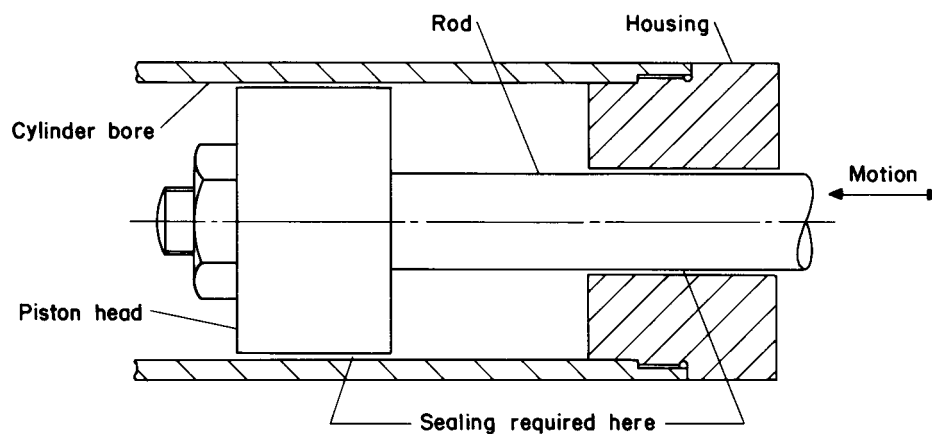


DYNAMIC SEALING OF FLUIDS. 2: GUIDE TO SELECTION OF RECIPROCATING SEALS

1. INTRODUCTION

This Item is the second of a pair (see Reference 1) dealing with the dynamic sealing of fluids. The Item is intended to assist during the initial stages of the design of a sealing arrangement for reciprocating duty and provides a method for selecting the most suitable type of seal.

In reciprocating duty either a rod moves axially through the housing of a machine or a piston head moves axially along the bore of a cylinder as shown in Sketch 1.1. Sealing is provided to limit or prevent the leakage of a fluid past the housing or piston head. The surface of the rod or cylinder bore is referred to as the counterface.



Sketch 1.1 Reciprocating duty sealing

In some applications the seal requires protection from atmospheric dust by a dirt exclusion device or an additional seal specially adopted for the purpose. The selection of dirt exclusion devices is not dealt with in this Item although comments are included, where appropriate, on the use of seals for this purpose.

This Item considers contact seals, clearance seals and membrane seals. The modes of operation of these three categories of seal are described and their outline characteristics given. A flowchart procedure allows the most appropriate category of seal to be selected.

Contact seals are the most important and widely used category of seal and a major part of the Item is consequently devoted to their selection. A flow chart procedure assists in this selection. The various types of contact seals are described and tables summarise both the characteristics of operation and the properties of some of the seal materials available for their construction. Further sections of the Item discuss leakage, friction, life, lubrication and surface finish requirements, material compatibility and the limits of operation of these seals.

2. SELECTION OF CATEGORY OF SEAL

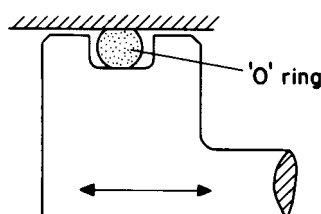
2.1 Categories of Seal Considered

Reciprocating seals may be divided into three categories according to the mechanism of operation. The categories are:

- (i) contact seals,
- (ii) clearance seals,
- (iii) membrane seals.

An outline of the characteristics of each category of seal together with their prime applications is given in Table 2.1. Seal types within each category may be used for sealing at the rod or the piston head.

2.1.1 Contact seals



An 'O' ring seal consists of a synthetic rubber ring of circular cross-section which is fitted with radial interference into a groove in the piston head, as illustrated, or into a groove in the housing in the case of a rod seal.

Sketch 2.1 'O' ring seal

A contact seal is a device which is installed in the piston head or housing and bears on the counterface. Factors such as the surface finish of the counterface and the presence or absence of lubrication and/or dirt particles are vitally important.

Positive sealing (zero leakage) cannot be guaranteed but it is possible with careful selection and installation to achieve very low leakage rates.

