THE DISCIPLINE OF BEST PRACTICES FOR GASKETS AND SEALS: **DESIGN & USE**

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GASKET AND SEAL DESIGN PARAMETERS FOR LOCOMOTIVE, MARINE, and POWER GENERATION DIESEL ENGINES

IT IS ALWAYS A MATERIALS CHOICE TO FIT THE APPLICATION

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EXECUTIVE SUMMARY: **DEFINING THE DIFFERENCE BETWEEN GASKETS AND SEALS**

Locomotive, Marine and Power Generation diesel engines in use today can go back to designs from the 1940's. Many of the gasket and seal designs applied to these engines came about because of the materials in use at that time and have in many cases significantly changed or can no longer be legally used, such as asbestos. Metal alloys now are stronger, casting processes have changed, fasteners are stronger, and computer aided design systems now assist in the designing of parts with processes not even thought of back then. In a few areas, materials commonly used today have only been recently invented, discovered, or made, resulting in significant changes in gasket and seal material and design. All these changes must be incorporated to extend the life cycles of all engines whether designed 80 years ago or yesterday. The ultimate design goal should be to extend engine service from overhaul to overhaul, without parts failures and with leak free service. For this paper, these materials and designs for gaskets and seals will be discussed specifically for these large medium speed diesel engines.

GASKETS

Gaskets are usually flat and stationary parts. The success or failure of a gasket is almost always due to material composition and proper loading or assembly torque. During operating service, maintenance procedures are always critical. Fastener application and location play an obvious part and where elastomers are used in the gasket composition, the durometer is also key. Gaskets are designed to fill a space between two flanges. Those flange surfaces will either be pristineor have some wear or even damage. A good material choice should consider "less than perfect" flange surfaces unless specified otherwise. All gaskets "store energy" to some degree upon compression (material resilience or tension), and almost all gaskets swell to some degree, except for PTFE (TeflonTM), graphite, and metals.

At some point, if allowed to remain in service long enough, ALL gaskets will usually fail with time and need to be replaced. It is always helpful to first study a failed gasket upon removal to assess the type of damage that has occurred, such as material failure due to over compression, and then secondly, to observe the flange surfaces that the gasket was clamped between. These two conditions on the flanges and the gasket will almost certainly highlight the leak paths to help determine the problem and the subsequent fix.

As an example, the lube oil pump gaskets applied to these engines tend to leak over time. One issue is during installation, the assembly gasket is applied to a vertical surface, and it is difficult to place and hold the gasket accurately. The bolting pattern is adequate, and the mating surfaces are usually flat and in good condition. But many of these gaskets observed being pulled due to leaking,have predominantly been “high swell” gaskets that contain natural rubber and EPDM binders, two common gasket materials that should not be used with applications involving oil. The chemical reaction produces extreme swell which in turn breaks down the binder preventing the gasket from storing energy. With the significant amount of thermal cycling experienced during service, the gasket becomes flat over time and will not swell further, losing torque compression, resulting in leakage. The drawing shown below, Figure 1, shows the outline of an oil pump assembly gasket removed due to leaking, the actual leak paths, and the inconsistent thickness readings around the gasket. The mounting flange surfaces were indeed flat and in good condition so torque values may not have been achieved accurately, indicating under compression on the left side and over compression on the right side. This gasket material failed on the right side after many thermal cycles. The gasket illustration, Figure 2, shows a redesign in red that provides for better loading over the entire gasket surface by decreasing the gasket area. It was also designed to “sit” on the ledge of the pump body for easier installation.

