1.0 INTRODUCTION

The modern axial industrial compressor is an good example of rather exclusively user-oriented development work on turbo-machines. This approach to development made it possible to satisfy with the axial compressor the steadily increasing demands on performance, e.g. mass flow, efficiency, pressure ratio and operation range.

The continuously increasing units of production in the chemical industry and steel works have greatly increased the demand on axial industrial compressors. This trend has been even further increased due to new fields of application in liquefaction plants for natural gas, uranium enrichment plants, coal gasification plants and closed-cycle gas turbines.

The increase of power per compressor unit was effected almost in parallel with the demand for axial compressors. During a long period the power per compressor unit was only slightly higher than 10 MW. However, during the last few years a fast increase in power is evident. Blast furnace blowers with a power consumption of 30 MW are standard in modern plants. Machines with a power consumption of more than 34 MW (Fig. 1) are not seldom in steel plants. For LNG plants, two casing machines with power demands of more than 160 MW have been designed.

Today the most important fields of application for industrial axial compressors are blast furnaces an already classical application of axial compressors, air separation plants and plants for the production of nitric acid. In addition, the axial compressor is used in open-cycle gas turbines and closed-cycle gas turbines where the cycle medium is either air or helium.

In Fig. 2, the end pressure and the suction volumes of some industrial axial compressors are shown. The applications concentrate on suction volumes of 1 - 2.10^5 m^3/h and pressure values of 4 bar. Blast furnace blowers (Fig. 3) are situated in the upper field of suction flow values.

The operating costs of air separation plants are mainly made up of energy and service costs. Hence, machines with high efficiencies are demanded (Fig. 4). Axial compressors with an efficiency of around 10% higher than radial compressors suit these demands particularly well. This effieciency is further increased by one or two intercooling stages like the compressor shown in the next figure (Fig. 5).

The NO plants use single train turbomachines consisting in general of a steam turbine, a tail-gas turbine, an air compressor and an NO compressor. Such a train is represented in Fig. 6. The air compressor is in general of the axial flow type. The axial design is of interest for the NO compressor too, in plants with production capacities of 800 tons/day and more. The suction volume varies between 44,000 m^3/h and 115,000 m^3/h and the discharge pressure between 2 bar and 11 bar. The design of these compressors has to take into account the soiling of the blade channels and the blades. A washing process has been developed for this peculiarity.

The demands made by the users of industrial axial compressors are: high efficiency, large range of operation, easy and reliable control, small amount of service work, long service life and - last but not least - low investment costs.

The design of the axial industrial compressors for air has been characterized during the last few years by two development steps. The result of these steps is represented in the following two figures 7 and 8. The first step is an increase of the circumferential speed, and in the second step the variable stator blading and the radial impeller has been introduced. The third phase shows the increase of speed of rotation due to a decrease of the hub diameter in the first stages. The actual step of development - not the last one - has resulted in an increased tip diameter of the first stage due to the application of a blade profile suitable for higher Mach numbers. The influence of these development phases on the suction volume and the flow channel is represented in Fig. 8. The flow rate of 480,000 m^3/h could be increased to 920,000 m^3/h while increasing the size of the casing only by 10%.

The incluence of various gases on the design of these compressors is discussed in the following.

2.0 AERO-THERMODYNAMICS

2.1 Real-gas behaviour

The large variety of gases, which are handled with axial compressors, necessitates an exact knowledge and experience of the thermodynamics before starting on the aerodynamic design. In particular, where the product handled is a mixture of different types of gases it is necessary to calculate the behaviour of this mixture, including the real gas effects.