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Paper 6

A NEW MULTI-STAGE COMPRESSOR TEST FACILITY FOR INLET DISTORTION INVESTIGATIONS

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ABSTRACT

At the University of the German Armed Forces in Munich a new test facility for Multi-Stage Axial Flow Compressors has gone into service. The test facility has been built up in an arrangement providing air from the outside in axial direction to the compressor through filters, a mass flow measurement nozzle, an inlet throttle, and a large plenum. The compressed air passes several throttles before it flows back to the environment. The facility is driven by a well regulated DC-motor of 1000 kW power and a maximum speed of 1000 rpm, which is increased by means of two gear boxes to the required compressor speed.

Within the research project the influences of different inlet distortions on the steady and unsteady compressor aerodynamics will be investigated. In order to perform measurements of compressor characteristics as well as in order to detect instationary effects a PC-based data acquisition system has been installed. Two PCs of individual configuration control the General Data Acquisition System for stationary measurements on the one hand and the Fast Data Acquisition System for the instationary measurements on the other hand.

The modular concept of the general system consists of a separate transducing and amplification unit for each sensor at the test stand, a transfer of analog data to the control room, a multiplexer AD-converter board inside the PC and finally the data storage on a hard disc. Each high precision amplifier board (combined transducer/amplifier board respectively) being of the same outlet voltage range and adapted to different inlet signals can be easily exchanged. This way a wide variation of the compressor instrumentation is allowed keeping costs within reasonable limits.

The compressor under investigation was built as a test rig for the five stage high pressure compressor of a RB 199 jet engine derivative. The inlet duct has been reconstructed with respect to the generation of different kinds of inlet distortions. Furthermore the compressor now is instrumented with a high number of static pressure taps, three hole and Pitot probes, and several temperature probes. The instrumentation serves to record detailed performance characteristics of the compressor as a whole, of all stages and flow characteristics of the blade rows and guide vanes. In addition flow field measurements are performed.

Measuring instationary effects when the compressor exhibits Rotating Stall a large amount of data arises. That's why the Fast Data Acquisition System requires special data handling to and within the PC. In order to keep distances short the PC is positioned near the compressor and the sensors. The high frequency response PC AD-converter board samples up to 1 MHz. The digital data are written unformatted on the large hard disc. For the topical investigations use is made of hot wire sensors and a six-channel Dantec anemometer unit.

NOMENCLATURE

Symbols:

A	[-]	empirical constant
B	[-]	empirical constant
DC	[-]	circumferential distortion index
f	[Hz]	frequency
p	[Pa]	pressure
q	[Pa]	dynamic head
r	[m]	compressor radius
β	[-]	grid porosity
φ	[-]	circumferential angle
θ	[-]	angle of distortion

Subscripts and Superscripts:

a	ambient
h	hub
M	mean
N	Nyquist
t	tip
t	total conditions
t0	total conditions in front of distortion generator
–	averaged

INTRODUCTION

Flow inhomogenities at the inlet of an installed jet engine have a strong influence on the compressor aerodynamics. They may arise from

- angular incoming flow e.g. caused by side wind or aircraft maneuvers,
- inhomogenity of the flow inside a supersonic inlet duct produced by a shock/boundary layer interaction or a nacelle/inlet interference,
- interaction between two neighboured engines or ground effects,
- recirculation of hot gas at vertical take off or at thrust reversal,
- inoming hot gas from launched missiles.

In addition, an HP-compressor experiences rotating inlet distortions generated by a stalling LP-compressor in a two-spool engine or modified steady inlet distortions having passed the LP-compressor.

The flow non-uniformity occurs in common flow properties such as total pressure, static pressure, velocity, temperature, flow angle, and gas constituency as a function of the spatial coordinates and time. The resulting inlet distortion for the compressor leads to a decrease of efficiency, pressure ratio and corrected mass flow rate of the compressor in connection with a loss of efficiency and thrust of the engine. It also tends to raise premature Rotating Stall or Surge with the fatal consequences of a large loss in thrust and possibly the damage of the engine. Also blade vibrations may arise.

Investigations on the complex flow phenomena caused by the most common inlet distortions, namely swirl and total pressure fluctuations, were performed at the engine test stand at the Institut für Strahlantriebe by *Meyer*, 1988 and *Pazur*, 1991. Since detailed investigations of the aerodynamics of an engine installed compressor could not be performed, a test facility for multi-stage axial flow compressors has been built up in completion to the jet engine test stand. The research topic requires on the one hand the mechanical set up for the inlet distortion generation and on the other hand a sophisticated measurement instrumentation of the facility and the compressor rig. Apart from the mechanical construction an electronic data acquistion system recording stationary and instationary sensor signals is of uttermost importance for useful data.