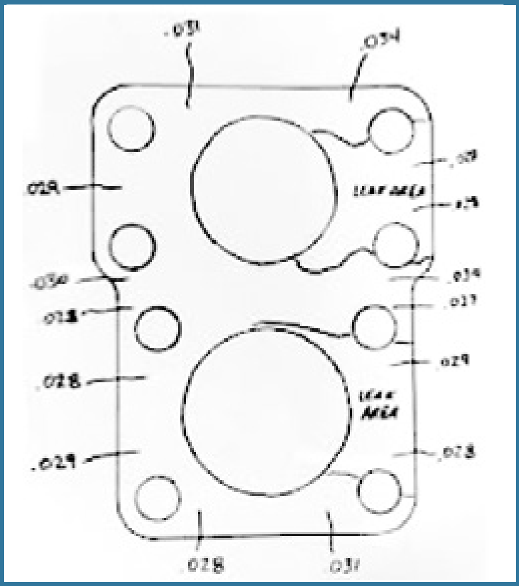


Figure 1

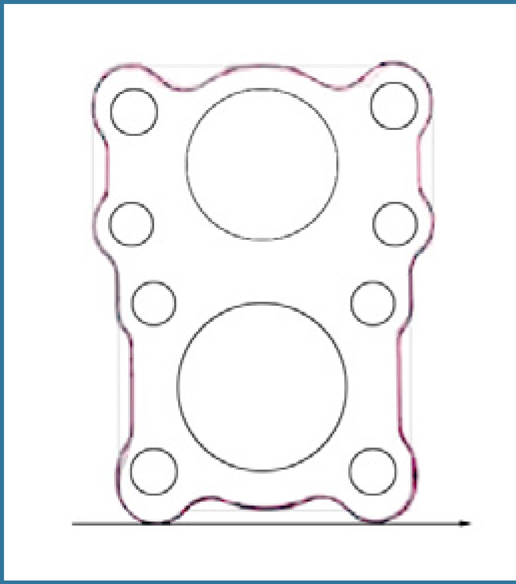


Figure 2

Another gasket design question is what the flange finish should be for the gasket application and how much deflection can a gasket absorb when the flanges are not parallel. Short answer is that for non-metallic gaskets such as compressed fiber gasket materials, the best finish is a smooth surface of 125 to 250 RMS finish. For a metal gasket such as copper gaskets, a smoother finish is better, 60 to 90 RMS. All gaskets require a little "tooth" between the flange surfaces and the gasket for a friction grip, especially for the non-metallic materials as the gasket can otherwise extrude. For deflection, a gasket can normally handle up to about 10% of the gasket thickness for flanges that are not parallel. Most metal gaskets will take some deflection although not that much, 2-4% at maximum.

Soft gaskets such as compressed fiber sheet, graphite, PTFE, and rubber that are more compressible are generally more forgiving to misalignment and to flanges that are out of parallel on closure. However, these materials, with the exception of graphite, to varying degrees, are more susceptible to creep relaxation and movement while under a load. The flange surface finish can play a critical role in the gasket's service life and long-term reliability. A very smooth surface finish will not create the necessary friction between these mating surfaces, making the nonmetallic gasket more susceptible to creep under load. This creep can translate to a loss in bolted joint tightness and potential leakage. A rougher surface finish is generally recommended for soft, non-metal reinforced materials to create the necessary friction for stability and compression between the mating surfaces. A typical surface finish recommendation for these materials is Ra 3,2 to 12,5 μm.

DEFINING THE GASKET APPLICATION

Gasket materials offered today can handle most conditions. The three biggest concerns would be temperature, pressure, and the pH of the medium being sealed. The fourth concern is the loading, (assembly torque) of the gasket material and the assembly bolt pattern. A normal bolt pattern for a standard flange gasket is where even loading occurs. An irregular design in the flange bolting pattern is susceptible to leaks. And the fifth and final concern is the fastener and assembly method.

TEMPERATURE:

This is usually one of the first concerns when choosing a gasket material as it must handle the extremes in actual operating temperature as well as those experiencing regional climates. For instance, moving a consist in southern Mexico during winter where it is hot and then running through the USA and up into Canada where it can be sub-zero, or vice-versa can create leaks, normally due to fastener stretch or relaxation. This severe temperature swing places serious constraints on the gasket if the material does not have enough resilience to operate in the extremes of weather. A chart is provided in Appendix A to help in those choices.

PRESSURE:

There are two pressures that gasket materials must deal with: a) the internal fluid or gas operating pressure and b) the assembly fastener pressure or clamp load/ bolt torque that needs to be applied to compress the gasket enough to negate the blow-out force of the internal operating pressure. The current engine operating pressures, fluid, or gases are not much of a problem today in these engines; however, the design consideration is for material that has good resilience to resist the degradation from stress relaxation and loss of clamp load, both due to fastener yield, temperature, and engine vibration.

FLUID / MEDIA PH:

The chemistry of the fluid or gas being sealed will always be critical to the success of the gasket. As mentioned earlier, almost all gasket material will swell to some degree so material composition of the gasket must be based on the fluid chemistry it will seal so that any adverse reaction is held to a minimum. As an example, sealing in an oil application will fail prematurely if EPDM was the chosen elastomer as it swells from the exposure to the oil.

