Total Train Capability

Dr. Gerd-Ulrich Woelk, Dr. Heinrich Voss

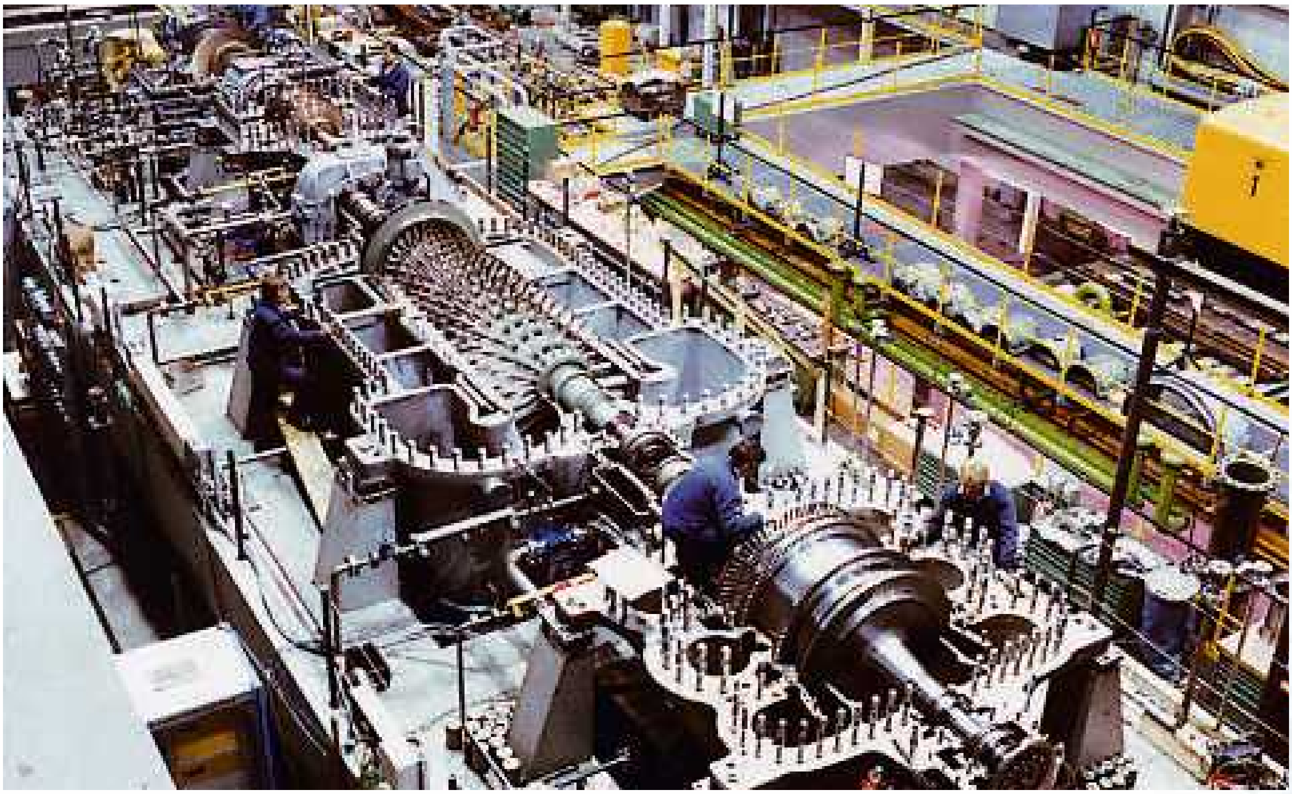
Engineering the Future – since 1758.

MAN TURBO

250 years

MAN TURBO: Total Train Capability

Dr. Gerd-Ulrich Woelk, Dr. Heinrich Voss



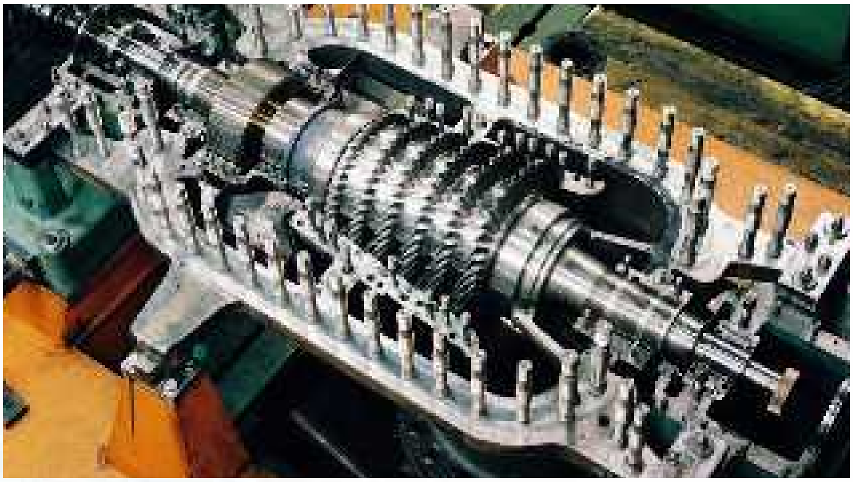
01 Machine set of a large nitric acid plant with double-flow process gas turbine

A number of chemical and petrochemical processes feature various material flows that have to pass through different process stages at set pressures and temperatures. The machine sets used in these processes normally consist of one or more turbocompressors of the same or different design to create the required pressures in the process, a prime mover in the form of a steam turbine or an electric motor and a process gas turbine if tail gas is available.

In certain cases – for example, at high gas temperatures, or where highly corrosive gas or large volume flows occur - this process gas turbine for utilising the energy contained in the tail gases can be particularly important with regard to the design and configuration of the overall train. The energy recovered via the process gas turbine then supplies a portion of the drive power for the compressors in the train, resulting in a prime mover with a correspondingly lower output.

The continuing development of process technologies, and in particular the steady increase in plant size, necessitate ongoing adaptation and optimization of the machines used. This applies to both the compressors and the prime movers.

This will be illustrated for example by machine sets for nitric acid, terephthalic acid, air separation and FCC (Fluid Catalytic Cracking) plants. Thanks to its extensive product range, MAN TURBO is capable of delivering all the turbomachinery in these trains for the process industry from a “single source”. The resulting advantages for the customers are highlighted below.



02 Process gas turbine of a nitric acid plant (single-pressure/high-pressure process), view on split flange

Turbomachinery trains in nitric acid plants

Nitric acid (HNO_3) is highly important as an intermediate product for the chemical industry, e.g. for the manufacture of nitrogen fertilizer and synthetic fibres. Plants have grown in size to cope with the increase in demand: whereas daily production was running at 33 to 100 tonnes during the years from 1930 to 1945, it is now 1,000 to 1,500 tonnes per day.

On an industrial scale, nitric acid is now manufactured from ammonia (NH_3), which is oxidized using air in the presence of platinum catalysts. The nitrogen oxides contained in the combustion gases are converted almost completely to nitric acid using water in an absorption tower. Since the reactions take place under pressure, a compressor group is required.

The core of nitric acid plants is thus formed by a turbomachinery train, normally consisting of an air compressor, nitrous-gas compressor, process or tail gas turbine and steam turbine. The chemical reactions involved in nitric acid production are exothermal in nature; the heat released is used to generate high-pressure steam, which is used mainly to feed the steam turbine.

The tail gas emerging from the absorption tower essentially contains nitrogen, small amounts of oxygen and water vapour and traces only of nitrogen oxides. It is expanded to roughly atmospheric pressure via the process gas turbine and discharged via a stack. In energy terms, the turboset is virtually self-sufficient, i.e. it is operated without the use of additional energy.

MAN TURBO has for many years been one of the world's leading manufacturers of machinery trains for nitric acid plants, especially following the merger with Sulzer Turbo in 2001. About 900 turbomachines have been supplied in the last 40 years for over 300 installations, including machines for the largest plant in the world, with an output of 2,000 tonnes per day. **Fig. 1** shows a similar machine set with a double-flow process gas turbine (in the foreground).

Various processes have evolved with regard to the pressure level for the process as a whole or for individual steps:

- Single-pressure processes, i.e. all reactions take place at roughly the same pressures. At 4 to 6 bar these are intermediate-pressure processes and at 8 to 13 bar high-pressure processes.

