Todd Omatick and Kyle Carpenter,
Elliott Group, USA, explain why experience
and expertise are key to LNG compression.

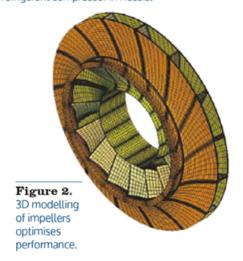
he recent and ongoing surge in North American shale gas production has given rise to numerous export projects in the US and Canada. The North American LNG market has been upended by the success of extracting hydrocarbons from what have been considered 'unconventional' sources. Only a few years ago, the US was on course to significantly expand its LNG import and regasification infrastructure. Suppliers in the Middle East, Africa and Asia anticipated that the US would develop into a major LNG consumer. Today, North America is on the brink of becoming a major LNG supplier. The regulatory environment that restricted exports is beginning to ease in response to the transformation of the market by effective new production technology. Several of the earlier import projects have been repurposed for the liquefaction and export of LNG. Over 20 North American LNG export projects are now in various stages of development. Competitive dynamics will pare the number of these projects that come to fruition, but there is little doubt that this region will supply significant amounts of LNG to the global market.

The prospect of LNG export from North America has attracted several new participants to this market, among them upstream producers and midstream transmission and distribution companies. The success of these projects will hang upon the experience and expertise of the partners they select to design and equip their liquefaction plants. Elliott Group is a US-based compressor manufacturer with experience working with large-scale LNG producers in every region of the world.





**Figure 1.** Installation of an Elliot 60MB61 LNG mixed refrigerant compressor in Russia.



# Compression - the heart of liquefaction

Large refrigeration compression trains are the critical operating machinery at the heart of every LNG process. All commercial liquefaction processes in use today run one or more compressed refrigerants through a heat exchanger to chill and ultimately liquefy the treated gas stream. The capacity of an LNG train, and by extension of the entire production facility, is determined by the size of the refrigeration compressors. Today's mega-plants typically operate two or more compression trains. The uninterrupted operation of a plant is dependent upon the reliability of this equipment.

Elliott Group has been a primary supplier of large refrigeration compressors for LNG projects since the beginning of commercial production. More than 100 Elliott compressors have been installed for LNG applications worldwide, producing in excess of 70 million tpy of LNG. Elliott has also supplied more than 750 compressors for refrigeration applications in petrochemical processing worldwide. The company supplied compressors for the first large scale, US LNG production facility at Kenai, Alaska in the 1960s. ConocoPhillips' Kenai LNG Plant was the largest liquefaction plant in the world when it began operations in 1969. For four decades Kenai was the only US LNG export facility, shipping over 1300 loads, primarily to Japan. Elliott compressors were also installed in Libya, Algeria, Abu Dhabi and Indonesia in the 1970s, and many of these machines remain in service today. The company has continued to supply ever larger and more efficient compressors for the world's largest LNG projects in Qatar, Russia, Yemen and China, as well as proven and efficient compressors for

peripheral plant services such as gas boosters, boil-off gas and end-flash gas (Figure 1).

#### Aerodynamic efficiency

The efficiency of the refrigeration compressors in the liquefaction process contributes directly to the profitability of the plant. A single compression train in a mega-plant can produce 4.8 million tpy. A 1% increase in compressor efficiency can result in a corresponding increase in LNG production, or 50 000 tpy in this case.

Elliott uses state-of-the-art design and prediction tools to optimise aerodynamic performance and increase compressor efficiency. Impeller and matched stationary flow path components are designed using computational fluid dynamics (CFD) analyses. Three-dimensional blade profiles, diffuser flow angles, crossover bend curvature, area ratio, and return channel vane shapes are optimised for each impeller stage to provide the best possible efficiency. Precise design of the flow distribution channels at the inlet and discharge volutes yields additional efficiencies (Figure 2).

The company's abradable rotating labyrinth seals are also carefully designed to enhance efficiency. The seal teeth attain tighter clearance with the rotor shaft, increasing impeller efficiency and expelling particulates. At higher gas densities and operating pressures, rotor stability contributes to efficiency. Elliott's proprietary analytical tools have resulted in increased rotor stiffness by increasing shaft diameter, reducing impeller weight, and increasing journal bearing sizes. These design improvements increase rotor stability at higher torque transmission and higher speed operation. Elliott also balances every rotor 'at speed' establishing first critical within a vacuum. This is an excellent way of balancing the rotor while confirming RDA.

