HYDRAULIC SEALS AND SEAL MATERIALS

BY

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Introduction

The requirements of modern naval defence equipment makes it necessary for ancillary component manufacturers continually to monitor materials and their designs to improve the performance, quality and reliability of their products.

Sealing devices are simple items compared with computerized hydraulic control systems, but their malfunction could prevent the satisfactory performance of these systems.

In a hydraulic or pneumatic sense a sealing device separates one environment from another so that useful work can be carried out. Usually seals are buried within the equipment, but they may also be used to protect electronics from the ingress of contaminants such as sea water.

The intention of this article is to complement the paper by Ochiltree[1] given at the previous conference. Whereas his paper covers the chemistry associated with the vulcanization of rubber materials (rubber technology), fluid compatability, etc., it is the intention here to concentrate on the selection of seal materials and seal designs for particular roles.

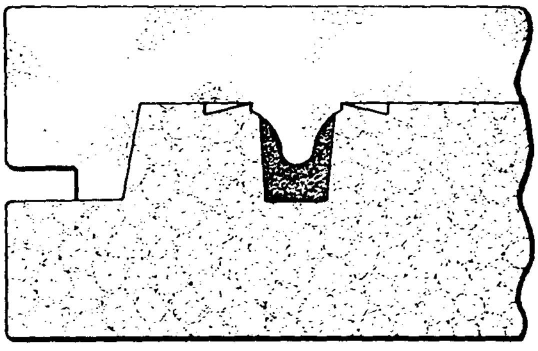

FIG. 1—TWO-PIECE COMPRESSION MOULDING

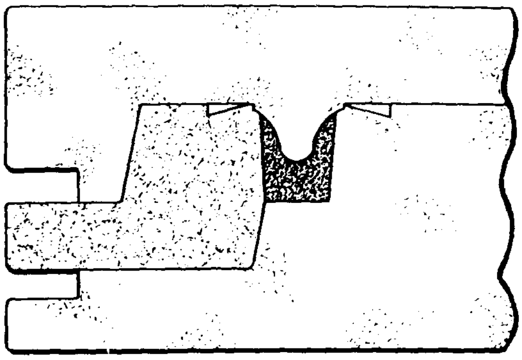

FIG. 2—THREE-PIECE COMPRESSION MOULDING

Manufacturing and Processes

Equipment manufacturers are often unaware of the expertise required to produce quality seals and mouldings the malfunction of which could affect the viability and good name of their products. A production method will be selected to produce seals or mouldings once the dimension and material type have been agreed. The rubber moulding processes used are compression (FIGS. 1 and 2) and transfer or injection (FIG. 3) moulding techniques. Naturally these are modified to suit the manufacturer's equipment. Multi-cavity moulds (FIG. 4), which can be expensive, are necessary when the production/requirements are large, but the corresponding unit price is fairly low. Each rubber type will have a different mould shrinkage subsequent to vulcanization, so the change from, for example, acrylonitrile butadiene (NBR or Nitrile) to fluorocarbon (FPM) will require a dimensional review and possibly new tooling. This will also apply to silicones, which exhibit low, medium or high shrinkage dependent on their grade.

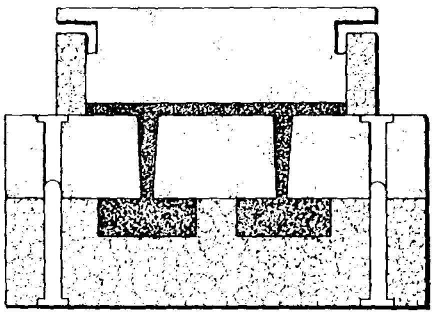

FIG. 3—TRANSFER OR INJECTION MOULDING

Selection of Materials

All rubber compounds are production evaluated to ensure that they will produce items by one or all of the above processes and will suit the product range and component size.

Silicone items should never be manufactured where they can be contaminated by carbon black particles. A compound which adequately meets a particular rubber specification may not be suitable for a specific production process. Another consideration must be the end use of the seal. A compound which is used to manufacture 'O' rings may not be adequate as a rotary shaft seal, although it be correctly manufactured and apparently suitable. It should be stated here that rubber is a very forgiving material, and dimensional changes within reason will not affect the seals' performance especially when used in a static mode.