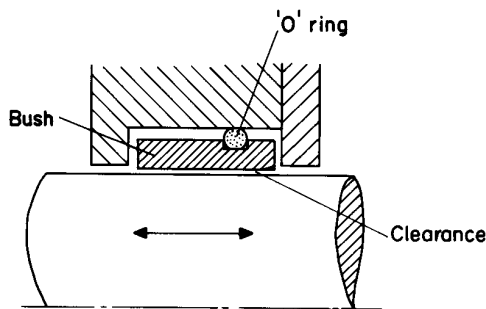
In operation friction is generated and wear of both the seal and the counterface will occur. Contact seals will consequently have a finite life and failure is usually indicated by a gradual increase in the leakage rate.

All contact seals have inherent pressure, temperature, and sliding speed limitations which are highly interactive.

There are many designs of contact seals and these are available in a variety of different materials such as rubber, leather, plastic and metal (see Section 3). A simple type is illustrated in Sketch 2.1.

Contact seals are versatile devices that can satisfy the majority of sealing requirements for liquids and for gases where traces of a liquid lubricant are present. Certain types of contact seal may be operated 'dry' but their pressure, temperature and speed limitations are in general much inferior to those of liquid lubricated seal installations. The elastomeric type of contact seals are sometimes used as an exclusion device, or wiper, to protect a bearing or another seal from atmospheric dust.

2.1.2 Clearance seals



In a bush clearance seal, illustrated in Sketch 2.2, the bush is often arranged to float in its housing to accommodate misalignment and shaft radial movement. One method of achieving this is to mount the bush on static 'O' ring seals. In some designs the bush is grooved to give a labyrinth action.

Sketch 2.2 Bush clearance seal

This category of seal operates with a definite but minimal annular clearance between a specially designed piston head or housing and its counterface. In principle no contact occurs in operation.

With clearance seals leakage rates are usually higher than with other seals. Smaller clearances can reduce the leakage but careful attention must then be given to exclusion of dirt particles and the possibility of contact due to differential thermal expansion or misalignment.

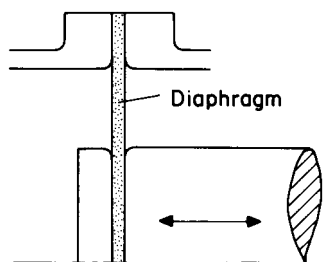
In general, clearance seals have no inherent pressure, temperature or speed limitations. However, leakage rates increase with differential pressure and so the maximum allowable pressure depends entirely upon the leakage rate that can be tolerated.

Clearance seals offer indefinite life and are often regarded as maintenance free.

Sketch 2.2 shows only one of the many designs of clearance seal that are possible and the designer is relatively free to choose the materials of the seal to ensure chemical compatibility and temperature resistance.

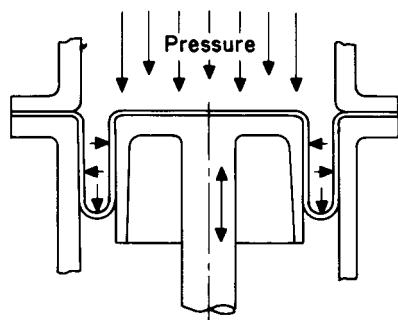
Clearance seals can be used for sealing liquids or gases. The volumetric leakage rate is likely to be high with gases and a liquid is sometimes introduced into the clearance to improve the effectiveness of the seal. Clearance seals find use where low friction is essential or where the differential pressure, temperature or sliding speed is beyond the capabilities of other seals.

2.1.3 Membrane seals



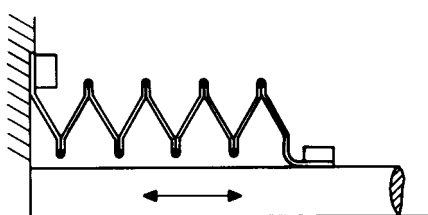
Sketch 2.3 Flat diaphragm

Flat diaphragms are often used as dynamic sealing devices or force transmitters but their allowable stroke length is limited.



Sketch 2.4 Rolling diaphragm

Rolling diaphragms provide greater stroke lengths than flat diaphragms but in general the allowable pressure differential is less.



Sketch 2.5 Moulded rubber bellows

Bellows may be fabricated, moulded or formed and are often used as dirt exclusion devices. Welded metal bellows, as illustrated, allow high temperatures but have a limited stroke compared with other bellows.

