PUMPS DESIGNED FOR PEAK PERFORMANCE

Andy Foreman, Amarinth Ltd, UK, describes the challenges of designing cryogenic centrifugal pumps for LNG processing, as well as outlining how these pumps are developed to handle the industry's unique demands.

The global demand for energy is growing again, and natural gas, the cleanest burning fossil fuel, is forecast to play a vital role in balancing economic growth and environmental responsibilities, with a projected growth in demand for LNG of 30% by 2040. Despite the short-term reduction in energy demand caused by the COVID-19 pandemic, the US Energy Information Administration (EIA) predicts that global energy demand will rebound to its pre-crisis level in early 2023 whilst also taking advantage of cleaner technologies than traditional coal and oil.

Cryogenic pumps

The production of LNG requires robust and reliable pumping solutions to move the gas through the necessary processes, often in challenging and hostile environments. At the front end, there is separation of gas and liquids, including mono ethylene glycol (MEG), from the raw gas feed. The separated gas then goes through steps to remove acid gases (such as CO_2 and H_2S), water (from the amine solvent used to remove the acid gases) before it is ready for liquification. Initial gradual cooling removes heavy liquids (such as benzene and other aromatics), and then the gas is finally liquified at atmospheric pressure by cooling down to -165˚C, which reduces it to approximately 1/600th of its original volume. From this point, any further processes and transfers including storing in tanks, bunkering, and loading and offloading onto vessels for transportation around the world, requires pumps that can operate dependably at this extremely low temperature. These pumps are termed

cryogenic pumps, as the cryogenic temperature range is defined as anything below -150˚C.

Amarinth designs and manufactures centrifugal pumps for the oil and gas industry and can deliver the duties demanded by the LNG industry, including many of the world's LNG plants and floating LNG (FLNG) vessels. In addition to oil and gas, Amarinth's expertise extends to cryogenic pumps used by other industries working with liquified gases such as oxygen, hydrogen, carbon dioxide, and nitrogen, some of which require temperatures down to -190˚C, even colder than for LNG, and so the company brings a wealth of knowledge and expertise to the LNG industry in the design of cryogenic pumps.

The cryogenic pumps for LNG are specialised and are specified for the unique demands of the industry, which includes submersion pumps in LNG at -160˚C, cooling down and warm-up procedures, low NPSH operation, condition and vibration monitoring, safety features, and specialised testing.

Specifications for LNG pumps

The design and manufacture of cryogenic pumps is tightly regulated, and so close attention must be given to published standards to ensure that the pumps operate reliably. The main specification for LNG centrifugal pumps, along with the rest of the oil and gas industry is:

- API 610 – Centrifugal pumps for petroleum, petrochemical, and natural gas industries.

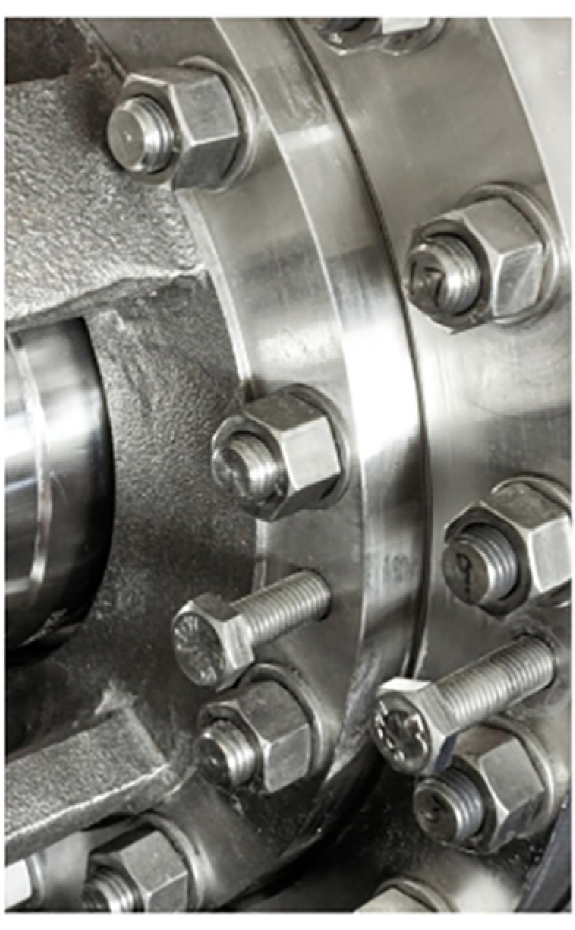

Figure 1. Pump materials must be carefully selected for cryogenic use.

Reference is also made to several other directives due to the cryogenic operating temperatures, including:

- NACE MR0103 – Petroleum, petrochemical, and natural gas industries – metallic materials resistant to sulfide stress cracking in corrosive petroleum refining environments.
- NACE MR0175 – Petroleum and natural gas industries – materials for use in H_2S-containing environments in oil and gas production – part one: General principles for selection of cracking-resistant materials.

