Description of the

Transonic Test Turbine Facility

at the

Institute for Thermal Turbomachinery
and Machine Dynamics

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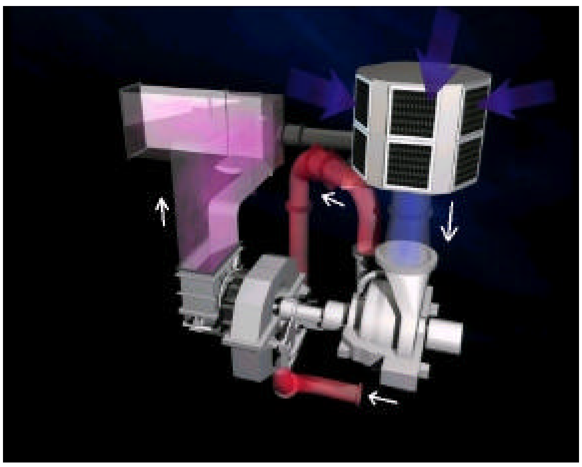

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INTRODUCTION

In 1995 work started at Graz University of Technology to design and build a transonic test turbine facility. This facility should be driven by the existing compressor station of 3 MW power and should allow testing of transonic gas turbine stages in full flow similarity. The test stand should give access of conventional pressure and temperature probes as well as of optical measurement devices such as Laser-Doppler-Velocimetry (LDV) and Particle-Image-Velocimetry (PIV) systems. Design and construction details of the plant can be found in Erhard (2000) and in Erhard and Gehrer (2000). Due to severe budget restraints all design work and much construction was done by institute's staff. Changing demands from research projects forced to several modifications. In November 1999 the turbine test facility was run for the first time. Since the commissioning more than 100 test runs with three different transonic turbine stages were performed. Measurement data were collected during an overall testing time of about 160 hours (see Seyr et al., 2001).

TEST RIG

Fig. 1 shows a schematic diagram of the turbine test rig. Pressurized air delivered by a separate electrically driven compressor station of 3 MW power is fed to the turbine stage to be tested. The test turbine drives the brake compressor shown at right. The pressurized air from the brake compressor can be added to the air from the compressor station in a mixing chamber. The air from the compressor station may be cooled to about 50 °C, whereas the temperature of the brake compressor air depends on the pressure ratio. The solution with the brake compressor is a very efficient alternative to a water brake because so most of the braking power can be recovered. The mixing chamber is equipped with inserts in order to homogenize the air temperature profile at the turbine inlet. The exhaust air from the turbine normally flows through an exhaust line directly to the silencers in the exhaust tower. Optionally a suction blower driven by a 750 kW helicopter engine may be inserted into the exhaust line to reduce the turbine back pressure and thus increase the turbine overall pressure ratio.

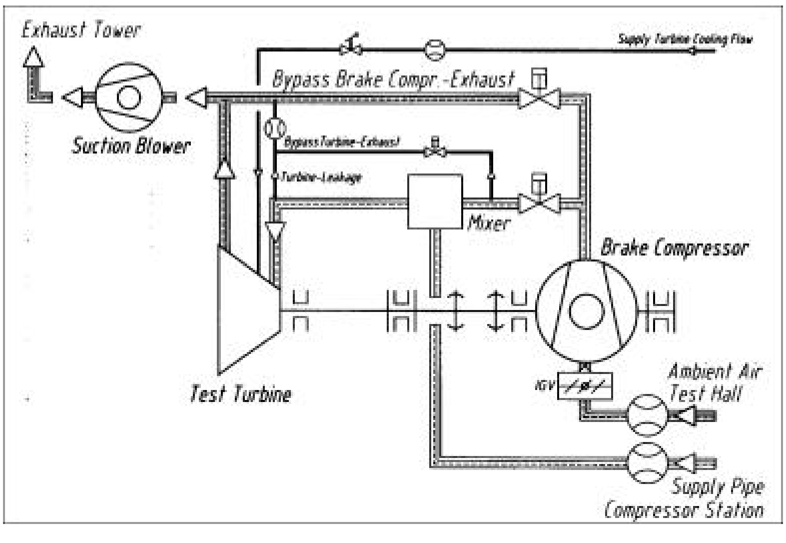

Figure 1: Schematic diagram of the turbine test rig

The operation of the facility and the interaction of the different components of this complex configuration are described by Neumayer et al. (2001).