MECHANICAL SET UP

The Compressor Test Facility

At the test facility multi-stage axial flow compressors of up to 1000 kW power can be run under ambient inlet conditions. However, lowering the inlet pressure by means of an inlet throttle allows operating compressors of even higher power requirements. Fig. 1 gives a side view of the test stand. The facility is driven by an electric motor shown on the left. It is a thyristor-regulated, water cooled DC machine of 1000 kW power and 1000 rpm maximum speed. The accuracy of the speed regulation amounts to ±1 rpm. The momentum is transferred via curved tooth couplings, a torquemeter and two gear boxes to the compressor driving shaft. The first gear box, a one stage spur gear box with single helical gearing and roller bearings, of a transmission ratio of 1.79 and a second gear box, a two stage high speed gear box with double helical gearing and split plain sleeve bearings, of a transmission ratio of 8.388 increase the rotational speed up to 15240 rpm. A sensor mounted at the motor driving shaft of the first gear box sends rotational speed impulses to the Siemens process computer which manages the speed regulation. The machine driving shaft of the gear box impels an oil pump in parallel in order to assure the facility's oil supply in the event of a breakdown of electric pumps. An inductive sensor installed at the housing of the compressor driving shaft forms part of the measurement instrumentation picking up the compressor speed.

The aerodynamic part of the facility is plotted on the right side of Fig. 1. The air coming from the outside is filtered two times before it enters the facility. The air is cleaned down to a particle size of lower than 5 μm. Thus sensitive sensors like hot wires are preserved from being damaged. The inlet mass flow rate is measured with a calibrated nozzle. Behind the nozzle the air passes a throttle which allows an optional reduction of the compressor inlet pressure and therefore a reduction of the Reynolds number. As mentioned above, this reduces the required driving power of the compressor. The air enters a large plenum where aerodynamic disturbances are diminished and almost eliminated by several grids. The grid nearest to the compressor is instrumented with temperature sensors. The compressor inlet total temperature is measured presuming adiabatic flow on the way from this point to the compressor. From the exit of the plenum to the compressor inlet the air is accelerated continuously. The compressor under investigation discharges a bleed mass flow after the third stage. The air is collected by 28 circumferentially dispensed tubes and measured by a mass flow measurement aperture in accordance with DIN 1952. The bleed rate is adjusted by a throttling valve before the air is fed to the main exit duct. Concerning the main air flow a first throttling device is located immediately behind the compressor exit. By shifting an axial slider the axial-to-radial compressor outlet diffuser is closed axisymmetrically. It enables the throttling of the compressor with a very small outlet volume. This way, the compressor can be forced to exhibit Rotating Stall. In addition to the calculated B-parameters (*Greitzer*, 1976) it has been proven by experiment that Rotating Stall occurs throughout the whole speed range of the compressor.

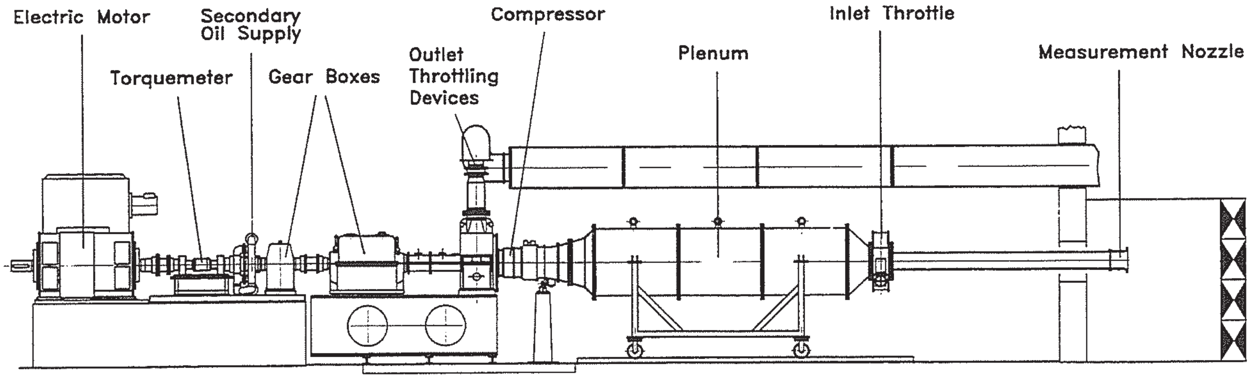

Fig. 1: Side view of compressor test facility

Afterwards the air is collected in a large chamber and led to further throttling devices, which now allow the development of Surge instead of Rotating Stall because in this case the outlet volume is very large. The determination of wether Rotating Stall or Surge occurs is very important for any investigation of instationary compressor flow. Apart from taking precautions to avoid mechanical damage of the compressor the instrumentation has to be adapted to the different flow conditions, too.
The further throttling devices consist of two parallel valves, a large one and a small one, allowing a slow and a quick opening of the flow area in the case of compressor instability. Through the following upper duct and a silencer the air goes back to the outside.
The test facility is supplied by oil, water and secondary air. The first serves the purpose of lubricating the gears and the bearings. The water is needed to cool the electric motor and the oil. The air seals the bearing chambers of the compressor rig.

