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Rerating rotating equipment optimizes olefins plant performance

The operators of mega ethylene plants are under constant pressure to meet enhanced performance specifications and more stringent environmental regulations, while, at the same time, reducing energy costs and improving feedstock flexibility. As ethylene plants have evolved in response to market demands (FIG. 1), technical advances in rotating equipment have boosted operating ranges and performance parameters for the centrifugal compressors and steam turbines—both are at the heart of ethylene plant operations. When considering the effect of changing market conditions on plant performance, particularly feedstock flexibility, producers must first evaluate changes to gas composition and process parameters in light of the plant's existing turbomachinery.

Rerating installed compressors and steam turbines can be a cost-effective, time-saving solution for increasing throughput without investing in new equipment. Advances in flow path design, stage performance, aerodynamics, manufacturing technology and materials science make it possible to achieve new process parameters within the existing casings, with minimal changes to foundations, piping and other connections. With careful planning, from review of process parameters through turnaround execution, equipment rerates can be accomplished during a normal maintenance shutdown.

The presented case study will discuss typical cracked-gas (CG) and refrigeration services within an ethylene plant, highlighting technical advances that make it possible to achieve new process parameters with rerated equipment. The case study focuses on a CG equipment train installed in an ethylene plant in the late 1960s that is still in operation due to multiple rerates to meet new processing requirements.

Cracked-gas service. CG turbomachinery configurations vary from installation to installation. CG trains usually consist of large-volume capacity compressors driven by high-power steam turbines. Generally, CG trains have two, three or four compressor casings and sometimes a speed-increasing gear between the casings, as shown in FIG. 2. The most common arrangement is three casings. Three-compressor trains include a double-flow compressor for the low-pressure (LP) section. Three- and four-compressor arrangements provide more flexibility when considering process changes than a two-compressor train. In most cases, interstage pressures can be modified to accommodate the change in casing flow and head to optimize total performance.

Refrigeration service. Refrigeration compressors are single-casing configurations with multiple side streams or side loads and/or extraction streams, as shown in FIG. 3. Propylene compressors are generally larger volume than the corresponding ethylene compressor. However, both applications require unique analysis when evaluating side-stream mixing performance to ensure that required interstage pressures and flows can be met. Refrigeration compressors have multiple nozzle connections that make the ability to reuse the casings a project objective.

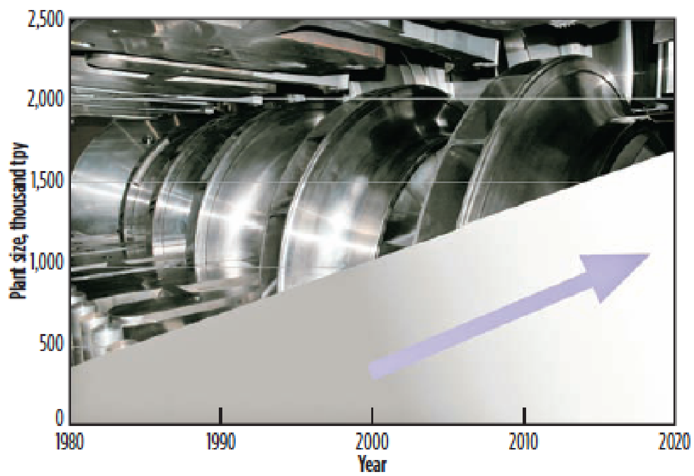

FIG. 1. Growth trend in ethylene plant capacity.

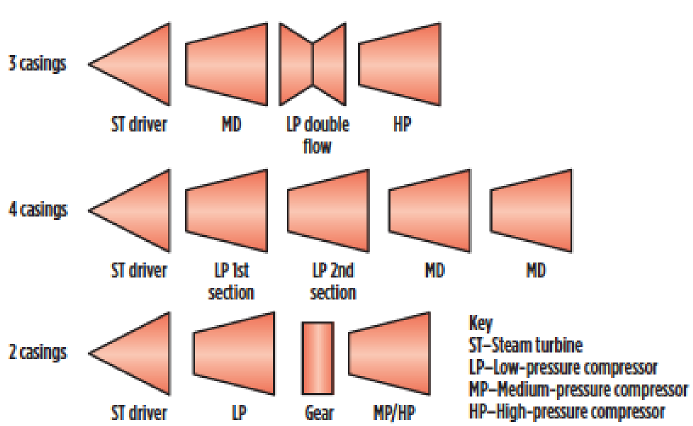

FIG. 2. Typical CG train arrangements.

Advances in compressor technology. Centrifugal compressors, by design, cover a wide range of flow capacities. The development of impeller "families" has enabled a wider flow range within a given compressor model. Since the 1960s, impeller efficiencies have improved from 65% to nearly 90%, and the range of flow has doubled. This broadened flow range, coupled with the development of improved compressor stage head and efficiency, has dramatically expanded a given compressor's operating range, as illustrated in FIG. 4.

Rerating installed compressors and steam turbines can be a cost-effective, time-saving solution for increasing throughput without investing in new equipment.