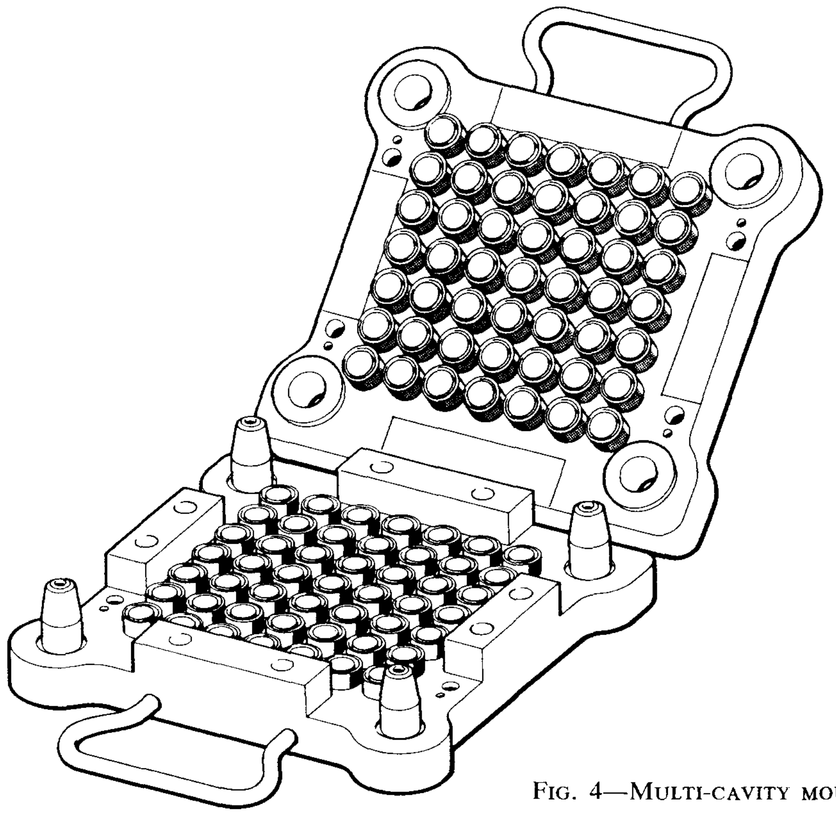

FIG. 4—MULTI-CAVITY MOULD

Rubber specifications are in the main compiled by rubber technologists who are very aware of the principles and complexities of compounding and manufacture, but seldom understand the requirements and performance required in a specific application. Also, production techniques and equipment will vary from one seal manufacturer to another, so compounds that meet specifications must process readily in numerous shapes, sizes, etc., in the equipment available. Thus it can be seen that, although the majority of items can be produced from a particular rubber specification, recompounding may be necessary to produce a specific item or a new specification may have to be written.

Before selecting a particular material or specification the following information should be established:

(*a*) Fluid media—hydraulic or pneumatic.

(*b*) Fluid type—hydrocarbon, synthetic, grease, etc.

(*c*) Working temperatures and pressures.

(*d*) Operational mode and speed—linear, rotary, static. Vibration should also be considered.

(*e*) Surface texture—dynamic surfaces, housing faces, etc.

(*f*) Frictional and lubrication requirements.

(*g*) Permissible leakage, if any.

(*h*) Service life and storage conditions.

(*i*) Quantities required (test, pre-production, and production).

(*j*) Quality and cost requirements.

Seal manufacturers' catalogues will supply much of this information.

It is the responsibility of the seal manufacturer to ensure that:

(*a*) The tooling will produce items to the drawings and contractual requirements.

(*b*) The compound selected or to be recommended will be adequate to meet these requirements.

(*c*) The method of production will produce acceptable items within the cost and time-scale required.

The most popular rubbers are discussed below, with their main areas of use and recommendations for shelf life and storage.

