

FROSTBYTE

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High Pressure LNG Fuel Systems in Marine Service

LNG as a marine fuel has shown great potential as a clean, safe, reliable, and cost effective alternative to diesel fuel in an ever changing global environment. Perhaps the most significant of these changes has been the International Maritime Organization implementation of MARPOL Annex VI. MARPOL Annex VI was initially implemented in 2005 to lower global SO_x and NO_x emissions, and then revised later that year, with the revision being implemented in 2010. This revision called for further increases in global emission regulations, as well as for the development of emission control areas (ECA) in which emissions would be further regulated. To comply with these regulations, a large focus was placed on the quality and compositions of fuels used in maritime service, resulting in a plan that would reduce the current diesel fuel sulfur limits from 3.50% to just 0.50%, to be effective as of January 1, 2020. As often occurs when necessity stokes the flames of ingenuity and invention, the notion of this potentially more costly and less available lower sulfur diesel fuel inspired many to look for prospective alternatives. Eventually this resulted in a push to research and implement the use of liquefied light hydrocarbons – LNG being the most common – as marine fuels. ACD has experience with both low pressure (approximately 8 bar) port injected engines, and high pressure (approximately 300 bar) direct injected engines, the more intricate of which is the high pressure variety.

High pressure fuel gas systems vary somewhat in design from one application to another, however they typically consist of several primary components, namely the reciprocating high pressure pump, drive motor, power transmission system (such as a gearbox or belt drive), centrifugal feed pump (often referred to as a boost pump), a high pressure heat exchanger (often referred to as a vaporizer), a lubrication system of one of various forms, piping and valves, control and diagnostic electronics, and a base frame. ACD has built these systems in both single pump and dual pump configurations, depending on the level of redundancy requested by the ship owner.

Pump Selection and Operation

At the heart of the fuel gas system is the high pressure pump. To achieve output pressures in excess of 300 bar, reciprocating piston type positive displacement pumps are utilized. Selecting the appropriate pump for this application is crucial, as there are many challenging demands placed upon

it. As LNG is a cryogenic fluid, the pump must be specially designed for this service, employing unique technologies, geometries, and material selections. The pump must be capable of running continuously for days or even weeks at a time. It must be of sufficient size to satisfy the relatively large (as far as reciprocating cryogenic pumps are concerned) flow rates required by an engine operating at maximum power, yet be able to turn down to comparatively small flow rates required by an engine operating at idle conditions. Finally, and perhaps most importantly, it is imperative that the pump be able to operate reliably, as the only opportunity to perform major maintenance is typically every five years in dry dock. ACD has made high pressure pumps of various sizes (ranging from just 1 liter/min to as high as 750 liter/min) and configurations for many decades, and based on the aforementioned criteria, a pump was chosen from ACD's SLS enhanced oil recovery line. While this was not a pump initially designed specifically for maritime service, it has decades of reliable operating experience in service conditions much more severe than those now being demanded of it, making it the ideal candidate to be configured into what is now known as the MSP-SL, the world's first high pressure pump to ever supply high pressure LNG fuel to an ME-GI engine in a marine environment. [See figure 1]



Figure 1: MSP-3 SL high pressure pump

A positive displacement pump is aptly called so because it creates fluid motion through the repeated increasing and decreasing of its internal volume. In the case of a reciprocating piston pump, this increase and decrease in volume comes from the extension and retraction of a piston into and out of a cylinder. In operation, pump flow is dictated by the demand of the engine using pump discharge pressure as control feedback, and adjusted by managing the speed of the pump accordingly.

Drive Systems

ACD has used several varieties of drive systems over the course of many years of manufacturing reciprocating pumps. Depending on operating conditions, these pumps will be driven by either an electric or a hydraulic motor, either directly or through a speed reducer such as a gearbox or a timing belt and sprocket system. The most common arrangement is that of an electric motor driving the pump through a speed reducer. On shipboard systems a gearbox is typically selected as the speed reducer, as it is physically a relatively small device that is able to transmit a relatively large amount of torque, a crucial feature when machinery space is a limitation. On land based fuel systems, used for engine testing, a timing belt and sprocket set is typically selected. Although the timing belt and sprocket set is somewhat larger than a gearbox, it has the same torque transmission capabilities, as well as being somewhat less expensive, and easier to maintain. Motor speed is controlled using a variable frequency drive, or VFD, using control feedback as mentioned in the previous section of this article.

