Colfax White Paper

Imo® Bimetal Rotor Housing: A Solution

The impetus for the development of the Babbitt lined steel rotor housing has its roots with the U.S. Navy, back in the late 1960s/early 1970s. It was at this time that the Navy undertook a major fuel conversion, from Navy Special Fuel Oil (NSFO) – an approximate blend of 60 percent Bunker C/40 percent distillate fuel – to a 100 percent distillate fuel.

Why the change? Although the NSFO fuel offered the advantages of worldwide availability and relatively low cost, it left harmful residues upon burning. This necessitated frequent cleaning of boilers to remove fireside deposits, in order to maintain boiler efficiency, prevent tube deterioration and prolong tube life; thus, the decision was made to develop a specification for a distillate fuel, with the goal of deploying one such fuel for all non-nuclear propulsion plants.

In 1969, the Navy initiated action to proceed with the fleet-wide conversion of non-nuclear steam-propelled ships to burn distillate. In order to operate routinely on distillate fuel, certain hardware changes were necessary. Sprayer plates, various controls and fuel-measuring devices had to be changed or recalibrated. In addition, ships had to be reballasted, to offset the effect of the lighter ND fuel. Most significant, however, were the changes required in the pumps, the heart of the fuel oil system.

In most instances the existing pumps had to be replaced or modified, in order to handle the low-viscosity distillate fuel. There were several key pump services involved that the Navy had to contend with. These included two services of interest to Imo:

1) Fuel oil service pumps (both main and port), which deliver oil to the burners at the pressures necessary for atomization. Pressures vary from 400 pounds per square inch (psi) to 1,150 psi, depending on the burner system employed.

2) Fuel oil transfer pumps, which transfer the fuel from storage tanks to the service (day) tanks, from which the fuel oil service pumps take suction. On some ships, such as carriers and oilers, these pumps are also used to transfer override to ships alongside. Pumping pressures vary from 50 to 150 psi.

The Navy selected Imo® screw-type pumps for the above services. Imo pumps were selected for these applications, due to:

- Their ability to develop all of the boiler front pressures required by the various ships in the fleet
- Their proven capability for handling distillate fuel for these services, having been operated (starting in the early 1960s) on destroyer escorts using JP-5 and diesel oil on a continuous basis, without any problems whatsoever
- The fact that aircraft carriers outfitted with Imo pumps had periodically burned JP-5 since 1963
- Other types of pumps' failure to perform satisfactorily, even when tried on distillate applications in low-pressure fuel oil burner systems
- Proven reliability in handling residual fuels
- The ability to incorporate modification kits, rather than undergoing replacement, on a high percentage of pumps
- Optimum pump standardization (reducing 250 models to 18)

The key requirement on the fuel oil service pump, from a design standpoint, was the need to handle a very low-viscosity fluid at relatively high pressures. Since the Imo pump operates on the same basic principle as a journal bearing, the choice of materials for the rotors and their mating housings was most important. Imo selected pearlitic gray iron with molybdenum disulfide coating for the rotor-housing material and pearlitic induction-hardened ductile iron for the idler rotors – both excellent bearing materials. The power rotor – which is in complete hydraulic balance and, therefore, imposes no load on the rotor housing – was made from a nitrided alloy steel. Imo had extensively used these materials on Navy, commercial marine, and industrial distillate and residual fuel oil applications.

Other combinations of bearing materials had been tried, but proved to be marginal, as compared to the Babbitt lined steel housings.

Because of the magnitude and importance of the Navy program, Imo conducted extensive testing on a number of different pump models, to prove out the suitability of these new pumps for the intended services. In addition to endurance tests of 1,000 hours' duration, these pump models were subjected to over-pressure tests, tests at varying speeds and at varying fluid temperatures. Test medium was JP-5 – the most difficult of the distillate fuels to handle, due to its low viscosity and minimal lubricity. Each and every pump delivered to the Navy was subjected to full performance testing on JP-5, as a quality assurance check before shipment was made.

Then the trouble started...