The HP-Compressor Rig 212

The five-stage HP-compressor Rig 212 has been selected for the topical investigations because few detailed measurement data of multi-stage high speed machines are available concerning distorted inlet flow and concerning the development into compressor instability. It was constructed as a test compressor for the design of a RB 199 jet engine derivative. Since the research program treats the compressor flow in a rather fundamental manner no disadvantages arise from the compressor being designed in the late sixties. What is more the Rig 212 offers the possibilities of a very detailed pressure and probe instrumentation.

Fig. 2 shows a longitudinal section of the compressor.
The compressor inlet duct can be divided in three areas:

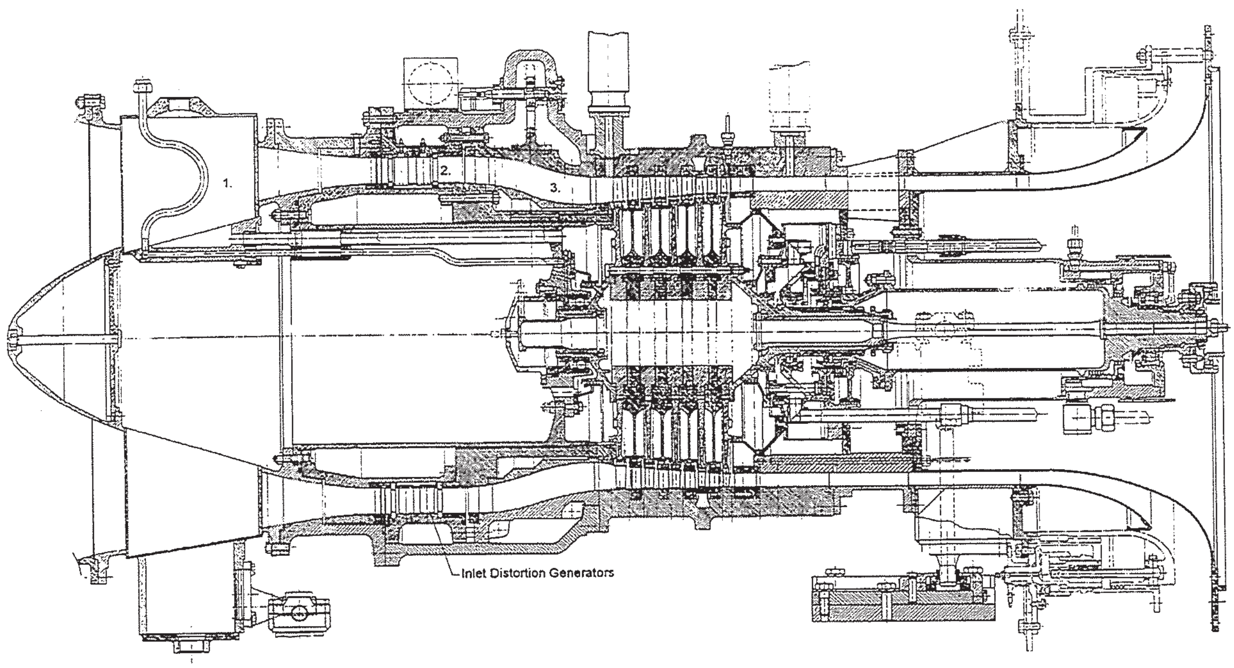

Fig. 2: High pressure compressor Rig 212

1. an area of decreasing flow cross section including six radial struts transferring the bearing forces to the outer casing,
2. an area of constant flow cross section and constant axial velocities predestinated for the installation of flow distortion generators,
3. an s-shaped duct simulating the flow progression from the IP-compressor to the HP-compressor in the engine.

The area No. 2. (Fig. 2) has been rearranged in order to enable a rotation of installed distortion generators more than 120° which is the circumferential distance of several probe positions farther downstream. Pressure distortion generators or guide vanes as shown in Fig. 3 and Fig. 4 mounted to the outer casing are rotated by a small actuator located outside on the housing and by a gear transmission. The distortion generators can be placed at different axial positions, and thus more complex distortion profiles may be produced combining several generators. To exchange a distortion generator the housing of the s-shaped duct is taken away giving free access to the duct. It is not necessary to dismantle the compressor from the test facility.