Hydraulic systems are utilized as an alternative to electric motors. A current policy enforced by the United States Coast Guard (USCG) on ships under its jurisdiction dictates that an alternate source of power must be utilized when that power source is located within a hazardous, potentially explosive environment. Hydraulic motors are directly coupled to the input shaft of the pump, and driven using a hydraulic power unit (HPU) that is located in a non-hazardous area of the ship. Motor speed is controlled by varying the output flow of the HPU, again using pressure control feedback. This method, although employed less often than the electric motor drive, has operated ACD MSP-SL pumps quite successfully on the TOTE ships *Isla Bella* and *Perla del Caribe*.

Primary Support Systems

As with many kinds of industrial equipment, there are several support systems that are crucial in the proper operation of these high pressure fuel gas systems. These fuel gas systems employ an array of piping, valves, transmitters, and inert gas purges that function in a way that, while important to operation, is not appreciably different than other industrial machinery of this class. However, there are two support systems that are appreciably unique, both in their selection and in their operation. These systems are the cryogenic boost pump, and the drive lubrication system.

The boost pump is a submerged centrifugal pump such as ACD's MSP-34.2 that feeds the high pressure reciprocating pump with fluid from the storage vessel at appropriate flow and net positive suction head (NPSH) levels. [See figure 2] NPSH is sometimes referred to as "net positive suction pressure" (NPSP), or often simply as "sub-cooling" and is a crucial thermodynamic property of fluid in pumping applications. NPSH is often thought of in error as being the same thing as line pressure, although these two terms are assuredly distinct. A fairly simple explanation of NPSH is



Figure 2 - MSP 34.2 submerged boost pump

that it is the amount of pressure on the fluid above the saturation pressure (the pressure at which a liquid boils at a given temperature). Having ample NPSH to feed the boost pump is critical in preventing cavitation of the high pressure pump, and to ensuring proper and efficient operation of the high pressure pump.

Although lubrication systems are quite common in industrial equipment, the way that they are configured and utilized in reciprocating pump drives is quite unique. ACD has built oil lubricated drives in three configurations for several decades, each working quite well when applied correctly. These three configurations are internally splash lubricated, internally pressure lubricated, and externally pressure lubricated. Internally splash lubricated drives are effective in applications where duty is intermittent, with somewhat frequent starts and stops, and where usage is relatively low. The frequent starts and stops are critical, as all of the oil in the lubrication system is contained entirely within the drive, and over time this oil will begin to heat up to unacceptable levels, requiring the pump to stop operation to allow the oil to cool. This splash system does not typically provide the same level of lubricant flow as does a pressurized system, so the relative load rating or relative life rating of the equipment is typically reduced. Splash lubrication systems are typically used in static environments, as dynamic environmental factors such as the listing and rolling of a ship may cause the oil in the pump casing to slosh to one side, potentially starving one or more drive cylinders of oil and reducing overall drive life.

Internally pressure lubricated drives are similar to splash lubricated drives in that all of the lubricating oil is contained within the drive casings of the pump. Oil pressure is provided via a crankshaft mounted oil pump.

This is advantageous as it forces lubricant into the bearing surfaces in the drive, allowing for higher relative drive load and life ratings. These drives are well suited for intermittent duty at relatively high loads. As with the splash lubricated drives, they do require a certain amount of down time to properly cool, and are best suited to static environments, as dynamic environments could potentially starve the oil pump pickup. These systems are well suited to operating conditions with narrow speed ranges, as the oil flow and pressure are dependent on the speed of the pump drive.

Externally pressure lubricated drives have the distinct advantage of being able to condition the lubricating oil under all conditions. Relative load and life ratings on these drives are high, and their physical size is relatively small for their output ratings. Oil is constantly filtered, and is maintained at optimum temperature using cooling and heating systems that are built into the lube pack, helping to extend the life of the pump drive to its maximum potential. The lube system provides consistent oil pressure, regardless of pump drive speed. The addition of subsystems requiring lubrication, such as gearboxes, becomes a simple task, as lubricant can be piped to these subsystems with relative ease. The reservoirs of externally lubricated systems increase the retention time of the oil and provide a total aversion to oil pump starvation, regardless of the list and roll of the environment. These characteristics make externally pressure lubricated drives very well suited to continuous duty applications in dynamic environments.

