.

The guide bearing is made up of three bonded layers. The first one, at the inner diameter, consists of a PTFE (Teflon) thin coating of a 10–30 μm thickness; the second layer is a porous bronze matrix impregnated with PTFE/lead (thickness about 0.25 mm), and the third is a steel backing strip (thickness about 1.25 mm). PTFE coating of the bearing and rod have roughness values of Ra = 0.61 μm and Ra = 0.35 μm respectively.

Experiments were performed to evaluate the wear resistance of the guide bearing and cylinder life. Tests were carried out on cylinders subjected to radial load in conditions very similar to those established by standards in [1] but under higher loads; more severe operating conditions were considered to enable an accelerated life test to be carried out. The methodology specifies cylinders supply pressure, compressed air filtration conditions, rod

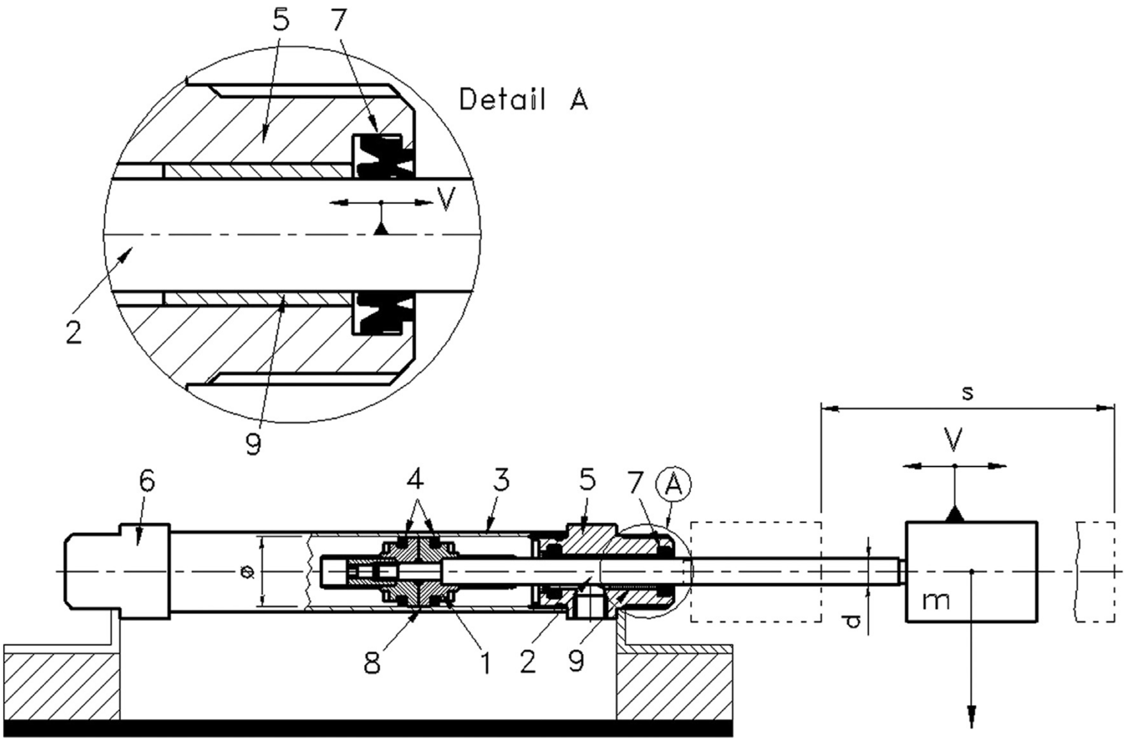

Fig. 1. Cylinder schematics and test set-up.