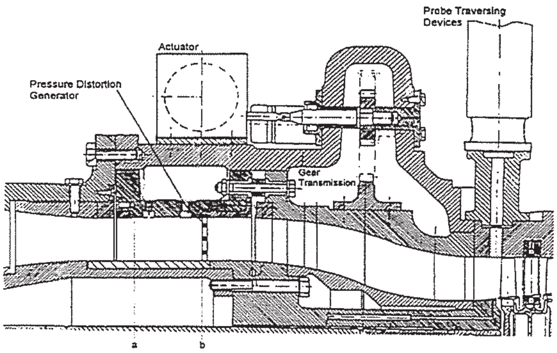

Fig. 3: Compressor inlet duct with pressure distortion generator

Each compressor stage is designed for axial inlet flow. All rotor blades are DCA profiles and all guide vanes are NACA 65 profiles. At the design point condition the relative inlet Mach number of the first rotor is 0.86 at the mean radius. The compressor design speed is 13860 rpm and the inlet mass flow rate amounts to 4.68 kg/s at INA-0 km inlet conditions. The outlet mass flow rate is reduced to 4.54 kg/s by a bleed behind the third stage. The total pressure ratio is 2.87. The inlet and outlet hub to tip ratios are rather high: 0.84 and 0.91, respectively. The overall dimensions of the compressor are quite small, which sometimes may cause some difficulties concerning probe instrumentation.

As can be seen from Fig. 2 the compressor outlet duct is of constant flow cross section and parallel to the compressor axis over a length of about two times the compressor mean radius r_M. Up to the distance of one half of r_M the outlet duct is instrumented with measurement probes. The following area contains eight radial struts transferring the forces of the second rotor bearing to the outer casing. Having passed the axial outlet duct the air enters an axial-to-radial diffuser and leaves the rig through the above mentioned first throttling device of the test facility.

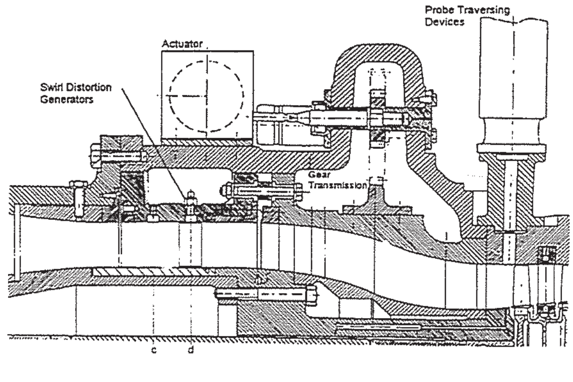

Fig. 4: Compressor inlet duct with swirl distortion generator

DISTORTION GENERATOR DESIGN

The investigations of the most common inlet distortions - total pressure and swirl- form a part of the measurement program. Spatial extensions and disturbance intensities are varied.

Pressure Distortion Generators

Since each spoiler is mounted to the outer casing and will not be guided by the inner endwall -the inner endwall is not rotating- each grid has to be of high mechanical strength to stand the aerodynamic forces. Therefore filigree screens of thin wires cannot be used. Perforated plates or parallel arrays of square bars or square mesh arrays of square bars are easiliy manufactured and allow a wide variation of solidity without weakening the mechanical strength too much. Furthermore, for the low turbulence levels predominating in the inlet duct a large amount of empirical data concerning the loss production of these types of grids are available. For the actual design of pressure distortion generators it has been made use of empirical correlations of *Roach*, 1986. The related pressure drop is well correlated by the equation

$$\frac{\Delta p_t}{q} = A\left(\frac{1}{\beta^2} - 1\right)^B \qquad (1)$$

where q is the upstream dynamic pressure and β is the grid porosity. A und B are functions of the Reynolds number, the Mach number and grid geometry, whose values are given in the reference. Grids have been constructed for total pressure drops of $\Delta p_t/q$ = 1.1, 2.1, 3.2 under compressor design condition. To give an idea of the produced circumferential distortion an index received from the minimum of all Integrals

$$DC(\theta)=\left[\frac{1}{\theta}\int_{\theta}\left(\frac{1}{r_t-r_h}\int_{r_h}^{r_t}\frac{p_t(r,\varphi)-\bar{p}_t}{\bar{q}}dr\right)d\varphi\right]_{min} \qquad (2)$$

at any circumferential location of the inlet compressor annulus, reported by *Reid*, 1969, is used. For the latter value of $\Delta p_t/q$, a DC(60°) of -0.66 at the compressor design speed and a DC(60°) of -0.80 at 80% related compressor speed is obtained. The DC(θ) values of the lower pressure drops are accordingly lower.