In addition, reference is made to the following industry, international standards, and directives:

- European directives – ATEX, EIGA/IGC/CGA guidelines.
- Marine class certifications – ABS, DNV, BV, LR.
- International electrical standards – IEC 60034, 60079.

However, manufacturers must also make sure that their pumps meet operators' hydraulic requirements, which may include duties such as low NPSH operation, and that they operate cost-effectively and are easily maintainable over their lifetime to minimise costs, and this is where the knowledge, skills, and ingenuity of a pump manufacturer successfully delivering pumping solutions to the broader oil and gas industry are very relevant.

Hydraulic specifications

Cryogenic pumps, like any other pump, must be well matched to the hydraulic requirements of the application to deliver reliable, long-term, cost-effective service. Design considerations include the required flow rates, suction pressure, and NPSH available and required (which will determine, for example, the usable and non-usable volume of a storage tank).

In some applications, such as where headroom is restricted, cryogenic pumps may operate at low NPSH and so special consideration will then need to be given to low NPSH pump design and high-efficiency impellers to prevent impeller cavitation occurring, which could have disastrous consequences.

Materials

The pumps are in direct contact with the LNG (usually submerged in the LNG) and so are operating at cryogenic temperatures. The pump, and associated equipment such as valves, must be therefore manufactured in suitable materials for these conditions.

For most pump applications in the oil and gas industry, the materials are selected for corrosion resistance, and certain compromises must be made. However, within LNG applications there is not the same issue with corrosion (as LNG is non-corrosive), and it is therefore possible to manufacture in a range of materials more based on their suitability for the specific functions of the cryogenic pump service.

The duplex stainless steels frequently used for oil and gas pumps become brittle as the temperature is reduced and so the primary selection for cryogenic services is stainless steel 316. This is an austenitic stainless steel and does not exhibit an impact ductile/brittle transition but a progressive reduction in Charpy impact values as the temperature is lowered and so it is much more suitable for cryogenic temperatures. Alternative materials such as

aluminium can also be used due to its stability, excellent thermal conductivity, ductility at low temperatures, and smaller variance in size with large temperature variations. Wear rings and bushings are often manufactured in bronze (and sometimes graphite) for their thermal characteristics in the required temperatures.

However, it is of the utmost importance that any materials selected can be cooled from ambient to temperatures between -150˚C and -190˚C and then warmed back to ambient temperatures without detriment to the build and integrity of the pump equipment.

Within the LNG industry, material traceability is also crucial to product integrity. API 610 sets out traceability requirements, and so pumps for cryogenic application in the LNG industry will often be 3.2 certified, or as a minimum of 3.1 certified.

Equipment

The greatest challenge is to maintain optimum temperatures of each element of the equipment so that it runs efficiently over the long-term to reduce lifetime costs for the operator.

Motors

The induction motors in cryogenic pumps are integral to the pump equipment, and so many of the usual challenges of matching motor shaft bearing loads to the pump is eradicated and the whole motor is optimised for the required pump application.

Although fixed speed pumps have their place, to vary performance the pump is mechanically throttled utilising discharge control valves, severely impacting pump efficiency (reduction). The efficiency and range of operation for pumps in cryogenic service can be significantly improved using variable speed controls. Adjustment of the speed allows for accurate control of the operating characteristics of the pump over a greater range with better overall efficiency. The efficiency of pump operation at flow points that are off design can be improved by varying the pump speed to a point on the pump hydraulic curve which matches the best efficiency point (BEP, the point at which the pump operates at peak efficiency) for the desired flow. This provides reduced operating costs, a higher level of control of the loading/offloading processes, and allows the pump to always operate at its optimum.

Seals

In LNG applications using submerged cryogenic pumps, LNG is allowed to enter the motor. This eliminates the need for seals, and in addition is used to cool the motor. Static seals would therefore only be required for the electrical and instrumentation elements. For cryogenic applications in general, there are a range of shaft sealing solutions should these be required for any reason. These include gas face technology single mechanical seals with purging outboard of the seal to ensure liquified gases do not escape into the atmosphere (due to their flammable state). Alternative solutions can utilise labyrinth seals with alternative containment measures.

Instrumentation

Careful consideration must be given to the instrumentation. These are best mounted within environmental heated enclosures, for example within heated cabinets.

Some pressure gauges can also be silicon oil filled, allowing them to operate at much lower temperatures than normal, but in general, instrumentation will need to be isolated from the extreme cold environment.