There are many determining factors to be considered when selecting a lubrication system. There is not a correct and incorrect way, per se, as there are likely multiple options available as solutions to each application, however for each application there is always a 'better' or 'best' way. For example, there are many features from an external lube system that can be

integrated directly into a drive, but would not be for practical purposes such as cost and physical size. Building a drive with the size and complexity necessary to accomplish all of these things is likely far less cost effective, as well as much larger and heavier, than building a purpose built lube system that achieves the same things.

System Design, Installation, and Commissioning

Although each application takes a somewhat different approach, the goal is always the same: delivery of high pressure natural gas to the fuel rail of an ME-GI engine. Installations are typically applied in two distinct ways, the first being aboard a ship as a fuel supply system for the main engine, and the second being a land based unit as a fuel supply system for engine testing at an engine manufacturer's test stand. In the case of shipboard systems, ACD has worked very closely with several EPCs to build a high pressure fuel gas pumping system that integrates well with the ships fuel storage, engine, control system, and overall architecture.

Shipboard systems are required to comply with marine classification society rules, the largest of which are the American Bureau of Shipping (ABS), DNV-GL, Bureau Veritas (BV), and Lloyd's Register (LR). Each classification society puts forth a set of rules that must be complied with before they will grant classification for a vessel. These rules are focused primarily around the safety and reliability of the vessel. ACD works closely with representatives from each of these class societies, and has manufactured approximately twenty-five high pressure fuel gas systems, being granted class society classification on each of them. As applied specifically to the high pressure fuel gas system, these rules focus primarily on engineering



Figure 3: Shipboard high pressure fuel supply system

practices, particularly for pressure vessels and piping, material selection, and electrical devices. Pressure vessel and piping design is subject to review by the classification societies, each having their own specific sets of rules to comply with. As an example, one of the most significant departures from typical high pressure piping design for reciprocating pumps came from the requirements of DNV-GL, which specifically disallow screwed connections in the main process line in favor of butt welded piping and weld neck flanges, resulting in a new piping design that ACD has since employed on all of its shipboard high pressure fuel gas systems. Materials are carefully selected to combat exposure to marine environments, resulting in many components being manufactured from specific grades of low carbon austenitic stainless steel. Electrical components, such as motors, transmitters, and conduit fittings, are subjected to heightened levels of testing to prove their robustness against the harsh environment of a ship. [See figure 3]

While not a requirement of classification societies, shipboard systems typically (although not always) utilize two identical pumps, each capable of meeting 100% of the engines fuel demand. This is done purely for redundancy, and the pumps do not operate at the same time. Once construction is complete, a factory acceptance test (FAT) is performed, during which time a class society representative inspects the build quality and functionality of the system before granting it certification. The final test for this equipment happens during gas trials, in which the ship has already gone through its initial sea trials, and is now ready to test the high pressure fuel gas system. During this test, ACD engineers and technicians are present, as are representatives from the EPC and engine manufacturer. In this phase, the overall fuel gas system is operated through its range to ensure proper and reliable functionality before being granted final class society approval.

Land based systems are typically not required to comply with classification society rules, resulting in a somewhat different system design, although with the same result. [See figure 4] ACD has provided land based fuel gas systems to every major ME-GI engine manufacturer licensee, each being fairly similar in design. Standard fitting types and material selections for high pressure cryogenic service are utilized, as are standard explosion proof or intrinsically safe electronics and electrical devices. Land based systems are designed to test the very smallest to the very largest of engines, and as a result, there are typically multiple pumps in a system that can be operated singularly or simultaneously to achieve large flow ranges, or turndown ratios. Though these systems will initially be operated primarily on LNG, they have been designed to pump fluid to pressures as high as 500 bar for future applications in other light hydrocarbons, such as ethane and ethylene.