#### **Sideload optimisation**

Most LNG tonnage worldwide is currently produced using the APCI process. Elliott compressors process approximately 35% of this production. The APCI process includes two refrigeration cycles: a propane pre-cooling cycle and a mixed-refrigerant (MR) cycle. The propane chiller cools both the incoming feed stream and the MR process gas to around -40°C. The propane compressor has multiple side streams, which increase the thermal efficiency of the process.

Adding one or more side streams to the main flow of a compressor increases the challenge of accurately predicting the machine's performance. Elliott's research into side stream thermal dynamics and pressure optimisation has resulted in an understanding of the effects of sideload temperature, pressure and flow on downstream stage performance and a compressor's overall efficiency. Computational flow path analyses and proprietary models confirm the proper design of the merging flow streams for minimum pressure loss, and contribute to the efficiency of the company's refrigeration compressors (Figure 3).

## Advanced manufacturing in two facilities

Elliott ensures the quality of its aerodynamic components, rotors and casings through the use of advanced manufacturing processes in each of its two world-class manufacturing facilities. The factories in Jeannette, Pennsylvania, USA and Sodegaura, Chiba, Japan are similarly equipped with advanced machine tools and testing capabilities. The two factories work closely

together to balance their production schedules and ensure timely project completion. The company maintains a dedicated materials engineering laboratory and metallurgy group to study materials such as low expansion high nickel alloys for use in very low temperature applications. Elliott also has a dedicated facility to produce API-614 lube oil and buffer gas consoles, a capability that significantly reduces the risk of delay for project completion.

Advanced five-axis, CNC machining centres ensure the quality of Elliott's impeller designs. Impellers are stress relieved, machine finished, balanced statically and dynamically, spin tested, and mounted onto the shaft with an interference fit to improve performance under off-design conditions. Diaphragms are fabricated from steel plate or in combination with cast steel where thickness precludes using steel plate alone. Precision machining ensures dimensional accuracy and a precise finish on gas path surfaces for enhanced performance.

On midsized compressor casings, the horizontal flanges are milled by giant CNC master head machining centres rather than welded on. End walls are made from a single solid plate. The resulting casings have fewer sealing surfaces and increased pressure capabilities. Larger horizontally-split casings have rolled barrel sections with welded horizontal flanges and endplates. Elliott's vertically-split barrel compressors feature a complete inner casing assembly bundle that can be inserted or removed from the outer casing as a single piece. The inner bundle casings are thicker to more effectively handle off-design conditions. Barrel compressor designs include innovative cradle tooling for simpler installation and removal of large bundles, and reduced turnaround time (Figure 4).

#### Driver experience

Large amounts of energy are required to chill natural gas to its liquefaction point at -260°F (-162°C). The power efficiency of the refrigeration process directly affects the economics of LNG production. In mega LNG plants, a single MR compression train can require 65 MW of power. The cost of energy to drive the compression trains, whether BTUs burned in a turbine or kilowatts to power a motor, reduces operating margins. Many factors influence the selection of compression drivers for an LNG plant. With a history of LNG production extending over more than 50 years, Elliott has direct experience with every type of driver application.

Early LNG plants used steam turbine drivers. Steam turbines are efficient, can deliver precisely the power specified for the process, and provide high reliability and high availability, operating for years without interruption or overhaul. But steam turbine installations are large, complex, and capital intensive, comprising boilers, condensers, desalination and water conditioning, feed pumps, and other auxiliaries.

The ready availability of natural gas at an LNG plant led to the general replacement of steam turbines by increasingly larger frame gas turbines. Gas turbines offer several advantages over steam turbines including uncomplicated design, lower capital expense, and a smaller footprint. On the other side of the equation, gas turbines produce higher CO2, and they require frequent and extensive on-site maintenance, reducing plant availability. A gas turbine might require a steam turbine or electric motor as a helper at start-up. A gas turbine's fixed optimal speed also dictates that the compressors and refrigeration process must be designed around the turbine. The associated design compromises might not make full use of the turbine's power.

Aeroderivative gas turbines offer greater thermal efficiency and a smaller footprint than industrial gas turbines. They might not need a starter motor, and they can be swapped out for simpler maintenance. However, they produce higher NO<sub>x</sub>, and their design complexity and higher operating pressures and temperatures create additional maintenance issues. Fuel quality is critical to aeroderivative turbines, and their power output is more directly affected by ambient temperatures.

