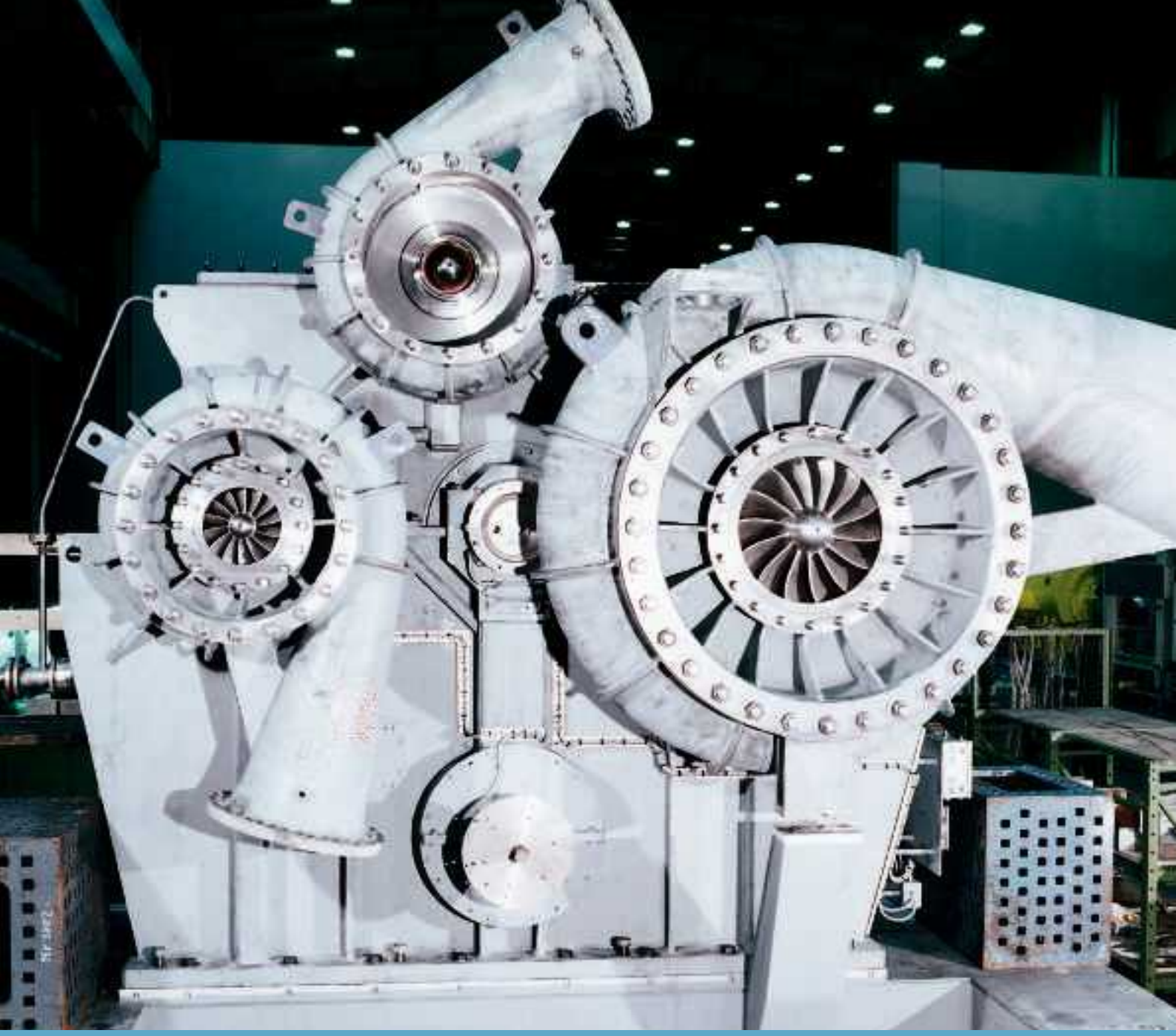

Turbomachinery for Terephthalic Acid Plants

Engineering the Future – since 1758.

MAN Turbo

250 years

MAN

Turbomachinery for terephthalic acid plants

Terephthalic acid is currently gaining in importance as a feedstock for polyester, with a sharp increase in demand being experienced.