A turbine stage to be tested must be scaled in such a way that the turbine mass flow does not exceed the maximum air supply of the compressor station, that is about 9.5 kg/s. In the case that the air from the brake compressor is added to the compressor station airflow the brake compressor characteristic has to be considered. Additionally, the maximum shaft speed is limited to 11550 rpm by the brake compressor disks.

Three remotely controlled butterfly valves are used for startup, control and shutdown. These valves will also shut down the machine in case of emergency. A detailed discussion on the emergency shutdown and on load changes of the facility can be found in Neumayer (2001).

Depending on the flow similarity requirements (corrected speed and pressure ratio) of the turbine stage that has to be tested it can occur that the brake compressor does not achieve the prescribed pressure ratio for the given speed. In this case the compressed air from the brake compressor is fed directly to the exhaust line, the bypass valve remains partly open to maintain the braking effect. For this test setup turbine inlet pressure is limited by the compressor station at above 5.0 bar.

In test setups where the air from the brake compressor is added to the compressor station airflow the maximum turbine inlet pressure is given by the brake compressor pressure limit. This limit is at about 4.6 bar at 11550 rpm.

This concept of the test facility allows a continuous operation of the test turbine within a widely adjustable speed range between 7000 and 11550 rpm. The maximum inlet pressure is 4.6, respectively 5.0 bar, the range of turbine inlet temperatures is from 40 to 185 °C, resulting in a maximum coupling power of 2.6 MW depending on the characteristic of the turbine stage mounted. The modular design of the test turbine allows quick modifications, the meridional flow path, the stage as well as the diffuser can be adapted in a wide range.

MECHANICAL & OPERATIONAL CHARACTERISTICS

- Continuously operating cold flow test facility in open cycle
- Use of a compressor as brake for enhancing mass flow
- Wide adjustable speed range of the test rig with the first bending mode of the two shafts below 7000 rpm and the second bending mode sufficiently higher than the maximum speed of 11550 rpm
- Stable tilting pad bearings also at the turbine shaft
- Overhung-type turbine shaft for easy disk assembly
- All casing parts horizontally split for easy maintenance (except diffuser inserts)
- Modular design for quick modification of test setup
- Possible cooling air flow supply of blades and cavity
- Test section with high flexibility of meridional path [mm] (see fig. 2):
  - Stage inlet adapters starting at D_{inner} = 360, D_{outer} = 620
  - Test section inserts maximum diameter D_s = 800
  - Diffuser insert flanges D_i = 720
  - Test section length L_{Test} = 406
  - Diffuser length L_{Diff} = 620

- Test turbine stage operational limits:
  - Inlet pressure max. 4.6 bar (5 bar)
  - Inlet temperature max. 185°C
  - Outlet pressure 0.97 without or 0.80 bar with suction blower operation
  - Maximum mass flow: 9.5 kg/s without and about 20 kg/s with air of brake compressor
  - Maximum speed 11550 rpm
- GHH brake compressor :
  - Nominal speed 11175 rpm
  - Nominal outlet temperature 229°C
  - Maximum coupling power 2.5 MW at -15° IGV position
- Flexible membrane coupling TSJE0420:
  - Maximum axial displacement +/-2.0mm
  - Maximum angular displacement 18´

