Klaus Stahlmann, CEO MAN Diesel & Turbo presents the MAX1 rig during the “Last Bolt” ceremony.

MAX1 — A NEW GENERATION OF AIR COMPRESSORS

Air Flows Meet Demands of Largest Air Separation Units Anticipated

By Roberto Chellini

Air separation unit (ASU) sizes are increasing to take advantage of economy of scale. They are applied in the production of synthetic fuels (GTL, CTL, BTL plants), but also for carbon capture and storage applications (CCS) and enhanced oil recovery (EOR).

The present generation of main air compressors (MACs) has been progressively extended to reach intake flows of 24.74 MMcfh (700,000 m^3/hr) effective in ASU, producing 3858 tons/d (3500 tonnes/d) of O_2. However, market trends are going to continue to reach for 5512 to 7716 tons/d (5000 to 7000 tonnes/d) of O_2 in the foreseeable future.

MAN Diesel & Turbo, Oberhausen, Germany, which manufacturers this type of axial flow air compressor, decided that the scaling-up approach, in some cases, had several limits (size, weight, costs, rotordynamics, etc.). The problem had to be solved using a forward-looking approach: combining industrial and gas turbine or aero-engine experience to develop a new generation of axial compressor blading.

In 2007, MAN Diesel & Turbo (previously, MAN Turbo) and MTU Aero Engines joined efforts to co-develop a new generation of axial/radial compressors capable of handling flows up to 53 MMcfh (1.5 x 10^6 m^3/hr) of air and pressures up to 362 psi (25 bar), depending on the flow. MTU's work on the new axial blading was carried on through MTU Aero Solutions, an MTU activity handling orders of third parties (R&D, testing, manufacturing, etc.).

The development program was supported by the German Federal Ministry

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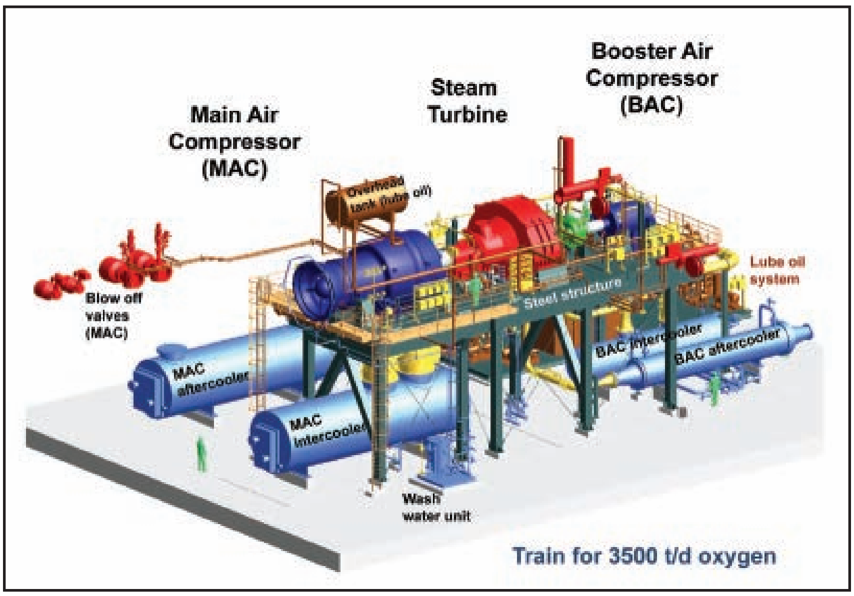
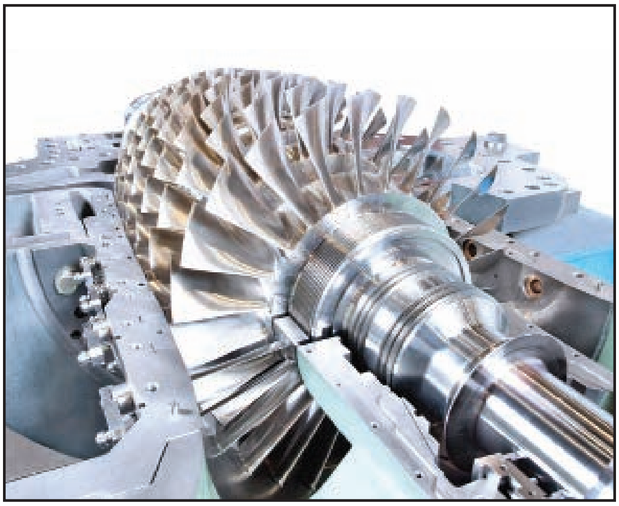
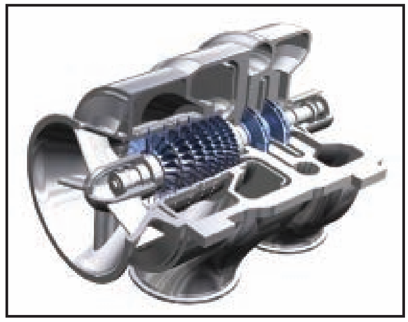