The initial ship conversion, from residual to distillate fuel, was carried out in early 1968. Subsequently additional ships were brought into the Navy's distillate-evaluation test program. Full-scale conversion of the fleet got under way in late 1969.

In August 1970, one of the ships failed all four main fuel oil pumps upon starting up its power plant, after conversion to distillate fuel. As more ships were converted throughout the latter part of 1970, occasional FOS pump failures occurred. The principal cause of these failures was identified as contamination by hard particulate matter. Then, in January 1971, an aircraft carrier experienced numerous pump failures upon startup, after conversion to distillate. At that time it became evident that a major operating problem existed.

Extensive observation and investigation of the carrier failures and subsequent failures on other ships, coupled with laboratory tests, pinpointed the pump-failure problem as being primarily due to the ingestion of built-up rust and sediment (including weld spatter) that had adhered to the walls of the storage tanks or settled in the tank bottoms during the time the ships burned residual fuel. Distillate, acting as a solvent, had loosened this material, thereby grossly contaminating the fuel.

Steps taken by the Navy to improve the situation included:

- Institution of more stringent requirements for cleaning ship board tanks and piping systems
- Introduction of additional filtration
- Enforcement of controls regulating quality of fuel taken on board
- The formation of distillate assistance teams (DATs) to visit the ships and shipyards during a ship's conversion, to assist the personnel involved in conversion work and subsequent operation of fuel systems

These actions significantly improved the situation, but did not eliminate the problems altogether. Imo – recognizing the impracticality and prohibitive cost to the Navy of thoroughly cleaning up the ships, as well as the fuel-supply system – embarked on a crash research-and-development program in February 1971, to provide a pump that would be reasonably insensitive to contamination. A new pump design was produced, tested and offered to the Navy for shipboard evaluation in August 1971.

Analysis of the failed pumps that had been returned for inspection, coupled with visits to the fleet, revealed that contamination damage of the idler bores was the common cause of all of the pump problems being encountered. Unfortunately the pearlitic-type bearing-grade iron selected for the idler rotor/housing combination, which had proven to be an excellent material for handling relatively clean and even mildly contaminated low-viscosity fluids, was found to gall, when handling heavily contaminated fuel.

The primary design objective in the development of a contamination-tolerant Imo pump was the determination of a material combination capable of a very high degree of tolerance to the foreign matter that had to be handled by the pumping elements. There are two well-recognized methods of handling contamination in hydraulic components:

1) Use of very hard materials for both contacting surfaces

2) Making one surface soft, compared to the other

The use of very hard materials for the rotors and their surrounding housing had been tried previously, with poor results. Being brittle, they were not well suited for pump elements subject to shock or complex stresses. Also, if both bearing surfaces were as hard as the contaminant particle, there was a definite tendency to lock, due to the wedging action. If the particle would not crush, the pumping elements would jam.

Imo had experienced good results in the past, utilizing a hard-on-soft (steel on bronze) material combination, on hydraulic, lube oil and heavy fuel applications. This bronze (composition 80-10-10) was not suitable for low-viscosity applications, due to its tendency to seize under boundary lubricating conditions, because of the formation of local hot spots. Babbitt, however, satisfied the requirements of contamination tolerance and nonseizing, but was in itself too weak structurally for use as rotor housing. A major breakthrough in the state-of-the-art of Imo pump design was achieved, with the introduction of the bimetal Babbitt lined housing; this successfully combined the strength of steel with the bearing properties of soft, nonferrous metals.

In Imo pumps the soft liner material performs two basic functions:

1) It accepts high bearing loads without film failure. These high loads are created by random damage caused by solid contaminant particles' being wedged between the idler and power rotors, causing the idlers to be pressed hard against their bores.

2) When a contaminant particle enters the clearance space between the idler and its bore, it usually will cause a radial scratch, but leave the space during one or two revolutions. The resulting groove heals over in the next few revolutions without galling. This process is quite impossible with harder materials, on which the scratches do not heal, but, on the contrary, produce progressively larger surface deterioration, causing ultimate catastrophic failure.