The intermediate-pressure process is preferably used for small and medium-sized nitric acid plants (with capacities of up to about 600 tonnes per day), while the high-pressure process is employed mainly by American engineering companies and utilizes process gas turbines that have gas inlet temperatures of between approx. 500 and 750 °C, **Fig. 2**.

03 Turbomachinery train of a nitric acid plant (dual-pressure process)

In installations that operate according to the intermediate-pressure principle, the process gas turbine is responsible for 30 to 50 % of the compressor drive power. If the high-pressure process is used, this figure can be increased to around 65 % in the case of turbine inlet temperatures of about 500 °C and to over 80 % for a temperature of about 600 °C. If the tail gas temperatures are increased by additional firing up to values between 700 and 750 °C, the process gas turbine can provide the entire compressor drive power.

- Dual-pressure processes operate either with ammonia combustion at atmospheric pressure and absorption at 4 to 6 bar or with ammonia combustion at 4 to 6 bar and absorption at 10 to 12 bar.

In the first case, the turbomachinery train consists of an uncooled axial or centrifugal nitrous-gas compressor, a steam turbine or electric motor and a process gas turbine, which covers between 30 and 65 % of the compressor drive power requirement depending on the temperature of the tail gases between 200 and 600 °C.

Fig. 3 shows the turbomachinery train of a nitric acid plant operating the dual-pressure process with ammonia combustion at 4.6 bar and absorption at 12 bar. This process is used primarily by European licensors of larger-capacity nitric acid installations producing in excess of 400 tonnes per day. The turbomachinery train consists of an axial-flow air compressor, a centrifugal nitrous-gas compressor, a process gas turbine and a steam turbine.

In dual-pressure plants with absorption at roughly 10 bar, tail gases are normally produced with temperatures of between 350 and 450 °C, producing roughly 60 to 80 % of the compressor drive input.

MAN TURBO's product range includes the machines required for all the processes mentioned.

For a long time the machines used were designed and built as single-shaft turbomachines, **Fig. 4**.

Companders in nitric acid plants

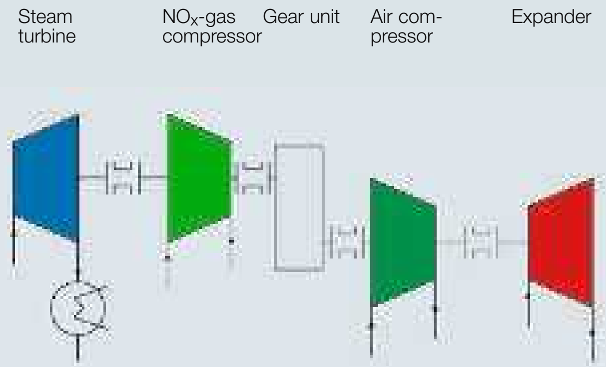
Following the introduction of multi-shaft gear type machines about 20 years ago, these were used only as compressors initially. If it was possible or necessary to recover energy from tail gases, the process gas turbine or expander in the machine set was at first just a multistage single-shaft machine or later a separate multi-shaft machine with axial or centrifugal stages on the gear pinions. Further advantages of multi-shaft technology resulted from the development of an even more compact and economical unit by integrating the expander stages into the gear unit configuration of the multi-shaft compressor: the compander was born.

The opportunity arose to use these new developments for an intermediate-pressure plant (single-pressure process) operating the Grand Paroisse process (without a nitrous-gas compressor), producing 500 tonnes of nitric acid a day.

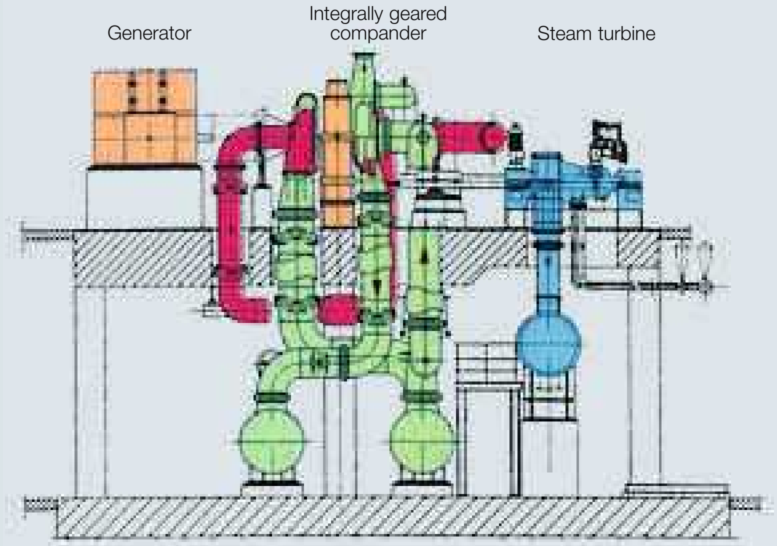
The machine train is consisting of a multi-shaft compander with three compressor stages for compressing the process air and two radial expander stages for recovering energy from the process tail gas, an extraction condensing steam turbine and a generator, **Fig. 5**.

The compander, the heart of the machinery train, was designed to facilitate the optimum speed for the first compressor stage together with the second expander stage and for the second compressor stage together with the first expander stage. The third compressor impeller – with the smallest outer diameter and highest speed – was mounted on a third pinion shaft above the bull gear, **Fig. 6**.

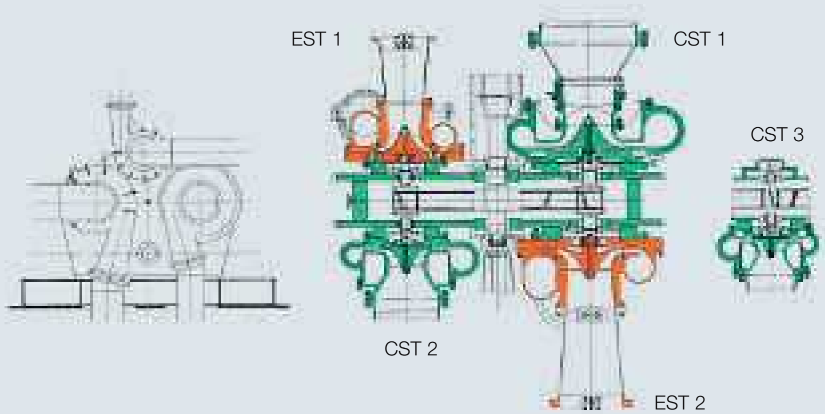
At the rating point, the expander stages cover roughly 64 % of the energy requirement of the compressor. The remaining power is supplied by the steam turbine. In this case, it utilizes the entire quantity of steam occurring in the exothermal process, driving both the compressor and the generator in the machinery train. The latter unit delivers 4,000 kW of electric power at 1,500 rpm. Since this electrical energy was valued relatively highly, the good efficiency rating of the multi-shaft turbomachine was used to full effect here.



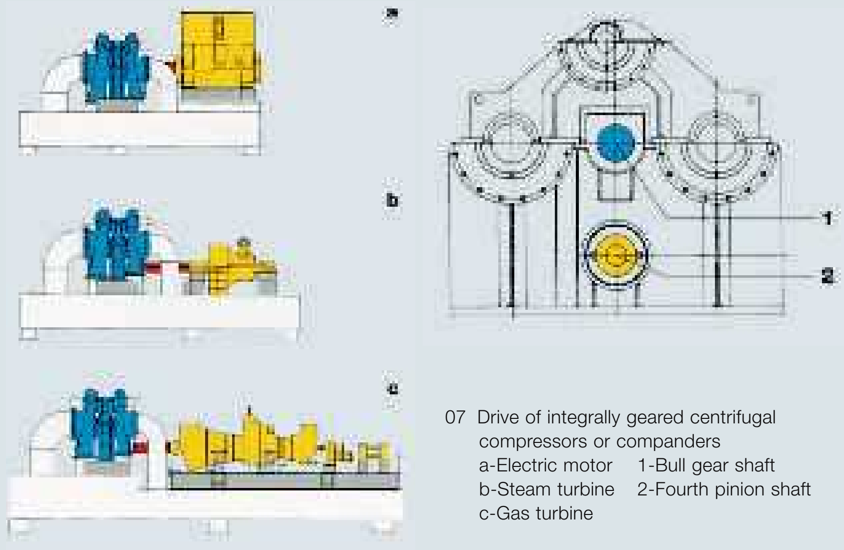
04 Machine set of a nitric acid plant, single-shaft technology (schematic presentation)



