Tribology International 118 (2018) 240–245

Contents lists available at ScienceDirect

Tribology International

journal homepage: www.elsevier.com/locate/triboint

Indirect contact pressure evaluation on pneumatic rod seals

G. Belforte [a], M. Conte [b], A. Manuello Bertetto [c], L. Mazza [a], T. Raparelli [a], C. Visconte [a,*]

[a] Department of Mechanical and Aerospace Engineering, Politecnico di Torino, Italy
[b] Anton Paar Tritec SA, Peseux, Switzerland
[c] Department of Mechanical, Chemical and Material Engineering, Università di Cagliari, Italy

ARTICLE INFO

Keywords:
Contact pressure
Radial force measurement
Seals
Pneumatics

ABSTRACT

This paper deals with the experimental evaluation of contact pressure at the interface between an elastomeric rod seal for pneumatic cylinders and its metallic counterpart without interposing any intrusive measuring device. A new test bench, which is able to measure the radial force exerted by a rod seal displaced at constant velocity on a sensorized portion of a cylinder rod over time, was designed and manufactured. The seal was pressurised to reproduce actual working conditions. A data postprocessing methodology was developed for an indirect evaluation of contact pressure starting from the experimental data set of the radial force exerted by the seal on the rod. At first, the measured radial force signal was filtered and properly fitted obtaining a differentiable function; then, contact pressure distribution was computed as a function of radial force time derivative, seal velocity and rod diameter. Preliminary experimental results are presented.

1. Introduction

The analysis of the elastomeric seal performance is a demanding task not only because of the variety of used materials, shapes and dimensions, but also because of the relevant influence of many operating parameters, such as applied loads, working pressure, lubricating conditions, temperature, and sliding velocity. In particular, the study of the contact characteristics at the rubber-metal interface is of great importance because both the sealing capability and the strength of the friction force depend on the contact pressure.

Much research has been addressed at the evaluation of contact pressure between a seal and its counterpart. Bignardi et al. [1] processed experimental data obtained on a pneumatic lip seal by a photoelastic reflection technique to compute analytically the contact pressure distribution at the seal-rod interface. Pinedo et al. [2] built an analytical tri-dimensional eccentricity model of a rod lip seal extrapolating contact pressure distribution from finite elements simulations and experimental measurements. Hermann and Dabish evaluated numerically the contact pressure distribution between a pneumatic rod seal and its countersurface [3]. Many research works reported the use of pressure sensitive films to determine experimentally contact pressure distribution over a friction couple, in various research fields. As an example, Lee et al. [4] employed film sensors to study the influence of interference fit on the contact characteristics between an hydraulic lip seal and a rotating shaft. The same kind of sensors was employed for static measurements of local contact pressure in pneumatic applications by Belforte et al. [5–7] and by Manuello Bertetto et al. [8]. To overcome the main drawbacks of pressure sensitive films, namely non-negligible thickness and laborious positioning [9], some other authors reported non-contact measuring techniques. A non-intrusive ultrasonic method was used by Marshall et al. [10] in a bolted connection. Prokop and Müller studied the contact pressure of PTFE rod seals by performing radial force measurements at certain axial positions step by step; contact pressure was indirectly obtained from this signal [11]. Debler et al. [12] developed a test bench to measure the radial force exerted over time by a rubber cuff seal mounted on a rod equipped by a strain gauge sensor of special design; also in this case, contact pressure was indirectly obtained. Tests were carried out under unpressurised working conditions. In the same paper both linear and non-linear models of the seal were developed; the material stiffness and model coefficients (two-parameter Mooney-Rivlin material) were adjusted for a good agreement with the radial force measurements.

This work is addressed to the experimental evaluation of contact pressure at the interface between an elastomeric rod seal for pneumatic cylinders and its metal counterpart without interposing any intrusive measuring device. Results were obtained using a specifically designed test bench able to detect the radial force exerted by the rod seal displaced at constant velocity on a sensorized portion of a cylinder rod over time [13]. With respect to [12], which is the main reference of our test set-up,

* Corresponding author.
E-mail address: carmen.visconte@polito.it (C. Visconte).

https://doi.org/10.1016/j.triboint.2017.10.002
Received 13 April 2017; Received in revised form 22 September 2017; Accepted 1 October 2017
Available online 5 October 2017

the measurement technique does not require the use of a specifically designed sensor; in fact, commercial uniaxial load cells were used to measure the radial force. Furthermore, the developed test bench permits the seal pressurisation to reproduce actual working conditions. A custom made data postprocessing methodology was developed for an indirect evaluation of contact pressure starting from the experimental data set of the radial force exerted by the seal on the rod. At first, the measured radial force signal was filtered and properly fitted obtaining a differentiable function; then, contact pressure distribution was computed as a function of the time derivative of the radial force, of the seal velocity and of the rod diameter. Preliminary results obtained on a type of rod seal for pneumatic applications are presented.

2. Indirect measurement of contact pressure

In order to contribute to a better understanding of the adopted measuring set-up, Fig. 1 shows a scheme of the seal assembled on the test bench. The rod seal, which is loaded by compressed air pressure on the left side, is displaced at constant velocity over a fixed cylinder rod (1), whose final portion is split into two sectors: the first one (1′) is an extension of the rod body, the second one (2) is free to move in y-direction and is connected to two load cells, which are not shown in this scheme. These sensors perform the measurement of the overall radial force oriented in the negative y-direction and exerted by the seal under test on the rod portion (2). To this aim, a gap (3) is provided between the rod sectors, which permits a relative motion without friction. During the test, the seal initially slides over the full rod (Fig. 1a); then, it gradually engages the sensorized portion of the rod (Fig. 1b); finally, it completely covers the sensorized rod tip (Fig. 1c).