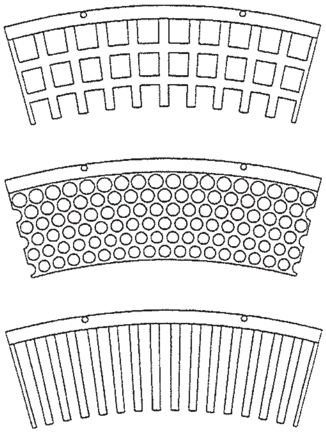

Fig. 5: Screens for the generation of total pressure distortions in the inlet duct

The grid geometries have been adapted to the annular inlet duct. The manufactured sector angles are 60° and two times 30° in order to spoil 30°, 60°, 90° or 120° of the inlet duct flow. Fig. 5 shows three examples of pressure distortion generators.

Swirl Distortion Generators

Because of the small height of the Rig 212's inlet duct, small vortices with opposite sign of the circumferential velocity component over the duct height tend to diminish while approaching the first rotor. Thus, effects on the compressor aerodynamics would be very small. Since the investigation of an axisymmetric bulk swirl is of little interest either, because it is likewise produced by a change in mass flow, it is intended to create a non-axisymmetric alteration of the first rotor incidence.

The swirl distortions are generated by guide vanes installed into the inlet duct as shown in Fig. 4. The incoming flow can be diverted in corotational and counterrotational direction using variable airfoils. To a certain degree the vanes are able to produce different outlet flow angles by a variable stagger angle. The number of vanes sets the circumferential extension of the swirl distortions. The distortion support (Fig. 4) houses up to 122 vanes, which is synonymic to a pitch of 2.95°. The preferred distortion sector angles depend on the distorted flow field seen by the compressor.

INSTRUMENTATION

Instrumentation for Stationary Measurements

A schematic view of the test facility with an enlarged compressor and the measurement planes is given in Fig. 6. Apart from the compressor the test facility has few measurement positions:

the pressure and temperature instrumentation to obtain the mass flow rate at the inlet in plane *11* and *12* and to obtain the bleed rate at the measurement aperture following plane *1.4*,

the compressor inlet temperature measured by ten total temperature probes evenly distributed over the plenum outlet cross section in plane *14* and

the above mentioned pick-up of the rotational speed at the compressor driving shaft farther to the right of the compressor outlet.

Each pressure probe or pressure tap is pneumatically connected to a transducer, which will be described in the following chapter. All temperature sensors are Pt 100 or Pt 10.

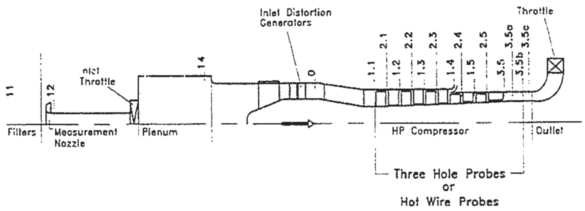

Fig. 6: Measurement positions of the compressor and of the test facility

Inside the compressor rig there are measurement planes in front of and behind every blade row. Plane *1.1* embodies twelve pressure taps at the hub and twelve at the tip. In each of the planes *2.1* to *2.5* there are eleven taps at the tip, whereby six positions are distributed over two blade channels and the remaining five are distributed over the residuary annulus. Plane *3.5* encloses six and *3.5a* encloses eight taps at the hub and the tip. Besides, plane *0* consists of further 24 pressure taps. As can be seen from the following chapter only a part of the whole number of pressure taps can be connected to pressure transducers at the same time. Thus the instrumentation depends on the respective measurement program.

Apart from the static pressure instrumentation Pitot traverse probes and three hole traverse probes are inserted

in the planes *1.1* and *3.5b*. There are three traverse probe positions in any of both planes. This way rotating the inlet distortion more than 120°, traverses of the whole distorted flow field at the compressor inlet and outlet are possible. Another five probe positions meant mainly for instationary instrumentation are available in plane *1.1*.
Four total temperature rakes of five NiCr-Ni thermocouples apiece and four total pressure rakes of five Pitot tubes apiece, positioned alternately over the annulus, are installed permanently in plane *3.5c*.

Instrumentation for Instationary Measurements

The topical research project makes use of the hot wire anemometry. An enhanced instrumentation inserting additional miniature pressure transducers is planned for the future. Since the strength of 5 mm Tungsten wire probes has already been proven to stand the dynamic head of the compressor flow under stationary and instationary flow conditions, subminiature hot wire probes fit very well the measurement requirements at the test facility. The prevailing use of X-wire probes in the plane *3.5b* (Fig. 6) will provide information of the instationary two-dimensional flow vectors at compressor outlet. Several single wire probes at plane *1.1* positioned close to the tip facilitate the detection of Rotating Stall very well. Thus the development into Rotating Stall is hopefully properly recorded. At the moment the total number of installed hot wire sensors is limited to ten by the number of anemometers available at the institute.