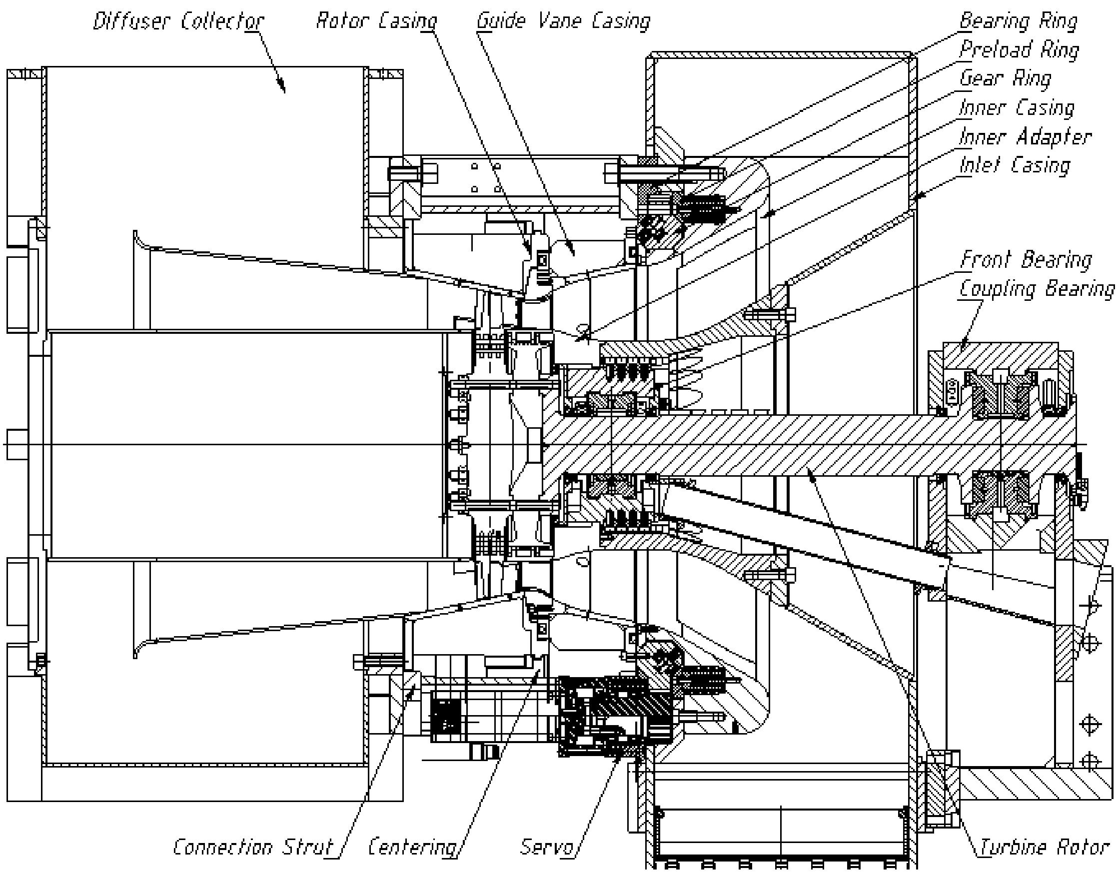

Figure 2: Main components of test turbine

INSTRUMENTATION

- Measurement of speed, torque and power at coupling
- Mass flow, pressure and temperature measurement at
  - compressor station supply pipe
  - GHH brake compressor inlet and outlet
  - stage leakage flow outlet
  - stage cooling flow inlet
  - bearing oil supply inlet and outlet

- Inlet casing pressure and temperature measurement
- Measurement of pressure and temperature at diffuser exit
- Suction blower pressure difference to ambient
- Four measurement planes for more detailed investigation (depending on stage inserts and testing to be performed)
  - plane A in front of the guide vanes (stage inlet)
  - plane B between guide vanes and rotor blades
  - plane C behind the rotor blades (stage exit)
  - plane D at axial diffuser exit
- Rotatable stator ring (+/-180°) allows radial and circumferential traversing in front of the stage, in the institute's TTM stage the guide vanes can also be rotated allowing different vane positions
- Optical access to the TTM Stage in the outer casing between vane exit and diffuser inlet

SAFETY CONCEPT

In the case of exceeding pre-set danger values by each of the following signals an automatic emergency shutdown of the machine train will be released through shut-down of the compressor station and fast opening (0.4s from 0% to 100%) of the two main valves in the overflow pipe:

- Electric circuit interruption to emergency supply
- 2 channel overspeed system at turbine shaft coupling
- XY Orbit / relative shaft displacement in the four bearing planes
- Axial displacement at each axial bearing for thrust control
- Temperature of all tilting pad bearings
- Inlet pressure for all four bearing supply pipes
- Pressure of the main and the auxiliary electrical oil pump
- Temperature and oil level of the oil tank
- Overpressure of the Turbine inlet casing

In the worst case of a coupling breaking the free accelerating turbine should be caught at about 25% overspeed.