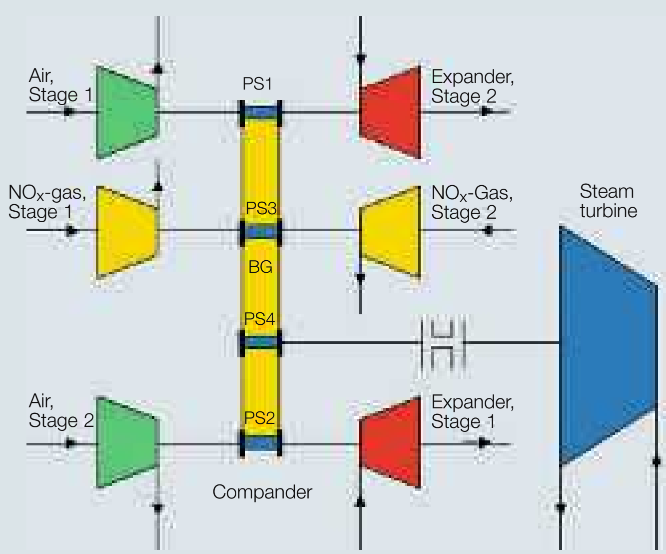
05 Machine set of a nitric acid plant, integrally geared technology



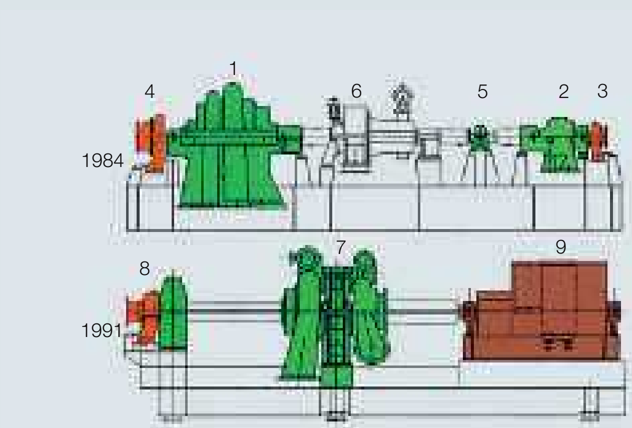
06 Compander comprising air compressor stages CST and expander stages EST



07 Drive of integrally geared centrifugal compressors or companders
a-Electric motor 1-Bull gear shaft
b-Steam turbine 2-Fourth pinion shaft
c-Gas turbine



08 Compander concept comprising air and nitrous-gas compressor stages and expander stages
BG-bull gear, PS-pinion shaft



10 Machine sets for a 150,000 tpy PTA plant based on single-shaft and multi-shaft (integrally geared) technology
1-Low-pressure compressor
2-High-pressure compressor
3-High-pressure expander stage
4-Low-pressure expander stage
5-Intermediate gear unit
6-Steam turbine
7-Integrally geared compressor
8-Integrally geared expander
9-Electric motor

The steam turbine output is transmitted directly to the bull gear via the pinion shaft located beneath it, without any external gear unit connected in between, **Fig. 7**. The generator is connected to the bull gear shaft via a coupling.

To be able to use a machine of this compact design also in processes employing the dual-pressure principle according to **Fig. 4,** the machine concept shown in **Fig. 8** was developed: the third pinion shaft lying above the bull gear takes up the two stages of the nitrous-gas compressor. The steam turbine output is introduced via the fourth pinion shaft.

Terephthalic acid plants

- From single-shaft to multi-shaft turbomachinery

Terephthalic acid, a dicarbon acid with the structure COOH-C_6H_4-COOH, is an important basic material in the manufacture of polyester fibres and various products for the packaging industry (e.g. films, containers, bottles). Due to the large demand, terephthalic acid is one of the world's most prodigiously produced organic chemicals and exhibits an upward trend, especially in the markets of the Far East. Processes in which paraxylene is oxidized using atmospheric oxygen have become the norm since the 1950s.

MAN TURBO played a substantial part in developing and optimizing the machinery used in the process and is thus one of the leading manufacturers of the core component of terephthalic acid plants: the turbomachinery train.

The principal machine used in this oxidation process is the air compressor. The off-gas produced by the process, normally consisting of over 90 % nitrogen with small amounts of residual oxygen and oxides of carbon as well as highly corrosive traces of acetic acid, terephthalic acid and bromides, is passed through an expander to recover energy. The resulting process heat is used to generate steam, which occurs in most cases in successive process stages as saturated steam at a corresponding pressure and temperature level. The steam is either expanded in a condensing steam turbine with admission options or mixed with the off-gas and then utilized together with this in the expander. The "off-gas" in this case then only comprises 40 % nitrogen, very small quantities of oxygen and carbon dioxide, and about 55 % water vapour along with the aforementioned highly corrosive traces of acids, bromine and bromides.

The steam turbine and/or expander provide the bulk of the power required in the compressor. The remaining power required and the power on startup of the train are provided by an electric motor or a motor/ generator, which depending on the balance of energy available while the process is operating can feed electrical power into the grid if there is an excess of power in the train.

Back in 1977 MAN TURBO built the first large turbomachinery train for a compact installation with an annual capacity of 300,000 tonnes, **Fig. 9**, consisting of:

- a low-pressure casing of the air compressor as an axial-flow compressor,
- a high-pressure casing as a centrifugal compressor with interstage cooling,
- single-stage axial-flow expanders overhung-mounted respectively on the two compressor rotors and
- a drive motor with two large gear units mounted on both sides.

The air aspirated from the atmosphere is compressed with double interstage cooling to 32 bar and fed into the process. The off-gas, at a temperature of 200 °C, is expanded in the high-pressure expander from 24 to 6 bar, reheated in an intermediate heater to 175 °C and expanded in the low-pressure expander from 5.3 to 1.15 bar.

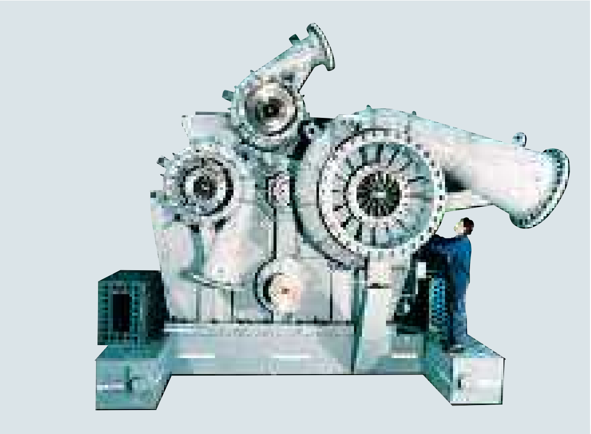
Around 40 % of the drive power for the compressors of 18,420 kW is supplied by the process gas turbines, with the rest being delivered by the electric motor.
This compact installation was designed, manufactured and tested by MAN TURBO in Oberhausen, then transported fully assembled and weighing 276 tonnes in all to the construction site in the UK.

When the demand for terephthalic acid increased in the late 1980s, MAN TURBO played a decisive role in further development and optimization of the machinery train to create more compact, efficient and low-priced machines.

Fig. 10 shows the move from single-shaft to multi-shaft technology in the case of terephthalic acid plants (PTA plants). PTA stands for Purified Terephthalic Acid.

The upper part of the picture shows a machine train designed in conventional single-shaft technology for a PTA plant with a capacity of 150,000 tonnes per annum in 1984.

09 Turbomachinery train for a terephthalic acid plant (compact module)



11 Air compressor for terephthalic acid plants

This machine train is made up of a six-stage low-pressure compressor with impellers with an outer diameter of 800 mm and a three-stage high-pressure compressor with impellers of an outer diameter of 400 mm for compressing atmospheric air to a discharge pressure of about 25 bar. Mounted on the outer shaft ends of the compressors in each case is an axial-flow high-pressure and low-pressure expander stage, respectively. The train also includes an intermediate gear unit and a steam turbine.

The design of a machine set of this kind, delivered in 1991 for a plant of the same size, has changed considerably, **Fig. 10 bottom**. The double-casing centrifugal compressor has been replaced by a six-stage multi-shaft turbocompressor, the first stage of which only has an outer diameter of 630 mm. The expander with high- and low-pressure stages is likewise designed as a multi-shaft machine. An electric motor is used in this case instead of a steam turbine. The new design results in lower investment costs and provides a better energy balance, i.e. reduced operating costs.