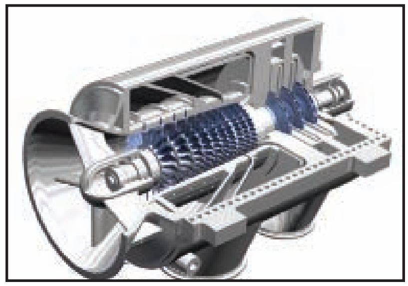
Computer rendering of an air separation unit (ASU) compressor train with a steam turbine driving both a booster compressor and a main air compressor. This train is for application on very large air separation units with an oxygen-producing capacity of 3858 tons/d (3500 tonnes/d).



The seven-stage MAX1 axial compressor with top casing removed, showing blade configuration.



Axial-Radial (AR) compressor for air separation production of 5512 tons/d (5000 tonnes /d) of oxygen at 122 psi (8.4 bar).



AR compressor for air separation production of 5512 tons/d (5000 tonnes /d) oxygen at 305 psi (21 bar).

of Economics and Technology, which has included this project in the 5th Program on Energy Research. The financial support was mandatory to reach the stage of testing the 1:3 scaled rig in only three years from the start of the program. Although this was the first approach in a long time that the two companies decided to work on together, the two engineering teams started a very close collaboration from the beginning. MAX1 will be MAN's first industrial axial compressor that is developed with support of an R&D partner from the aero-engine sector.

In Oberhausen, MAN combines experience with axial compressors of the industrial type (AR and AG line) and the gas turbine compressors of the MAN gas turbine families. However, according to Dr. Kai Ziegler, MAN Diesel & Turbo vice president and head of engineering compressors, gas turbine compressors are not suitable for industrial use for many reasons. They do not have the necessary operating range and efficiency, and the necessary robustness and flexibility in terms of flow rates or pressure ratios. Furthermore, power generation gas turbine compressors are often designed to operate in a 95 to 105% speed range, which would not meet applicable API standards for industrial compressors.

The main air compressor in an ASU plant has to meet a wide range of operating requirements and therefore must operate flexibly within the whole compressor map. For these reasons MAN teamed up with MTU in the development of a novel concept: a hybrid axial flow compressor, which would combine the advantages of conventional industrial compressors, such as operating range, efficiency and robustness, with the advantage of gas turbine compressors, the higher power density, i.e., high-stage pressure ratios.

The joint MAN/MTU development program started with comprehensive matrix studies in all areas of the design, taking into account all aspects, e.g., aerodynamics, mechanics, rotordynamics, production, costs, etc., in order to ascertain the overall optimization for the new hybrid generation. The result, internally called MAX1, sets a new benchmark for large main air compressors. It maintains the typical configuration of a heavy-duty industrial compressor featuring a nodular cast-iron or welded steel casing and a solid rotor, as do all MAN industrial compressors. Besides the new axial blade geometry, all parts and design features are well referenced in the axial/radial (AR) compressor as it has been developed.

In order to adapt the compressor intake flow — within a given frame size — exactly to the specification of the various customers, the blades can be trimmed from their design length down to obtain a flow reduction up to 25%. This is another feature not feasible in gas turbine compressors, but essential in industrial applications. MAX1 as a main air compressor in an ASU (AR type) consists of seven axial stages followed by two radial stages (after interstage cooling) designed to deliver an exit pressure of 116 to 130 psi (8 to 9 bar).

However, the number of stages in both stage groups can be increased, e.g., in a compressor size of 5512 tons/d (5000 tonnes/d) O_2, up to 10 axial stages and three radial stages to reach a compression ratio of 21. Also, two interstage cooling levels can be achieved, without overhung mounted impeller, the first after the axial section and the second between the radial stages.