Contrary to what one might expect, the test-stand evaluation testing and subsequent field experience demonstrated that there was no significant embedment in the soft bearing material of contamination particles entering the clearance space. In fact, only a very small percentage became embedded at all; the great majority of particles simply passed through.

In order to prove the suitability of this new pump design for the difficult pump conditions that existed, various pump models were subjected to rigorous testing. In addition to 1,000-hour endurance tests conducted on several different pump models, over-pressure tests were run at 2,000 psi – assuring at least a 100 percent design margin. Tests were also run at various speeds, to prove the capability of the pump for operation at minimum and maximum specified speeds.

Most significant, though, was the contamination testing that was conducted. Pumps were operated in test loops and subjected to various contaminant charges. Pumps handled the equivalent of two tons of contaminant during the course of one 80-hour test. The test medium was JP-5 heavily contaminated with iron and steel grit, particle size to 0.015 inch, having a hardness of Rc 50-65. Despite this rigorous contamination testing, no bimetal pumps failed. They continued to pump at full rated discharge pressure, albeit at some loss in volumetric efficiency.

Four Imo bimetal pumps were delivered to the U.S. Navy in late 1971, for installation and field evaluation on board an aircraft carrier. These units were installed and operated alongside eight pumps of the original iron-on-iron kits. During the course of steaming to the Vietnam War zone, seven failures occurred on the iron pumps, due to contamination. The bimetal pumps kept pumping without any problems. It was later reported that the bimetal pumps were still operating, without any difficulty whatsoever, despite the fact that the boilers had lost fire four times, due to water in the fuel. Additional bimetal-pump kits have been furnished to the Navy for replacement, as needed, of the original iron-on-iron kits. In addition to the units on the carrier, a number of pumps with bimetal kits installed have operated for well over 5,000 hours without problems. This program was closely monitored, yet there had not been one report of a bimetal pump's having failed in service, as the result of handling contaminated fuel – yet they were operated side by side with pumps possessing iron internal components that continued to fail.

Comparative tests between the Imo bimetal contamination-tolerant pump designs and other pumps were undertaken by the Navy in late 1975 and early 1976. The following test programs, which presented conditions far more severe than existed in fleet, were conducted:

- Contamination test – 1,000 hours operation (planned) on distillate fuel contaminated with pyretic silicate (iron oxide), silica sand and steel grit, at increasing contamination levels, up to 800 milligrams (mg) per 100 milliliters (ml) – equivalent to a pumping rate of 250 pounds (lb.) of contamination every hour. The test was halted at 622mg per 100ml contamination concentration level, due to accelerated wear experience by both pumps.

- Freshwater test – 50 hours operation at 400 pounds per square inch gauge (psig), handling one percent JP-5 and 99 percent fresh water
- Seawater test – 10 hours operation at 400 psig, handling 50 percent JP-5 and 50 percent seawater
- Emulsion test – 10 hours operation at 400 psig, handling 50 percent seawater, four percent NSFO and

46 percent Navy distillate fuel contaminated with iron oxide.

During this comparative testing, a number of problems (necessitating pump refurbishment) were encountered with the other pump, which was supposedly specifically developed to handle these requirements. No pump failures were experienced with the Imo bimetal pump, even though it had not been specifically designed to meet the requirements of the testing outlined above.

The development of the bimetal contamination-tolerant Imo pump has benefited the Navy in many ways. Most important, of course, has been the elimination of pump failures wherever bimetal units have been utilized; thus, essential fuel system reliability has been achieved. Ship availability and readiness can be counted on, regardless of fuel to be burned – be it JP-5, diesel fuel, marine (DFM), Navy distillate or NSFO.

Also important is the fact that the bimetal design proved to be an ideal solution to a technological problem. Every pump already in Navy service could be retrofitted with a bimetal conversion kit; no piping or driver changes were required. This solution saved the Navy millions of dollars. Additional millions were saved, since it was no longer necessary to continue with the stringent fuel-management controls instituted prior to the availability of the bimetal-pump design.

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