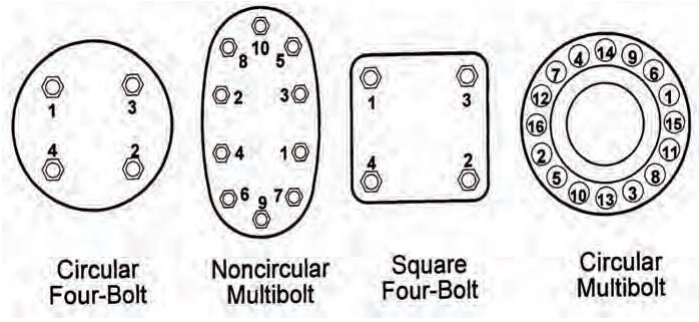
Marine Exhaust Systems: Special Sealing Challenges

Sealing exhaust systems is particularly important to the marine industry because of the temperatures, air volumes and noise levels associated with leaks. OEMs typically recommend graphite-filled, spiral-wound gaskets for use in the flanged piping connections of these high-temperature, low-pressure systems. However these gaskets are prone to failure due to loss of mass through oxidation of the graphite, high vibration levels and thermal expansion and contraction. Accordingly, gasket selection is an important part of ship maintenance and repair.

Gaskets are designed to accommodate vibration, thermal expansion and contraction, and a range of loading conditions. Most failures occur when gasket stress, or pre-load induced by tightening the flange bolts, falls below the range for which the gasket is designed. Following are the major factors that contribute to loss of gasket stress in marine exhaust systems.

Thermal cycling occurs throughout a ship's journey with weather, speed and fouling all impacting engine load. For example, bottom growth and fouling can cause a medium-speed diesel to reach temperatures of over 1,832°F (1,000°C). The expansion and contraction of flanges caused by such temperature spikes can loosen flanged joints and reduce gasket stress.

Bolting patterns and sequence for various flanges



Vibration also adversely affects gaskets, particularly in high-temperature systems. Graphite-based gaskets for high-temperature applications possess little organic content, which can burn off and create leak paths. However the absence of such elastic materials inhibits gasket recovery after compression. By contrast gaskets for lower temperature applications can be made of rubber, which due to its elasticity has excellent recovery properties. Unfortunately graphite lacks the recovery capabilities of an elastomeric gasket, making it more susceptible to loss of bolt load and gasket stress in high vibration systems.

Loss of gasket mass due to oxidation is another major concern. While graphite is ideal for use in non-oxidizing environments, marine exhaust is highly oxidizing. Graphite begins to oxidize at 850°F (450°C), which marine exhaust systems consistently exceed. The carbon in graphite gaskets combines with oxygen from the air to create CO and CO2., causing them to literally lose mass to the atmosphere. The rate of oxidation depends upon the temperature and amount of oxygen to which a gasket is exposed.

Upon installation a gasket is placed between two flanges and torqued to the recommended bolt load for sealing. As a gasket loses mass through oxidation, voids develop in the space between the flanges, decreasing bolt load and gasket stress.

The gasket is now held loosely in place and exposed to potentially high-velocity exhaust, a situation analogous to putting ashes on the dashboard of a moving car and opening the windows. As oxidation progresses, sealing performance degenerates until the gasket fails and exhaust escapes from the system.

TESTING

The purity and chemical doping of the graphite in a gasket will largely determine its performance at elevated temperatures. To measure its effect on rates of oxidation and loss of mass, two exfoliated graphite gaskets were placed in an oven at 1,000ºF (540ºC) for 17 days. The two gaskets were periodically removed, weighed on a Mettler scale and immediately returned to the oven. Even with its higher level of graphite purity and additives, the tang-core gasket still exhibited a sizeable loss of mass over an extremely short period of exposure.

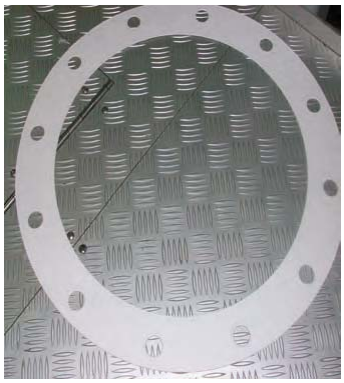
GASKET SELECTION

A simple acronym, STAMP (size, temperature, application, media, pressure) can serve as a useful guide in selecting the right sealing solution for virtually any application. For large vessel exhaust systems, the two primary concerns are temperature and the parameters of the application itself. Of less concern are the media, just exhaust air, and pressure, which tends to be low in marine exhaust systems.