In the course of this development, preferred configurations of the turbomachinery train have evolved in recent years, depending on the process involved:

- The air compressor is always designed as a multi-shaft machine with four to six stages depending on the process pressure level, **Fig. 11**.
- The drive function is implemented via a condensing steam turbine with axial exhaust, **Fig. 12**, or a motor/generator, **Fig. 13**, and an expander, **Figs. 12 and 13**.

A number of process changes have occurred over the years that have influenced the turbomachines in the train accordingly. The pressure level in the process, and thus the compressor outlet pressure, has been reduced from around 30 bar to current values of between 17 and 20 bar, resulting in correspondingly lower inlet pressures for the expanders.

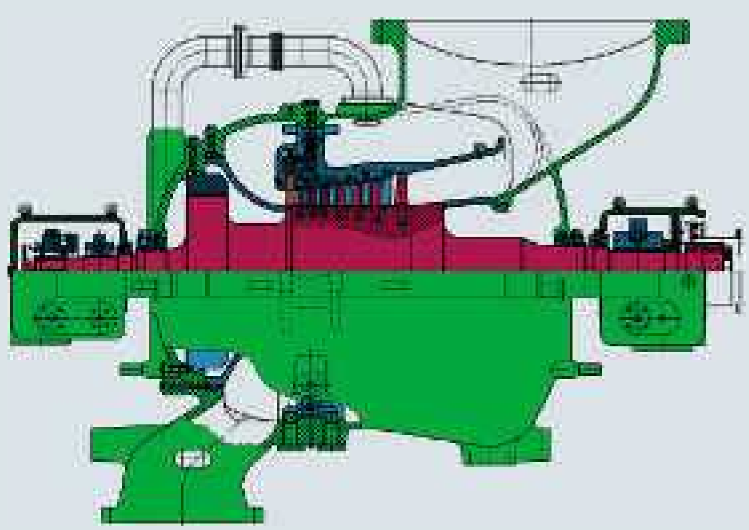
12 Machine set of a PTA plant with steam turbine and expander drive

For 2-stage or 2-casing expanders with axial or radial stages, inlet temperatures were between approx. 150 and 200 °C for a long time, with both stages having roughly the same values due to intermediate heating. Process optimization due to energy balance led to expander inlet temperatures of 300 to about 550 °C on newer machines. Here high-temperature gear-type expanders with two radial stages and no intermediate heating are used, **Fig. 14**, or single-shaft axial expanders with reaction blading and adjustable inlet guide vanes, **Fig. 15**.

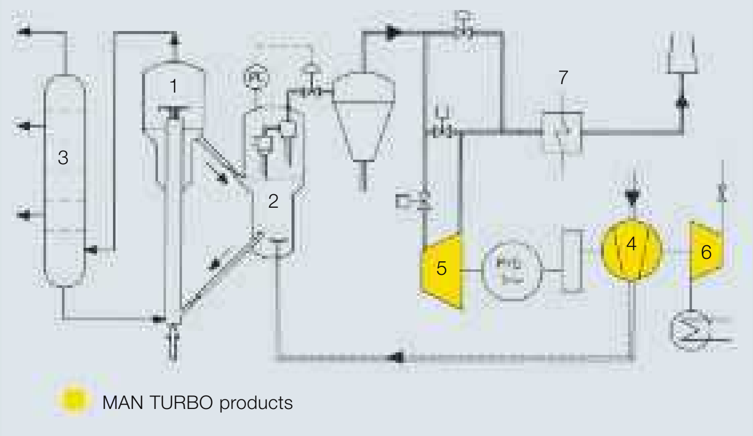
Installation sizes – and thus the dimensions and weights of the turbomachines in the train – increased steadily. Whereas annual capacity ranged between 120,000 and 300,000 tonnes of PTA up to the mid-1990s, this subsequently increased up to 500,000 to 700,000 tonnes of PTA a year. The turbomachinery for trains of this magnitude were supplied from the product range of MAN TURBO, e.g. **Fig. 12**.

13 Machine set of a PTA plant with motor/generator and expander

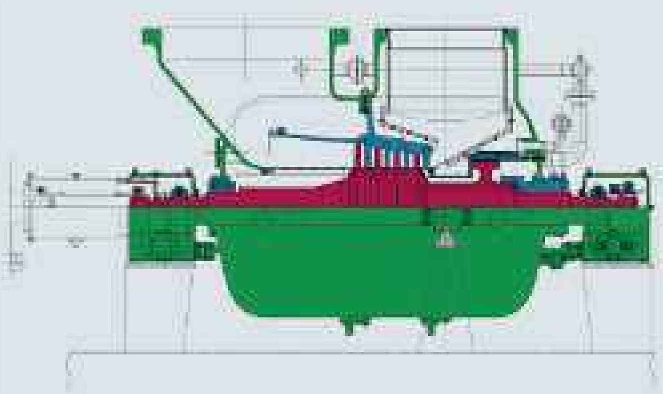
14 High-temperature expander in multi-shaft (integrally-geared) technology, 2 radial-inflow stages



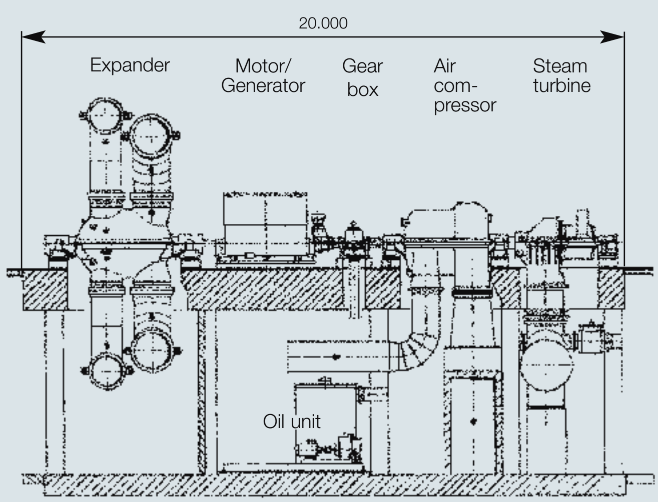
15 Single-shaft axial-flow expander with variable inlet guide vanes



16 Flow sheet of FCC process with energy recovery system
1 Reactor
2 Regenerator
3 Fractionating column
4 Air compressor
5 Expander
6 Steam turbine
7 Waste-heat boiler



17 Process gas turbine for an FCC plant



18 Turbomachinery train for an FCC plant

Fluid Catalytic Cracking (FCC) plants

The global demand for light hydrocarbons is on the increase since a number of years. The reason for this lies primarily in growing motorization and the greater use of these products in the manufacturing industry, e.g. for the production of plastics or synthetic fibres.

This demand is no longer being met by simple distillation of crude oil, but increasingly by the additional cracking of the large molecules of heavy hydrocarbons and crude oil residues into the smaller molecules of light hydrocarbons. A catalytic process, “Fluid Catalytic Cracking” (FCC) has been introduced as a proven conversion process, employing a small-grained powder of Al_2O_3 and SiO_2 as the catalyst. The catalyst passes continuously through the reactor together with the feedstock, **Fig. 16**. During execution of the cracking process in the reactor, carbon is deposited on the catalyst particles in the form of coke. To reactivate the catalyst, it is drawn off continuously into the regenerator, where the coke deposits are burned off. The purified catalyst is returned to the reactor and finely mixed with the feedstock, thus closing the catalytic cycle.

In modern FCC plants, the off-gas produced by burning the coke has a temperature of 700 to 760 °C at a pressure of roughly 3 bar.

The energy contained in the off-gas is rendered usable in an energy recovery system essentially consisting of a process gas turbine and a waste heat recovery boiler connected in series to it. In the process gas turbine, **Fig. 17**, the off-gas is expanded to approximately atmospheric pressure. The power generated is taken up primarily by the air compressor; the compressed air maintains the catalyst in the regenerator in a fluidized phase and serves to burn the coke deposits. To this end, the compressor used must compress atmospheric air to approx. 3.5 to 4.5 bar.