The principal machine used for this oxidation process is the air compressor. Exhaust gas is utilized for energy recovery purposes in a gas expander, while the heat produced in the process is used to generate steam. Most of the power required for the compressor is produced by the steam turbine and expander; the remaining power may be power demand or surplus power which is balanced by a motor-generator.

Experience

MAN Turbo played a major role in developing and optimizing the engineering aspects of the processes involved here and is therefore one of the leading manufacturers of the core component of such installations – the turbomachinery train. MAN Turbo built its first large turbomachinery train back in 1977 for a plant with a capacity of 300,000 tonnes of terephthalic acid per annum. As the demand for PTA grew at the end of the 1980s, MAN Turbo played a critical part in developing and optimizing the machine train further.

The requirement for compact, efficient, low-cost machines was met as follows:

- The compressor was developed as multi-shaft integrally geared type, driven directly by the steam turbine;
- The expander was likewise designed as integrally geared machine with highly efficient radial-flow turbine stages and respectevily as axial type for high temperature off-gas.
- The steam turbine with several admissions and at least an axial exhaust casing to reduce machine house height.

MAN Turbo has now built many machine trains of this kind for virtually every PTA process and is thus one of the principal manufacturers in this field.

Versatility

- As a supplier of axial and centrifugal compressors as well as steam turbines, gas turbines and tail-gas expanders, MAN Turbo has the most comprehensive turbomachinery programme in the world.
- Besides turbomachines for PTA plants, MAN Turbo supplies compressors and turbines for a large number of processes.

Air compressor

The air compressor used today is a multi-shaft integrally geared compressor, with up to three pinion shafts arranged around a central bull gear for these applications.

Impellers are overhung on the end of each pinion shaft. Each impeller has its own volute casing bolted onto the gear case; with larger stages, additional support is provided for the volute casing. The air compressors can have 3 to 6 stages depending on the process conditions. The overall machine efficiency is excellent thanks to axial intake in each stage, the optimum speed for each pinion shaft and the option of interstage cooling.

The first four impellers are normally unshrouded, milled impellers of stainless steel with twisted blades. Due to the possibility of higher leakage rates, the final stages have a shroud disc with cylindrical blades.

Varying the diameter, outer contour, exit angle and circumferential velocity ensures that the impellers are matched precisely to the process conditions, meaning that MAN Turbo geared compressors always operate at optimum efficiency and within the maximum working range. Process conditions are normally controlled via adjustable inlet guide vanes (stages 1-4). Control can also be effected by means of speed adjustment if a steam turbine features in the train.

To seal off the compressed air from the atmosphere, labyrinth seals are used in the initial stages, while carbon ring seals are employed in the later stages. The impellers are locked to the pinion shafts by so called Hirth serrations.

The individual pinion shafts run in segmental sleeve bearings. Back-to-back arrangement of the impellers on the shafts ensures that the thrust is largely neutralized, any residual thrust remaining being transmitted to the bull gear by means of thrust collars. A thrust bearing is provided to accommodate axial forces in the bull gear. For cases where a turbine is included in the train, MAN Turbo has developed a special design element – the 4th pinion shaft. This stub shaft is fitted in the lower area of the bull gear and connected directly to the steam turbine.

For large compressors the compound gear design was established; where as the 4th pinion is located between the bull gear and the first pinion.

The 4th pinion shaft offers the following advantages:

- Compact construction
- Smaller losses
- Reduced oil consumption
- No additional casing required
- Fewer bearings
- Fewer couplings and
- Fewer spare parts.

Expander

The expander is designed as a geared machine for lower off-gas temperatures and as an axial machine for temperatures above 450 °C. The materials for each individual element are naturally adapted to the aggressive gas. The gas chambers are sealed externally by labyrinth seals with intermediate chambers for buffer air.

The MAN Turbo integrally geared expander

Generally the two stage expander is equipped with radial type impellers. As with the compressor, the pinion shafts are arranged on the bull gear in the central plane. The gas flow is directed through a volute casing bolted onto the gear case via adjustable inlet guide vanes (wide operating range, process pressure control) into the first impeller. Axial discharge via downstream pipelines is to a reheater, in which the gas is heated up again. It is then conveyed via pipes and volute/ guide vanes to the second impeller, before passing out into the atmosphere via a stack.

