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Enhancement of seal life through carbon composite back-up rings under shock loading conditions in defence applications

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Abstract

The life of Nitrile Butadiene Rubber (NBR) O-ring seal having shore hardness of A70 and A90 under shock loading conditions was investigated by a specially designed pneumo-hydraulic shock test rig. Shock tests have been carried out on bare seals, seal with conventional polytetrafluoroethylene (PTFE) back-up rings and seal with newly developed carbon composite back-up rings to study its behaviour under different operating conditions until failure. Experiments were conducted by varying annular gap ranging from 0.3 to 0.5 mm, oil temperature from 30 °C to 70 °C and rate of pressure rise from 600 to 2400 MPa/s. Significant enhancement in seal life was observed with carbon composite back-up ring at reduced annular clearances compared to seal life with conventional PTFE back-up ring and without back-up rings.

Keywords: Hydraulic seal; O-rings; Shock load; Seal extrusion; Pneumo-hydraulic shock absorber; Back-up rings

1. Introduction

Hydraulic seals are used in a variety of critical applications involving machinery and are several times more expensive compared to seals. The critical importance of the seal can be quantified by the failure of a static O-ring due to cold temperature freezing, causing catastrophe of NASA space shuttle "*Challenger1986*". Therefore, the precise design and evaluation of reciprocating hydraulic seals are of supreme importance to avoid such costly mistakes.

O-rings are the simplest and most versatile seals among various types and cross sections of hydraulic seals having wide applications involving static and dynamic loading conditions. O-rings are employed in reciprocating hydraulic actuators involving long stroke and large diameter seals. The most important application includes the use of O-rings in reciprocating hydraulic rod and piston seals. The life of reciprocating dynamic O-ring seals is influenced by extrusion, spiraling, finish of sliding surface and hardness of the seal.

Shock is defined as a non-periodic excitation of a system characterized by sudden relative displacement in a system. All structures in general and aerospace structures in particular experience shock loads of different magnitudes throughout their service life. Shock is generally measured through time histories expressed in seconds and amplitude expressed in g's of the shock event. Shock can also be measured in terms of velocity, displacement, force, pressure, etc. Shock testing is commonly performed by imparting kinetic energy to the system by drop hammering, impact, shaker, pyro-shock, etc. The failures caused by shock include crack or deformation of structural elements, failure of weld joints, hydraulic seal failure, etc.

High pressure hydraulic seals are the common and most critical elements of any hydraulic system. Many of the defence equipment experiences shock/blast loads during deployed conditions. These blast/shock loads create short duration peak pressures, which are several times higher than the system operating pressure that will affect the seal life and in turn affect the reliability of the system. Shock isolators/dampers are generally used to isolate the shock loads and safeguard the delicate components of the system. One such pneumo-hydraulic shock absorber is shown in Fig. 1, in which the dynamic seals experience a short duration pressure surge of 1000 bar during shock load isolation.

Experimental research on hydraulic seals has been in progress for several decades. Over the years, theoretical and experimental investigation of tribological characteristics of

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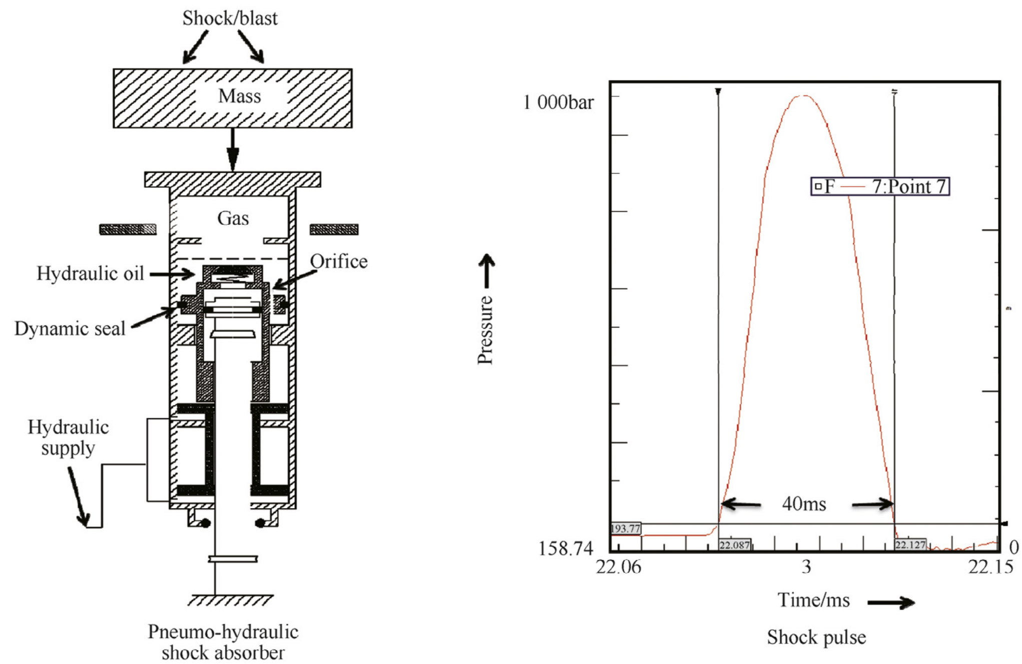