19 Works testing of the machine set for an FCC plant

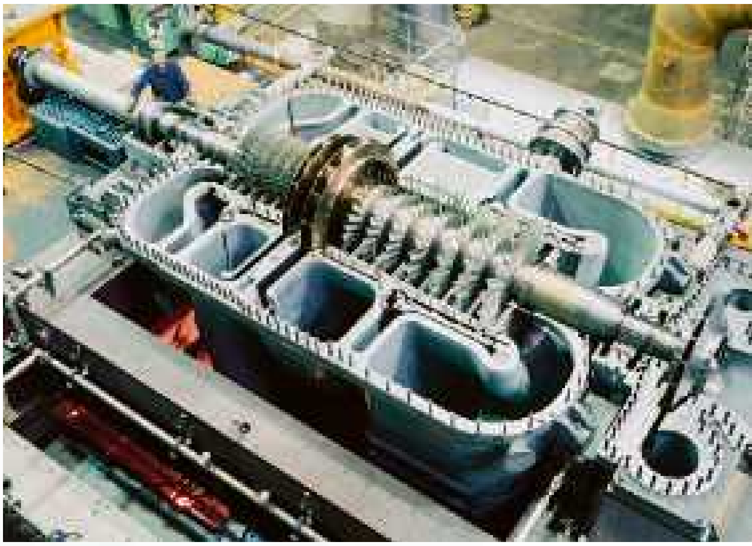
The heart of an FCC plant is the turbomachinery train, comprising for example the air compressor, a steam turbine, a process gas turbine and a motor/generator, if necessary with a gear unit, **Fig. 18**. Thanks to its wide product range, MAN TURBO can act as a “single source” for all the turbomachinery in the train.

The machine set in **Fig. 18** was tested in the same configuration on the works test stand. During testing, the hot gas for the expander was produced via the double combustion chamber of a gas turbine fired with light heating oil, **Fig. 19**. In the FCC plant, the expander produces an output of 12,000 kW at a gas inlet temperature of 727 °C and an inlet pressure of 2.9 bar. The gas throughput is about 200,000 kg/h. Roughly 80 % of the output is required to drive the axial-flow air compressor, with 5 % covering the losses from the gear unit and the trailed condensing steam turbine operating in windage mode. The mechanical power surplus of the expander available at constant speed, amounting to about 15 %, is taken up by the asynchronous motor/generator, which then operates in the generator mode, and is turned into electrical power. On startup and loading of the turbomachinery train, the drive power for the air compressor is provided by the condensing steam turbine together with the asynchronous machine operating in the motor mode until the expander starts to produce power.

In installations with a capacity in excess of 20,000 barrels per day – which calls for at least 100,000 kg/h of air, although this figure can be considerably higher depending on the feedstock and formation of the amount of coke to be burned off – the axial-flow compressor has for years been the generally accepted machine for compressing the process air.

MAN TURBO is currently contracted to supply the world’s largest axial-flow compressor for this application area, for a plant in Oman, with an effective suction flow rate of 635,000 m^3/h, equivalent to a mass flow rate of approx. 675,000 kg/h. The compressor is driven by a 36 MW condensing steam turbine, meaning that the train does not include any high-temperature expander and the steam turbine covers the entire compressor drive power requirement. A trend towards this train configuration has become evident in recent years.

20 World's largest nitrogen production plant



21 Axial-flow compressor with interstage cooling for air separation plant

Air separation plants

In addition to the widespread requirement for air separation plants in the field of oxygen production, a wide range of applications integrated into large processes has arisen:

- Enhanced Oil Recovery (EOR): Nitrogen injection to increase the yield of oil wells
- Synthesis gas production: Methanol plants
- Integrated Gasification Combined Cycle (IGCC): Combined cycle power stations with integrated coal gasification
- Gas to Liquids (GTL): Plants for the manufacture of fuels and other hydrocarbon products from natural gas.

In these processes turbomachinery trains ranging from 50 – 80 MW are increasingly called for. Steam is frequently produced in the processes, so that the energy balance can be optimized by using steam turbines as drivers. Energy assessments have to be carried out not only for the individual components but also take the compactness, reliability and availability of the entire train into account too.

Manufacturers of turbomachinery for integrated air separation plants have to handle large flow rates, which in the case of projects nowadays are in the order of 1.3 million m^3/h for suction flow rates and 1.6 million m^3/h for exhaust steam volume flows. Limitations are currently imposed by the heat exchangers available, the flange dimensions of coolers and steam reheaters.

The complex process of designing a complete train has led to the experience among customers that the provision of a machine train by a ”single source” offers advantages. Following the integration of Sulzer turbomachinery, MAN TURBO now occupies the top slot worldwide for machinery trains for air separation plants.

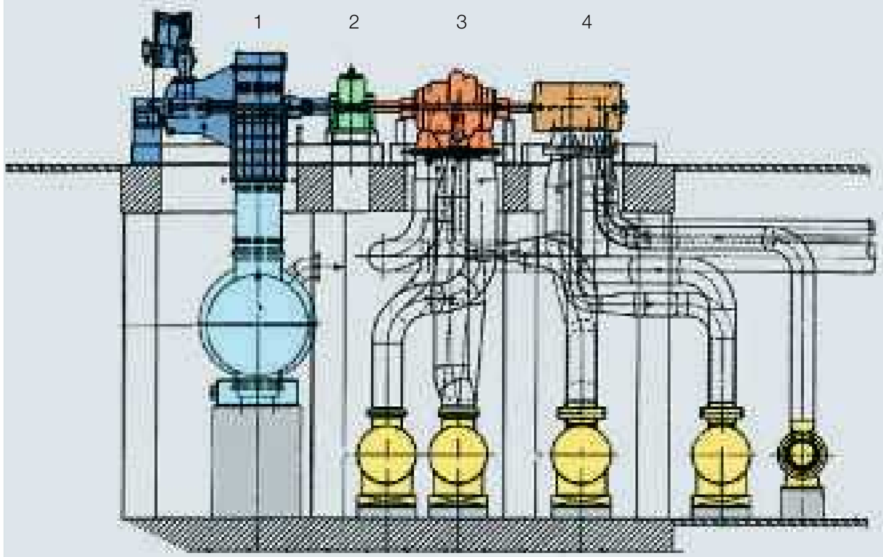
Machinery trains for Enhanced Oil Recovery

Fig. 20 shows the world's largest air separation plant for the production of nitrogen on the Gulf of Mexico. The falling pressure in the oil well is built up again by injecting around 1.3 million Nm^3/h of nitrogen at 121 bar, to increase productivity. MAN TURBO secured the order for this project, comprising four axial-flow compressors with motor drive for the air separation and steam turbine-driven centrifugal compressors for the nitrogen. The installed power currently exceeds 500 MW. Four gas turbine units, consisting of gas turbines, generators and waste heat recovery boilers, supply the electrical energy for the four 50 MW motors of the air compressors, **Fig. 21**, and steam for the four 55 MW turbines of the double-casing nitrogen compressors, **Fig. 22**.

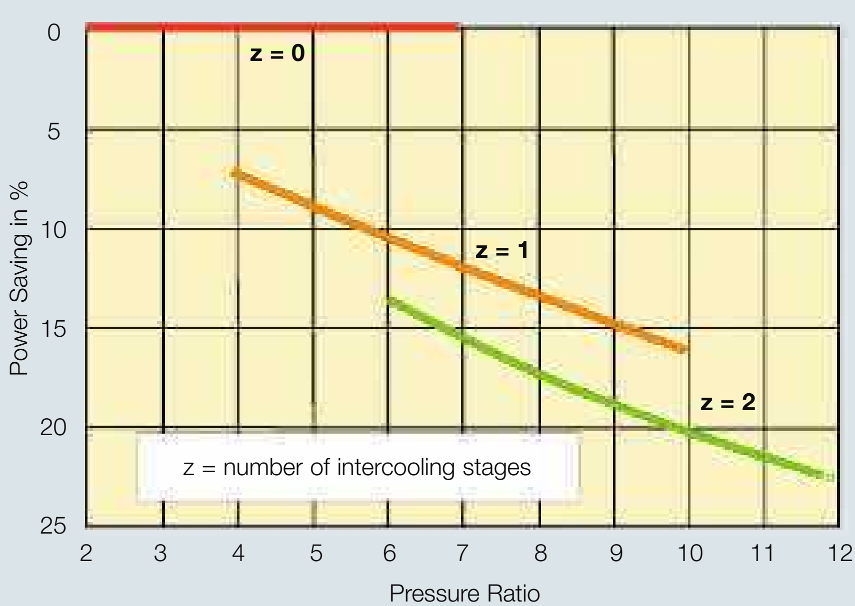
The axial-flow compressors with interstage cooling each compress a suction flow rate of over 600,000 m^3/h to a pressure of 9.5 bar. Due to the minimization of the electric drive power, a type of axial-flow compressor was selected that includes an intermediate-pressure section with axial blading following the first interstage cooling and an overhung-mounted centrifugal stage following the second interstage cooling. Double interstage cooling comes closer to isothermal compression and permits drive energy savings in the range of 15 – 20 % compared with compression without interstage cooling, **Fig. 23**.