The MAN Turbo axial expander

The axial expander design is of a horizontal split casing and a solid forged rotor usualy equipped with 7 axial stages. The gas enters the expander from the bottom and leaves the gas on the top. The control is by means of variable inlet guide vanes on the first stator blade row.

Steam turbine

The process releases large quantities of heat, which are used to generate steam. In terephthalic acid plants this occurs as saturated steam. MAN Turbo builds condensing steam turbines of the reaction type with and without sidestream admission for this purpose.

The MAN Turbo modular system

For the most important subassemblies of MAN Turbo steam turbines, such as bearing housings, the control valve/nozzle chest, control-wheel casing and exhaust casing, as well as for the connecting elements, a modular system of geometrically graded component sizes has been developed. Combining the various modules in an optimal manner permits flexible adaptation of the machine to the specific duty.

To ensure that the blading is free from vibration resonance throughout the speed range, a thick cylindrical drop-shaped profile with an integral shroud band was developed for the rotor blades in the reaction part of the turbine. This profile is extremely robust and can be used within a wide stagger angle and pitch range. The availability of this range of blading in different chord lengths permits to safely avoid resonance vibrations through the correct combination of the blading from the modular system. The tapered, twisted rotor blades of the final stages and tapered non-twisted stator blades are also selected from a similar standard blade range. The rotors are forged from a solid piece and balanced when fully bladed at full operating speed under vacuum conditions in several planes.

Motor

Prior to the start of the process, no off-gas or process steam is available. To be able to start up the machine train and deliver air at the required process pressure, a motor is required, when no boiler steam or external steam for steam turbine start is available.

By improving the efficiency of individual machines and the processes, it has proved possible in most plants to ensure that the power of the turbine/expander is higher in normal operation than the requirement of the compressor, i.e. the motor then operates as a generator.

Base frame/steel foundation

Generally machines are installed on individually base frames for installation on purchaser's concrete foundation.

The entire machine train can also be shop-mounted on a common steel foundation; this offers the following advantages:

- All installations and assembly work, including piping between stages and coolers as well as cabling, carried out in the manufacturer's works
- Easy handling during string testing
- Less time for erection
- Simplification of other local work.

Control and safety equipment

A complex machine train makes very great demands on the control and protection systems in terms of quality and flexibility. Such systems must consider the requirements of the process and provide all functions from start-up to emergency shutdown of the machine train and process. MAN Turbo has developed electronic control and protection systems.

Anti-surge control (turbolog ASC)

In the performance characteristics of a turbocompressor the surge line is the dividing line between ranges of stable and unstable operation. Reduction of the volume flow rate beyond this line causes separation of flow from the blading, causing the gas to flow periodically from the discharge to the suction end of the compressor – a phenomenon referred to as compressor surging. The resultant extreme load reversals and temperature fluctuations in the gas-handling components of the machine must be avoided. This is the task of the antisurge control, a system which, by controlled opening of the blow-off or bypass valves, always keeps the compressor flow rate in the stable range of the performance characteristic. Specially developed by MAN Turbo for this purpose is the electronic control and protection system called “turbolog asc” is on Simatic S7 hardware as MAN Turbo standard.

This system incorporates components which greatly improve the dynamic response of the controller and thus allow the distance between the blow-off line and the surge line to be minimized; surging is safely prevented under all operating conditions.

In addition to anti-surge control, an independent surge detector is provided on MAN Turbo compressors. During surging the mass flow rate temporarily drops to zero and the temperature suddenly rises. Both values are measured by the surge detection system, and if one of them passes a limiting level the blow-off valves are opened and, where necessary, the machine train is shut down.

Speed control (turbolog STMFC)

To allow the speed of the train and thereby the pressures and flow rates in the process to be controlled and the machine train to be protected against overspeed, MAN Turbo has developed the turbine control and protection system “turbolog” based on Simatic S7 hardware.