Compressor design technology has advanced through the use of tools such as computational fluid dynamics (CFD), finite-element analysis (FEA), solids modeling and rotor dynamic analysis. These tools enable design engineers to model a three-dimensional view of the aerodynamic flow path and the effects that design will have on overall performance.

CFD analysis can be used to create impeller stage ratings. Higher and lower flow stage ratings are derived from the tested components to form a family of stages. Within each family, impeller geometry is fixed. Blade heights are varied for higher and lower flows. Stage analysis results are continuously checked and verified against actual aerodynamic performance and field tests. This allows the design engineer to match impeller performance and stationary diaphragm performance to achieve optimum overall stage performance. By creating and extending impeller families, the application engineer can now select from several impeller designs to optimize stage-to-stage performance throughout the compressor aerodynamic flow path.

Refrigeration compressors usually have multiple sidestreams that require accurate prediction methods. CFD analysis has enhanced the designer's ability to accurately optimize the mixing of two flows while minimizing pressure drops for more reliable performance prediction. Propylene compressors represent a particular challenge when rerating an existing unit. In many cases, with multiple side streams, there may only be a single impeller in a specific section, for which the end user provides a pressure tolerance. The ability to select from various impeller families improves the likelihood that a solution can be achieved.

Improving the performance of the entire flow path also requires consideration of all of the stationary components including the diaphragms, seals and casing volutes, as shown in FIG. 5. For example, diaphragms are milled and bolted to eliminate rough surface finishes inherent with older cast technology. Interstage sealing is accomplished with abradable and deflection-tolerant interstage seals to maintain efficiencies for longer periods. These advancements in stage performance make it possible to reuse existing compressor casings with minimum impact on the equipment train driver. Improve-

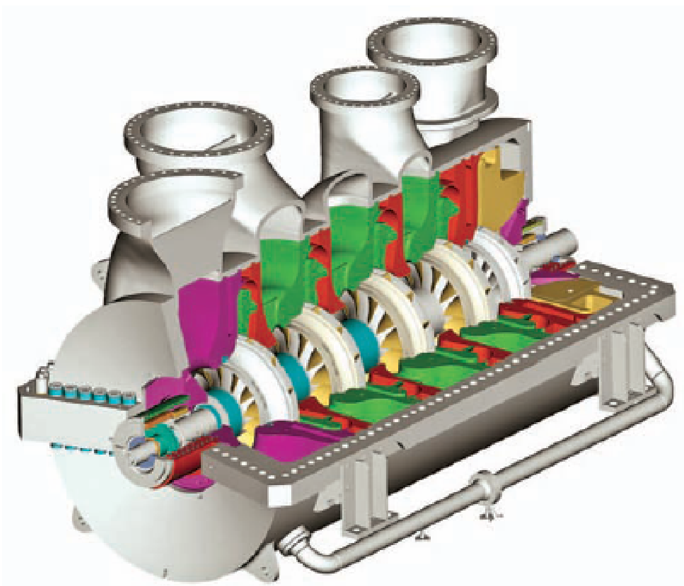

FIG. 3. Refrigeration compressor with multiple side streams.

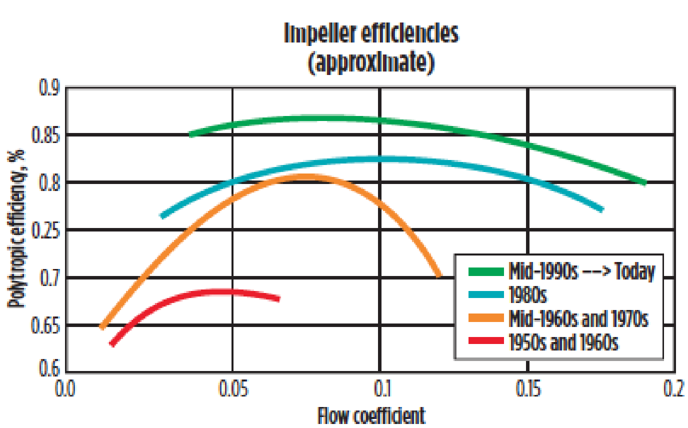

FIG. 4. Evolution of impeller performance.

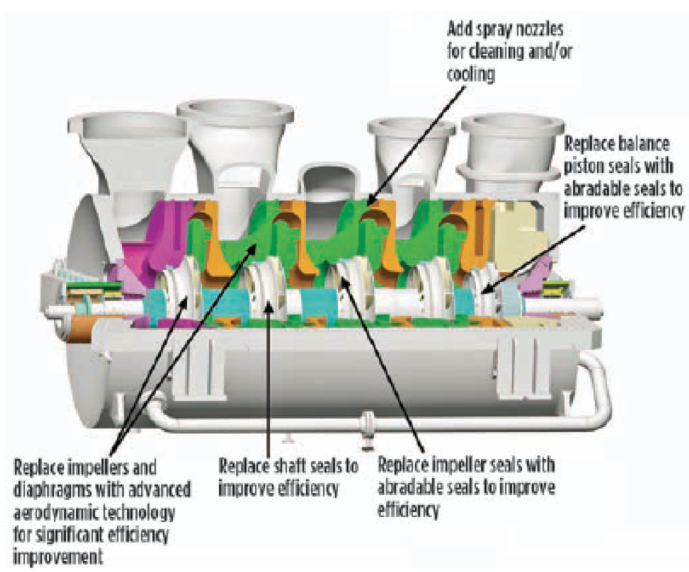

FIG. 5. Typical compressor component upgrades.

