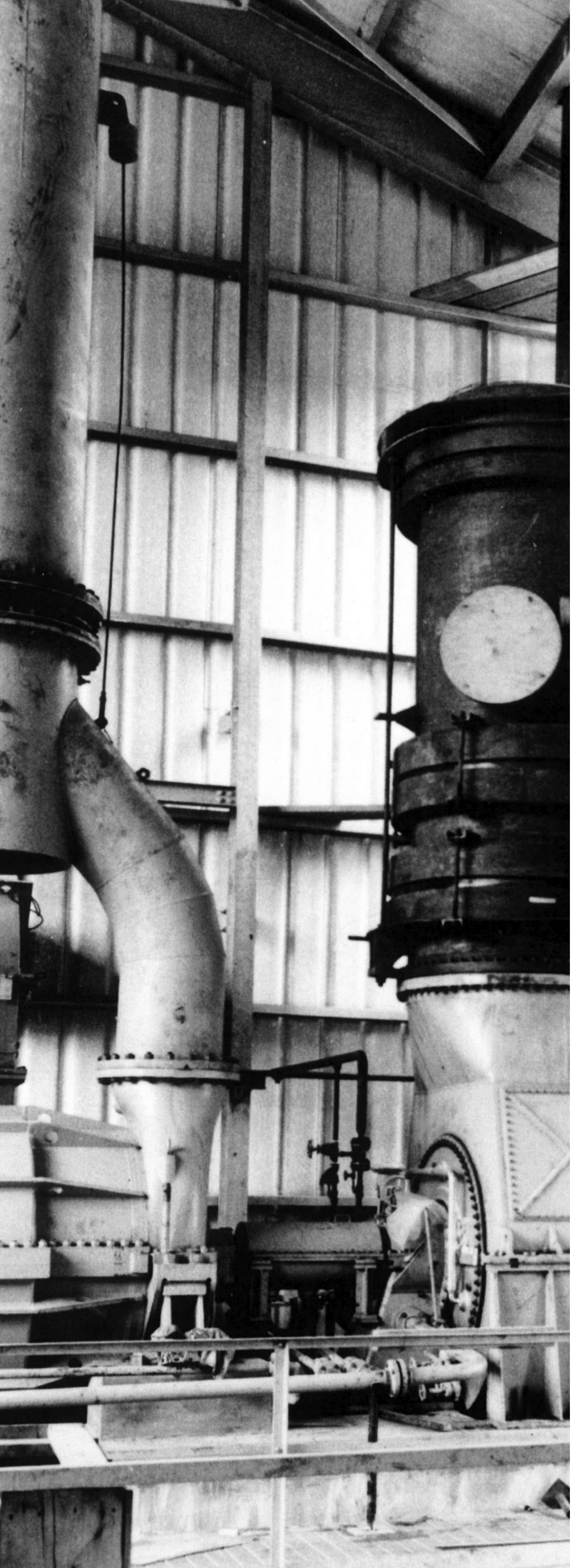

EXPANDER EVOLUTION

Phillip Dowson, Mike Minnerly, and Carl Schuster, Elliott Group, USA, discuss the evolution and improvements in FCC expander technology since their 1960s introduction.

Fluid catalytic cracking (FCC) hot gas expanders have been harvesting valuable thermal energy from hot flue gas for more than 50 years. Elliott Group pioneered this technology and has set the pace with each succeeding generation of FCC power recovery expanders. As energy recovery, emissions control, and carbon management become increasingly important operational issues, refiners throughout the world are showing fresh interest in new FCC expanders and rerates of existing equipment. Elliott's current TH expander design represents the fourth generation of expander technology and offers multiple advancements in the key areas of reliability, maintainability and performance. The right technology for the right time, Elliott's fourth generation TH expander design has set the standard for environmentally and financially effective FCC power recovery.

Background

The idea of converting the energy in combustion exhaust gas to power has been in practice for nearly 100 years, since German naval vessels were first equipped with turbochargers in the 1920s. The first experiments in applying the power recovery concept to a refinery process took place in the 1950s, when Shell and Marathon approached Elliott to build and test a hot gas expander for the FCC process. The idea was to feed hot flue gas from the cracker's regenerator into a turbine, producing power that could be used to drive process machinery.

