

CRYODYNAMICS[®]

SUBMERGED CRYOGENIC PUMPS & EXPANDERS

WHO WE ARE

ELLIOTT GROUP, CRYODYNAMIC PRODUCTS

For over 40 years, Elliott Group, Cryodynamic Products has been providing custom engineered products to the liquefied gas industries for a wide variety of marine, land-based, floating, and most recently, small-scale applications.

Because Cryodynamic Products has thousands of installations around the world and is the only company to deliver continuous design improvements for so many years, we have become the recognized specialist and leader in the design, manufacture, and testing of submerged electric pumps and expanders.

Cryodynamics® equipment is designed to operate in liquefied gases with temperatures ranging from ambient (warm) to cryogenic. Our submerged motor operates in a non-conductive liquefied gas.

Examples of the liquids our products operate in are:

LNG or Methane (-162°C, -258°F)

Nitrogen (-196°C, -320°F)

Propane (-42°C, -44°F)

Propylene (-48°C, -54°F)

Butane (+0.6°C, +33°F)

Ethane (-89°C, -128°F)

Ethylene (-104°C, -155°F)

Ammonia (-33°C, -28°F)*

**Cryodynamics motors are submerged in the oxygen-free cryogenic liquid, removing the potential for ignition, and making the design ideal to safely accommodate caustic chemicals such as ammonia.*

Cryodynamics pumps and expanders are available in a handful of configurations:

- **Suction Vessel-Mounted Pumps** are used as single-stage transfer pumps or multi-stage for vaporizer feed and send-out service. (see page 5)
- **Retractable Units** are designed for liquefied natural gas (LNG) storage tank installations via columns which contain the pump and provide a discharge. When the pump needs to be removed, the pump is lifted, closing the spring-loaded suction valve, allowing pump withdrawal from a loaded tank. (see page 4)
- Serving aboard most of the world's **Marine LNG Carriers** as cargo, spray, and emergency pumps, these pumps are stationary mounted at the tank's bottom with complete power feed and deck penetration assemblies, manufactured on site by Cryodynamic Products. (see pages 6-7)
- **Expanders** exemplify our drive for advancing LNG process technology and productivity. These machines directly produce approximately 5% increased plant output while generating substantial electricity as a peripheral benefit. These machines are available in either one- or two-phase designs and can be provided with variable speed technology. In addition, expanders are applicable to numerous applications including floating LNG. (see pages 10-11)



ELLIOTT GROUP
EBARA CORPORATION
CRYODYNAMIC PRODUCTS

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QUALITY

QUALITY

Cryodynamic Products maintains quality management systems in accordance with the ISO 9001 standard. We are committed to adherence to the highest quality management standards in all of our operations.

Cryodynamic Products has also achieved ISO/TS 29001:2010 quality standards, which provide more industry-specific requirements for petroleum and natural gas related companies.



QUALITY SYSTEM:

- Do things the right way the first time, even when it is difficult.
- Provide products that meet our customer's design, safety, and performance specifications.
- Provide long-term support, customer service, and reliability.
- Provide exceptional value by continually improving our products and processes.
- Solicit employee expertise and experience to help direct process improvement efforts.

TEST FACILITY

The Cryodynamic Products test facility includes several test vessels and heat exchangers that can be configured to test a full range of cryogenic equipment. With five pump test tanks and one dedicated liquid expander vessel, the test stand can evaluate up to six different pieces of equipment each day, greatly increasing throughput and decreasing the total time spent to complete a project. For example, a typical set of marine pumps for an LNG carrier can be fully tested in as little as three days. In addition to regular Factory Acceptance Test (FAT) activities, Cryodynamic Products also offers its cryogenic liquefied gas testing services to various companies and universities for the purpose of research and product development.

Our in-house engineering staff works closely with our customers to develop test configurations to meet the specific needs of the equipment being evaluated. Customizing flow arrangements, instrumentation, and even data acquisition software allows customers to fully evaluate their equipment in the actual field operating conditions, something they may never have been able to do in their own laboratories without substantial capital investment.

PRODUCT SAFETY

SAFETY IS BUILT INTO THE DESIGN

Cryodynamics pumps and expanders incorporate the safest designs for rotating equipment in the industry. The motor is submerged in the oxygen-free cryogenic liquid, removing the potential for ignition and minimizing the amount of electrical components installed within the hazardous area.

Additionally, there is no need for rotating seals, eliminating a source for leaks. This allows the design to safely accommodate caustic chemicals such as ammonia or methane. Moreover, rotating components are contained within casings that are submerged within a secondary tank or vessel, further protecting personnel from potential hazards. Lastly, Cryodynamics expanders feature a radial in-flow runner that greatly decreases the runaway speed to well within acceptable mechanical limits, reducing the possibility of physical damage.