This system provides control far superior to the requirements of NEMA specification SM 23, class D. Depending on the specific requirements, it is designed for any of the following functions:

- Turbine speed control
- Speed-controlled starting of the turbine from standstill
- Combined control of speed and extraction pressures
- Back-pressure control
- Inlet pressure control
- Power output control.

Overspeed detection unit

The most important safety device of a steam turbine is a fully testabel overspeed tripsystem. Applicable rules (API, German VGB) require, that the overspeed detection unit is independent from the speed governor. MAN Turbo provides a triple modular redundant (TMR) overspeed trip system (Braun).

Workshops

To meet today's demands for high quality, economic production and short delivery, advanced workshops qualified to the latest standards are required.

The new fabrication shops and test facilities of MAN Turbo’s turbomachinery sector satisfy these requirements in every respect. High-capacity working facilities have been combined in fabrication isles for an optimum flow of materials, including equipment for the machining of casings, blade fabrication, impeller fabrication, rotor machining, and assembly.

The main machining operations are performed by CNC machine tools. The machine tools incorporate the latest technology.

Complete PTA trains with job steel foundation can be erected and tested at the same place.

Test facility

MAN Turbo owns and operates different testbeds for turbomachinery in order to execute factory acceptance tests. One test centre for compressors, steam, process-gas and industrial-gas turbines as well as for individual components has been integrated into the production shops.

Machines/machine trains are completely assembled in the assembly bay and subsequently transferred to the adjacent test stand by two 80 t cranes.

After erection on the 44 m long steel foundation and connection to the permanent piping systems (steam, air, water, oil), all kinds of tests to DIN/VDI/ASME/API can be conducted:

- Mechanical testing of the individual machines
- Mechanical testing of a complete machine train
- Thermodynamic testing with air and other gases in open or closed loop systems.

The drivers used during testing are either those supplied under a particular contract or the various test stand drivers which are available, i.e.:

- An 18 MW condensing steam turbine
- One 6.5 MW and two 2.5 MW variable-speed motors which can, if necessary, be coupled together.

In 2004 an additional packaging and test centre for large strings was commissioned.
It is now possible to work on up to three machine trains at the same time, on an area of over 4400 square meter. Modules up to 600 tonnes are by no means an exception.

Two cranes, each capable of lifting 150/180 tonnes, and with a crane hook height of over 17 metres, guarantee the necessary flexibilty in the machine assembly and testing.

This test bed includes a cooling water circuit with three cooling towers, a 20 MW electrical power supply in addition to the steam supply (50 bar, 500 °C, 55 t/h).

Quality assurance

MAN Turbo's Quality System complies with ISO 9001 and is the basis for the reliability of the company's high-quality products.

The QA division, which reports to the Chairman of the Executive Board, initiates, coordinates, and monitors all activities affecting quality, while also issuing, and controlling the compliance with, QA Manuals and Procedures, such as:

- Design
- Material procurement
- Production planning
- Fabrication
- Functional tests
- Procedural qualifications
- Calibration of gauges and test equipment.

Main points of an inspection plan for a machine train in a terephthalic plant:

- Testing of specimens taken from workpieces of machine components
- Ultrasonic examination after rough machining and finish-machining
- Magnetic-particle testing
- Dye-penetrant examination
- Radiography
- Dimensional and visual examination
- Heat stability testing
- Hydrostatic testing
- Overspeed testing
- Run-out measurement on rotors
- Clearance measurements

Erection and service

All erection and service activities for MAN Turbo machine trains are carried out by MAN Turbo's centralized machinery service sector.

Service activities ensure the greatest possible availability and operational reliability of MAN Turbo turbomachinery even after many years of operation.

This objective is pursued through

- The use of meticulous erection procedures,
- Thorough commissioning/trial operation,
- Regular inspection,
- Preventive maintenance,
- Fast repairs,
- Readily available spare parts and intensive advisory services.

The company's service consultancy team further ensures expert feedback on a regular basis to promote the consistent development of MAN Turbo's products and services.

The following provisions have been made to ensure comprehensive service to our customers:

- A close-knit network of representatives in many countries of the world
- Service outlets at strategic points
- An independent service workshop at the company's Sterkrade works.

An emergency service is available at Sterkrade outside normal working hours.

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