The early expander trials revealed the fundamental challenges to reliable expander operation: the extreme high temperatures, chemical corrosion and kinetic erosion caused by the hot, particulate laden flue gas caused the rapid erosion of critical rotating and stationary components such as the rotor disk, blades and stator vanes. Drastic thermal differentials also imposed substantial stress on the structural elements of the machine. Elliott and its partners persevered with innovative research in materials, coatings and steam cooling to arrive at a durable, reliable design that delivered the anticipated payback. Shell, Exxon and Gulf installed first generation Elliott expanders in the 1960s.

Following a jump in oil prices in the late 1970s, Elliott developed its second generation expander architecture with better corrosion and erosion resistance and maintainability. A significant innovation was a longer shaft design that improved the balance of the overhung rotor and made rotor maintenance and removal safer. This proven shaft design prevails in the industry today.

Expander reliability and maintenance continued to evolve through the 1980s, 1990s and 2000s with improvements in materials, coating and design. Third generation enhancements, such as Elliott's free vortex stator vane design, extended the operating life of critical components to exceed typical turnaround cycles. Advances in process controls and valve technology contributed to the adoption of expander gear generator trains in place of the expander combustion air compressor designs that characterised the earliest expander installations. Uncoupling the expander as a direct driver from the FCC process minimised the risk of process interruption linked to the expander while significantly offsetting the refinery's electrical power requirements.

Building on more than 50 years of field tested experience, Elliott introduced the fourth generation of expander design and technology in 2009 with innovations and improvements in mechanical design, aerodynamics, blade coatings and materials. New maintenance strategies enable operators to extend maintenance cycles to six or seven years or more, and more accurate lifecycle data allows expander users to plan beyond the rated life of their equipment. Years of production experience prove the reliability and maintainability of Elliott's TH expander design. With improvements in design, materials and manufacturing, as well as periodic maintenance, and upstream improvements in particle separation, Elliott expanders are now seeing nine to ten year intervals between rotor removal and overhaul, exceeding the industry's requirements between shutdowns.

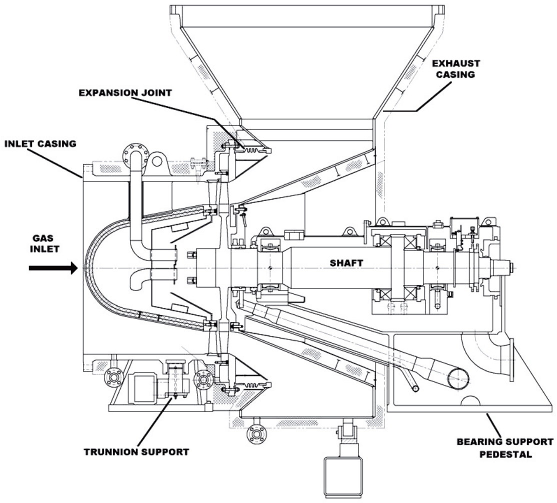

Figure 1. Basic components of a hot gas expander.

Figure 2. Elliott TH-100 expander blade after nine years of continuous operation.

The harsh life of an FCC expander

Although the principles behind an FCC expander are straightforward, optimising its performance in the harsh operating environment of a cracker is not. Hot gas expanders operate at high speeds with extreme heat differentials while being literally sandblasted by residual entrained catalytic particles. Depending upon customer requirements, expanders can deliver between 3000 hp (2.2 MW) and 60 000 hp (45 MW) of shaft power. Typical flue gas inlet temperatures can exceed 1346 °F (730 °C) at a pressure of 16 psig (1.12 kg/cm^2-g) to 35 psig (2.25 kg/cm^2-g). Exhaust temperatures can range from 932 °F (500 °C) to 1022 °F (550 °C) at a pressure of 1.0 psig (0.07 kg/cm^2-g) to 3.0 psig (0.21 kg/cm^2-g). Mass flow rates through a hot gas expander can vary from 110 000 lbs/hr (49 896 kg/hr) to 1.7 million (77 114 kg/hr).