Temperature essentially dictates the type of gasket to be used. For temperatures below 850°F (450 oC) the material of choice is graphite, which offers good sealability and conforms to flange imperfections to prevent leak paths. The two most common types of graphite gaskets for marine exhaust systems are spiral-wound and tang-core-reinforced sheet, both of which are suitable for use below 850°F. Above this temperature, graphite gaskets should be avoided in favor of non-oxidizing, ceramic-based gaskets with low organic content.

With regard to application parameters, knowing the flange type, material and bolting information allows available gasket stress to be calculated, indicating the

The installation of reinforced ceramic sheet gasketing in the exhaust system of the 225-ft. (68.6m) yacht Attessa after spiral-wound graphite gaskets oxidized and caused leaks.



type of gasket to be used. Spiral-wound, reinforced sheet and corrugated metal gaskets are all available with various sealing elements and differ functionally in terms of required gasket stress to effect a seal and the maximum pressure the gasket is able to seal.

Made by winding alternating strips of metal and softer, more compressible filler materials, spiral-wound gaskets were developed to provide improved performance in high-pressure applications. The metal windings are made of various grades of carbon steel, stainless steel, nickel and titanium. The filler elements are usually graphite, ceramic or PTFE materials, and are based on the temperature and chemical resistance requirements of the application.

Graphite/stainless steel spiral-wound gaskets are suitable for marine exhaust systems, provided the available bolting and flange configuration can produce sufficient gasket stress. Minimum recommended stress for these gaskets is 10,000 psi, the highest of the three types under consideration.

Also suitable for marine exhaust systems are reinforced graphite and ceramic sheet gaskets. The reinforcement elements in these gaskets usually consist of various configurations of stainless steel foils, as well as tang and wire mesh inserts. Both sheet and corrugated metal gaskets require less bolt load than spiral-wound gaskets since there are no metal windings to be compressed. Minimum recommended stress for reinforced sheet gaskets is 5,000 psi.

Corrugated metal gaskets combine a metal core with a compressible sealing element. A variety of metals is available for the core, and either graphite, PTFE or ceramic-based materials may be used for the sealing elements. Corrugated metal gaskets conform to flange irregularities even under low bolt loads, and can be used when the space between the flanges will not accommodate a spiral-wound gasket. Minimum recommended stress for this type of gasket is 3,600 psi.

Gasket Type	Minimum Stress Recommendation
Spiral-wound	10,000 psi
Reinforced sheet	5,000 psi
Corrugated metal	3,600 psi

INSTALLATION

It is important to note that previously compressed gaskets, as evidenced by an imprint of the flange, should not be reused. Having been compressed, they will not recovery sufficiently, resulting in premature loss of bolt load. In addition the flange bolts should be well lubricated and flat washers hardened. Liquid or metal-based anti-stick and lubricating compounds should never be used on the gasket.

During installation the gasket should be compressed uniformly by first hand tightening the bolts, then going side to side on the flange, applying load to the bolts with a torque wrench (Figure 3). It is recommended that the bolts be tightened in one-third increments with the final pass at the target torque value made consecutively from bolt to bolt. A final check and re-torquing can be made 12 to 24 hours after installation.

CONCLUSION

Under certain circumstances, OEM-supplied graphite gaskets may be suitable in exhaust systems for new engines with limited vibration. However normal wear and tear over time can result in failure and leaking joints, the fumes and noise from which can adversely impact the safety and comfort of crew members and others. These leaks can be avoided by taking into account the state of the equipment and the operating conditions of the system when selecting the sealing solution. Limited temperature resistance and resiliency will effectively eliminate graphite from being used in systems that exceed its capabilities Graphite oxidizes at different rates, depending on its purity and the use of doping agents to inhibit oxidation. Testing demonstrated the susceptibility of graphite to oxidation at a relatively low temperature. These test results combined with actual failures of graphite gaskets in service indicate the need to consider alternative sealing materials such as ceramics to withstand the extreme temperatures in marine exhaust systems.

ABOUT THE AUTHOR

Wayne Evans is Product Development Engineer & Sherwin Damdar, Senior Product Engineer, Garlock Sealing Technologies