Fig. 1. Effect of shock load on pneumo-hydraulic shock absorber.

reciprocating hydraulic seals such as leakage, friction, wear and extrusion has been carried out by numerous researchers. Numbers of test rigs have been built and various methods were employed for determination of tribological characteristics. Nikas, Müller, Field and Nau investigated the leakage and friction of reciprocating hydraulic seals [1–4]. Hirano and Kaneta investigated the friction characteristics of flexible seals for reciprocating motion [5]. Nau determined the friction of oil lubricated sliding seals by conducting a number of experiments [6]. Iwanami and Tikamori experimentally determined leakage from O-ring packing [7]. Kawahara et al. [8] and Kaneta [9] also contributed to the experimental investigation of tribological characteristics of reciprocating hydraulic seals. Nikas formulated algebraic equations to describe the shape and contact pressure of the extruded part of the seal with the rod [10]. Significant theoretical work was carried out by Salant [11–13], Nikas [14–17], Fatu and Hajjam [18] to determine the tribological characteristics of reciprocating hydraulic seals. Bhaumik et al. investigated the contact mechanics in reciprocating hydraulic U-seals for defence applications [19]. Thatte and Salant developed a transient numerical model for reciprocating hydraulic seals to take account of the varying rod speeds [20]. However, no theoretical or experimental data to assess the influence of shock/blast load on hydraulic seals were found in the literature. Therefore, in order to quantify the performance of hydraulic seals under severe operating conditions, it is necessary to design a test rig capable of generating shock pressure peaks to test the sealing elements of the hydraulic system.

In view of the above, in the present investigation, a special test rig has been developed and seal life as a function of parameters such as annular gap, rate of pressure rise, seal hardness, oil temperature, etc., was investigated with and without the use of back-up rings. It was observed that the seal life was enhanced significantly with carbon composite back-up ring at reduced annular clearances compared to seal life with conventional PTFE back-up ring and without back-up rings.

2. Pneumo-hydraulic test rig for hydraulic seals subjected to shock loading

The test rig [21] capable of generating various types of shocks pulses by variation of parameters such as peak pressure, pulse duration, pulse shape, etc., shown in Fig. 2 has been developed to simulate the performance of static and dynamic hydraulic seals. The test rig is integrated with a data acquisition system for capturing test data for further analysis. The shock test rig will generate controlled hydraulic pressure pulse in a test chamber. The test chamber having bore diameter of 63 mm, rod diameter of 36 mm and stroke length of 300 mm is similar to a hydraulic cylinder integrated with rod/piston seal to be tested under dynamic conditions. The schematic of hydraulic system for the test rig consisting of hydraulic power pack, hydro-pneumatic accumulator, controlled valves, impact cylinder, test chamber, transducers and data recorder is shown in Fig. 3. The hydraulic power source consists of 2 cc/rev, 30 MPa, fixed displacement radial piston pump driven by an electric drive unit. The accumulator of 50 L capacity is charged by a hydraulic power source to the desired pressure depending on the peak test pressure. After charging the accumulator to relief pressure setting, the pump flow is by-passed to the reservoir of 60 L capacity through the maximum pressure set relief valve and a return line filter. The pump pressure is also available to the DC valve for operation of pilot operated check valves provided in the circuit for forward and reverse motion of impact cylinder of bore diameter of 125 mm, rod diameter of 90 mm and stroke length of 500 mm. The DC valve solenoids are energized by a power supply through a timer to control the pressure pulse