A flexible membrane spans the gap between the piston head or the rod and the stationary part of the machine to provide positive sealing. Flexing of the membrane occurs in operation. The main types are shown in Sketches 2.3, 2.4, and 2.5.

Compared with contact seals and clearance seals, membrane seals are short stroke devices. The allowable stroke depends on the individual design, the differential pressure and the frequency of reciprocation. In general the shorter the stroke the higher the allowable pressure.

Membrane seals are manufactured from a variety of materials including rubber, leather, plastic and metal. They have a finite life and rupture of the membrane can occur without warning due to fatigue or excessive pressure.

These seals are used for sealing liquids or gases in relatively low pressure applications. They are particularly useful where positive sealing is required. Membrane seals, especially diaphragms, are often used in pressure operated switches. Bellows find use as dirt exclusion devices to protect bearings or other seals from atmospheric dust.

2.2 Choosing the Category of Seal

Before deciding on the design of seal to use, the designer should first consider which category of seal most suits the application.

The mechanism of operation of each category of seal is distinctly different and the designer must weigh the individual merits and limitations associated with each mechanism before making a choice. The flowchart of Sketch 2.6 is intended only to assist in making this choice and should be used in conjunction with Table 2.1 which outlines the characteristics of each category of seal. The additional comments of Section 2.3 should also be considered together with the practical experience of the designer. Thus a category of seal eliminated by using the flow-chart alone cannot be totally excluded as certain combinations of operating conditions and other requirements can necessitate reconsideration.

2.3 Additional Factors to Consider

Complete freedom from leakage is rarely required except when sealing toxic fluids or where incompatible fluids must be separated. Appreciable leakage can often be accepted on internal seals. Where the leakage will be into the atmosphere, environmental considerations often determine acceptable leakage rates.

Dynamic friction can represent a considerable power loss. However, static friction is more important in some applications and can cause erratic or jerky operation particularly where the system is compliant (see Section 3.3.3 and Table 3.3).

Adequate space must be available to accommodate, install and service the seal. Attention should be given to the accessibility of the seal position for maintenance, to the consequences of seal failure and to the acceptable time interval between seal replacements.

The life and reliability of a seal are influenced significantly, sometimes critically, by the engineering standards of the installation. The tolerances, such as those relating to surface finish, dimensions and alignment, that can be justified in the machine design should be considered. The level of skill of the workforce that will be called upon to install and service the seal should also be taken into account.

Provision of lubrication, where appropriate, should be considered as well as the degree of solid particle contamination. With an internal seal cleanliness is usually ensured but where the seal is exposed to a dusty atmosphere some form of dirt exclusion device may be required.