GENERAL DATA ACQUISITION SYSTEM

Transducing and Amplification

Following the way the signals move on starting from the measurement positions at the test facility or inside the compressor respectively, at first each signal enters a cabinet containing high precision amplification units. The cabinet located next to the compressor is plotted schematically in Fig. 7. It has to be distinguished between pneumatic signals for the pressure measurements, electric signals of two different voltage levels originating from the resistance and thermocouple temperature sensors, and an electric sine wave emanating from the inductive rotational speed sensor. The former and the latter are transduced to a DC-signal before amplification, while the temperature signals can be amplified immediately. Hence, four different types of amplifier cards, to be plugged in the four 32-channel amplifier units, are used. Nevertheless, all amplifier cards being Europe format and being of the same outlet voltage range (±10 V) can be placed at any location of the units. Each amplifier card consists of two individually configured channels and each amplifier unit houses 16 amplifier cards.

Concerning the pressure measurements it is made use of combined pressure transducer/amplifier cards. Off the shelf pressure transducers are installed on the amplifier board in very little distance from the high precision amplifiers. Thus the non-amplified signals are widely preserved from electric noise. The transducers have different input ranges and allow either differential pressure or gage pressure measurements. Only one channel is instrumented with a high precision transducer for absolute pressure measurements, which delivers the ambient pressure at the test facility. Its measurement accuracy is 0.01% full scale within the whole measurement chain while the other's is 0.06% full scale. These accuracies are reached by doing calibrations of at least ten up to twenty points over the measurement range. Changing the instrumentation means almost always an alteration of the measurement ranges. Therefore, in order to keep the accuracy at an optimum, further pressure transducer/ amplifier cards of different input ranges are available.
The pressure tubes are plugged in pneumatic couplings mounted to the front plate of the cards.

The rotational speed sine wave signal is frequency-to-voltage converted before amplification. The progression of the conversion is linear. After offset compensation a maximum error of ±1 rpm is obtained at 16000 rpm full scale. Beside of the f/U-converter a thermocouple amplifier is incorporated in the amplifier card (to be seen as card No. 16 at amplifier unit No. 4 in Fig. 7).

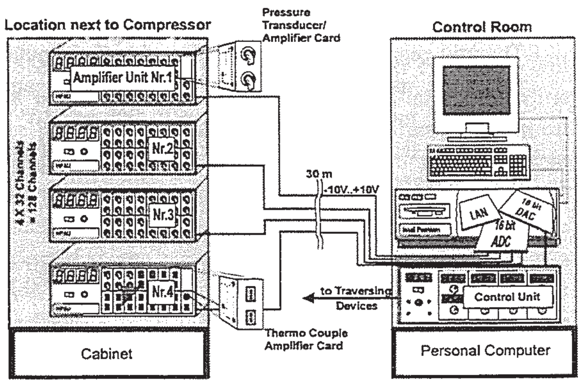

Fig. 7: General data acquisition system

The amplification of the platinum resistance sensor signals is done in two steps. An IC manages the resistance measurement in a three electric wiring, which compensates for the electric resistance. The second amplifier increases the voltage up to ±10 V. The measurement range is ±200° C with an accuracy of ±0.25 K at ±200° C and ±0.15 K at 0° C. The inaccuracy is caused by the non-linearity of the platinum resistance over temperature but can be reduced by calibration.

The amplification of the thermocouple voltages is performed in a similar way. Instead of the resistance measuring IC, a monolithic thermocouple amplifier with cold junction compensation is implemented in the circuit. A chip-integrated thermistor measures the junction temperature of the connector at the card's front plate and compensates for the secondary thermo voltage emerging at this place. With respect to the non-linearity of the thermo voltages the amplifiers have to be calibrated. The thermocouples themselves have to be calibrated, too. The overall accuracy can be guaranteed to ±1 K within the measurement range of ±200K, but experience shows that it is about ±0.5 K.

PC-Based Data Acquisition and Control

The amplified signals are transfered via 30 m of cable to the control room and the PC. The data are sampled by two 16 bit 64 channel PC analog-to-digital converter boards at a rate of 30 kHz each (Fig. 7). The data are evaluated for an online monitoring, which displays the current operating point in the compressor characteristics field. What is more, several measurement channels can be displayed simultaneously. The data storage on a 2 Gbyte hard disc is controlled by the data acquisition software. After the measurements the data are archived via the local area netware at an external storage. The data acquisition software also controls the traversing devices by a 16 bit 6-channel digital-to-analog converter board and by an analog control unit including the actuator's power supply. Three probes can be moved in transverse direction, i.e. radial direction of the compressor, and they can be rotated at the same time. The tracking of the three hole probes, when the angle of attack exceeds the range of calibration, is managed by the software automatically.