The weight of the MAX1 is reduced by approximately 25% compared to a similar machine of the present AR line. The MAX1 also features a reduction in axial stage number and an increase in rotating speed of one-third, which reflects the step change in technology. In spite of its higher power density, the MAX1 is even more robust than the units of the present AR line and features equal performance in terms of operating range and efficiency.

The Test Rig

The last bolt ceremony of the 1:3 scaled compressor test rig took place on July 22 at the MTU Aero Engines premises in Munich, Germany. After assembly in Oberhausen, the rig was transported to Munich for final assembly on the MTU test bed. Since this test bed was originally built to test aero engine compressors with a weight that does not exceed 3.3 tons (3 tonnes), it had to be adapted to the test rig with a weight of 8.27 tons (7.5 tonnes). The test program is planned to start on Sept. 20 and conclude on Oct. 22.

The test rig, featuring seven axial stages (but no radial stages), will be driven by a variable speed electric motor through a step-up gearbox. The rig's nominal speed is 11,000 rpm, but the variable speed motor offers the possibility to plot the performance of the rig in a very wide speed range.

The rig is designed to handle a flow of 3.53 MMcfh (100,000 m^3/hr) of air. The first four rows of guide vanes are adjustable. For testing purposes, each row is connected to an individual actuation cylinder so that their angle can be adjusted independently. Once the

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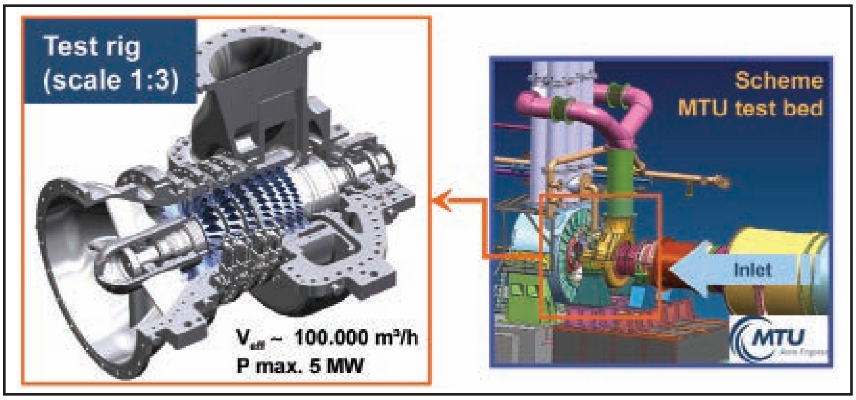

Schematic of test rig alongside the MTU test bed showing direction of air flow.

optimum position is determined, the four rows will be interconnected and a single actuator will adjust the angle to the process requirements in future customer machines.

The rig is heavily instrumented with strain gauges, tip-timing probes, thermocouples and pressure probes to collect performance data under a variety of operating conditions. If the testing program will confirm design data, as expected, the MAX1, MAC with seven axial and two radial stages (standard ASU pressure 116 to 131 psi [8 to 9 bar]) will be released for sale at the end of this year. After an additional rig test MAC1, with 10 axial stages, will be released toward the end of 2011. MAC versions for higher pressures (up to 363 psi [25 bar]) will be released for sale in the second quarter of 2012. After completion of the MAX1 development, plans are to continue the MAN/MTU R&D partnership on a long-term basis.

The Steam Turbine Driver

In parallel with the development of the MAX1, MAN Diesel & Turbo is further developing its industrial steam turbine modular system capable of driving both the MAC and the booster air compressor (BAC) of a future 7716 tons/d (7000 tonnes/d) O_2 ASU train. Regarding the thermodynamic design, the increase of the compressor speed by one-third is beneficial to the steam turbine, which can be built smaller because of the increased power density.

ASU makes available a large quantity of steam at low pressure 232 to 290 psi (16 to 20 bar). The air compressor train (MAC+BAC) of a 7716 tons/d (7000 tonnes/d) O_2 ASU will absorb 188,000 to 201,000 hp (140 to 150 MW). In order to increase the output of the condensing steam turbine, the backpressure has been increased up to 6 to 9 psi (0.4 to 0.8 bar).

To cope with these requirements, MAN Diesel & Turbo has redesigned the last three stages of the low-pressure section designated StaKoMod, which builds a complete frame size series with volume flows from 1237 cfs (35 m³/s) at 16,000 rpm up to 36,000 cfs (1020 m³/s) at 3900 rpm.

The MAX1 project is expected to ensure MAN Diesel & Turbo's leadership in the supply of large air compressor trains for the present and future ASU demands.

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