LITERATURE

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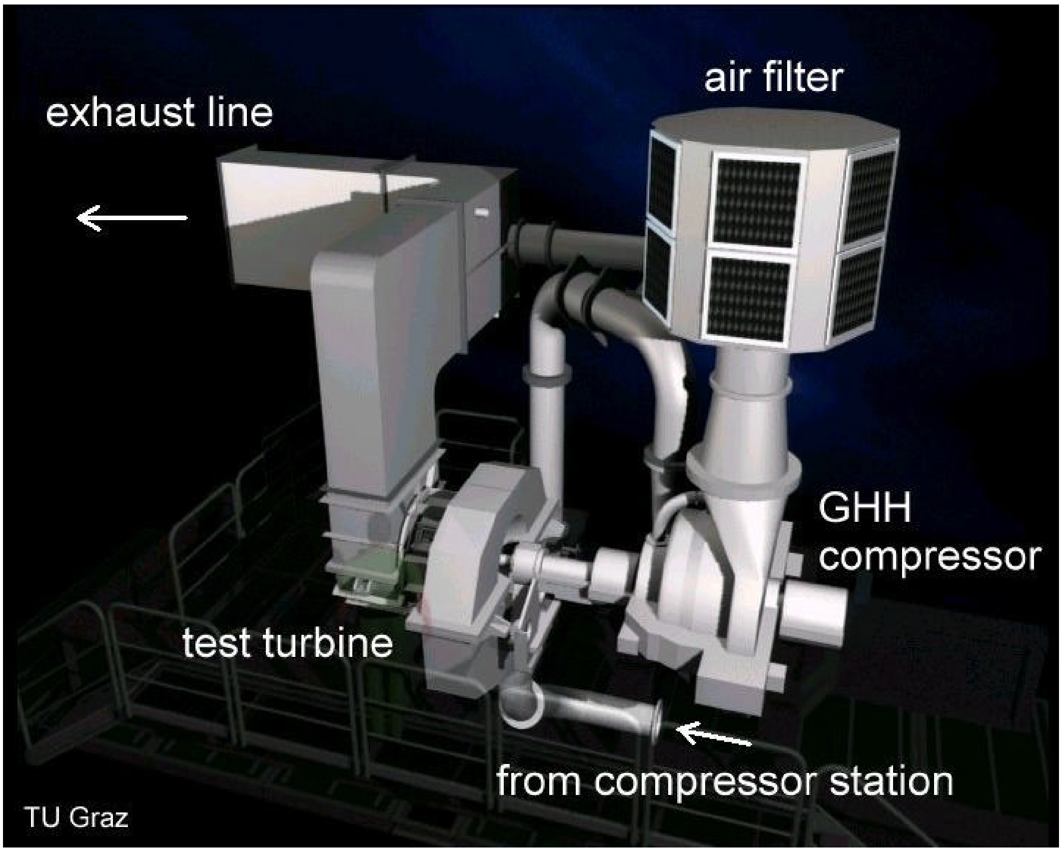