Conclusion

As LNG and other light hydrocarbons continue to prove themselves as clean, safe, and reliable fuels, technology and infrastructure will continue to develop to support the endeavor. Our mission is to help promote the industry with safer, cleaner, more reliable technologies and world class field service. ACD is currently developing and investing in its next generation of purpose built marine grade high pressure equipment, and will continue doing so as this industry grows.

For more information, go to www.acdllc.com

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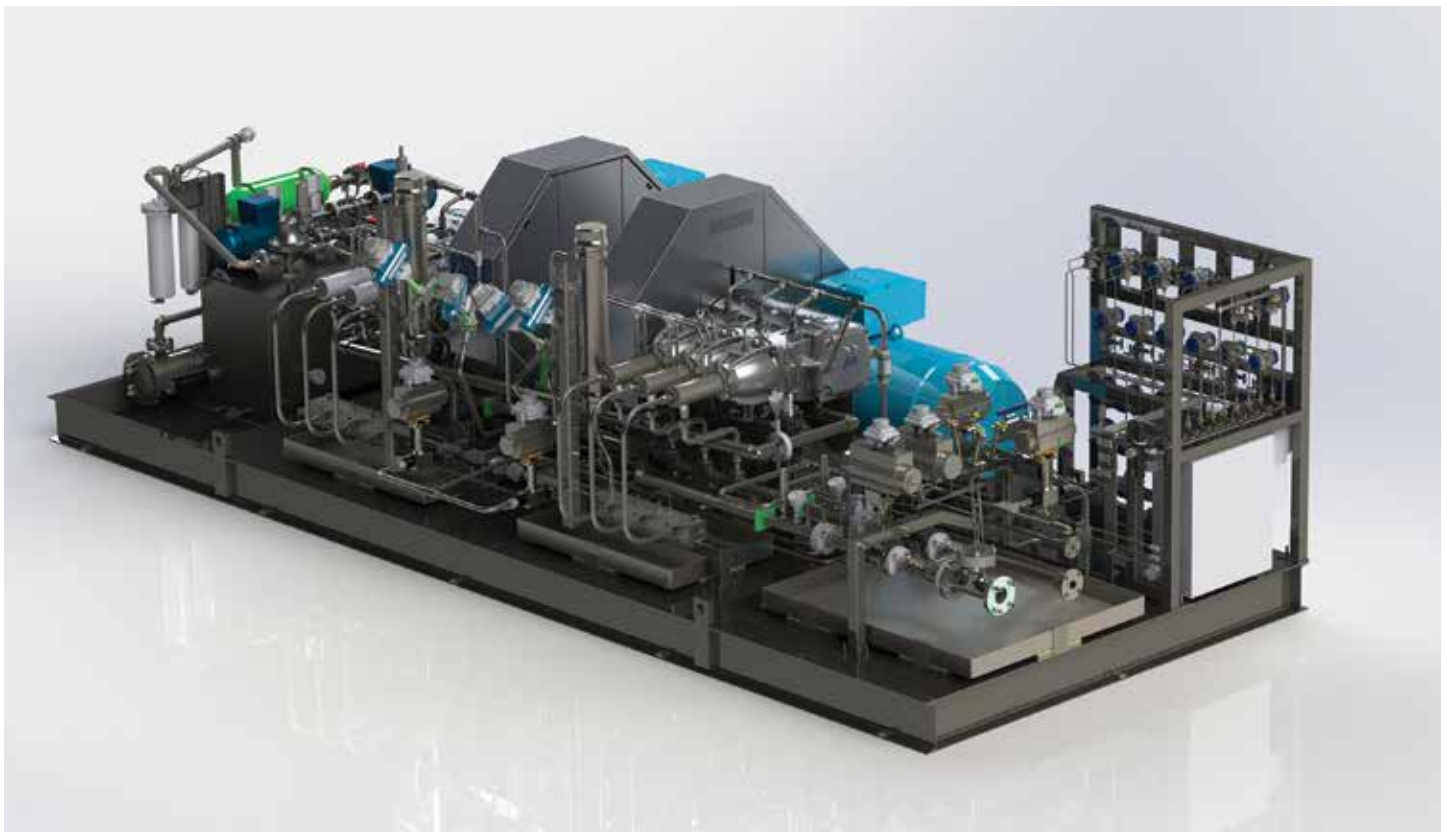


Figure 4: Land based high pressure fuel supply system