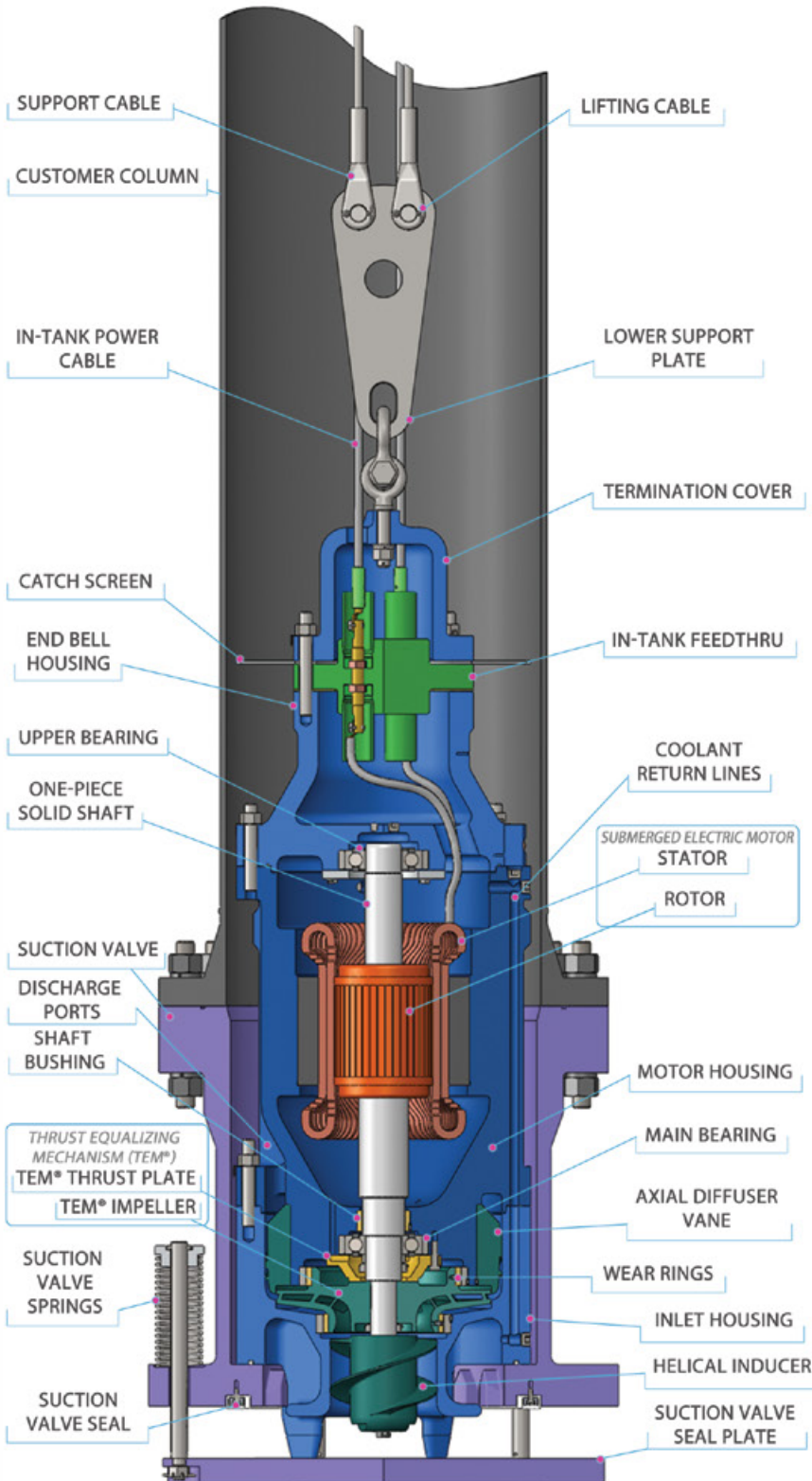
TEST FACILITY / PRODUCT SAFETY

PUMPS

IN TANK (RETRACTABLE)

Our unique in-tank design allows the pump to be installed inside a storage tank in a vertical pump column with a suction (foot) valve located at the bottom. Because the pump is installed through the top of the tank, no connections below the maximum liquid level of the tank are needed. This design eliminates the possibility of major tank leakage due to pipe or connection problems and also permits the storage vessel to be located below ground level.

The submerged pump and motor unit is designed to fit into the smallest practical column diameter by using an axial diffuser design. The column acts as a guide to seat the pump during installation and also performs as the discharge pipe from the pump to the top of the tank. Each pump is fitted with an inducer (an axial flow impeller) located at the lowest possible level of the tank to improve the net positive suction head required (NPSHR), allowing operators to lower tank liquid levels to extremely low levels. To isolate the tank contents from the pump column, a suction valve that incorporates a dual pressure sensitive seal is used. The suction valve is flanged to the lower end of the pump column and is closed by coil springs as well as by the hydrostatic pressure of the liquid in the tank.