Trains for synthesis gas manufacture

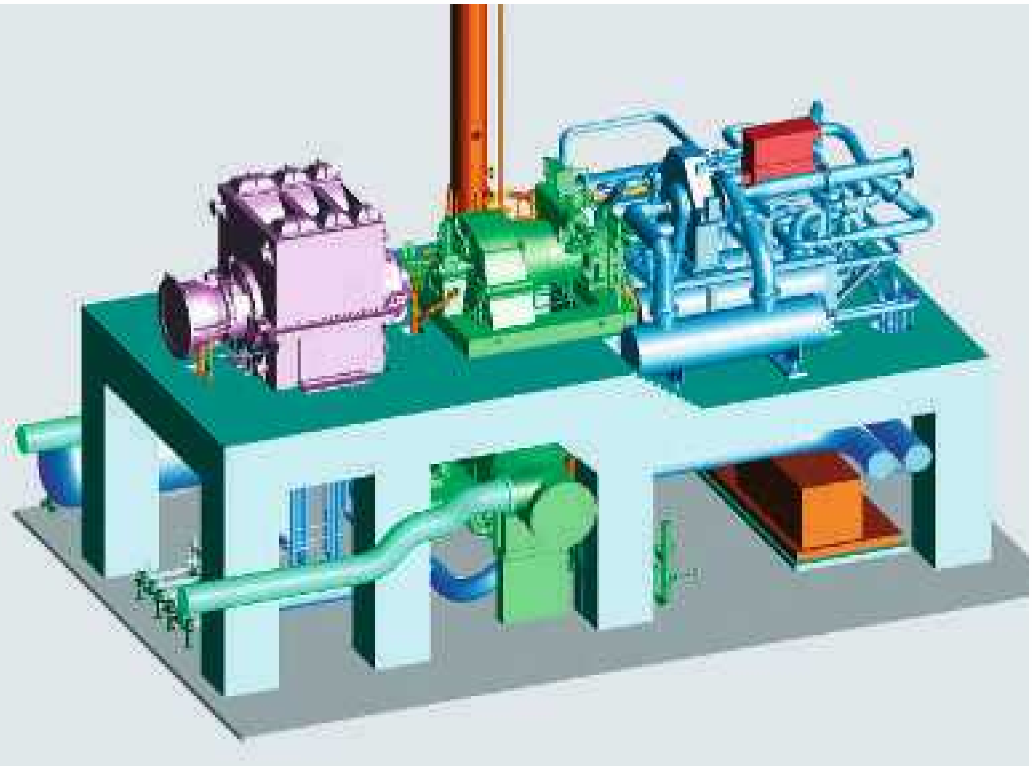
The gasification of coal, orimulsion, petroleum coke and other refinery bottoms normally requires pure oxygen at the appropriate process pressure. Air separation units are integrated with their machinery train into the process as a whole in this case.



22 Nitrogen compressor train arrangement
1-Steam turbine with condenser
2-Gear box
3+4-LP and HP nitrogen compressors with intercoolers



23 Power saving on compression with intercooling



24 Machinery train for a methanol plant

25 Machinery train for an air separation plant in the GTL process, works test assembly

One example of this is a MAN TURBO train recently supplied to a methanol plant in Trinidad, **Fig. 24**. The unit is driven by a 55 MW steam turbine with drives on both sides, on one side for the air compressor and on the other side for the booster compressor and generator. Here the main air compressor (MAC) comprises an isotherm compressor with integrated coolers that is designed for a flow rate of 500,000 m^3/h.

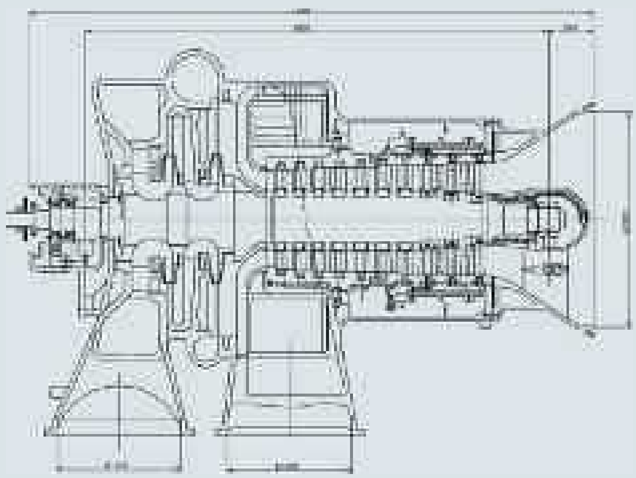
The synthesis gases produced are used either for chemical processing or can be used as fuel for a combined gas and steam turbine power plant (IGCC).

Machinery trains in GTL plants

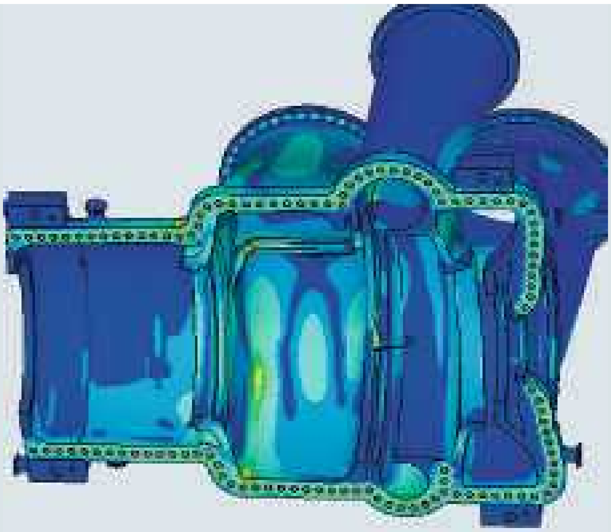
As an alternative to the long-term use of large natural gas reserves with corresponding pipeline networks, the GTL process is used to exploit smaller reserves in unfavourable geographical locations. The GTL process converts the natural gas into high-value, sulphur-free fuels and other, heavier hydrocarbon products, passing through the following phases:

1. Production of synthesis gas from natural gas through the combination of oxygen with carbon,
2. Conversion of synthesis gas into synthetic crude oil,
3. Refining of synthetic fuels and other products.

Many GTL processes currently in the market use variations of the Fischer-Tropsch process to obtain paraffin hydrocarbons from the synthesis gas. This process is exothermal and generates steam. For this reason, the machinery train of the air separation plant is driven by a steam



26 Sectional view of the combined axial-centrifugal compressor



27 Finite element (FEM) analysis of the lower part of the casing

turbine. It is the task of the turbomachinery designer to bring the energy balance of the compressors including interstage cooling and the steam consumption of the drive turbine into line with the plant parameters.

GTL processes require the largest compressors ever built for industrial applications. The suction flow rates are in the range from 600,000 to 1,300,000 m^3/h for the air compressor to deliver.

In 2003, MAN TURBO secured an order for two compressor trains for a GTL plant in Qatar. Each train included a 55 MW axial-flow compressor with a flow rate of 700,000 m^3/h, an 80 MW steam turbine and a centrifugal compressor with a maximum of 25 MW, **Fig. 25**. The entire infrastructure, such as related gear units, couplings, piping, oil unit and steel foundations were also supplied along with the complete compressor control system Turbolog. Each module weighed 500 tonnes as a result.

The axial-flow compressors and steam turbines were built in Oberhausen, while the centrifugal compressors were produced in Zurich and Schio. The train is being assembled in Oberhausen on steel foundations and subjected to a full string test.

In contrast to the axial-flow compressors for Mexico 10-stage compressors are being deployed in Qatar, containing a high-pressure section with two centrifugal stages, **Fig. 26**. For reasons of the power balance and to minimize the construction outlay, single interstage cooling is sufficient for these compressors. The relatively expensive axial blading in the high-pressure section can also be dispensed with.