FLANGE TYPE AND AVAILABLE CLAMP LOADING:

Design of the flange surface is a big consideration along with the actual surface finish. Standard ASA designed flange gaskets are easier to work with as the clamp load is totally symmetrical. All fasteners are equidistant around the bolt circle for even distribution of the gasket assembly clamp load. Flange thickness is also critical for proper gasket loading and we find that in some cases the thickness will change, making it difficult to properly load. Many OEM designs are difficult to properly load because the bolt holes are predetermined locations and not always evenly spaced. Flange widths can also change up from wide to narrow and back to wide. Fastener sizes can also vary in certain applications, usually due to flange design.

As a result, the gasket flange design and material choice become just as critical to a long leak free operation. Two examples; a) Figure 3 shows a gasket that is easy to load with bolts equally spaced and b) Figure 4 illustrates a gasket with irregular bolt holes and thinner flanges making it difficult to load the gasket evenly.

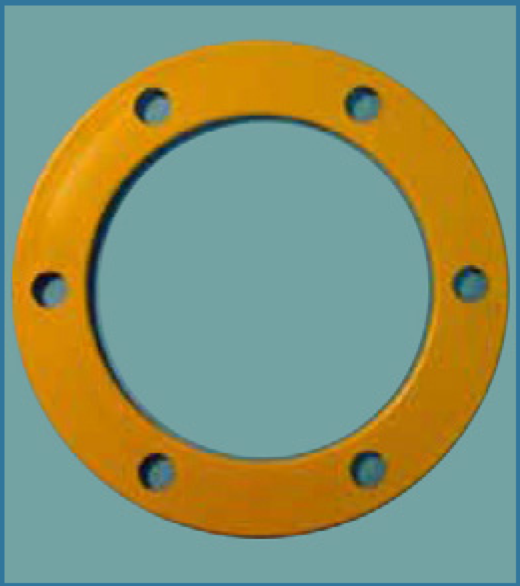


Figure 3

Figure 4

FASTENERS – INSTALLATION PROCEDURES:

A fifth concern for the sealing of gasket materials, is the critical selection of fasteners by metal type, hardness, and other characteristics. One of the biggest factors for premature leakage is either a lack of proper clamp load or over-torquing the fastener, regardless of any of the other factors. Gasket clamp loading requires proper procedures for the torquing of the fasteners, usually in three passes of an exact pattern for even distribution of the clamp load. Fasteners should also be lubricated as unlubricated threads never achieve a true torque reading by as much as half. While there are charts for torquing an unlubricated bolt you will not achieve uniform load. A graphite/oil lubricant is highly recommended, but the OEM recommendation takes precedence. Lastly, if an impact gun is used during assembly, only use it for the first pass and use a torque wrench properly set after that. If the bolt is over-torqued, it can quickly crush the gasket in the area around the fastener and cause a leak.

GASKET DESIGN PROCESS:

Existing locomotive and marine diesel engines were designed in the past with different standards than those followed today. There was, and still is, a propensity for the design engineers to just “follow the flange” for the gasket design. Bolt pattern also can be an issue where even spacing and different bolt sizes were used for many legitimate design reasons. If asked to fix a consistent “leaker”, the gasket designer should ask for a drawing of the flanges so that an FEA (finite element analysis) can be conducted to help in redesigning the gasket to best respond to the existing flange condition and bolting situation. This is a service that should be available with fluid sealing specialists.

Linear Finite Element Analysis

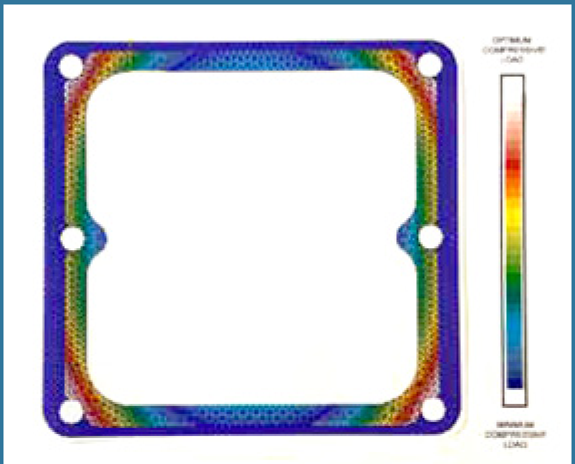


Figure 5

In Figure 5, the minimum compressive loading can be clearly seen along the top and bottom flange because of the lack of a bolt in the middle of the flange, as compared to the left and right flange design. In this case, by narrowing the gasket width and providing the addition of “stabilizing” embossments, a better load is created.