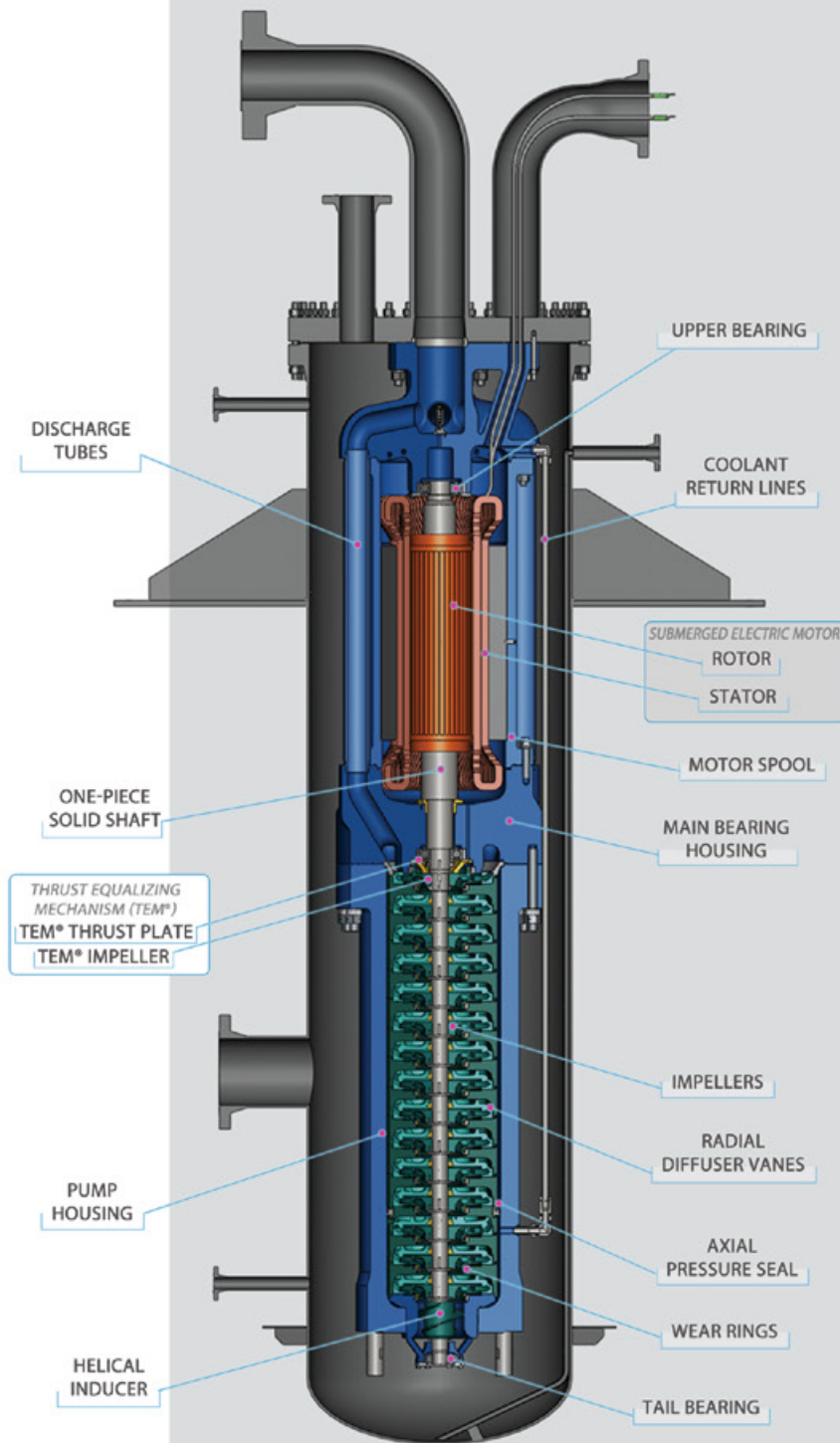
PUMPS

SUCTION VESSEL MOUNTED

In this design, the entire pump and motor assembly are contained within a suction vessel built to the appropriate pressure vessel code for each application, making the installation safe, simple, and reliable. The suction vessel functions as the outer pump casing. It is fabricated with a suction nozzle, welded couplings (for drain and liquid level indication), support brackets, headplate with discharge nozzle, conduit for electrical cables, and a vent nozzle. The result is a compact, uncomplicated installation with low noise levels and significant safety advantages over conventional pumps.

Suction vessel-mounted pumps are widely used as single-stage transfer pumps and for multi-stage vaporizer feed service. Flow capacities are available up to 3,000 m³/hr and differential heads can exceed 3,300 meters. These machines can also be variable frequency drive (VFD) driven to meet multiple duty points.

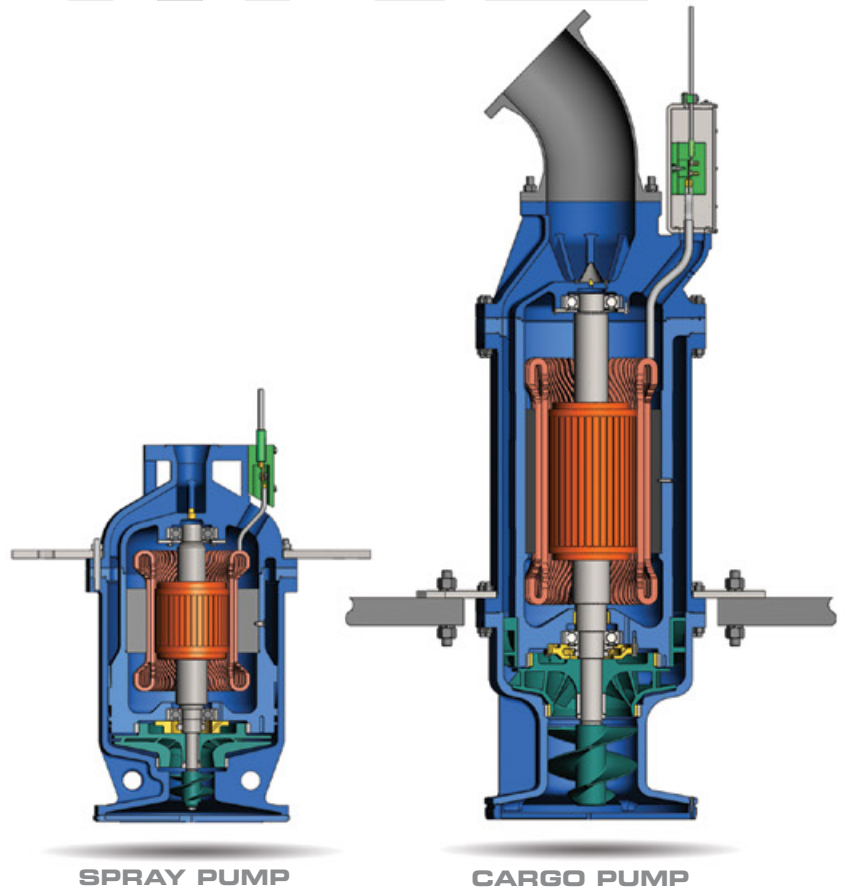
For multi-stage pumps traditionally used for vaporizer send-out applications, Cryodynamic Products has developed a radial diffuser, stiff shaft design that provides a more compact, reliable machine. By combining radial diffuser vanes, which allow a much shorter stage length, with a much larger shaft diameter, the rotor becomes much more stable, normally operating well below the first critical speed. This new design has proven to be extremely reliable in send-out systems that require a large, multi-stage pump to perform on a continuous, 24 hour-a-day basis.



MARINE

MARINE APPLICATIONS

Cryodynamic Products offers complete packages for all of your marine pump requirements. Units are available for all shipboard and floating applications, including main cargo unloading, stripping/spray, fuel and emergency (retractable), high pressure, and expander service. Flow capacities range from 5 to 3,000 m³/hr with heads available over 200 meters. Included are electric power feed cables and deck penetration assemblies custom manufactured to meet all requirements of major ship classification societies. Special designs with built-in internal filtration are available to handle cargo that is likely to suffer particulate contamination, such as liquefied petroleum gas (LPG).



CARGO & SPRAY (STRIPPING) PUMPS

Cargo pumps are used to offload LNG at the import terminal. Efficient offloading – less than 12 hours – allows the ship to quickly return for the next load of LNG. Cryodynamics pumps are designed to draw down the tank liquid, leaving as little LNG in the tank as possible, reducing the amount of remnant LNG returned to the source, and increasing the amount efficiently delivered as usable LNG. Cryodynamics cargo pumps are available in single- and multi-stage designs. Spray/stripping pumps spray LNG onto the inside top of the cargo tanks to help keep them cold and reduce boil-off gas vapor. Cryodynamics spray/stripping pump designs have an extremely low NPSHR, allowing cargo tanks to be offloaded to minimum liquid levels.

EMERGENCY

In the highly unlikely event that both cargo pumps were to fail on board, an emergency pump can be used to empty the stranded LNG from the cargo pump storage tank. Thousands of Cryodynamics cargo pumps have been delivered and there is no history of any of our emergency pumps ever being used due to pump failure, a testament to the reliability of the design.

MARINE

DUAL-DUTY & MULTI-LIQUID

Dual-duty cargo pumps allow a single machine to accommodate both feed and offloading pump applications. The multi-fluid cargo pump allows the ship to offload not only LNG but liquefied petroleum gas (LPG) or liquefied energy gas (LEG) without modification to the pump. The pump is designed specifically to operate at various temperatures and densities, thereby allowing one pump for multiple applications.

