# DEVELOPMENT AND TRIBOLOGY OF RECIPROCATING HYDRAULIC SEALS

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**Abstract:** The development of reciprocating hydraulic seals radically decreased the efficiency and immensely reduced the seal housing volumes and also the overall economy of high pressure hydraulic drives. To reveal tribological behaviour of reciprocating seals it is necessary to analyse the relationships of seal design, tribological features and the main operating characteristics. For environmental protection leakage control has great importance. Leakage calculation of reciprocating high pressure hydraulic seals is based on the sealing pressure distribution profiles, i.e. diagrams which are playing an important role in research and development of piston and piston rod seals too.

***Key words: t**ribology of seals, reciprocating hydraulic seals, piston and piston rod seals, efficiency of friction seals, seal design.*

## 1. INTRODUCTION

Reviewing the development of seals, stuffing box was the first overall used sealing solution for pressurized media in all directions of motion for rotary pump shafts, valve seals and also for piston and piston rod seals . The advanced stuffing box designs and seals (gland packings) are still in use nowadays but only in a more limited fields of application.

During the last decades all kind of seals, including friction seals, went through reasonable developments in the applied materials, technology, design (form and sealing surface or edge shape), accuracy and reliability as well. In this advancement process the major aims of research and development are to economise, improve reliability and last but not least to improve environmental protection. These aims are realised by reducing continuously the losses (both leakage and friction), i.e. improve efficiency and also by reducing the required sealing space while adequate sealing life is obtained.

Following the overview of friction seals development in general, the particular problem of friction losses are much more emphasised for reciprocating seals –then for rotating seals- as lubrication conditions are subject to change at each direction change of motion. Therefore the lubrication film is rebuilt at the start and the end of each stroke.

The tendencies of mechanical efficiency and space requirement changes are presented well by comparative studies of some frequently applied hydraulic seals [7],[9]. Let be compared the above changes for V-packings ( which seal type may be considered improved gland packings), U-rings and a modern compact seal of simple design. In the diagrams the tendencies show an astonishingly fast improvement in mechanical efficiency ($\eta$) while the sealing space volume ($V_s$) and the axial seal width ($L_s$) are reduced immensely (Fig. 1). Simultaneously these results show reasonable improvements in economics both in hydraulic equipment design and system operation as well.

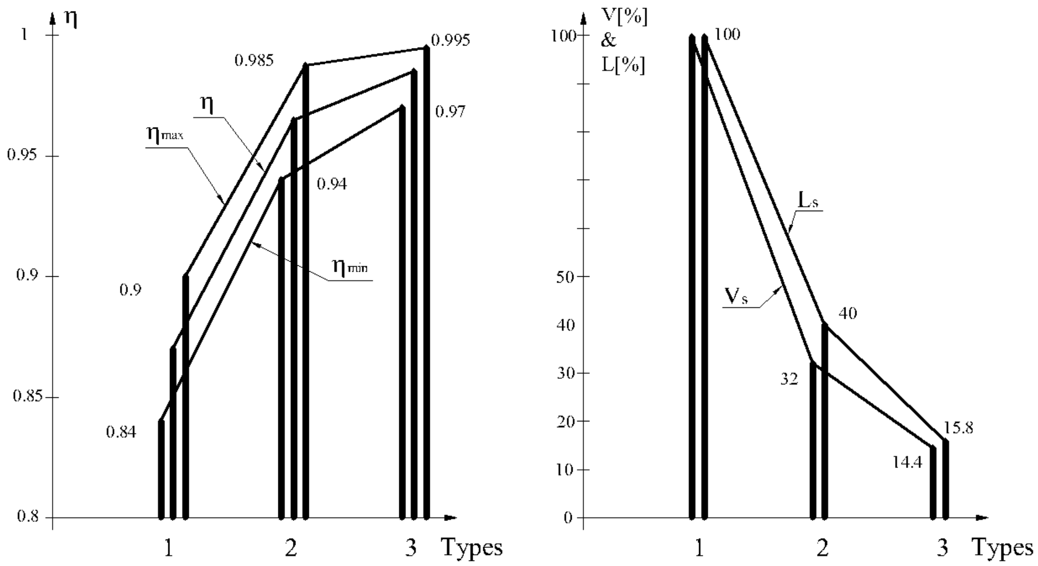


Fig. 1 Reciprocating hydraulic seal mechanical efficiency and housing volume development. (1-th column: V-packings, 2-nd: U-rings, 3-rd: compact seal with O-ring and reinforced PTFE piston ring seal.)

## 2. ANALISING TRIBOLOGICAL FEATURES

In order to clear sealing operation principles, the formation of lubricated film and leakage characteristics should also be examined. This requires deep analysis to reveal the tribological features and relationships of the reciprocating seals. Research works attempted time and again to expose the closer relationships and interaction among the seal design and the working conditions, the tribological features and the main operating characteristics and of reciprocating seals. A brief description of the influencing factors of these relationships is as follows:

- *Design and working conditions*

Design characteristics: seal shape and form, sealing edge shape, sealing gap and fits

Materials and surface properties: chemical resistance, rubber hardness, surface roughness and hardness of the friction metal surface …

Operating conditions: working pressure, temperature and reciprocating speed…

- *Tribological features*

Sealing force and sealing pressure distribution.