Electric motors are popular as LNG compression train drivers in locations where the availability of 400 - 500 MW of power can be ensured. Motors offer higher availability than turbines and require little auxiliary infrastructure and fewer support personnel. Variable speed electric motors can be closely matched to process and compressor design, optimising the overall process efficiency and eliminating the need for gearboxes with large flow compressors.

Elliott's experience includes 3.2 million hp in installed electric LNG compression.

#### Full-load, full-speed testing

An LNG refrigeration compressor string is a complex system. Two large MR compressors might be driven by an electric motor or a gas turbine with an electric starter motor or steam turbine

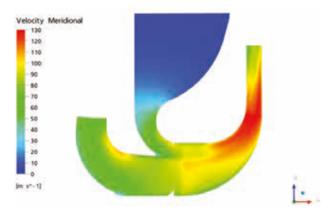


Figure 3. Sideload mixing in a propane compressor.



Figure 4. Removing the inner barrel of an Elliot 88MB mixed refrigerant compressor.

### **Innovations**

Elliott's innovations in LNG include the following:

- First baseload plant refrigeration compression train.
- First gas turbine-driven refrigeration compression train.
- First MR process plant.
- First large frame, horizontally split compressor in propane refrigeration service.
- First VFD starter motors for frame gas turbines driving refrigeration compressor trains.
- First dual-mixed refrigerant compressor trains.
- First dual-shaft gas turbine drives.
- Largest 4-section propane refrigeration compressor in operation.
- Largest dual-mixed refrigerant compressors.



**Figure 5.** Full-load test of MR and C3 compressors with gas turbine and 12 MW electric motor.



**Figure 6.** Installation of a large propane compressor with three side streams in the Middle East.

helper, all from different manufacturers. To ensure maximum efficiency of the entire train, Elliott design engineers conduct performance simulations that fully model the performance of the LNG train under various customer-specified and factory process conditions including:

Start-up.

- Controlled and emergency shutdowns.
- Anti-surge valve selection confirmation.
- Process upset conditions.
- Alternate gas operations such as nitrogen purge and defrosting operations.

Performance simulations are essential design tools, but they cannot reveal all system integration issues or demonstrate actual string performance. The optimal way to evaluate the performance of a compression string prior to site installation and start-up is to conduct a full-load, full-speed test of the entire string at the factory. Elliott's test facilities in Jeannette and Sodegaura are capable of simultaneously testing multiple compressor strings, including gas turbines and electric motors, under full-load conditions (Figure 5). The company's testing capabilities include:

- Testing to API 617 and ASME Power Test Code (PTC-10) requirements.
- A permanent gas turbine test stand incorporating all required utilities and necessary auxiliary equipment.
- Full-load string testing capabilities with a gas turbine driver over 75 MW (100 500 hp).
- A permanent motor test pad for full-load string testing to 25 MW (33 500 hp).
- Full variable frequency drive (VFD) capabilities including compressor drive and gas turbine start-up.
- Customer-specific testing capabilities for LNG process applications.
- Dedicated metallurgy and materials engineering laboratories.

## Installation, maintenance, overhaul and upgrades

Elliott's Global Service organisation offers a full spectrum of turbomachinery services. The company's field service teams install, start-up and repair compression trains at plants around the world. The Global Service network also comprises 22 full-service repair facilities in the Middle East, Europe, Asia and the Americas. In the US and Canada, two facilities support the Pacific seaboard, two support the Atlantic seaboard, and three facilities in Louisiana and Texas support operations in and around the Gulf of Mexico.

Elliott Engineered Solutions upgrades and rerates critical turbomachinery to increase reliability, efficiency and performance, and reduce unplanned outages.

#### **Experience matters**

In LNG operations, the goal is years of reliable, efficient production. Expert engineering, precision manufacturing, and full-load testing of highly efficient, highly reliable refrigeration compressors are important considerations when evaluating the critical compression components of an LNG process. Hands-on experience is another important consideration. Knowledge of how a compression train operates in a specific process, with a particular driver, in different environments and regions of the world, helps to ensure efficient system integration and operation, trouble-free installation and start-up, and years of reliable production. Elliott brings the experience of a market leader to each project, with a proven record in refrigeration compression that precedes its pioneering contributions to LNG liquefaction in the 1960s and continues to the present day. **LNG** 

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