Uprating Feasibility Studies for Turbocompressors in Refinery and Chemical Processes

Improving Existing Equipment

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With long-standing experience of rerating and upgrading turbomachines, Sulzer Turbo Services adapts older turbomachines to the requirements of modern chemical or petrochemical plants, providing savings in both cost and time to the customers.

New turbomachines are designed to maximize performance at the design point with mechanical and hydraulic margins being just sufficient, allowing little room for change. Older machines, on the other hand, have a robust design, large margins in the casings and structural components, and operate at comparably low rotational speeds. They are therefore ideally suited for modifications or new service applications.

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Generally, turbomachines transfer energy between a rotor and a fluid. Whereas a turbine transfers energy from a fluid to a rotor, a compressor transfers energy from a rotor to a fluid and increases velocity or pressure of a gas. Turbocompressors are the primary component of many industrial processes, e.g., air-separation units, inorganic chemical plants, natural-gas installations, petrochemical plants, refineries, or refrigeration plants (Fig. 1).

1 Almost all industrial processes require turbocompressors. The picture shows a refinery. Sulzer Turbo Services adapts existing machines to changing process requirements.

Upgrading Existing Equipment

Older turbomachines were designed to outlive the facilities they were originally installed in and to be flexible during their operational lifetime. During the lifecycle of a typical process facility, quality or type of the feedstock can change and type of product or capacity requirements may vary. Newer machinery trains run at speeds very close to the mechanical limits of the impeller materials and are designed for small operational windows. Their impeller diameters are usually at or near the maximum diameter for the casings, and the casings are just large enough to accommodate the existing aero assembly, leaving very little room for changes.

Reduced Delivery Times

Today, delivery time for new machinery trains can be longer than 24 months. For that reason, there is a renewed interest in the upgrading of casings and components for both facility upgrades and new projects. For rerated compressors, delivery time from order placement is usually just half of that of new machines, and the savings relating to civil works can be quite attractive.

The experts of Sulzer Turbo Services can evaluate a used compressor to determine its suitability for rerating using a systematic process which considers both the existing and required operational conditions. The minimum data needed for this first review are inlet pressure, temperature, flow rate, relative humidity, and gas properties (compressibility, molecular weight, and specific heat capacity) for each condition. Specific heat capacity is the measure of the heat energy required to raise the temperature of a specific amount of a substance by 1 degree Kelvin. The desired final pressure is the only required value for the discharge side.

Initial calculations yield discharge temperatures, power requirements, and rotational speed. Calculated data are compared with actual field measurements or operational records and adjusted to match efficiencies, speed, and power. The comparison of the new operating point with the original operational compressor data delivers the magnitude of the changes required. Inlet and exit nozzle sizes determine the final limits for the casing and the available area for the increased volume flow to pass without choking or exceeding the permissible velocity limits. If the casing can handle the new flow requirements, then the Sulzer engineers can start a detailed evaluation.

Quick Prestudy

One simple equation governs the flow rate and the 3 quantities that can be changed in order to increase the volume flow: flow area, flow velocity, and gas density (Fig. 2).

Changing the flow area is the most complex method of increasing the flow rate. This measure implies a new aero assembly including im-

Flow Rate (kg/s) = Flow Area (m^2) × Flow Velocity (m/s) × Gas Density (kg/m^3)

2 Flow area and velocity as well as gas density determine the flow rate. In order to increase the flow rate of a compressor, at least 1 of the 3 quantities has to be increased.

pellers, diaphragms, and structural parts. An increase of the flow area is accomplished by wider impellers, impellers with larger diameter, new impeller blade designs, larger diffuser passages, or a combination of all of these. The new parts only have to fit in the old casing space.

Vane profiles designed and manufactured using modern tools are called 3D designs because the blade profile also varies normal to the main flow direction (Fig. 3). The increased active surface of the blade provides additional velocity and volumetric capacity to the stage, as well as an improvement in the per-stage efficiency. These profiles allow maximum flow coefficients of 0.15 as compared with the 0.075 for older 2D types. Thus, just 3 stages with 3D impellers can replace 4 stages of an air compressor with 2D impellers, achieving the same result with 7–10% less power consumption. The reduced mass (one stage less) is the major cause for the power savings in this example (Fig. 4).

Minimal Modifications

The advantage of the above example is that the increased compressor capacity is available without having to revise the installation. Modifications to the foundation and auxiliaries are minimal, and the machine internals can be replaced during a normal outage window. Process seals, bearings and protection systems are usually upgraded at the same time.

Flow velocity is increased by increasing impeller diameter or rotational speed of the unit. The stationary compressor sections convert the increased velocity (kinetic energy) of the gas at the impeller outlet to higher head (potential energy). This procedure gives the same result as an increase in the actual flow coefficient.

A 1% increase in speed corresponds to an increase in the flow rate of about 3%. The mechanical strength of the rotating parts, rotordynamic response characteristics, and reductions in the assembly interference of impellers and couplings determine the final design limit.