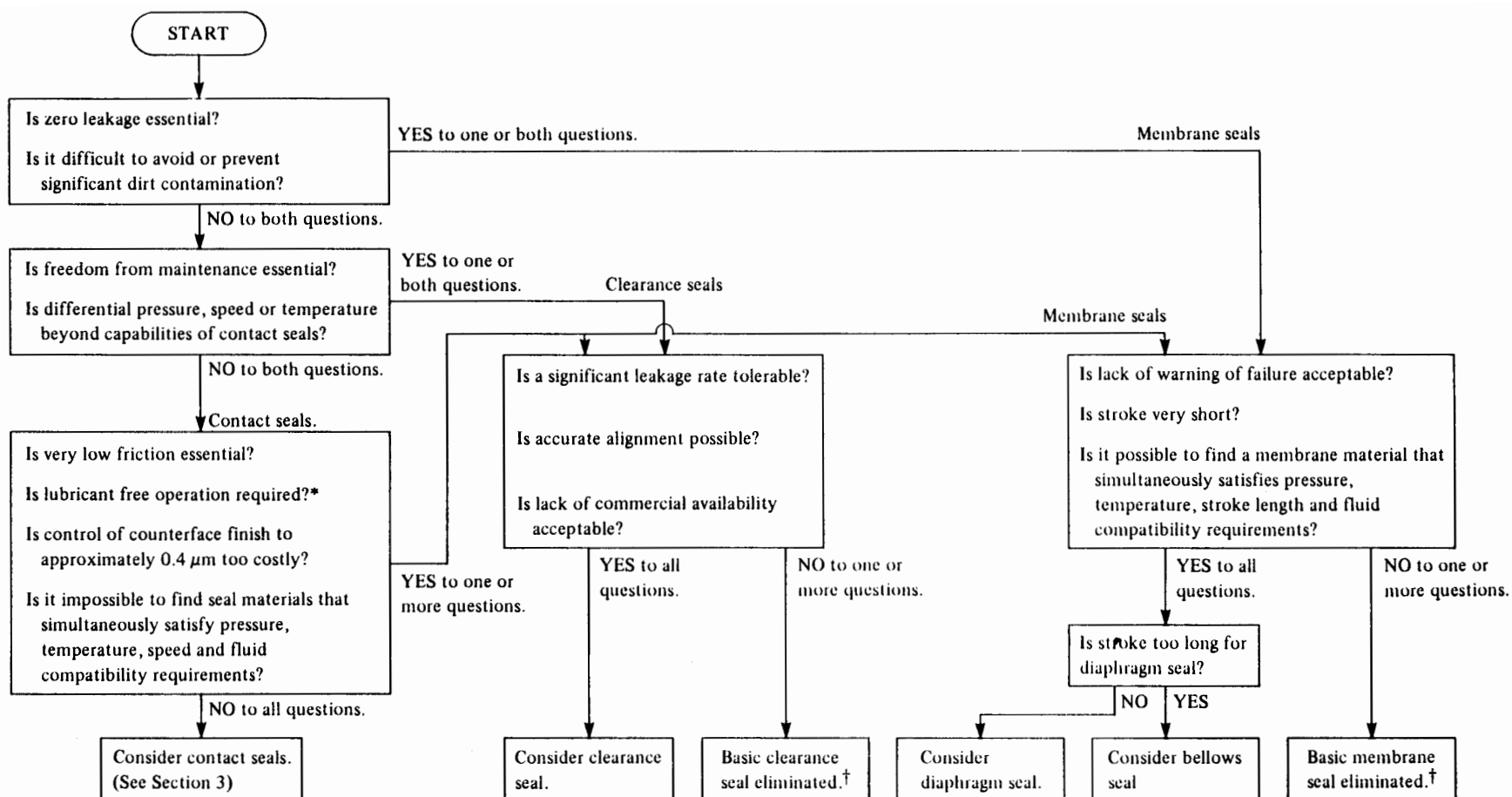
The pressure, temperature and sliding speed to which the seal will be subjected should be assessed as accurately as possible. Seal failures or inadequate seal performance can often be traced to working conditions different from those assumed to apply.

Cost is not a simple aspect as it includes not only the seal cost but installation, maintenance and replacement costs. Seal cost depends on seal design and on the number required. Table 2.1 contains information on the relative cost of the seal only, when supplied in small numbers. The complexity of the subject demands that the user of this Item draws on his engineering judgement in assessing the likely total cost implications.

Most applications can be satisfied by a contact seal and this category is indeed the most widely used. While clearance seals offer very long life they inevitably leak. Membrane seals offer positive sealing but they can fail without warning. Contact seals often provide the best compromise between long life and low leakage and are described in more detail in the next section.

