Partner 25: TECHNISCHE UNIVERSITÄT GRAZ

A) Principal Information

1) PIV-NET activities

Since Particle Image Velocity is used at the ***Institut für thermische Turbomaschinen und Maschinendynamik***, Inffeldgasse 25, A-8010 Graz, Austria, http://www-ttm.tu-graz.ac.at and the ***Institut für Strömungslehre und Wärmeübertragung,*** Inffeldgasse 25, A-8010 Graz, Austria, both Institutes particpated at two workshops within the first year of PivNet activity.

- PivNet kick-off meeting and workshop 'Standard of recording and evaluation and the file format for PIV data as developed in EUROPIV', Dec.4th and 5th, 1997
- Workshop on application of PIV in aerodynamics, Nov. 10th, 1998

2) PIV-equipment at Technische Universität Graz:

- pulsed ruby laser and PIV evaluation software AEA visiflow (Institut für Thermische Turbomaschinen und Maschinendynamik)
- DANTEC Flow map system, argon ion laser , Dantec double image 700 and correlation software (Institut für Strömungslehre und Wärmeübertragung,)

3) Present fields for the application of PIV technique at Technische Universität Graz

Institut für Thermische Turbomaschinen und Maschinendynamik:

- PIV investigation of particles in high speed flow -
- 3D PIV investigation in rotating turbomachinery

Institut für Strömungslehre und Wärmeübertragung

- Investigation of multi-phase-flows
- Investigation of turbulence in particulate flows

4) Activities planned with other partners in the PIVNET

Application of a newly developed stereoscopic system to the investigation of flows in a transonic test turbine rig.

B) Detailed annual activity report - PIV related activities at TU Graz

1) PIV investigation of surface erosion by high speed particles in turbomachinery flows

Institut für Thermische Turbomaschinen und Maschinendynamik
R.Pöschl, J.Woisetschläger, H,Jericha

Objective

The objective of this investigation was to clear up the mechanics of erosion at high velocity impact at flat impact angles. Beside the use of PIV for velocity measurements in such flows, a scanning electron microscope study had been performed to better understand the microscopic erosion mechanism of particles with supersonic speed as well as an extended numerical investigation of the particle trajectories using an euler-lagrange approach in a commercial viscous unsteady flow simulation program (FIRE, AVL Graz) at the institute for thermal turbomachinery and machine dynamics.

Background

In certain industrial processes heat is available in hot gases at atmospheric pressure. A typical example is biomass combustion. A novel design for such a process is given in the inverse gas turbine process [1]. In this process the hot exhaust gases from the combustion process are expanded in a gas turbine to a vacuum pressure of about 0.4 bar. Afterwards the gases are cooled, the water condensed and the uncondensable gases are compressed to ambient temperature.

In those plants gases have to be handled highly loaded with dust particles. A certain amount of particles still enters the gas turbine usually designed as one stage turbine with transonic flow conditions. In this harsh environment information about erosion behaviour of the blade material is of special importance. Particles passing through a gas turbine blading are continuously reduced in size due to the cracking as consequence of repeated impacts on blade surfaces. This erosion can alter blade profiles severely and decrease flow efficiency drastically [2,3].

Supersonic Erosion Test Stand

The erosion test stands is designed as a replaceable cylindrical insert into the structure of the Transonic-Cascade (Fig.1) The main parts of the erosion test stand are the wedge-shaped specimen which is attached to an specimen-holder being adjustable within the two contour parts. The latter give the channel the needed shape of a naval nozzle. For observing particles in the half depth plane of the 2D-Channel, a light sheet window made of glass has to be included in the contour part. This design feature requires a linear part in the continuously curved contour at the position of the leading edge of the specimen. To generate an appropriate mathematically defined contour a B- Spline function was used to guarantee continuity of shape and curvature.