MATERIAL CHOICE EXAMPLE:

With all the above criteria, a design decision on the choice of material to use can be made. As an example, assume an application that involves diesel oil with a maximum operating temperature of 220°F, 60psi pressure, a square flange with bolts in the corners, standard Grade 5 fasteners torqued to 35 lbs/ft. This would be a simple application with many options. In this case the temperature and operating pressure is easily accommodated by most materials, either straight elastomers or a compressed fibered sheet. Some experienced mechanics may have a preference from experience, but the current service goal is Overhaul to Overhaul unless it has a maintenance requirement for periodic change. Because almost all gasket materials will swell to some degree, it should be controlled by staying away from any elastomer that shows a high swell in oil (in oil service). That eliminates EPDM, EPT, EPR (ethylene Propylene) and natural rubber. Best choice would be a Compressed Synthetic Fiber sheet with a nitrile binder. Identify a gasket sheet from suppliers using ASTM Line Callout: F712100A9B2E23K7M5 or F712100A9B4E22K5M6. Both are Nitrile bound fibers with great resistance to oils, temperatures well above the application, and pressures from vacuum to 1,200 psi (83 bar). Vendors who understand the business will use a sheet that meets this callout. An explanation on the break-down of the codes is provided in Appendix B to help understand and define the right choice for the seal application.

Fluid sealing specialists will also tell you that THINNER IS ALMOST ALWAYS BETTER THAN THICKER, except for flanges that are warped and those that are not flat, or those not able to be exactly parallel to each other upon closure. Although most engine internal pressures, other than around the cylinders, are usually under 100 psig, the operating pressure pushes against the thickness of the gasket material, referred to as the blow out force. The loading on the gasket creating the compressive force, also must be greater than the internal pressure. The lower the profile, the less the pressure impacts on the gasket. Thinner material is also preferred as thicker materials show a greater decrease in torque retention over time. And in applications with increasing temperatures, torque retention worsens. This can be seen below in the definitions of compressibility and recovery. The biggest reason for failed gasket applications is lack of load and second is poor choice in material.

STANDARDIZATION OF PHYSICAL CHARACTERISTICS

The following are industry standards that should help in picking and comparing materials to ASTM standards (American Society for Testing and Materials). These standards help to fairly compare gasket materials and can help in determining what should work for a particular situation. However, these are standard lab tests that help to establish and compare materials. They are not indicative of a successful leak free application. Please consider these as just a start to an application.

SEALABILITY

Sealability is measured according to the ASTM F37 specifications. It is an indication of the materials sealing ability under a set of conditions. A seating stress of 2000 psi is imposed through the flanges on the material sealing iso-octane at an internal pressure of 14.7 psi. The test is done at ambient temperature and the number shown is the amount of leakage in milliliters per hour. The lower the number the better the material.

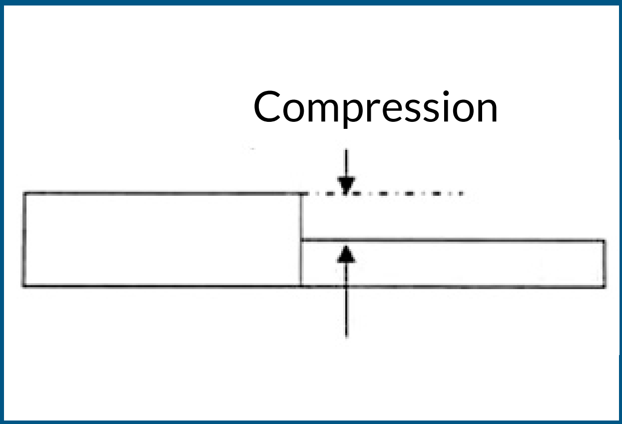


Figure 6

COMPRESSIBILITY

Compressibility is measured according to the ASTM F36A specifications. A load of 5,000 psi is imposed on the material and the loss of thickness is measured and expressed as a percentage of the original height. The compressibility of a material indicates, to a degree, its ability to fill flange scratches, nicks, or voids and to flow or move to assist in sealing misaligned or warped flanges. In general, the higher the number, the easier it is to seat the material.