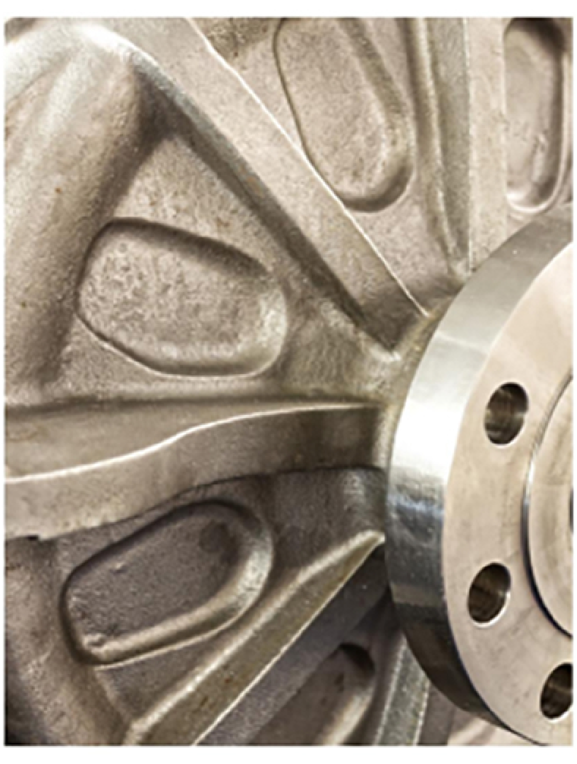

Figure 2. 316 stainless steel is frequently used for cryogenic pump casings.

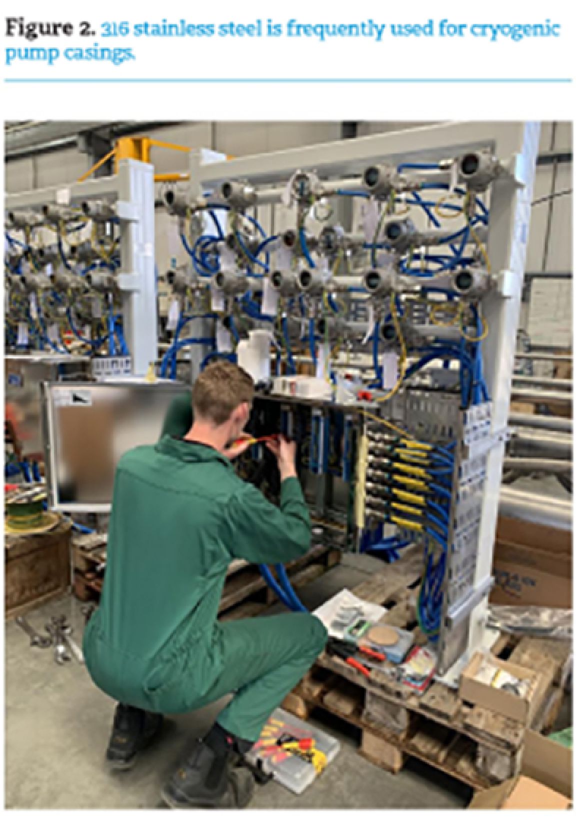

Figure 3. Comprehensive condition monitoring equipment ensures cryogenic pumps operate safely and reliably.

Condition monitoring

Cryogenic pumps usually function within what is defined as a hazardous area, and so it is of the utmost importance that these pumps maintain a high integrity. Therefore, the pump is closely monitored for mechanical vibration with the use of accelerometers within the pump housing and resistance temperature detectors (RTDs) to ensure no hotspots occur within the motor arrangement. These monitoring devices all need to be intrinsically safe (i.e. designated IS devices within the International Standards) to operate within the defined hazardous area.

As with any pumping scenario, parameters such as pressure, flow, and motor amps will be monitored as indicators to pump running performance compared against new parameters. These also provide early indicators of other potential failures, such as presence of vapour should LNG start converting to its gaseous state.

Cooldown and warm-up procedures

Before operating with LNG, pumps (along with pipelines, tanks, and other ancillary equipment) must be pre-cooled to prevent stress on their materials from overly rapid cooling, or the LNG converting to gaseous form. Similarly, warm-up procedures are also an important consideration, particularly when pumps and equipment are being prepared for inspection or maintenance. Cooldown and warm-up procedures therefore need to be carefully considered when specifying the pump so that the pump manufacturer can model the thermal expansion properties of the equipment to minimise stress and possible separation of components.

Testing

As a result of the unique design of cryogenic pumps and the very low operating temperatures required, they cannot be tested with water in the usual way. Cryogenic pumps for the LNG industry must be tested with LNG to verify their performance, in so far as possible, under the conditions of actual usage. This will verify, for example:

- Performance of the motor and its ability to start in the cryogenic environment.
- Pump performance characteristics operating in the cryogenic fluid, which is also crucial for NPSH testing, particularly for when the pumps will be used in low NPSH environments.
- There is no internal leakage due to differential shrinkage and expansion when all the components are working at their actual operating conditions and temperature and during cooldown and warm-up.

Summary

The unique requirements of moving LNG at cryogenic temperatures mean that the pumps must be specifically designed for the required application, meeting an extremely high standard of durability and reliability. As a result, a broad range of skills and expertise are required in the specification, design, material selection, manufacturing, and testing of these pumps which needs to be drawn from the demands of the oil and gas industry as a whole and specialist cryogenic experience. This ensures that the pumps will meet the required duties and operate reliably and efficiently over their lifetime in extreme conditions. LNG