Fig. 2 highlights that the radial force measured at a certain instant of time is the resultant of the axisymmetric contact pressure distribution over the corresponding contact area between the seal and the sensorized rod. While the contact area between the seal and the sensorized rod tip increases, the sensors detect an increasing radial force until a maximum value is reached.

Since the seal motion occurs at constant velocity V, the contact pressure distribution along the z coordinate can be obtained as a function of the force F time derivative, the rod diameter d and the seal velocity V:

$$p(z) = \frac{1}{d}\cdot\frac{dF}{dz}\cdot\frac{dt}{dt} = \frac{1}{d}\cdot\frac{dF}{dt}\cdot\frac{1}{V} \tag{1}$$

Details on the analytical procedure can be found in Ref. [13].

This method of measurement reproduces actual working conditions without introducing any additional deformations of the seal; this characteristic represents a great advantage with respect to other experimental methods, as those making use of pressure sensitive films.

3. Test bench

A test bench for the indirect measurement of contact pressure at the seal-rod interface was designed and manufactured, on the base of the solution proposed in Ref. [13].

A sketch of the measuring portion and a photo of the manufactured test bench are shown in Fig. 3 a) and b), respectively. In particular, it is possible to identify: the seal holder (1), which permits to pressurize the sealing lip of the seal; a pneumostatic bearing (2), used to obtain a smooth motion even at low velocity; the fixed parts (3) and (3′) of the measuring rod and the sensorized rod portion (4); the couple of load cells (5), which measure the radial force signal over time; precision screws (6), which were used to adjust the gap h_1 between the two portions of the rod correctly (see the detail in Fig. 3a); the pair of pneumatic bearings (7) and the pneumatic pad (8), which permit to correctly align and centre the sensorized rod portion (4) with respect to the rod extension (3′). In particular, the pair of pneumatic bearings (7) has also the aim to balance the friction force exerted in z-direction and any torque produced about the x or the z axis; the pneumatic pad (8) balances any torque about the y axis. The choice of pneumatic guide bearings, namely low friction bearings, ensures that the seal radial force F exerted in y-direction is correctly measured by the load cells; any additional friction would misrepresent the measurement. More details on the test bench characteristics can be found in Ref. [13].

In this test bench, the generation of the measuring signal is obtained by displacing the sensorized portion of the rod in the negative y-direction. Since this displacement causes a modification of the shape and of the diameter of the rod, it has to minimized. To this aim, load cells FGP FN 3030 (accuracy + -0.1% F.S) with a full scale of 1000 N, definitely higher than that required, were chosen to ensure a high stiffness; thanks to the parallel assembling configuration, the equivalent stiffness of the measuring device is of $4.2 \cdot 10^7$ N/m. Both the load cells were calibrated out of the test bench. After having mounted them in the working configuration, a known weight was hanged on the sensorized portion of the rod, to further verify that the sum of the force measured by each cell was equal to the loading weight.

The radial force signal was recorded by a NI USB-6229 data acquisition system at a frequency of 1 kHz.

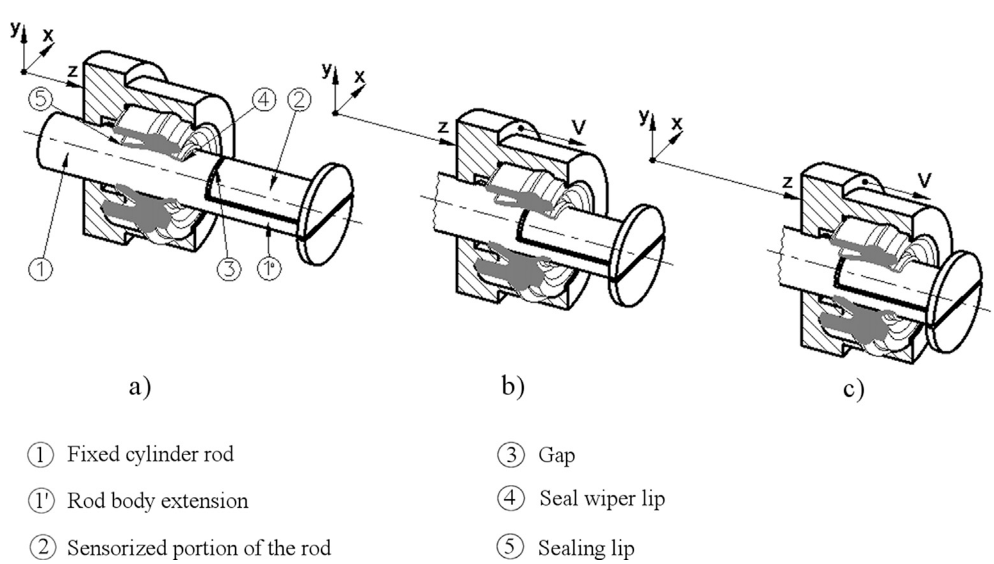

Fig. 1. Dynamic measurement of the seal/rod radial force.