TABLE 2.1 Outline of Characteristics of Seal Categories

	Contact Seals	Clearance Seals	Membrane Seals
Nature of device	Separate device installed in piston or housing.	Usually integral part of machine design.	Separately installed flexible membrane.
Leakage characteristics	Sliding contact minimises leakage. Often negligible but cannot guarantee positive sealing. Can be zero when static.	Can be substantial. Leakage controlled by definite but minimal annular clearance.	Zero. Membrane provides positive prevention of leakage.
Factors of primary importance for correct operation and selection	(i) Condition of counterface such as surface finish, lubrication and dirt contamination. (ii) Temperature, differential pressure and speed. (iii) Chemical nature of sealed fluids.	(i) Alignment and machine deflections. (ii) Differential thermal expansion.	(i) Stroke length and frequency of reciprocation. (ii) Temperature and differential pressure. (iii) Chemical nature of sealed fluids.
Common maximum allowable differential pressure (MN/m ²)	10 to 70 Depends primarily on seal construction.	No inherent limit. Depends entirely on leakage rate that can be tolerated.	1 The shortest stroke designs allow the highest differential pressure.
Usual temperature range (°C)	–250 to 250 Depends primarily on seal materials.	Usually no problem. Relative freedom of seal material choice.	–70 to 150 Depends primarily on seal membrane material.
Common maximum allowable sliding speed (m/s)	0.3 to 5 Depends primarily on material in contact with counterface.	Usually no limit.	Usually not relevant.
Counterface surface finish requirements.	Usually better than 0.4 µm Ra.	Usually not critical	Not relevant.
Lubrication requirements.	Liquid lubrication usually required.	Usually not relevant.	Not relevant.
Tolerance of dirt particles.	Dirt contamination should be avoided or prevented.	Usually no problems depending on clearance.	Usually no problems.
Fluid compatibility (see Table 3.4)	Compatible seal materials can usually be found but requirements may conflict.	Usually no problems. Relative freedom of seal material choice.	Compatible membrane material can usually be found but other requirements may conflict.
Power loss	Can be appreciable.	Usually negligible.	Usually unimportant.
Break-out friction	Can be appreciable.	Zero.	Zero.
Life	Finite due to wear of seal and possibly the counterface.	Usually very long.	Finite due to fatigue.
Failure indication	Usually gradual increase in leakage rate.	Failure rare.	Failure can be sudden.
Commercial availability	Most types available in numerous materials and design variants.	Extremely limited availability.	Some stock sizes and materials available.
Maximum readily available size (m)	0.3 to 1.0 depending on type. Unlimited (Compression packings).	Not available. Built into machine	0.3 (Diaphragms) 0.15 (Bellows)
Relative cost (seal only)	0.1 to 500	10 to 1000	1 to 30 (Diaphragms) 5 to 100 (Bellows)
Prime applications	Majority of moderate speed, pressure and temperature sealing applications. Elastomeric types can be used as dirt excluder.	High speed, pressure and temperature sealing on pumps and compressors.	Low pressure, short stroke applications. Diaphragms can be used as force transmitters, bellows as dirt excluder.



* Some designs of contact seal may be operated dry but their pressure, temperature and speed capabilities are in general inferior to liquid lubricated installations.

† A category of seal eliminated by using this flowchart alone cannot be totally excluded as certain combinations of operating conditions and other requirements can necessitate reconsideration.

Sketch 2.6 Flowchart for Selection of Category of Seal

3. SELECTION OF CONTACT SEALS

3.1 Types of Contact Seal Considered

The contact seals considered have been divided into the following types:

- (i) moulded seals,
- (ii) compression packings,
- (iii) mechanical packings,
- (iv) piston rings.

Examples of these types are illustrated in Table 3.1.

3.1.1 Moulded seals

Moulded seals consist of a continuous ring or set of rings (occasionally split rings are used) which are commonly manufactured entirely from an elastomeric material such as synthetic rubber (*e.g.* nitrile or polyurethane). Alternatively the seal may be manufactured from an elastomer impregnated fabric or a plastic such as PTFE. Some seals have a composite construction consisting of two or more materials usually bonded together. The various moulded seal construction alternatives are summarised in Table 3.2

Moulded seals are installed in an external groove in the case of a piston head seal, or an internal groove in the case of a rod seal. The seals are fitted with interference between their sealing surfaces and the counterface but most of the force necessary for effective sealing is provided by the differential pressure when in operation. Seal containment is important with moulded seals and to prevent extrusion under high pressure, rings (anti-extrusion rings) made from a relatively rigid material are sometimes fitted. More commonly a composite seal construction incorporating an integral anti-extrusion feature, such as a moulded-in rubber/fabric section, would be specified.

Many designs of moulded seals are available and a few are illustrated in Table 3.1. The designs can be classified as either “squeeze” or “lip” types, typified by the ‘O’ ring and the ‘V’ ring.

Lip type seals accommodate differential pressure in only one direction and so when a “double acting” seal assembly is required two seals are used, each housed in a separate groove. They should not be fitted with the lips facing each other (“face to face”) since this would lead to high pressure between the two seals. Lip type seals are commonly fitted in tandem as “multi-ring packs” (see Table 3.1) and are available as split rings for ease of installation.

Squeeze type seals are normally intended to float axially in their housings and are usually accommodated more economically than lip types. Many variants are double acting and are unsuitable for mounting in tandem due to the possibility of the development of high interseal pressure. Most squeeze type seal installations rely on a single sealing surface and their performance is, therefore, more susceptible to seal damage than a multi-lip installation. Split squeeze type seal rings are available to aid installation and replacement.