RECOVERY

Recovery is also tested under the ASTM F36A specifications. Recovery is the measured rebound or increase in thickness from the compressed measurement once the load is removed. It is written as a percentage of increase over the compressed measurement and indicates the ability of the material to resist temperature and pressure. The higher the number, the better the material is at holding torque.

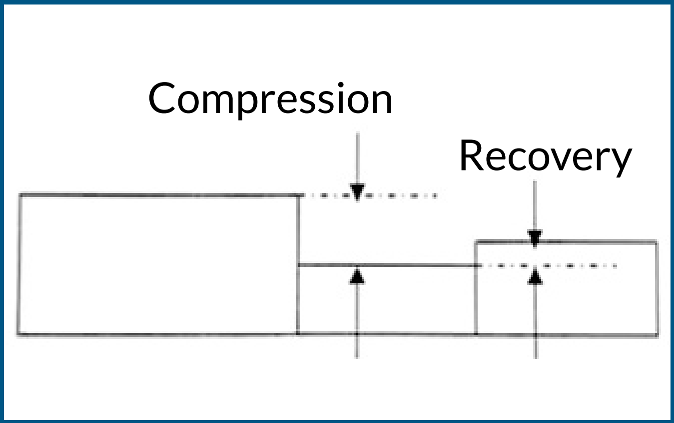


Figure 7

CREEP RELAXATION

Creep Relaxation, also referred to as Torque Retention, is measured according to the ASTM F38 specification and indicates the materials ability to hold stress or bolt load over a specific period. It is expressed as a percentage of the original load and shows the amount of lost stress from that load. A lower number indicates a more stable material retaining torque and resisting leakage.

TENSILE STRENGTH

Tensile Strength is measured under ASTM F152 and is given in pounds per square inch. It is the total force required to pull the material apart and is not related to the sealing function of the material. It relates more to the manufacturing process.

HOT COMPRESSION TEST

One of the other tests that is used as a standard, although many don't use it, is the HOT COMPRESSION TEST. This is used in the auto industry and is considered a "force to failure" test.

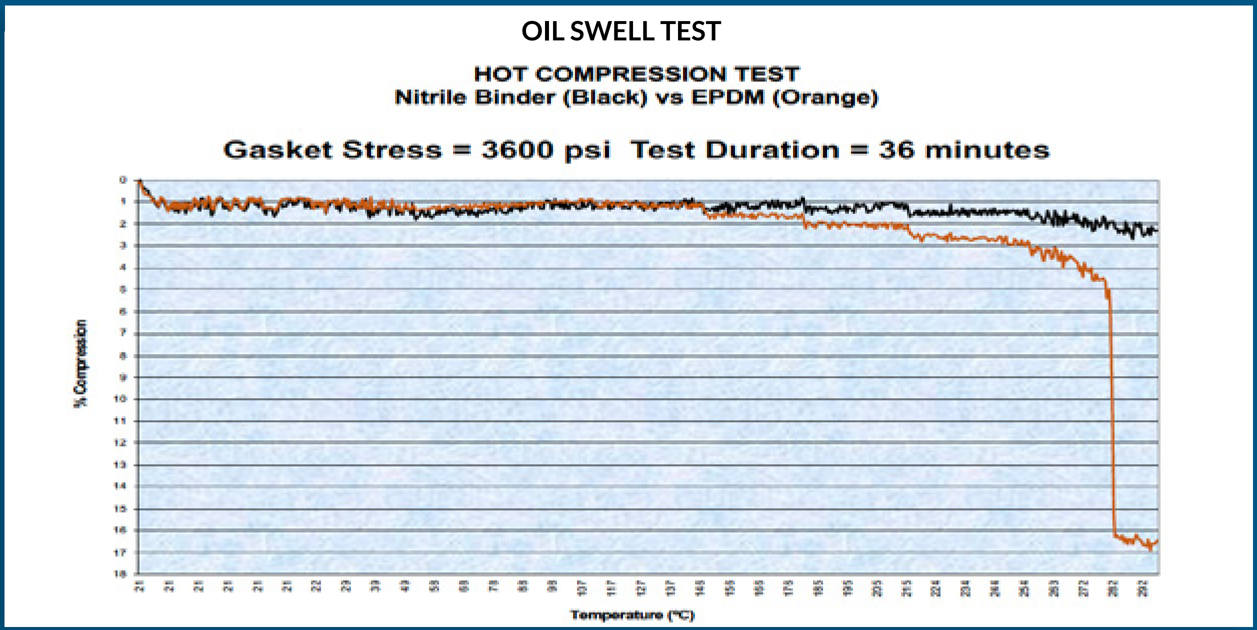


Figure 8

After the first 7 minutes at 21°C, the temperature increases every minute until it reaches 291°C. The test is to measure the loss of compression through the material as a percentage of the original height. This test shows a clear loss of bolt load, or loss of torque. This helps pick the best elastomer for the application, whether as a homogeneous material or a compressed sheet with fibers and fillers.