FUEL

Cryodynamic Products has developed low-flow, high-head LNG fuel pumps. These submerged pumps meet the rigorous conditions of marine fueling applications. Their rugged construction allows years of uninterrupted service, even while operating with fuels containing some amount of contamination.

FLOATING

Submerged motor pumps and expanders are well suited to the growing demand for floating installations. The compact design of a submerged motor pump results in a machine approximately half the size and one-third of the weight of an equivalent external motor pump, an important advantage where space and weight are at a premium.

Suction vessel-mounted pumps are used in high-pressure send-out service on floating storage and regasification units (FSRUs) and in several processes on floating production, storage, and offloading units (FPSOs). Retractable pumps service the storage tanks on the vessels and expanders can be found on the FLNG topside modules.

Pumps on floating installations are subjected to additional loads due to ship hull motion. These loads are present during sea towing and during operation while moored at site. Vessel-mounted pumps and expanders incorporate additional lateral supports to reduce the stress on the vessel mounting lugs. Within the vessel, the pump is protected from lateral loads by a lower support rod. Retractable pumps use a deep-seat style suction valve or a rigid retraction system to eliminate pump unseating from the valve seal surface during hull motion. In cases of extreme loads, a shaft locking device can be applied, preventing movement of the shaft during shutdown. It can be externally controlled and wired into the plant safeguarding system with appropriate interlocks.



STANDARD PUMPS

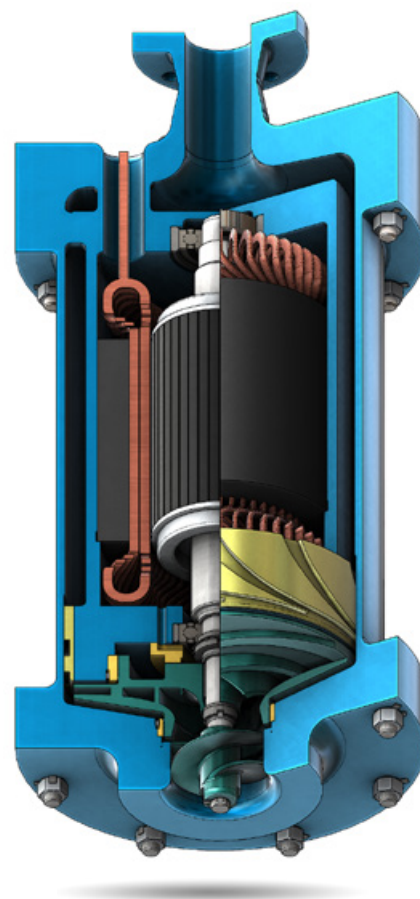
for Small-Scale Applications

SUMP MOUNTED (ECS)

In this design, the entire pump and motor assembly are contained within a suction vessel built to the appropriate pressure vessel code, making the installation safe, compact, lightweight, and uncomplicated with low noise levels and significant safety advantages over conventional pumps. VFD or fixed speed options are available.

RETRACTABLE (ECSR)

This unique design allows the pump to be installed inside a storage tank in a vertical pump column with a suction (foot) valve located at the bottom. Because the pump is installed through the top of the tank, connections below the maximum liquid level of the tank are not needed. This design eliminates the possibility of major tank leakage because of pipe or connection problems and also permits the storage vessel to be located below ground level.