Nitrile (*NBR*) *Rubbers* can be divided into three grades according to their acrylonitrile content.

High —mineral oils, petrol, kerosenes: temperature range from −30°C to 120°C.

Medium—mineral-based fluids: temperature range from −40°C to +80°C.

Low —mineral-based fluids: temperature range from −50°C to 120°C.

Low nitriles can be compounded to have a temperature range of −54°C to +135°C. A fairly new hydrogenated nitrile polymer is also being evaluated, offering temperature resistance up to +150°C and increased abrasion resistance. Nitriles have a shelf life of seven years followed by subsequent inspection after every three years.

Polychloroprene (*Neoprene CR*) *Rubbers* have excellent ozone and weathering resistance, so they are used for mouldings, boots, and gaiters. The temperature range is −40°C to +120°C and the storage life is identical to that of nitrile rubbers.

Ethylene Propylene (*EPR, EPDM*) *Rubbers* are used with hot water, steam, and phosphate ester type fluids. They have good gas permeation resistance, but must not be used in contact with mineral-based fluids. The temperature range is −50°C to +120°C but this material has been used in steam valves at higher temperatures. There is no specified restriction on storage life.

Fluorocarbon (*FPM*) *Rubbers* are used in high temperature applications (−20° to +175°C) in synthetic engine lubricating fluids, aviation fluids and hot air. Although much more expensive than nitriles they are being used in marine applications where a storage/shelf life of twenty years is required, there being no life restriction on this material. A low temperature grade is available at increased cost, where temperatures of about −35° can be withstood.

Silicone (*VMQ, PBMQ*) *Rubbers* are used in hot air applications or where compatibility with some solid propellants is required. The temperature range is −65°C to +200°C; again there are no storage life restrictions.

Fluorosilicone (*FMQ*) *Rubbers* are used in some fluid applications and are heat stable with a temperature range of −65°C to 200°C, and again there are no storage life restrictions.

With rubbers it is possible to blend and/or include fillers, or apply surface treatments to enhance specific properties. Coating of 'O' rings aids assembly so that damage is less pronounced and service life increased. A reduction in friction is seen initially, but the PTFE coating is quickly removed when the 'O' rings are used in a dynamic mode.

The use of *PTFE* (*Polytetrafluoroethylene*) is not restricted to surface coatings, but it can be used in seal designs which are energized by rubber or metallic springs to compensate for wear, creep, etc., and which make use of the low friction associated with PTFE on the dynamic surface. PTFE is a polymer formed by carbon and fluorine. Unfilled PTFE is used at temperatures between −100°C and +100°C but some filled PTFE types will operate at temperatures of +250°C, if only for short periods. Whereas the coefficient of friction of rubber varies between more than 1·0 unlubricated and 0·4 lubricated, PTFE varies from 0·16 dry to 0·02 lubricated. The additions of fillers and the method of processing will modify the polymer to give specific properties which are essential to the end use and seal design. Some of the most popular fillers are chopped glass fibres, carbon, carbon fibres, bronze, ceramics, etc. Thermoplastic materials such as nylon and polyacetals are usefully incorporated into sealing ring designs as anti-extrusion devices and bearing rings.

Seal Types

There are three main types of seal designs:

(*a*) Static seals: relatively little or no movement at the sealing face, e.g. pipe couplings.

(*b*) Dynamic seals: linear movements at the sealing surface, e.g. piston head seals.

(*c*) Rotary seals: movement is non-linear and revolves within a sealing lip, e.g. rotary shaft seals.

Static Seals

Static seals are the least likely to cause in-service problems if assembled correctly, but aids are always recommended to prevent damage and rolling. 'O' rings are used extensively and successfully in this mode, but above 200 bar rectangular seals may give longer life, being more stable and less prone to rolling. The hardness and abrasion resistance of the seal material will have a great influence on its extrusion resistance and therefore soft grades cannot be used with large extrusion gaps. It should be remembered that temperature and fluid absorption will soften the rubbers most widely used in hydraulic equipment. Above 100 bar fluid pressure, it is necessary to include anti-extrusion devices. These can be manufactured from rubberized fabric, polyamide, polyacetal and PTFE materials, being either spiral or single turn. A solid configuration is preferred but the material must recover after being stretched during assembly.