SEALS

Seals are somewhat different than gaskets because of their material composition and that their general shape conforms to either a cavity or rotational surface and are used in both static and dynamic applications such as reciprocating rods and rotating shafts. They cover a broader area of materials and shapes and are usually activated by pressure ranging anywhere from vacuums to very high pressures. The most common would be the O-ring that can operate as a stationary seal (like a gasket) under compression, or as a dynamic seal handling rotational or reciprocal sliding movement. Other types of designs can also handle rotational movement. There are all kinds of designs, shapes, and materials used for hydraulic and pneumatic applications in cylinders, and other types of equipment. Seals are generally designed for motion, pressure, and temperature and the selection of materials is almost limitless.

Most of the seals on these engines are O-ring in shape and design although there are some square O-ring applications and extrusions as well. The bottom oil pan seal is a lengthy round cross section extrusion which should be a simple application to seal if the material, diameter, and durometer are correct.

SEAL MATERIALS AND THEIR PROPERTIES:

The most common materials used today are Nitrile, EPDM, Silicone, and VitonTM. Elastomers must be chosen by service: fluid, air, or gas to be sealed, operating temperatures and consideration for outside temperatures when shut down. Engine thermocycling must also be considered.

NITRILE (BUNA-N):

is one of the most useful, general-purpose oil resistant synthetic polymers used on the engines. It can be used in oils, solvents, hydraulic fluid, and water. It is acceptable for temperatures ranging from -50°F. to +250°F. Although it should not be used in highly polar solvents like acetone and MEK, ozone, chlorinated and nitro hydrocarbons. It is not recommended for ethanol.

EPDM (ETHYLENE PROPYLENE):

is also a synthetic polymer that shows excellent resistance to aging through a combination of exceptional resistance to sunlight, ozone, water, and low (-70°F) and high (+325°F) temperatures. However, it does not have good resistance to fuels, oils, and solvents and is not recommended for aromatic hydrocarbons. It is approved for alcohols and ketones and recommended for ethanol.

SILICONE:

is a unique elastomer that shows very low compression set with excellent resilience. It is excellent in resistance to water, weather, and sunlight aging, heat ozone, and oxidation. It has a temperature range of -150°F to +500°F. It is not recommended for use in solvents and oil.

FKM (VITON™):

FKM's generally have a wide range of chemical resistance and high service temperatures to +400° to 500°F with time limits, but low temperatures only to -20°F. FKM's are used extensively in industry as O-rings, hydraulic seals, rod and shaft packings, diaphragms, gaskets, and pump parts. There are three families of FKM's, A, B, and F. The A family is the universal choice for most applications and most OEM's will almost always have it generically written in as VitonTM or FKM. However, any application where hot aqueous solutions are involved, only the F family should be considered as the A family type will crack over time and fail. B family is best for diesel oils and fuels, especially when at or above 250°F.

ENGINE SEALING RECOMMENDATIONS AND APPLICATION DESIGN EXAMPLES:

WATER JUMPER ELBOW

Figure 10

O-rings used on locomotive, marine and power generation diesel engines are designed mostly for static applications. As an example, the water jumper elbows on the EMD engines, Figure 10, provides a perfect illustration. The nozzle side has two O-rings that are static, do not physically move but compensate for the vibrational movement from contact with the cylinder head itself. They seal the coolant water cycling through the power packs and has been a problem. The OEM has specified these to be FKM from the “A” family. The problem is that they are not designed to handle hot water for any length of time. Only FKM from the “F” family can handle hot aqueous solutions and should have been specified for long life cycle. The flange side of the elbow is completely static and used as a gasket under compression. The OEM supplies those as Silicone. The flange mounted O-rings do not have to be lubricated as the force is only through compression. The OEM design size for all of these is slightly different. The nozzle side O-rings, regardless of material, must be lubricated prior to power pack assembly being dropped into the block. If applied dry they will roll, twist, and will split causing failure. Any application where motion will be created on or by the O-ring, especially a rolling motion, must be lubricated. After analyzing the material and dimensions it is possible to get all three in the same size and material.