Casings of this complexity cannot pass through the design process and subsequent pressure testing unless they have been subjected to a detailed mechanical examination. Finite Element Analysis (FEM) is a proven method of ensuring optimum dimensioning of components. **Fig. 27** shows the results of FEM analysis of the overall compressor casing, which has passed the pressure test in Oberhausen in the meantime without any problems.

Following its commissioning, the GTL plant in Qatar will be the largest worldwide. The same is true of the air separation plant, producing 3,500 tonnes of oxygen per day and train.

MAN TURBO's expertise in being able to construct and test such packages entirely in house was an important factor in the decision to award the contract to the company. The cooperation between the different company sites in building the components of such trains underlines the flexibility of the company with regard to the delivery of these demanding units.

Machine control and protection systems

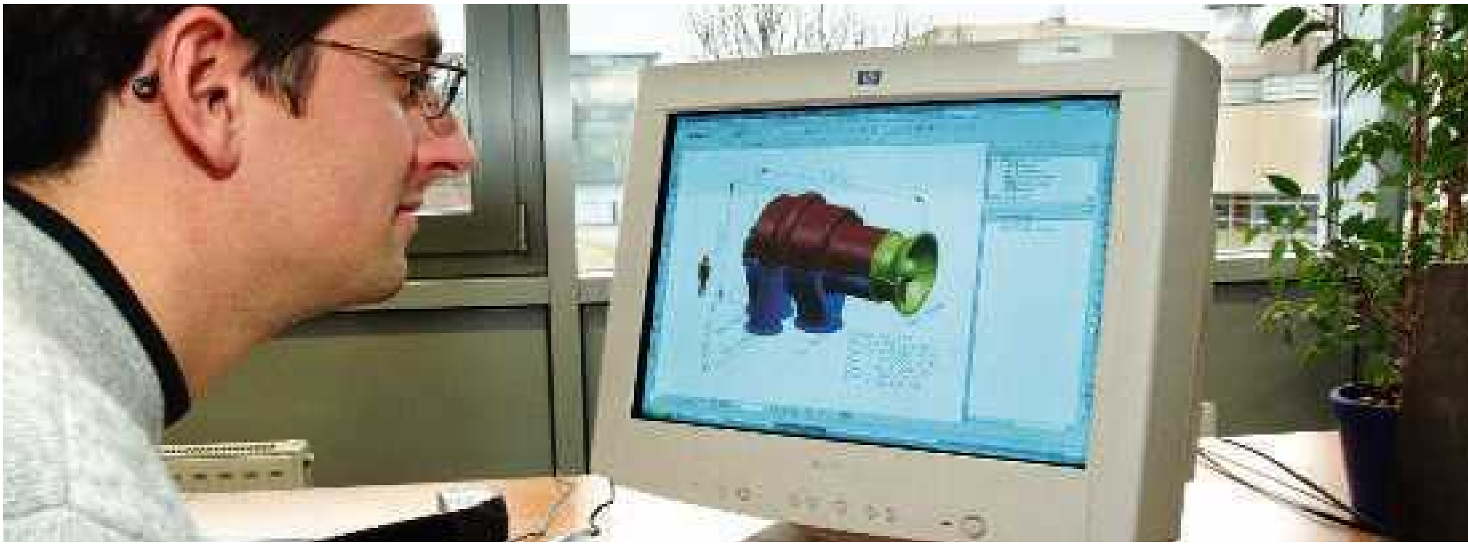
In the complex machinery trains described here, considerable demands are made on the quality and flexibility of the machine control and protection systems. Taking the processes into account, systems of this kind must cover the entire spectrum from startup via a safe production process to shutdown of the machine. A machine monitoring system coordinated to the protection requirements of the respective machine train is a basic prerequisite for trouble-free, continuous operation of any chemical or petrochemical plant. The Turbolog family is a digital machine control and monitoring system developed by MAN TURBO to meet the special requirements of turbomachinery. It is modular in design, freely programmable and thus flexible enough to be adapted individually to any task. It has an integrated alarm manager, graphic operating data display and a high-speed data recording facility, **Fig. 28**.

28 Turbolog machine control and protection system

The following are some of the tasks performed by the Turbolog system: it protects compressors against surging – an unstable operating mode that is critical for the machines –, controls the speed of steam or process gas turbines, safeguards the machine train against overspeeds, monitors the bearings for acceptable vibrations and temperatures and maintains process pressures or flow rates at preset values.

The integrated data storage function registers and stores all operating values at regular intervals – e.g. every minute – on the system's hard disk, thus creating a comprehensive database for automated machine diagnosis. All data are also recorded event-driven at intervals of 100 milliseconds. Thus even highly transient events, such as a surge, can be analysed accurately.

Using remote data transmission, every machine controller can be connected to the MAN TURBO central system via a telephone line. From here, the control and adjustment software can be analysed, parameterized and programmed in the same way as on site at the plant. And if problems arise during ongoing operation of the machine, expert advice can be made available in this way very quickly and without incurring unreasonable costs.



29 Machine design using a 3D-CAD system

A “single source” of supply

Flexibility and versatility

As a manufacturer of complex turbomachinery trains, MAN TURBO is capable of calculating, designing, manufacturing and testing all machines in the train, compressors and turbines alike. Rationally graded modular systems with standardized elements exist for the individual machine series, facilitating optimum adaptation of the turbomachines to all process requirements without sacrificing characteristic performance or efficiency ratings.

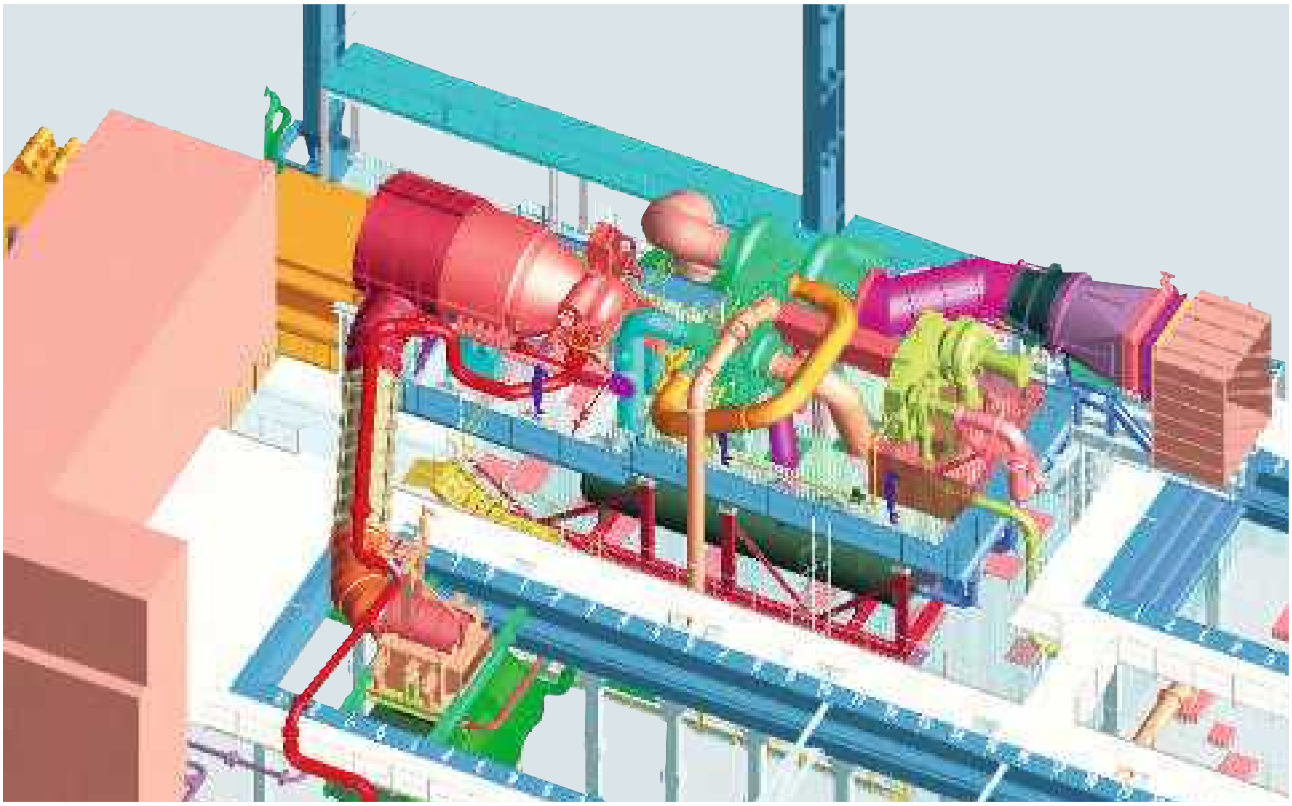
Quality and economic efficiency

The high technical standard and efficiency of MAN TURBO’s machines and machine trains are guaranteed not only by intensive R & D and state-of-the-art CAD, computation and production techniques, **Fig. 29**, but also by high-speed balancing and overspeed testing facilities and test stands for testing and verifying mechanical, rotor-dynamic and thermodynamic characteristics.