Lubricating film-thickness (height) and film-profile, lubrication influencing factors.

- Temperature magnitude and distribution
- *Main operating characteristics*
- Friction force, friction loss.
- Leakage, loss of working media.
- Wear, seal life and endurance.

By time reasonable advancements were achieved in this subject, first by testing the lasting behaviour of the fiction force and leakage and also the friction characteristics in the functions of working pressure and reciprocating speed.

The advancements were continued by the static and dynamic sealing pressure measurements -on the friction surface of the seal- in the lubricating film and later by measuring and plotting the lubricating film temperature and thickness distribution along the contact surface of the seal [4], [5].

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## 3. MAIN OPERATING CHARACTERISTICS AND REQUIREMENTS

The main operating characteristics are determined directly by tests in order to obtain the formation of the friction force and the leakage during a lasting operation period of seal endurance tests. The formations of friction force are also determined – at a certain operation time - in the function of working pressure and reciprocating speed by friction characteristic tests [5],[6].

The indirect determinations of operating characteristics are done by estimations and calculations which are still relying (more or less) on test results.

The main operating characteristics of seals should meet requirements formed by the need of the particular application field. These requirements may prescribe limitations for any or all of the operating characteristics like:

- Clean appearance of the equipments, economy, (safety) and environmental protection.
- Limited or even zero leakage is required as it is considered the best outcome for operation and also for environmental protection. In practice zero leakage is defined as „dry piston rod" surface, which is resulted by the balanced leakage between the outstroke and in stroke working media transport of the piston rod.
- Good mechanical efficiency, economic operation, operation safety, reliable starting, operation and restarting conditions of the hydraulic equipments. They all need perhaps small, controlled and most of all predictable friction force formation during any operation conditions.
- Economic operation, maintenance and reliability of hydraulic equipments need controlled, low wear and adequately long life.

## 4. LEAKAGE CONTROL AND CALCULATION

Out of the seals main operating characteristics the leakage control is the utmost relevant to reduce or eliminate unnecessary environmental loading. Industrial hydraulics applies mostly oils or emulsions as working media. They are characterised mostly by low ability for disintegration and considered as hazardous materials from which the environment must be protected. Therefore primer emphasis should be given to leakage elimination especially in case of outdoor hydraulic equipments.

According to the inverse hydrodynamic theory the sealing gap i.e. the lubricating film profile between the seal and the friction surface can be determined from the sealing pressure distribution diagrams and the leakage may be calculated by the help of the maximum gradient ($dp_t/dx$) taken from the direction of the motion [1].[2]. At the maximum pressure gradient the formulae of the gap height and the leakage calculations are:

$$h = C\sqrt{\eta v/(dp_t / dx)}$$

$$Q = \pi Ds(h^*_{out} - h^*_{in})/2$$

(Where $C$ is a constant $\eta$ is the viscosity of the media, $v$ is the speed of the motion, $D$ is the seal friction diameter and $s$ is the length.) For the formulae of $h$ "flexible model" is applied where a flexible seal moves on a lubricated rigid surface (and the gap profile changes are decided by tests along the consecutive points of seal width).

Consequently controlling and eliminating leakage is one of the major targets of research and development since methodical hydraulic seal research works are carried on. Studying the relationships of leakage calculation the sealing pressure distribution curve (profile) can be modified and improved. From the factors effecting lubrication the sealing pressure distribution profile was found one of the best tool to control leakage.