Dynamic Seals

There are many types of dynamic seals in defence applications. The equipment may remain inoperative for periods of ten years and yet has to operate instantaneously. Most rubbers over this period would adhere to the metallic surface, and the load to break this would be high, with leakage quickly apparent because of the broken and rough surface of the seal.

Some dynamic seals therefore incorporate PTFE at the dynamic surface. In most types of plastic-faced rubber-energized seals the PTFE sleeve forms the low friction dynamic element whilst the rectangular rubber component exerts a constant and uniform loading on the sleeve. This ensures adequate sealing forces at the dynamic surface. Included in these seal designs are stepped and unstepped variants (FIG. 5); the stepped versions are used for gland or piston rod applications, the rubber lip preventing low pressure weepage. In some aerospace flying control applications it is necessary to use unstepped seals on the pressure side and stepped seals on the atmosphere side as a secondary seal. Between these two seals a bleed return to the system reservoir is required. The PTFE sleeve also performs as an adequate anti-extrusion device which allows the housing dimensions to be minimal. Pressures of more than 550 bar have been sealed statically, but when used in a dynamic mode the pressure/velocity (PV) abilities of the PTFE must be considered at the operating temperature.

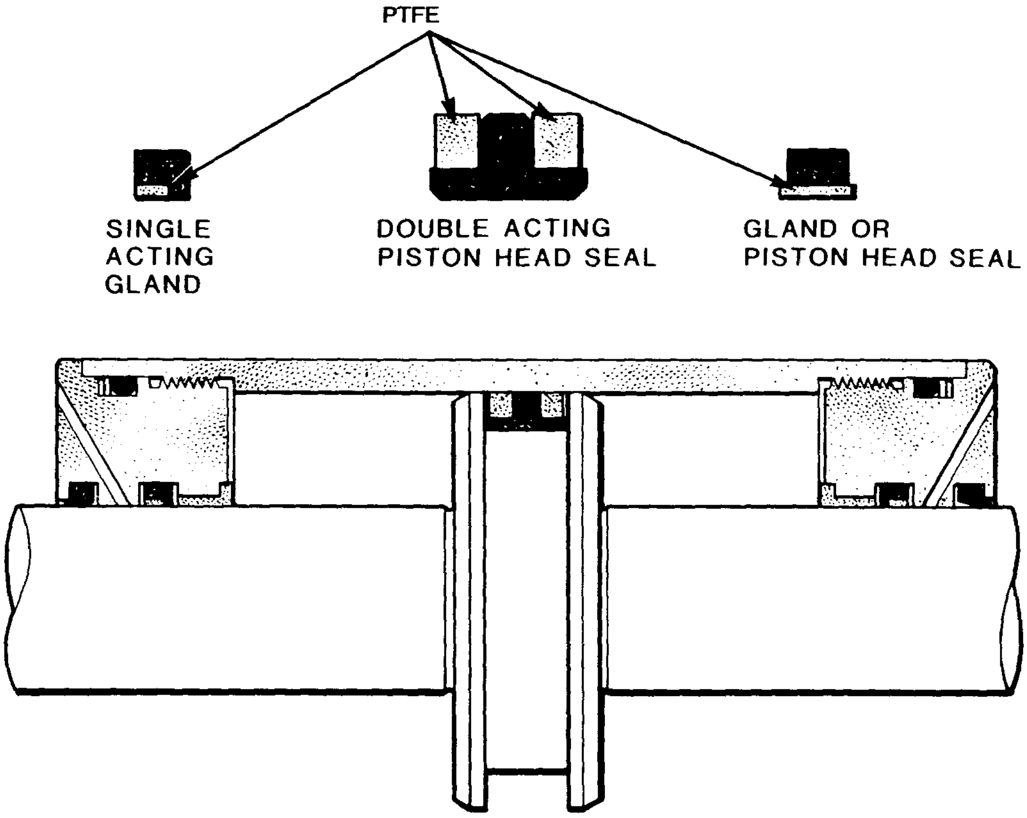

FIG. 5—HIGH PRESSURE PTFE/RUBBER SEALS

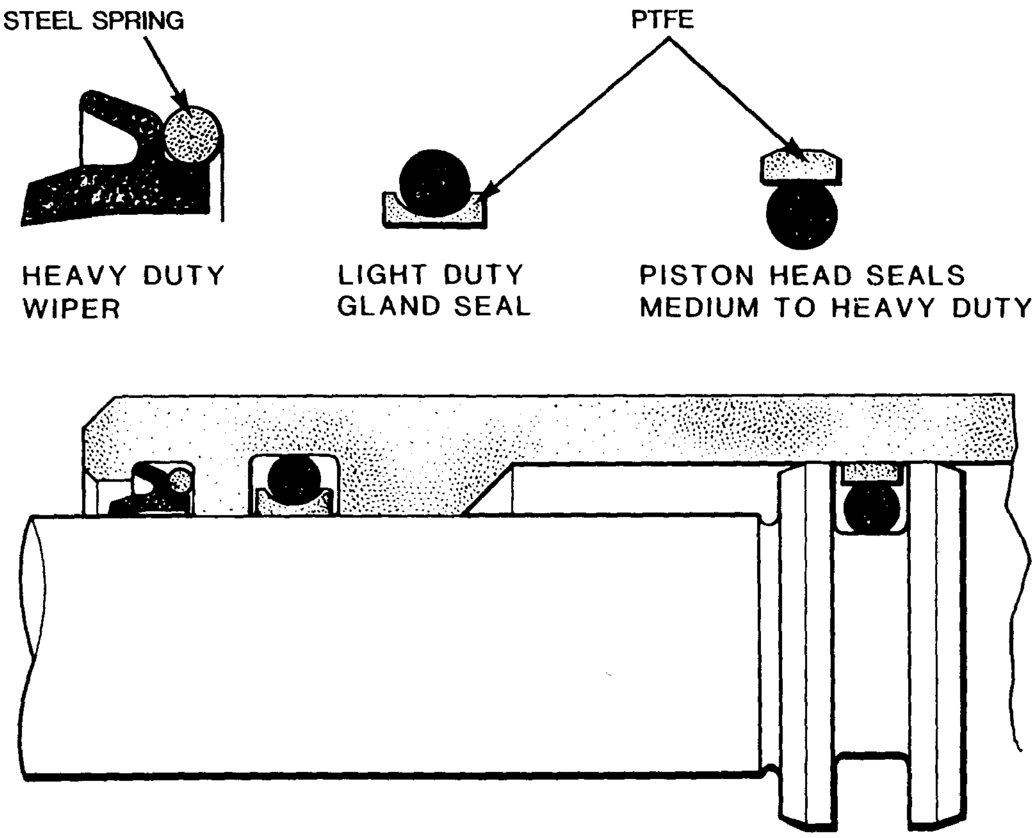

FIG. 6—LOW TO MEDIUM PRESSURE PTFE/RUBBER DYNAMIC SEALS

Other types illustrated include a less costly variant for light to medium duty (FIG. 6). This design relies on the loading from a standard 'O' ring through the reduced section of the PTFE sleeve and is specified where friction is not critical. Anti-blow-by grooves are recommended for some applications, these being in the form of slots on the sleeve edges to ensure that the pressure energizes the 'O' ring.

Rotary Seals

The formed rubber lip (garter spring) type seal (FIG. 7) is generally limited to pressure of 0·8 bar and running speeds of 20 m/sec.