In the FCC process, preheated feedstock is injected into a reactor where it breaks into fractions such as light olefins and high octane gasoline with the aid of hot catalyst. The cracking process deposits coke onto the catalyst that must be removed prior to its reuse. The spent catalyst is cycled to a regenerator, where the coke is burned off in an exothermic process. The hot flue gas from the regenerator passes through a series of cyclones and separators that remove most of the entrained catalytic particles from the gas stream. The flue gas is then directed to an expander that recovers its thermal energy and converts it to power. Under normal operating conditions, the catalyst concentration in the flue gas at the expander inlet is on the order of 100 ppm. During upset conditions, however, the catalyst content may exceed 1500 ppm, significantly aggravating erosion of stator vanes and rotor blades.

Corrosion is another critical consideration in expander operations. Corrosion is related to the high temperatures at which expanders operate. The effects of creep and gaseous corrosion increase at elevated temperatures. The nature of the corrosive attack is primarily influenced by the feedstock and the additives injected during the cracking process. If not addressed, hot corrosion can lead to rotor blade or disc failure.

Fourth generation expander design

This harsh operating environment poses special challenges for expander design and performance, reliability, and maintainability. Additional operational considerations are increasingly demanding process parameters, extended maintenance cycles, and more stringent environmental regulations. Elliott took these challenges

Figure 3. FCC regenerator in a US refinery. An Elliott TH-140 expander gear generator train are in the center on the first deck.

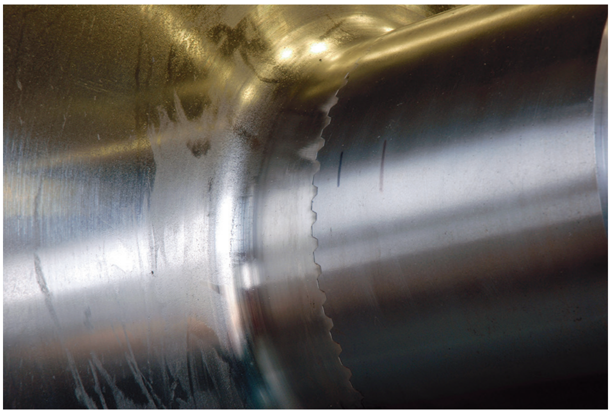

Figure 4. Spline connection: rotor disk on left; shaft on right.

into account when enhancing its expander design for the latest generation of refineries. Design improvements address such issues as blade erosion, operating stresses and creep life, differential expansion, power transmission, overspeed protection, and afterburn protection. These innovations, described below, apply to every frame of new Elliott expanders installed today. As a key element of expander life extension programs, Elliott Engineered Solutions also includes these features in rerates of installed Elliott expanders as well as expanders from other manufacturers.

Stronger, simpler inlet casings

The entering flue gas stream subjects the expander's inlet casing to temperatures up to 1400 ˚F (760 ˚C.) For maximum creep life as well as superior repairability, Elliott uses AISI 304H stainless steel for these components rather than more typical 347 stainless. 304H is a superior material for this application, maintaining its creep properties longer under thermal stress than 347 stainless. 304H is also commonly used in refinery piping due to its reliability and long lifecycle in high temperature service.

The barrel of Elliott's fourth generation inlet assembly is a single large forging of 304H stainless for maximum strength and simplicity in manufacturing. The casing's hot wall design is simpler to manufacture and repair than the double wall designs typical of previous generation expanders. Elliott also strengthened the inlet casing's trunnion supports to accommodate the intense heat and load at the inlet. The casing design and material operate with greater reliability at high temperatures and large stress margins. This also reduces steam cooling requirements, thereby saving energy and reducing system complexity.

The inlet's nose cone uses Elliott's proven constant taper design for uniform acceleration and catalyst distribution, minimising deposition and erosion. The nose cone struts have been redesigned from a radial to a canted configuration to reduce the stresses that can cause cracking at the casing. The flow path through the inlet can be optimised for either power or lifecycle performance, as required by the application.