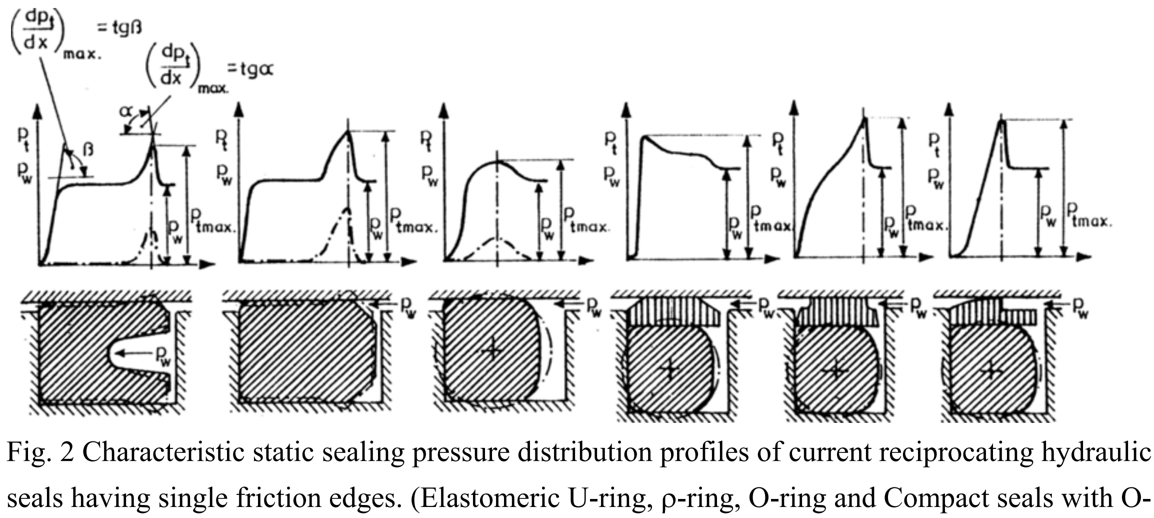

Fig. 2 Characteristic static sealing pressure distribution profiles of current reciprocating hydraulic seals having single friction edges. (Elastomeric U-ring, ρ-ring, O-ring and Compact seals with O-ring and reinforced PTFE piston rod seal.)

## 5. SEALING PRESSURE DISTRIBUTION

The run out –shape- of the pressure distribution curves depend on the seal material, design, etc. For example, for different seal types (profiles and material) the static sealing pressure distribution curves show characteristic similarities and changes (Fig. 2) [1], [3],[8].

Theoretically correct information on the operating sealing pressure distribution is obtained by tests based on dynamic sealing pressure measurements. Here the time dependent material behaviours of seal materials and the effect of reciprocating motion (and speed) are considered on the sealing pressure distribution.

Nevertheless the static pressure distribution has been using for research since today due to some remarkable conclusion and considerations:

- The sealing edge is rather form keeping for modern high pressure reciprocating hydraulic seals. Therefore, the critical pressure gradients directions of the static and dynamic pressure distribution curves do not show reasonable differences. At least the values of calculated leakage by the help of measured sealing pressure gradients (tangents) do not give significant difference comparing to the measured leakage values. However this correlation between the calculated and measured values was proved mostly for high-pressure elastomeric seals of pistons and piston rods [3].
- Regarding the in- and outgoing static sealing pressure distribution diagrams the sealing pressure gradients did not show sensible changes (Fig. 3) [8]. This can be considered as a proof of the above statement for static and dynamic pressure distribution curves.

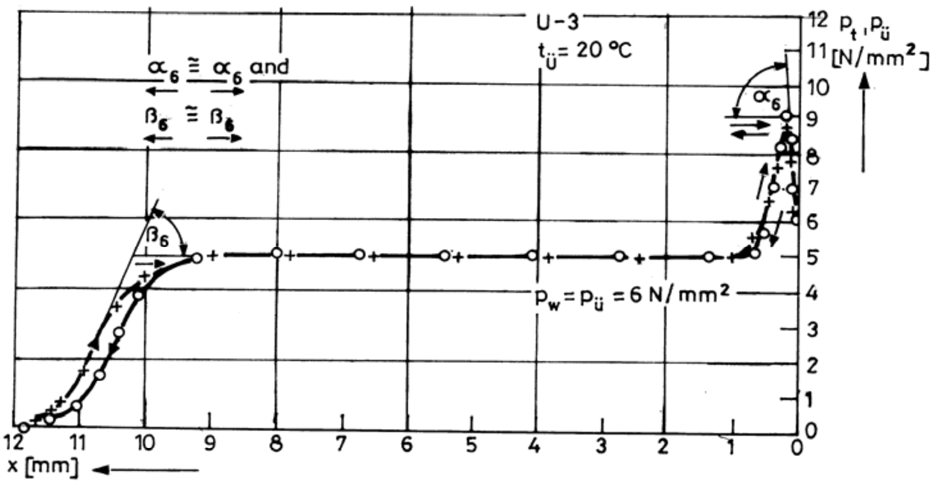


Fig. 3 Out- and ingoing static sealing pressure distribution diagrams (The tested seals were Polyurethan U-rings. Hardness : IRHD88, medium Hydro 20 oil).

- By modifying the profile it is possible to change the maximum sealing pressure for safer initial sealing effect and also possible to change the maximum sealing pressure gradient to modify the leakage values expected during operation. As a consequence the leakage during operation-being the resultant of the transported media during outstroke and in stroke- can be reduced or even eliminated „completely” to get „zero leakage”. Continuing this way of logic, suggested by the above formulae, a „negative leakage value” can also be produced by a proper modification of the sealing pressure distribution profile . (It can be obtained by proper selection and changes of seal design and material characteristics or even by setting different speeds for in and outstroke.) In such a case the outstroke tends to transfer less medium (lubricant) then the in stroke. Consequently the lubrication condition deteriorates, the friction increases between the seal and the friction surface and the increased friction effect produce extensive wear and very short seal life. Therefore a delicate balance must be found to fulfil all requirements regarding leakage limitation (elimination) and seal life.

## SUMMARY

Reciprocating hydraulic seals showed great improvements during the last decades in design and in the main operating characteristics (friction and leakage) as well. Analysing the tribological features of seals help to reveal the relationships among design, working conditions and main operating characteristics.

Environmental protection demands priority to leakage control and elimination in application and development too.

In leakage calculation the sealing pressure distribution curves have an outstanding role. However the static sealing pressure distribution seems to remain one of the important tools for seal development to eliminate leakage.

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