Figure 3: Main components of test turbine facility

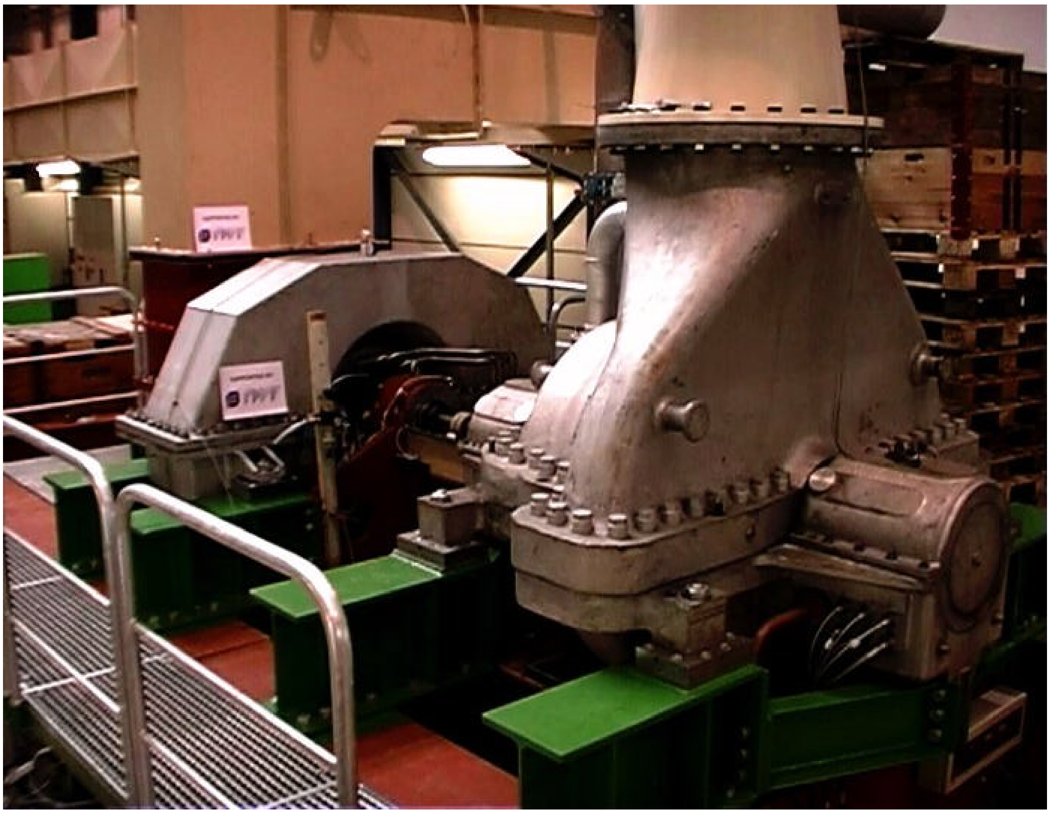
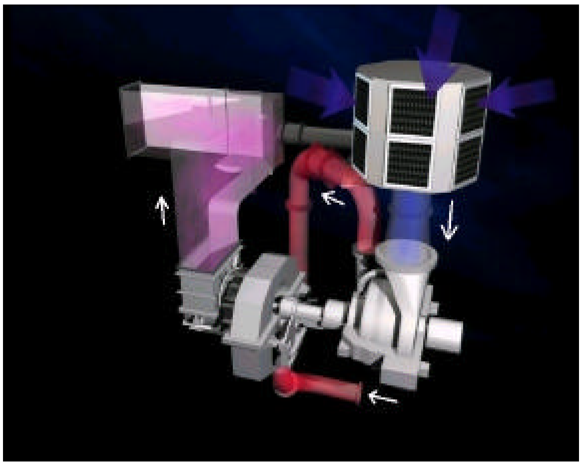


Figure 4: View of the brake compressor and the turbine mixing chamber



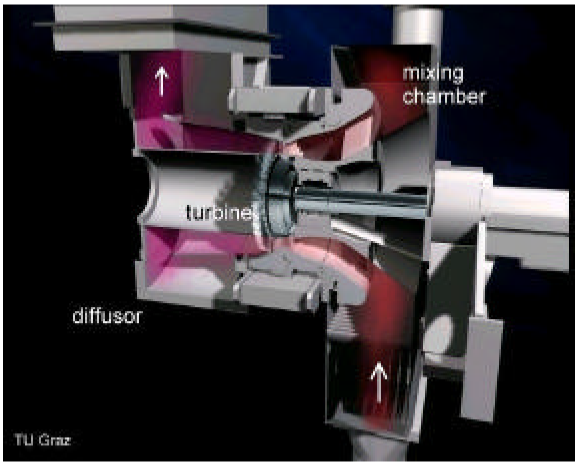
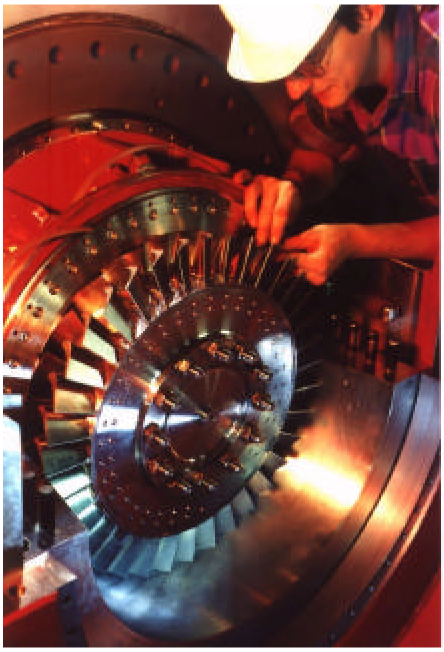