Part of the design criteria was to change the size so that both locations could be handled with one O-ring. The other was to change the sizes, durometer, and the material to help eliminate the fretting damage being done to the block where the nozzle O-rings encounter the block drilling.

VALVE COVER SEALS

A particularly difficult sealing application or "headache" for the EMD engines is the top deck valve covers that sit atop the engine. Mechanics have gone through several iterations of seal designs over the years to get the proper material and seal design. One current valve cover elastomeric seal that has successfully solved this application is by using the correct seal material and shape, and has been known to actually pull a slight vacuum indicating a tight seal and no leaks.

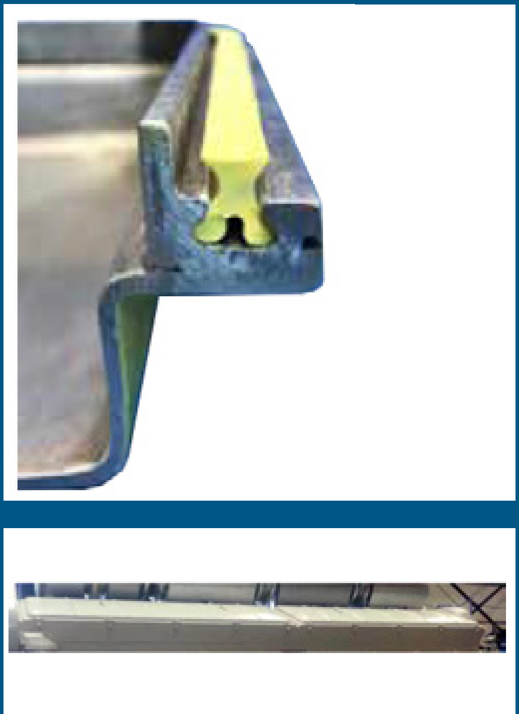


Figure 11

Figure 12 (A & B)

FINALLY, AN EXAMPLE OF A FUEL LINE INJECTOR SEAL

The fuel lines are often handled roughly during re-use and the bulbs at the end at times need to be smoothed out with crocus cloth. Now with this non-OEM seal, that step can be eliminated.

GASKET AND SEAL DESIGN FACTOR SUMMARY

GASKET DESIGN FACTORS

The fuel lines are often handled roughly during re-use and the bulbs at the end at times need to be smoothed out with crocus cloth. Now with this non-OEM seal, that step can be eliminated.

- **TEMPERATURE:** Pick a material that allows both lower and greater temperature range required. If your application will run hot oil at +240° pick a material that will take more than that so that you don't risk an engine malfunction that will push the temperature past the design designation.
- **PRESSURE:** Important to make sure that your loading through the gasket exceeds the operating pressure (blow out force) over time.
- **pH:** Know your material so that you don't choose one that will not hold up to the medium that you are sealing.
- **FLANGE SURFACE FINISH:** Friction between the gasket surfaces and the flange surfaces are far more critical than believed. DON'T USE OILS, GREASES, ANTI-SEIZE PASTE, OR RTV SILICONE SEALANT ON GASKETS. You can use 3M Spray #77 or Permatex #2 gasket adhesives.
- **FASTENERS:** Should be lubricated for proper torque readings, however, torque can be specified as wet or dry. You should always use a torque wrench on the last pass to be accurate.
- **TORQUE:** Proper loading requires a "star pattern" on round gaskets and "opposing crisscross patterns on rectangles and odd patterns. Uniform clamping force is required to prevent leaks.