FAST DATA ACQUISITION SYSTEM

Hot Wire Anemometry

As long as it is used in constant temperature mode the hot wire anemometry is highly dedicated for high frequency measurements. The hot wire anemometry profits from the increased convective heat transfer at higher velocities. The constant temperature mode keeps a heated wire at a constant temperature independent of the fluid velocity and the cooling rate. The velocity measurement signal results from the output voltage of the amplifier regulating the wire temperature. Hence, the measurement frequency depends mainly on the amplifier characteristics.
At the compressor test facility a 6-channel Dantec anemometer unit has been installed. It is incorporated in the cabinet located next to the compressor (Fig. 8). The length of the cables connecting the hot wires inside the compressor with the anemometers is 5 m. In this configuration, using 5 mm Tungsten wires, measurement rates up to 500 kHz are possible. The main features of the system are the configuration from the PC via RS 232, an integrated signal conditioner including signal amplification and analog filters, and a temperature measurement in parallel. The fluid temperature measurement is important for the bridge configuration and the data evaluation corresponding with the calibration. During the measurements the bridge configuration can be adapted automatically to the fluid temperature, but it is not absolutely necessary for measurements of initiating compressor instability, because temperatures remain relatively constant. Besides, the temperature sensor is not able to follow instationary or even dynamic changes of the fluid temperature because of its thermal inertia. However, the temperature sensor can be installed in the compressor inlet and outlet, where the hot wire measurements will be performed.

PC-Based Data Acquisition and Control

The hot wire signals leaving the signal conditioner are already amplified to a range of ±10 V. They pass a switched capacity filter unit of eight 8-pole low pass Bessel filters, or they are sampled directly by the high frequency PC analog-to-digital converter board. Though the anemometer unit offers 4-pole low pass analog Butterworth filters, they are not sufficient concerning their damping and concerning their phase fidelity. The filters are needed to avoid aliasing effects. The critical frequency

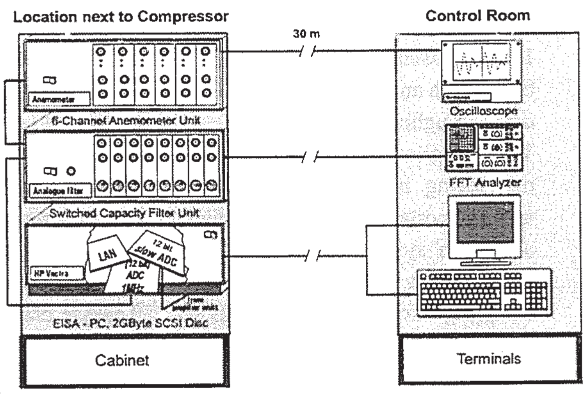

Fig. 8: Fast data acquisition system

is called Nyquist frequency f_N equal to half of the sampling frequency. For incoming frequencies lower than f_N the AD-converter obtains the right frequencies. Otherwise pseudo-frequencies appear falsifying the measurement results (for more information see *Bernstein*, 1995 or *Best*, 1982). Since the useful data in the frequency domain are limited by the corner frequency of the anti-aliasing filter determined by a 3 dB signal damping, and since at f_N the damping should attune to 50 dB to avoid

aliasing effects, the sampling rate must be higher than two times the requested frequencies. The flatter the damping characteristics of the filter the higher the sampling frequency has to be set. Therefore, an 8-pole filter is much more adequate than a 4-pole one.
In contrary to the Butterworth filter, the Bessel filter assures a linear phase shift over the frequency. The original phase can be reconstituted.

The filtered data are converted analog-to-digital by a 16 channel 1 MHz PC board at an accuracy of 12 bit. Each channel includes a sample-hold device necessary for the acquisition of the hot wire signals especially of two or three wire probes at exactly the same time.
Due to the high signal frequencies there would be a considerable damping of the signals if transferred over large distances. Thus the PC is housed together with the anemometer unit and the filter unit to the cabinet next to the compressor (Fig.8). The large amount of data entering the PC requires a special handling. The data transfer to the hard disc (9ms, 2.2 Gbyte) is managed by the EISA bus and the EISA to FAST SCSI host adapter AHA 1742A. The EISA bus works at a transfer rate of 33 Mbyte/s. The data acquisition software working with the operating system MS DOS takes advantage of the REPEAT STRING commands offered by the analog-to-digital converter board WIN30DS. This way the data are transferred block by block to the internal FIFO buffer. The blocks are stored until the default buffer size is attained. Releasing a direct activation of the ASPI driver the whole buffer is transferred unformatted without processor overhead to the SCSI drive. The data acquisition uses two disc buffers for this activity and proceeds working during the data storage. Thus the data can be stored at the full sampling rate of 1 MHz. Installing a second SCSI hard disc another ADC board with another 1 MHz sampling rate could increase the data throughput considerabely.
The installed CPU 486D4 100 manages an online monitoring including an FFT in parallel. Furthermore, some important measurement channels of the general data acqisition system are analog-to-digital converted at the EISA-PC by another board synchronously but at lower sampling rates and stored at another 250 Mbyte hard disc. This way the hot wire measurement data are related to the compressor operating point.
As can be seen from Fig. 8 the terminals of the high speed data acquisition system are located in the control room. The monitor needs a main driver as a result of the distance between the PC and the control room.