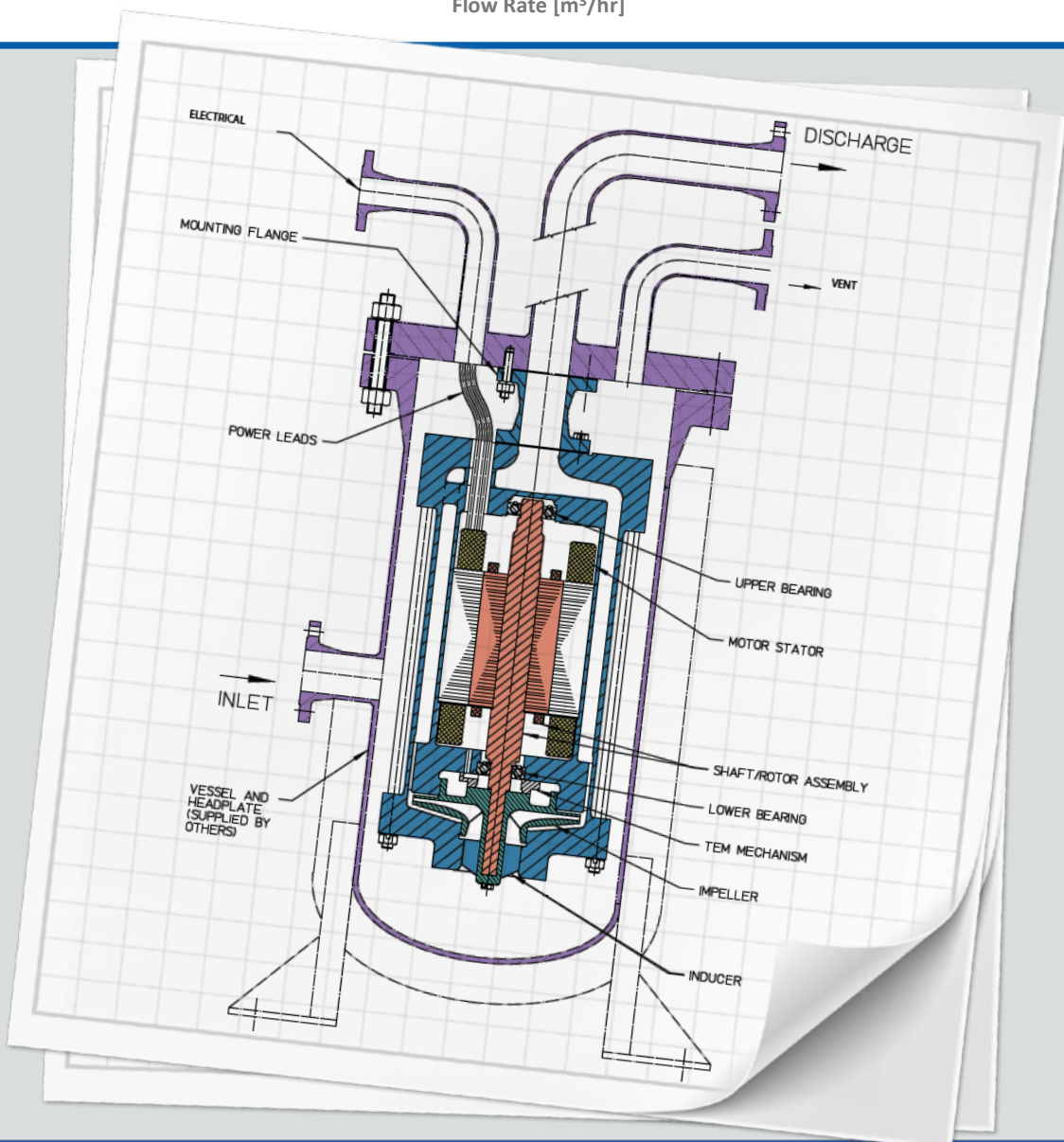
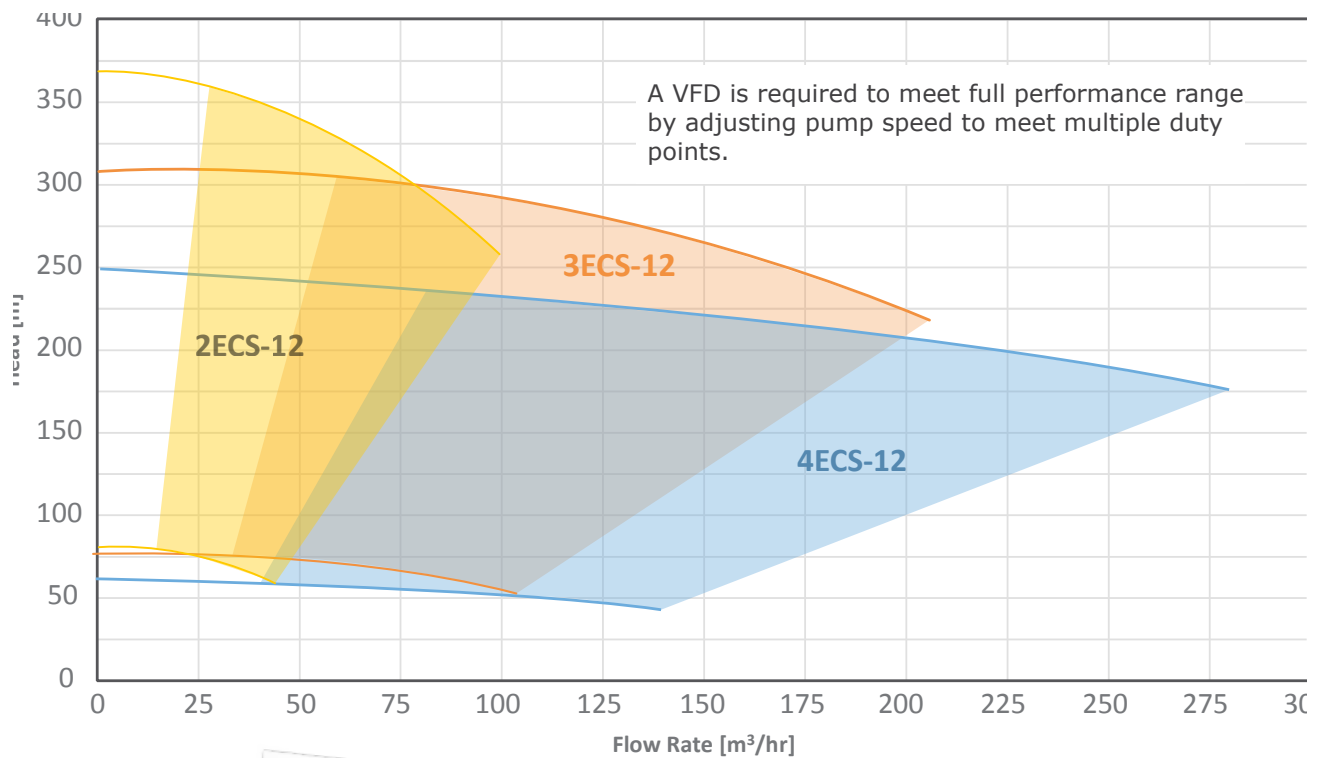


CHARACTERISTICS

Model	2ECS/ECSR	3ECS/ECSR	4ECS/ECSR
Max Flow m ³ /hr	99	205	278
Max Head m	360	301	233
Liquids	LNG, LPG*	LNG, LPG*	LNG, LPG*
Design Temp	-196° C	-196° C	-196° C
Max Power kW	65	91	94
Max RPM	5100	4800	4800

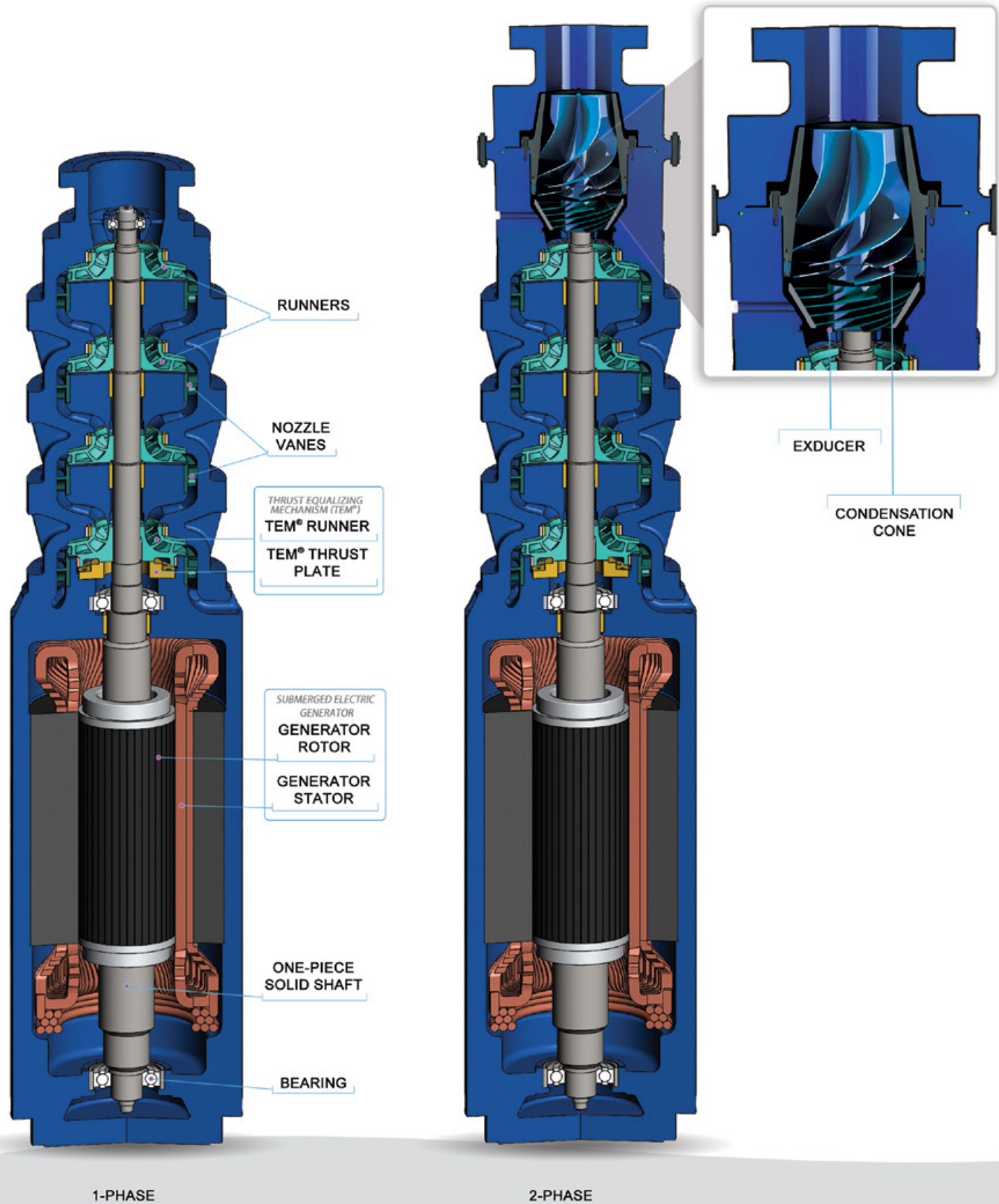
*Brochure technical information specific to LNG only. Technical information for LPG applications available upon request.