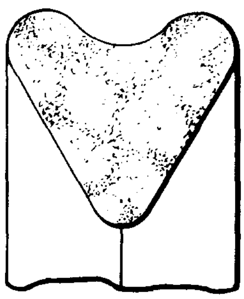

FIG. 7—LIGHT DUTY FORMED LIP RUBBER SEAL

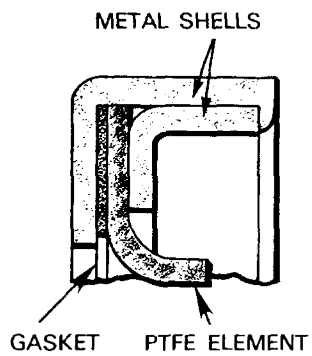

FIG. 8—HEAVIER DUTY UNIDIRECTIONAL PTFE SEAL

In recent years a major breakthrough has been made in the use of PTFE sealing elements. These are available in plain lip and unidirectional types (FIG. 8) but do not require the expensive moulds associated with conventional rubber designs because the PTFE sealing element is sandwiched between two metal shells. On assembly over the shaft, the sealing lip is deformed, but contact pressure is maintained because of the memory of the element which was initially a flat washer. At pressures of 1 bar, surface speeds of 40 m/second can be accommodated. A gasket is provided between the outer shell and the seal element to prevent internal leakage. On metal shell seals a chlorosulphated polythene sealant is used to seal imperfections in the housing diameter but on rubber-covered variants this is not required.

To seal high pressures in a rotary mode it is usual to use carbon face mechanical seals (FIG. 9).[2] These require additional space and are more expensive than the other types. Pressures of 100 bar and temperatures of

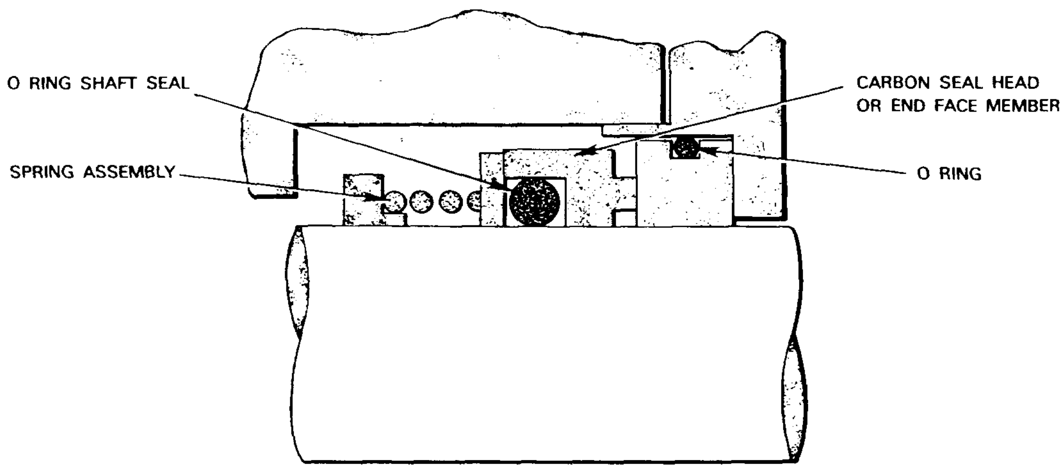

FIG. 9—A BASIC MECHANICAL FACE SEAL DESIGN

about 200°C can be accommodated. Surface finish and squareness of the carbon and metal faces are both critical, requiring the carbon face to be lapped to within three light bands.

The use of PTFE has in recent years been applied to 'U' rings, the sealing lips of which are energized by thin metal finger springs. They can be used in static, dynamic or rotary roles and temperatures of −50°C to +250°C can be accommodated with low friction.

It is apparent that PTFE seals are extremely useful because they are compatible with many fluids, including propellants and some acids, the only apparent restriction being the compatability of the energizing material, e.g. rubber. In some plastic-faced rubber-energized designs a minute weepage will be seen, usually quoted as being less than five drops per 25 cycles in a linear mode. The leakage will be directly related to the viscosity of the fluid.

References

1. Ochiltree, B. C.: Rubbers for seals and hoses for hydraulic systems; *Proc. (1st) Conference on Hydraulic Engineering in the Fleet, R.N.E.C. Manadon, Feb. 1982.*
2. Phillips, J.: Mechanical seal design for high and variable pressures; *Journal of Naval Engineering*, vol. 28, no. 2, June 1984, pp. 239–249.