Figure 5: Flow scheme of the facility and flow inside the turbine



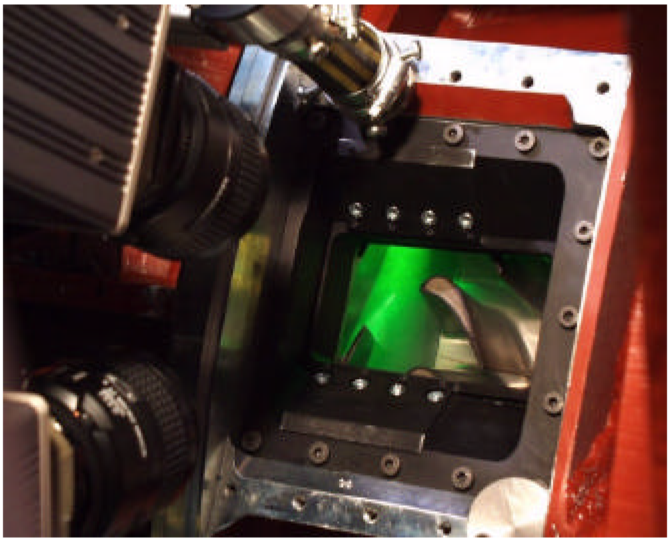


Figure 6: View of turbine rotor

Fig. 7: Instrumentation for PIV measurement

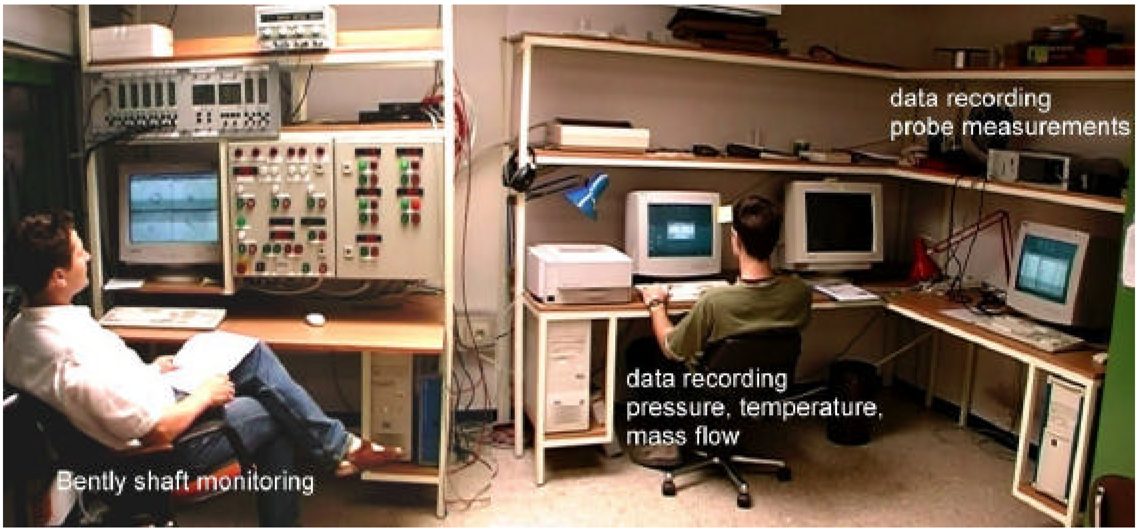


Figure 8: Control and monitoring station of the test facility