HEAD VS. FLOW



EXPANDERS

EXPANDERS



EXPANDERS

CRYOGENIC EXPANDERS

Expanders have become standard equipment in most new liquefaction plants. Used in the pressure let-down section of the process in place of a conventional Joule-Thomson valve, these machines improve process efficiency by five to eight percent. The expander reduces the pressure of the liquid in a near isentropic expansion. The enthalpy reduction results in energy that is removed from the liquid and that can be exported as electrical power to the plant power grid.

The entire expander and generator assembly are contained within a dedicated vessel built to the appropriate code for each application, making the installation safe, simple, and reliable. The configuration is identical to that used in our line of vessel-mounted pumps. The result is a compact, lightweight, uncomplicated installation having low noise levels and significant safety advantages over external air-cooled generator designs.

Cryodynamics liquid expanders have been used in APCI, APX, Linde, and Shell double mixed refrigerant (DMR) processes and account for more than 80 percent of all the cryogenic liquid expanders in our unique industry. Superior performance and reliability is achieved by using the same thrust equalizing mechanism (TEM®) and submerged motor/generator technology proven in our line of cryogenic pumps.



GREEN BENEFITS

- For a typical 4 MTPA LNG liquefaction system, expanders increase production by ~60,000 tonnes per year.
- The same system (4 MTPA) also produces ~7,000 MWh of peripheral electricity to supplement your facility's system, reducing overall power consumption.
- Expanders remove otherwise wasted energy from the LNG stream, decreasing total power consumption and further cooling the cryogenic fluid.



FEATURES



THRUST EQUALIZING MECHANISM (TEM®)

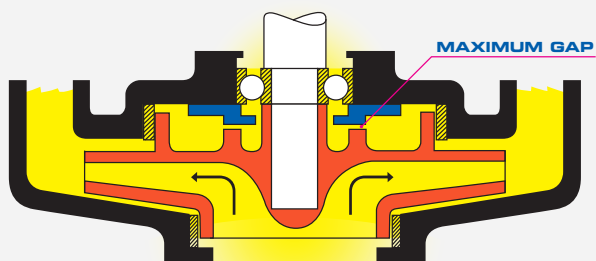
Within all Cryodynamics pumps and expanders, the submerged motor or generator is cooled and the bearings lubricated by a predetermined portion of the liquid being pumped. A small portion of the pumped fluid passes through the back wear ring of the highest pressure impeller or runner stage. This fluid is routed through the TEM to eliminate axial loads on the anti-friction bearings.

The operation of the TEM is simple. The upper wear ring (fixed orifice) is larger in diameter than the lower wear ring (fixed orifice), resulting in a net force in the upper direction. Because of this upward force, the pump shaft and all of its rotating components move upward. This movement reduces the gap between the impeller and the stationary plate (variable orifice), thus restricting the wear ring leakage flow and causing the pressure in the upper chamber, inside the upper wear ring, to increase.

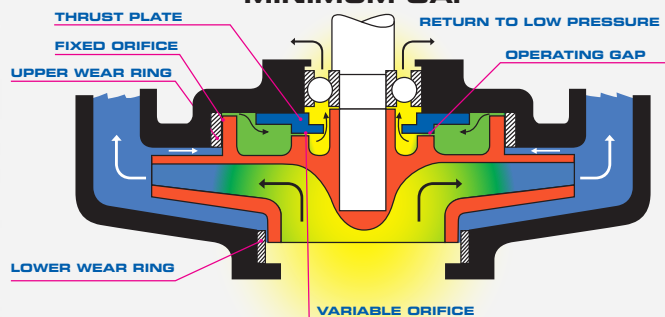
Due to increased pressure in the upper chamber, the thrust is reversed and now acts in a downward direction. This causes the rotating assembly to move downward, thereby opening the gap between the stationary plate and the impeller throttling ring, allowing the pressure in the upper chamber to decrease. The gap between the stationary plate and the impeller's throttling ring then adjusts automatically to produce pressure in the upper chamber sufficient to offset the upward thrust. The end result is an equilibrium created between the upper and lower impeller surfaces that provides an extremely stable system with zero thrust loads on the bearings. This feature substantially increases the reliability and life span of the bearings and reduces equipment maintenance requirements.

The TEM is verified during performance testing by the use of a proximity probe placed at the end of the shaft to measure actual axial movement. The validity of this approach has been demonstrated through thousands of pumps delivered and millions of hours of successful operation.