Customer benefit

Delivery of the machines in a train, including a machine control and protection system matched to the respective requirements, from a ”single source“ offers further advantages for the customer:

- undivided responsibility for the train as a whole,
- considerable simplification of the coordination tasks required and thus
- smooth handling of orders,
- simple erection and commissioning by staff with experience of complex machinery trains and
- the optimum after-sales service, with a contact person responsible for service and spare parts or with a comprehensive service agreement and thus
- a high level of availability with reasonable service costs.



30 Test stand set-up of a PTA plant in the 600,000 tonnes per year class

Summary and outlook

The examples given show the influence of process parameters and of the process technologies used on the design of individual turbomachines and on the configuration of the overall machine set. The importance of process gas turbines for energy recovery has been highlighted against the background of rising energy costs and more stringent environmental conditions, factors that ultimately have an effect on the economic efficiency of processes and of entire installations. The use of these machines for energy recovery in the now “classic” application areas described is likely to be strongly encouraged. New application areas are being opened up in GTL plants, for example, which operate using compressed air instead of oxygen, or in IGCC plants for expanding synthesis gas.

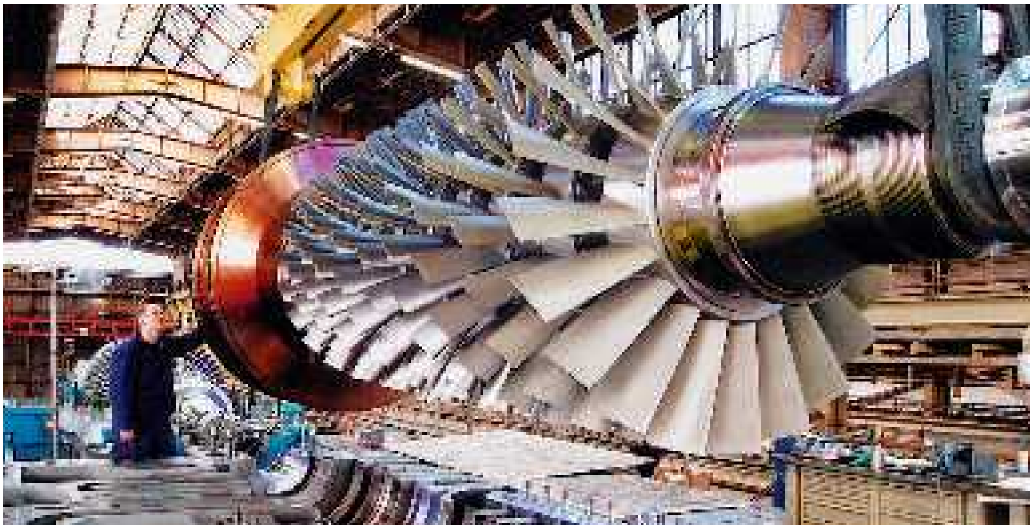
The advantages of obtaining all machines in a train including the machine control and protection system from a ”single source“ have been illustrated in detail.

The trend in the past was for continuous enlargement of the installations, especially in the field of terephthalic acid production and air separation, and also with regard to turbomachines for ethylene and methanol plants, which have not been covered here.

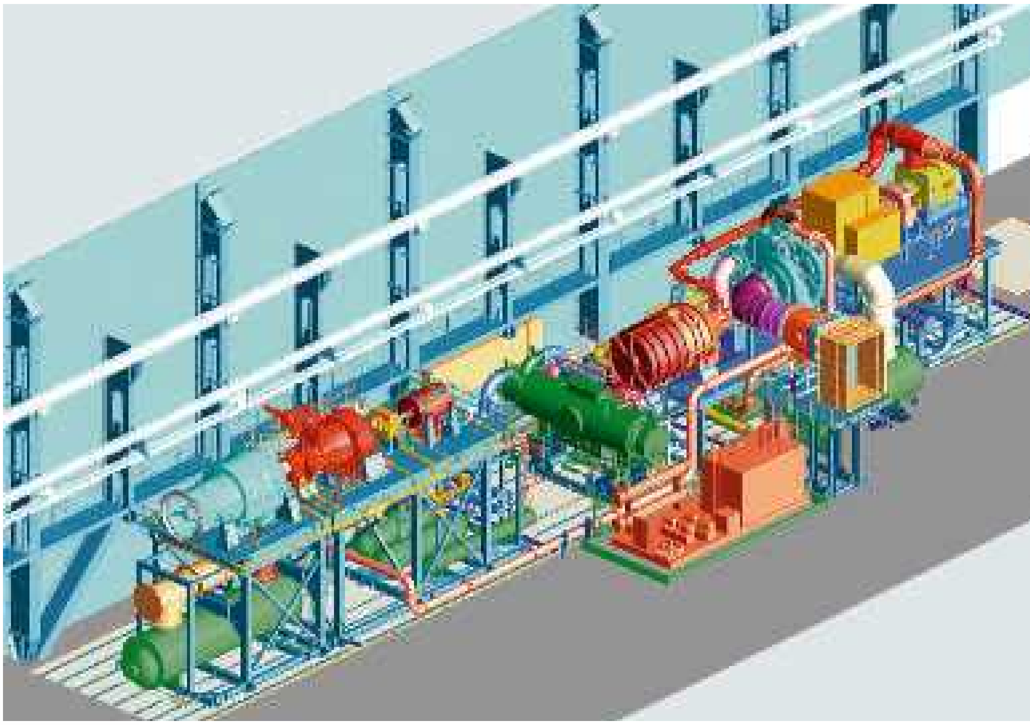
Cost and time pressure – shorter delivery times with reduced erection times – are now leading increasingly to package-style concepts, i.e. the delivery of complete machine modules or sub-modules on base frames and steel foundations.

These modules ought normally to be tested at the manufacturer's plant using as many original components as possible, something that can be done at MAN TURBO too on its large machine and string test stand for the machine sizes hitherto delivered. **Fig. 30** shows the test stand set-up for example of the machinery train set for a PTA plant in the 600,000 tonnes per year class. The module shown in **Fig. 12** en route for packaging following testing, has a length of 16 m, width of 6 m and height of 10 m, and weighs 310 tonnes.

MAN TURBO has taken account of the continuing increase in plant size, i.e. the increase in the dimensions and weights of turbomachines and thus of the modules, with its construction of a works assembly and testing site suitable for these modules, **Fig. 31**, complete with the necessary infrastructure and energy supply. In the future up to three large "packaged modules" can be erected in parallel on this area which is approx. 100 m long and 12 m wide, **Fig. 32**.



31 Works erection of a "packaged module" for a GTL plant



32 New works assembly and test field for large "packaged modules"

MAN TURBO AG
Steinbrinkstrasse 1
46145 Oberhausen / Germany
Phone +49. 208. 6 92-01
Fax +49. 208. 6 92-20 19
www.manturbo.com

MAN TURBO AG
Egellsstrasse 21
13507 Berlin / Germany
Phone +49. 30. 44 04 02-0
Fax +49. 30. 44 04 02-20 00

MAN TURBO AG
Hermann-Blohm-Strasse 5
20457 Hamburg / Germany
Phone +49. 40. 3 70 82-0
Fax +49. 40. 3 70 82-19 90

MAN TURBO AG Schweiz
Hardstrasse 319
8005 Zürich / Switzerland
Phone +41. 44. 278-22 11
Fax +41. 44. 278-29 89

MAN TURBO S.r.l. De Pretto
Via A. Fogazzaro 5
36015 Schio (VI) / Italy
Phone +39. 0445. 6 91-5 11
Fax +39. 0445. 5 11-1 38

In the interests of technical progress,
subject to change without notice.
Printed in Germany.
April 2008
TURBO 956 e 0408 1,0 ba