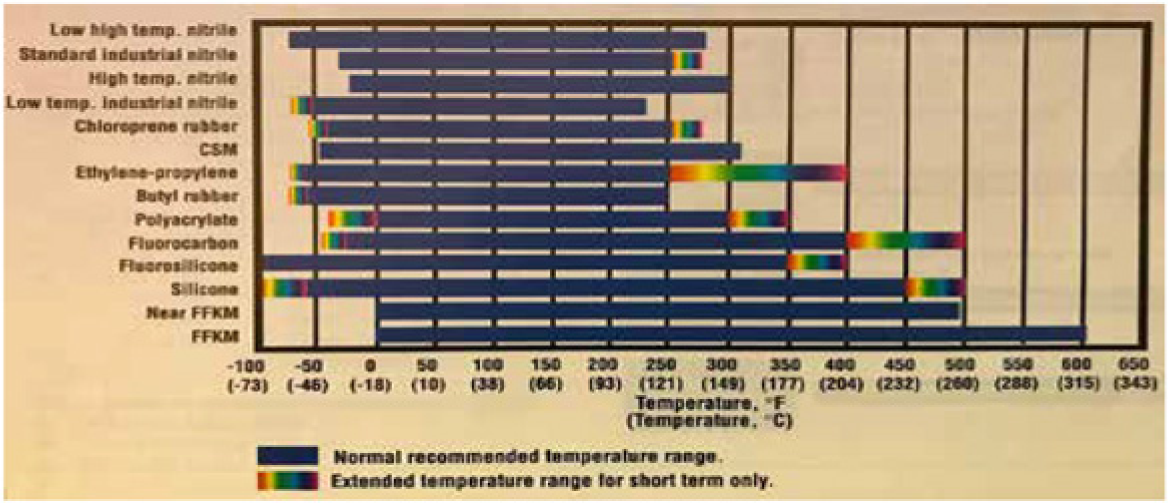
SEAL DESIGN FACTORS

- **STATIC O-RINGS:** If the ring is just to be laid flat and compressed, no lubricant is needed. If it will be mounted into grooves, either in a cylinder wall or rod to be pushed into place, then you must lubricate those O-rings.

- **DYNAMIC O-RINGS:** MUST be lubricated so that they do not roll, twist, and split. Lubricants should be either silicone or ester-based lubricants as they offer the best reduction of friction while not compromising the elastomeric polymer used in the O-ring. DuPont Molykote is one example but there are many offerings in industry.patterns on rectangles and odd patterns. Uniform clamping force is required to prevent leaks.

To reiterate the purpose of this narrative, all these changes to both gaskets and seals must be incorporated today to extend the life cycles of all engines whether designed 80 years ago or just yesterday. The ultimate design goal should be to extend engine service from newly manufactured to the first overhaul and then subsequently overhaul to overhaul, without parts failures and with leak free service.

APPENDIX A: TEMPERATURE EFFECT ON GASKETS



APPENDIX B: ASTM F104-11 Standard Classification System for Nonmetallic Gasket Materialsgoing to make up a number for these purposes.

F712100A9B2E23K7M5
First number 7 calls out the TYPE of Material. 7 is for NON-ASBESTOS material.
Second number 1 calls out the method of process of manufacture. 1 is for COMRESSED SHEET
Third number 2 calls out the compressibility under Test Method F36. 2 = 5 to 15%
Forth number 1 calls out thickness increase when immersed in IRM 903 Oil. 1 = 0 to 15%
Fifth number 0 calls out the weight increase when immersed in IRM 903 Oil. 0 = Not Specified
Sixth number 0 calls out the weight increase when immersed in water. 0 = NotSpecified
A9 calls out the sealability characteristics by Test F37 and those details will go on Engrg. Dwg.
B2 calls out Creep Relaxation by Test F38. B2 represents 15%
E23 calls out weight and thickness increase from immersion in ASTM Fuel B. The first number represents the weight increase, and the second number represents the thickness increase.
K7 calls out Thermal Conductivity characteristics as determined by Practice F433. Those results will usually be placed on an engineering drawing. This is not used as a certifiable requirement unless agreed to between the manufacturer of the sheet and the buyer/end user.
M5 calls out the Tensile strength of the material determined by Test F152. In this case M5 represents 1,500 psi.

When looking for a material, it is best to go through the actual F104-11 Line Callout to understand what you are going to run on your engine. It is helpful to be able to compare the sheet characteristics of various suppliers and understand how the material might react to your application with all of the above information. Every supplier can supply the line callout at request and that should be required to assist engineering and purchasing.

About Master Packing and Rubber Company

Master Packing & Rubber Company was founded in 1982. To get our foot in the door, we would ask potential customers for their most problematic seal applications. These hostile environments are what we cut our teeth on. Developing advanced materials and utilizing computer simulated design analysis, innovating has allowed us to create real solutions for our customers. Today, our success is based on this foundation. We are constantly looking for new materials and methods, leveraging our experience and know how, to deliver the best seal solutions available.

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