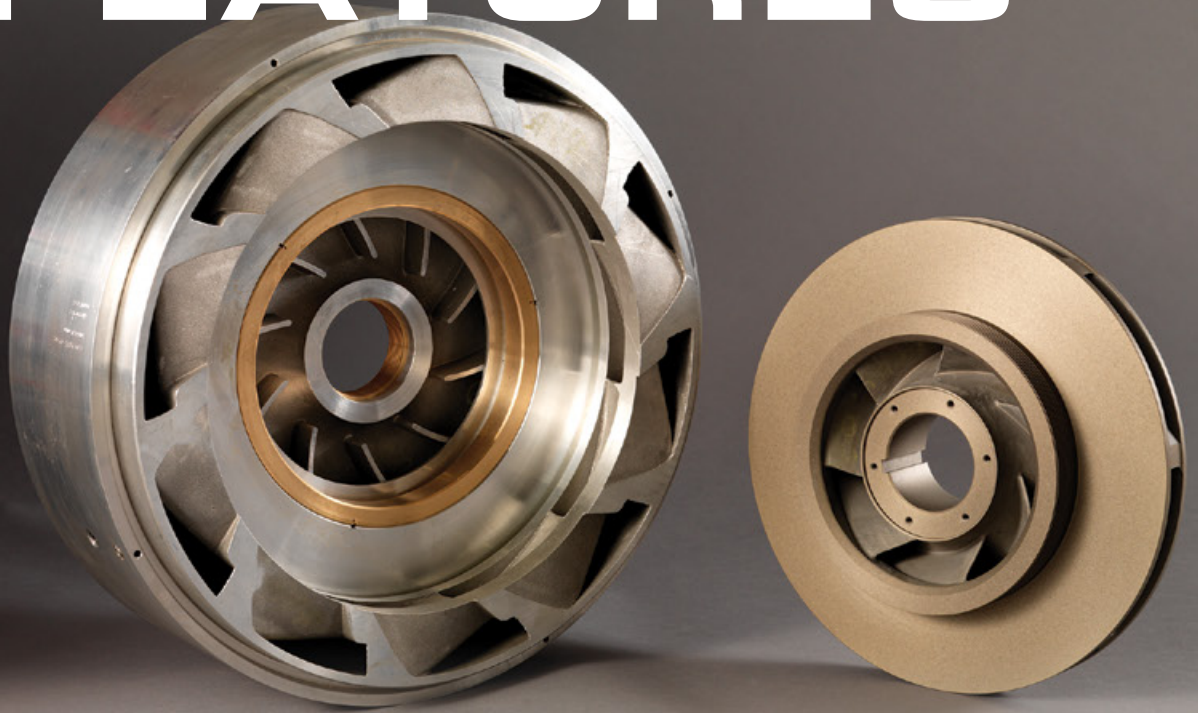
**TEM® IN NON-OPERATING CONDITION
MAXIMUM GAP**



**TEM® IN OPERATING CONDITION
MINIMUM GAP**

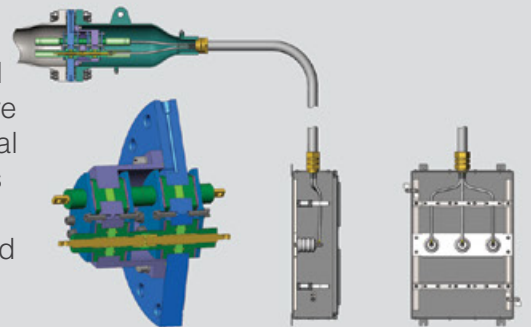


FEATURES



ELECTRICAL SYSTEMS

Cryodynamics electrical systems are designed to meet all applicable codes for hazardous area locations and are certified by various recognized agencies. The penetration from atmosphere into the cryogenic liquid is accomplished using specially designed electrical penetrations (feedthrus). Two types are generally used, one with a fiberglass type terminal block assembly with positively locked and sealed solid copper conductors, and a second type with glass/ceramic seals in a stainless steel flange. Each electrical penetration seal assembly is pressure tested, helium leak checked, and subjected to a high potential test before being accepted for use. Each feedthru system uses a vapor space either between two feedthrus or internal in a double-seal arrangement that can be purged with nitrogen to provide a safe, reliable method of installation. Junction boxes and systems supplied are in compliance with the requirements of the U.S. National Electric Code and NFPA 59A for electrical penetrations into liquefied gas vessels, or to standards such as ATEX or IECEx, meeting the appropriate Exe and/or Exd classifications.



VIBRATION MONITORING SYSTEMS (VMS)

Depending on your project, your VMS can be designed with either a PCB 4-20mA transmitter arrangement or a Bently Nevada 3500 compatible interface module. These packages for your system or control room can include:

- Accelerometers
- Cabling
- Feedthru(s)
- Junction Boxes
- an Instrument Racks
- Power Supplies
- Monitors
- Cabinets

VMS assemblies can also be mounted on the headplate with an instrument box and accelerometer. All systems are custom engineered to meet the stringent requirements of increased safety for hazardous area locations and to provide the most reliable signal possible for condition monitoring.

FEATURES

POWER CABLES

Feed cable systems are specially designed to be submerged in cryogenic liquefied gases. They have been formally tested and accepted by Underwriter's Laboratories (UL E129750) and listed as Flexible Power Feed Cables for Liquefied Gases up to ± 200 degrees Celsius. The cables are TFE insulated and are protected by braided stainless steel armor. They are UL approved for use with supply voltages up to 8,000 VAC. Sizes range from 4 to 250 AWG/KCMIL (on 600 volt units) and 2 to 4 AWG/KCMIL (on 5,000 volt units).