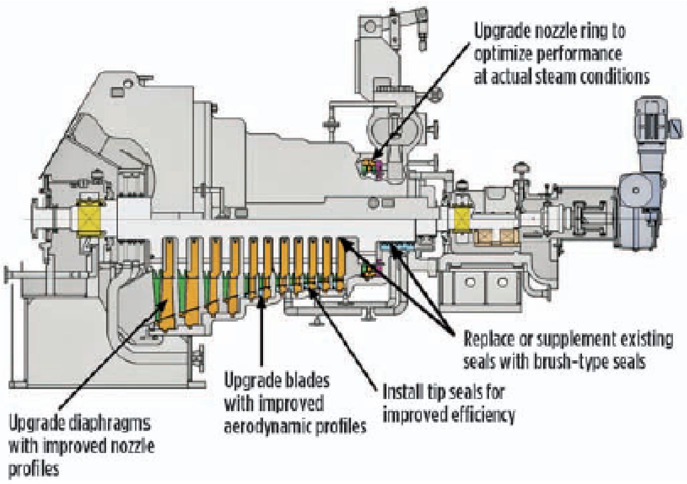

FIG. 6. Typical steam turbine component upgrades

ments in manufacturing technology have also contributed to improved compressor design performance. For example, five-axis milling techniques allow high-performance impeller blades to be used for higher flow and/or head to expand a compressor's operating range.

Advances in steam turbines. Significant plant capacity increases that result in higher compressor flow—and, therefore, power—cannot be achieved without a correspondingly significant increase in steam flow. Steam turbine drivers must use the existing steam operating conditions to match the rerated compressor train speed. Casing size limitations provide unique challenges to reconfiguring the existing steam flow path to achieve the desired power and speed.

CG and propylene drivers are usually high-power units that may require significant changes when the compressor power has increased. Even with improvements in stage efficiencies over the years, an increase in power usually requires an expanded steam flow area inside the turbine, which may or may not be possible within the physical limits of the existing casing. Additional modifications to the existing aerodynamic flow path, such as removing stages, are usually required to increase the steam flow area.

CFD analysis and other analytical tools have advanced performance and reliability in turbine component design, specifically rotating blades and stationary diaphragms. CFD analysis on high-pressure (HP) and LP staging is used to optimize both the rotating and stationary turbine components. Additional improvements include replacement of labyrinth seals with brush-type seals and tip seals (**FIG. 6**).

Case study. This case study references an ethylene plant that was originally built in the late 1960s with a two-body CG compressor train, as shown in **FIG. 7**. Over the years, the LP compressor was rerated three times prior to this project, and the HP compressor and steam turbine driver were rerated

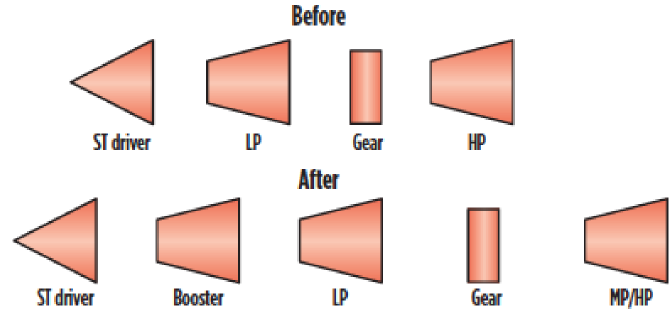

FIG. 7. Rerate case study: Before and After.

twice. These earlier rerates increased plant operating flow and power by 55% over the original installation specifications.

Recently, the end user decided to change the plant's feedstock and to expand the plant capacity by an additional 58%. The owner asked the compressor's original equipment manufacturer (OEM) to conduct a feasibility analysis. The OEM worked closely with the end user, the engineering contractor and the ethylene process licensor to evaluate process conditions and develop a solution.

Early in the analysis, it became clear that such a large flow increase would require installing a booster compressor to reduce the volume flow into the existing units. Reducing the volume flow to the LP and HP compressors allowed these units to be rerated yet again for a fourth and third time, respectively. To meet the required increase in flow and to accommodate the feedstock revision, the LP and HP compressors required all new rotors and stationary components, but with a reduced number of stages in each unit.

Advanced high-performance impeller technology was used to achieve the expanded flow requirements while limiting the overall train power to an increase of approximately 35%. This allowed the steam turbine driver to be rerated for the third time. The steam turbine also required a new rotor and new diaphragms, with a reduced number of stages.

The end user was able to achieve its operating objectives for capacity increase and feedstock flexibility while minimizing site work and reusing the existing casings, with minimal investment in new turbomachinery hardware. From the original plant installation in the late 1960s, the total train power has increased by more than twice the original design. Application of the latest in compressor and steam turbine technology has enabled the existing compressors and steam turbine to remain in operation for nearly 50 years. HP

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