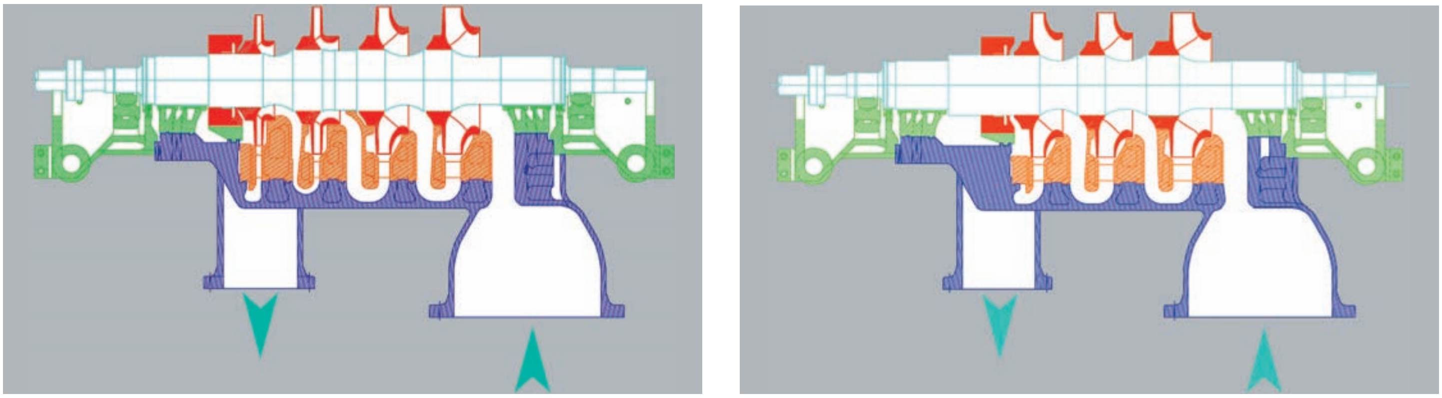
Both of the cases above will affect the plenums and piping attached to the compressor nozzles, as the higher flow velocities in the casings increase the friction losses downstream. Combinations of these 2 methods have resulted in flow increases of over 430% compared with the original unit.

Increasing Gas Density

Gas density can be increased in several ways including suction boosting and refrigeration of the inlet gas—the latter is an extremely expensive solution rarely used. Suction boosting is the addition of a single stage, high flow, high Mach-number blower upstream of the compressor suction flange with an intercooler to maintain nominal suction temperature (Fig. 5). This solution requires sufficient space to install new equipment, piping, controls, and auxiliaries without requiring extended downtime for the civil works.

The largest advantage of suction boosting is that no changes to the main compressor unit are required

3 Modern tools allow designing complex blade geometries. Impellers with such new blades have higher capacity and efficiency than older machines with 2D blades (right).



4 Original 4-stage compressor and new aero bundle with 3 stages in the same casing (right).

to change the system capacity. Capacity increases of 110–220% are possible depending on pressure ratio and booster flow Mach number. In the event of a blower failure, the compressor will settle back into its original performance envelope.

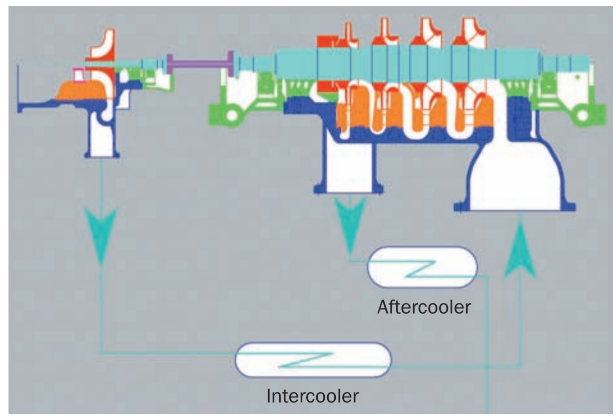
All Costs Considered

After choosing the desired method in cooperation with the customer, the Sulzer engineers assess the impact on the remaining train components. All auxiliaries and the driver must be evaluated for existing operational limits and suitability for use in the new configuration. Increases in flow rate or discharge pressure (head) demand a higher power consumption by the compressor. In the case of a motor drive with ample margin, exchanging the gear set in the speed increaser is sufficient. A steam turbine drive may require partial or full replacement of the internals to support the new power requirement.

Other critical points include the oil system, seal systems, drive couplings, boiler and steam-piping capacity, condenser and condensate removal systems, location and capacity of high-voltage electrical distribution centers, transformers, control systems, and downstream control volumes.

Information Early in the Process

When looking at the overall costs and benefits for the rerate of a unit it is important to include all of the significant costs. Sulzer Turbo Services shows the actual cost of the engineering and the price for the revision parts as separate line items. If a specific project is still interesting for the facility after the first evaluation, the detailed engineering studies can be contracted to determine the exact changes needed to each component. These studies include thermodynamic layout for the new requirements, impeller selection, stress calculations, material selection, and power requirements. With this 2-step procedure applied by Sulzer Turbo Services, the customer can gather maximum information about rerating potential of a specific compressor at minimal cost and very early in the process of planning a plant upgrade or new plant. ◀



5 Booster compressor with inlet guide vanes and intercooler added to the original compressor train.

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