SUBMERGED MOTOR GENERATORS

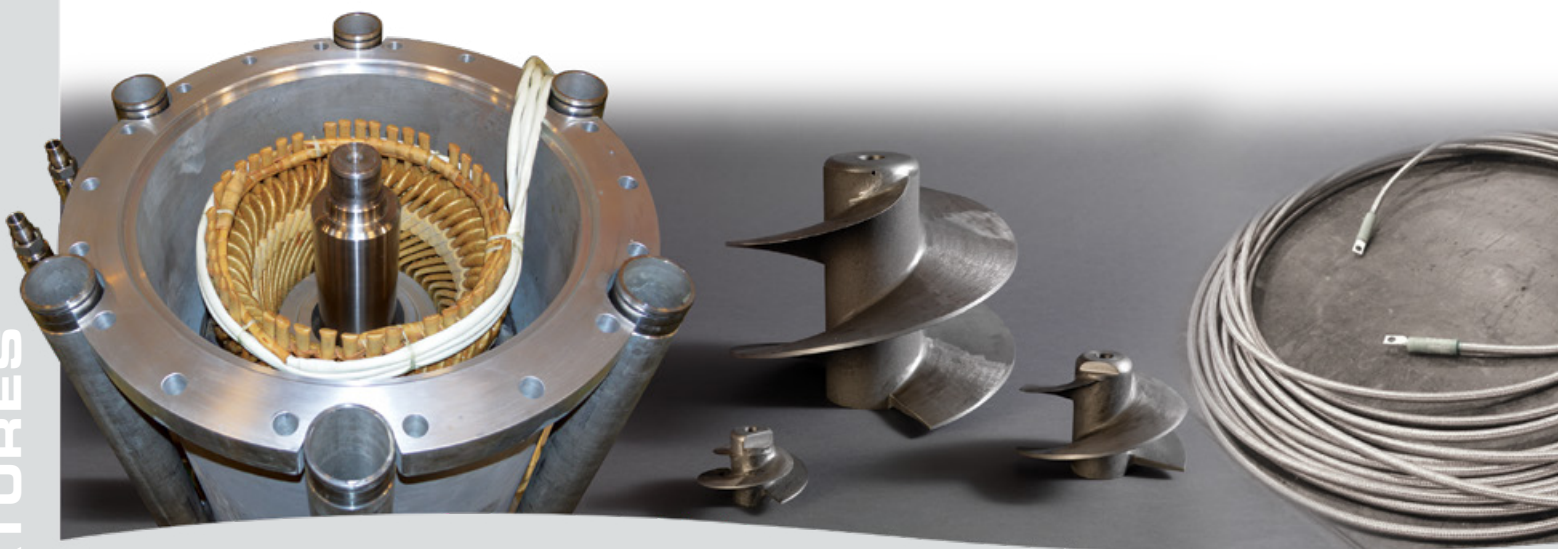
Every motor/generator design is project specific and based on the requirements of a given application. From design concept to finished product, every motor or generator is built to withstand the extreme operating conditions of the application. Using proprietary insulation systems, highest quality materials and best-in-class assembly techniques, rugged and durable service is ensured for demanding real-world applications. All motors and generators meet the NEMA MG-1 electrical test standards for insulation systems. However, since the machines can only operate safely in cryogenic fluids, standard temperature class testing is not relevant.

Contrary to normal ambient pump challenges, any heat that may be generated by the submerged motors or generators is negated due to the cryogenic fluids that pass through the windings, thus allowing a large power density ratio compared to typical air motors. Also, since there is an absence of oxygen in the pump during operation and no concern for an explosion, hazardous area classification standards do not apply.

INDUCERS

When low suction pressure or low tank levels are expected, Cryodynamics pumps are fitted with a high-solidity helical inducer as the first hydraulic stage. This allows the unit to operate at extremely low tank levels that virtually eliminate "dead stock" while maintaining stable operation over a wide flow range.

The inducer blades are tapered, with a thicker blade width at the root, to provide the strongest blade design possible. This design has proven extremely effective and reliable in all Cryodynamics pumps built to date. Combining the well-proven technology with computational fluid dynamics (CFD) software continues to improve NPSHR and pumpdown suction performance, allowing for lower liquid levels.



SUPPORT



PROJECT MANAGEMENT

A dedicated project manager is assigned to every order, providing a main point of contact for the customer throughout the life of the project. The project manager oversees project progress, from the initial receipt of a contract through planning, engineering, documentation, manufacturing, testing, and on to the closeout of the contract. Project management's goal is to provide leadership, communication, and accountability for each individual project to ensure predictable results that meet or exceed the goals and requirements for every project. Our experienced, dedicated project management staff coordinates among the project disciplines with the ultimate goals of customer satisfaction, quality, on-time performance, cost control, and risk management.

PRODUCT DEVELOPMENT

Many of our customers' processes require equipment that is not commercially available and by building upon existing technology, we develop new concepts to solve customer problems. We continually work with our customers to review how our technology will meet their needs. By exploring the application of new technologies to products and systems, we bring significant and fundamental improvements to the marketplace, built upon a base of proven equipment.



SERVICE

GLOBAL SERVICES

Cryodynamic Products provides a full package of aftermarket services and parts for pumps and expanders. We are your partner in maintaining your equipment at peak reliability levels. Let us work with you to keep your plant operating with the high levels of availability that you require. With thousands of machines delivered, our team has years of experience helping customers operate, troubleshoot, and maintain their equipment. Specialists can assist you with any aspect of pump installation, maintenance, or repair. We also provide operation and maintenance training. Our factory support team stands ready to supply original equipment manufacturer (OEM) spare parts, technical support, upgrades, and improvements.



INSTALLATION AND START UP

FIELD SERVICE	TECHNICAL SUPPORT
Installation support	On-call support
Field support for installation and proper set up of equipment	Fully supported factory team supporting customers
Commissioning	Training
In-field support of start-up activities and verification of equipment and system	Specialized training can be organized at customer location or at factory
Condition monitoring	Long-term support
Equipment assessment and maintenance recommendations	Contracts for guaranteed response time and 24/7 support

MAINTENANCE AND SUPPORT SERVICES

FIELD SERVICE	TECHNICAL SUPPORT
Factory refurbishment	OEM parts
Fully dedicated repair center with repairs to full OEM standards	Ensure full factory quality and warranty
On-site repairs	Spares management
Field support of repairs when return to factory not possible	Spare parts lists fully integrated with business system and interchangeability
Upgrades	
Rerates and improvements to older equipment	

ENVIRONMENT

Elliott Group's Safety in Action directive defines who we are as a company and guides our approach to the environment, health, and safety. We are committed to protecting our people and our planet, focusing on the 4Cs that comprise Safety in Action: culture, compliance, conformance, and competency.





Elliott Group is a global leader in the design, manufacture, and service of technically advanced centrifugal compressors, steam turbines, power recovery expanders, cryogenic pumps and expanders, and axial compressors used in the petrochemical, refining, oil & gas, liquefied gas, and process industries, as well as in power applications.

Elliott Group is a wholly owned subsidiary of Ebara Corporation, a major industrial conglomerate headquartered in Tokyo, Japan.



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T H E W O R L D T U R N S T O E L L I O T T



COMPRESSORS ■ TURBINES ■ CRYODYNAMICS ■ GLOBAL SERVICE