New stator vane design

Elliott's fourth generation expanders use an integral stator assembly attached to the forged casing rather than the nose cone, reducing load on the nose cone struts. The stator assembly is secured to the casing with shear rings, eliminating expensive, high temperature internal bolts that can fracture during operation with the potential to cause system failure, or seize, complicating maintenance and repair.

Stator vanes use an aerodynamic tapered, twisted 'free vortex' design matched to tapered, twisted rotor blades. The tapered twisted blade shape minimises erosion due to conservative stator exit velocities, while maintaining efficiency. It distributes gas flow and entrained catalytic particles more evenly along the entire height of the blades and completely eliminates secondary erosion at the platforms of rotor blades. This design was pioneered by Elliott and is now the industry standard.

Proprietary superalloy reduces hot corrosion

Elliott's rotor blades and disks are made from high performance superalloys such as Waspaloy, IN-738, A286 or the patented RK1000 superalloy. RK1000 has four times the hot corrosion resistance of standard Waspaloy, with similar mechanical properties. RK1000 is particularly effective against sulfide penetration that promotes hot corrosion. Hot corrosion is also mitigated through blade coatings such as sprayed chromium carbide, and plasma sprayed coatings on disk roots.

Rotor assembly's axial spline reduces stress

The Elliott TH expander design uses an axial spline to attach the rotor disk to the shaft rather than the radial pins and rabbet fits typical of other designs. The spline design contributes to rotor reliability by maintaining concentricity and avoiding the stresses incurred by rabbet shrink fitting.

Elliott has also developed a more reliable blade root design. The enhanced fir tree design features four lands instead of three, reducing stress at the blade root and extending blade life. A new, no stress locking pin eliminates the need to peen the blade root in position and eliminates the stress on the metal that peening can cause.

Expansion joint absorbs thermal growth

The significant temperature differential between the inlet and exhaust gas, and the variance in thermal expansion that results, are a significant source of wear and a potential cause of failure in expanders. The Elliott TH expander design addresses this challenge with a one piece fabricated exhaust casing that features an expansion joint to absorb deflection of the exhaust casing wall