FIRST EXPERIMENTAL RESULTS

Since the instationary measurements are still at trial no plotted measurement results are enclosed. Nevertheless first experiments have proved the functionality of the system. The full data acquisition rate of 1 Msample/s has been obtained. Besides, Rotating Stall using a single-wire probe has been properly recorded.

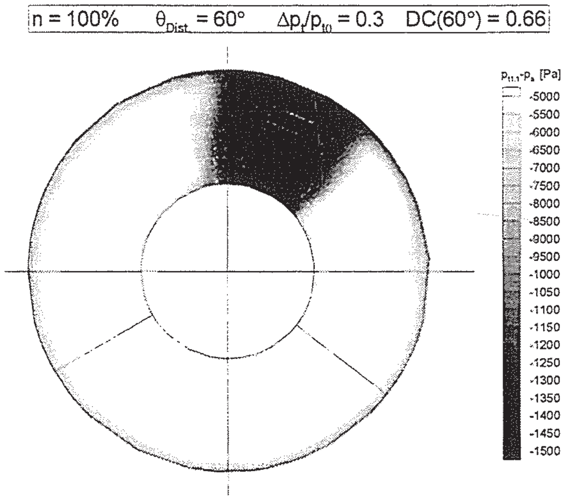

Fig. 9: Profil of total pressure at compressor inlet created by a square-mesh array of square bars

Concerning the general data acquisition, apart from compressor characteristics, stage and blade row characteristics measurements under undistorted inlet flow condition, the effects of a 60°-circumferential inlet distortion with a related pressure loss (eq. (1)) of 0.32 have

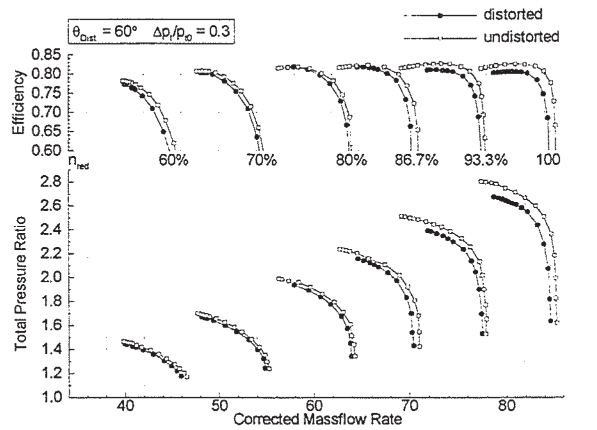

Fig. 10: Compressor characteristics under distorted and undistorted inlet flow conditions

been investigated so far. Fig. 9 shows the inlet total pressure distribution at design speed, which results in a circumferential distortion factor DC(60°) = 0.66. The effects on the compressor characteristics are plotted in Fig. 10 compared to the undistorted values. In addition to the measured distorted temperature field at the exit, blade to blade traverses after the last stage by three hole probes provide detailed information about the loss production inside and outside the distorted sector. The investigations will give considerable hints with respect to the initiation of stall originating from the distorted area.

SUMMARY AND OUTLOOK

A complete description of the new compressor test facility at the Universität der Bundeswehr München has been given. Within the research project the effects of circumferential inlet distortions on a 5-stage HP compressor will be investigated. The compressor is driven by an electric motor of 1000 kW power at a design speed of almost 14000 rpm. The rotational speed as well as the throttling of the compressor are well regulated. The compressor has undergone a sophisticated measurement instrumentation facilitating detailed compressor characteristics measurements and flow field traverse measurements. The instrumentation can be both stationary and instationary. Because of a very modular signal transducing and amplification it is easily adapted to different measurement requirements. The instationary measurements make use of a modern hot wire anemometry system. The presented stationary and instationary data acquisition systems are PC-based. According to their different tasks, controlling the acquisition of many measurement channels at a low rate and controlling the acquisition of a few channels at very high speeds, each of both PCs is configured individually.

First measurement results have shown the functionality of the whole concept. When the topical measurement program will be finished the construction and inset of a high speed rotating inlet distortion generator is planned. The instrumentation will be enhanced by miniature pressure transducers installed directly into the compressor.

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