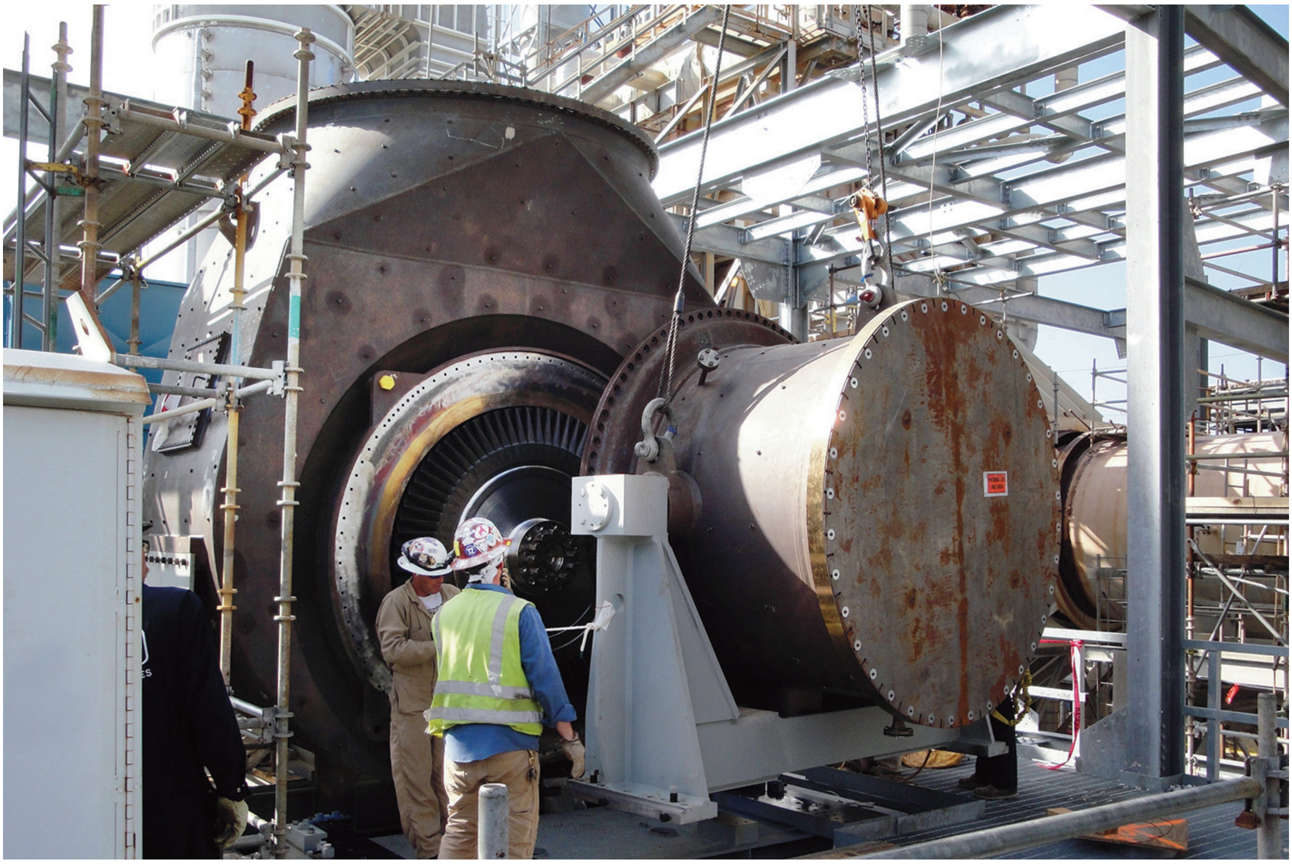

Figure 5. Removing the inlet casing to access the expander rotor.

caused by thermal growth, minimising bending stresses on the attachment bolts, preventing bolt failure and flue gas leaks.

Front removal simplifies rotor maintenance

Removing an expander rotor from the exhaust or coupling end of the casing is a complex, time consuming operation that often requires the removal of many other components such as the bearing support, auxiliary piping connections, and even the gear or driven equipment. Elliott's TH expander is designed for the removal of the entire rotor assembly as a unit from the inlet end of the casing, requiring only the removal of the inlet casing with nose cone, and without disturbing the exhaust casing and any of its connections, including the bearing support. Elliott supplies special tooling for removing the rotor assembly. This procedure simplifies and speeds maintenance in the plant environment, reducing the overall time required during an outage.

Maintenance and remaining life assessment

Equipment maintainability is a primary consideration for a critical process such as FCC. Maintainability is at the forefront of Elliott's fourth generation expander design. Materials for all components are selected for repairability as well as reliability. The system design is optimised to minimise thermal and kinetic wear, and to permit faster disassembly, repair and reassembly.

Production imperatives frequently dictate that expanders remain in operation far beyond the initial design life of the equipment. Elliott Materials Engineering has developed tools and techniques for determining remaining life of Elliott TH expander components and similar equipment from other manufacturers. These machinery audits are extremely valuable for designing ongoing maintenance and repair schedules, as well as for indicating rerate strategies that can cost effectively increase the efficiency and output of older equipment.

Conclusion

Although hot gas expanders have been operating in refineries for 50 years, they are not ubiquitous. There are fewer than 200 of these units installed worldwide today. Changing market dynamics are leading refiners everywhere to take a serious look at adding an expander to their FCC process. Energy costs and environmental regulations require operators to more actively manage energy consumption, emissions and the plant's carbon footprint. Hot gas expanders can play an important role in 'greening' the refinery operation.

Although the rationale for installing an expander is becoming more compelling, many refinery managers and engineering contractors still find themselves in a position of evaluating a system about which they have relatively little experience. Thus the decision on how to implement an expander solution in a refinery requires a high degree of technical support and education from the supplier. A one size fits all, flange to flange approach to specifying and installing a hot gas expander is less helpful and less effective than a collaborative dialogue with a manufacturer who thoroughly understands the FCC process and environment. Under these circumstances, refiners and engineering procurement contractors (EPCs) today are turning to Elliott for the majority of new expander solutions; solutions built upon 60 years of experience, superior ROI, and superior reliability over an extended product lifecycle.