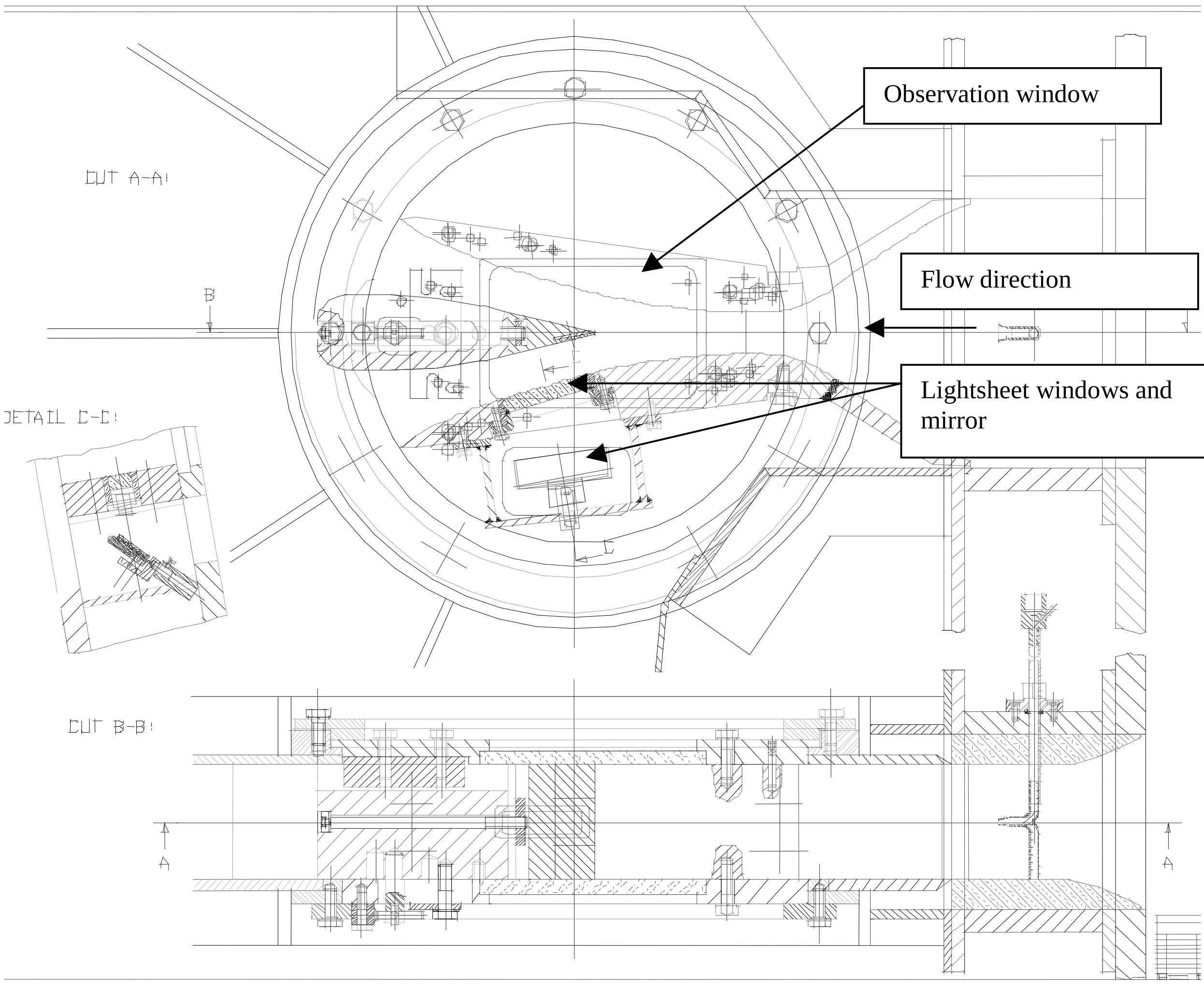

Fig.1 Design drawing of the erosion test rig

For flow visualisation a colour - Schlieren technique was used. In this technique four knife edges are arranged quadratically thus providing sensitivity in all four directions [4]. With that method location and gradient orientation of shock waves can be visualised.
The flow pattern around a blunt wedge (test specimen) in the erosion test stand is characterised by two oblique shock waves which appear nearly parallel on both sides of the specimen (Fig.2). Using the 4-Colour- Schlieren- Technique both of them can be seen. The detached shock is located a few mm in front of the leading edge and another one starting from the wedge surface. This incoming oblique shock wave initiates a local very small separation zone in the boundary layer of the channel contour which causes another oblique shock wave (i.e. reflected one) and an expansion wave to turn the supersonic flow around this tiny obstacle [5]. After a short expansion zone another oblique shock wave crosses the channel and raises the pressure level to approximately ambient condition.

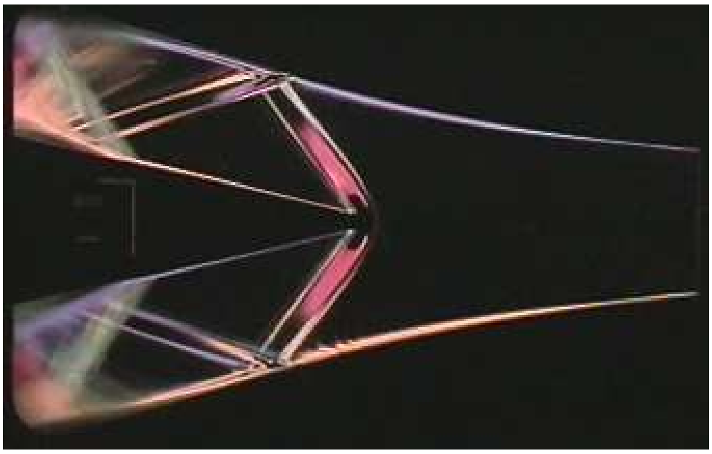

Fig.2 Shock wave distribution at blunt wedge

Particle Seeding

The different experiments conducted required two types of solid particle seeding. In the case of continuous seeding for the laser measurements a cylindrical tank of approximately 1 litre capacity was filled with particles (quartz grains of known size). Compressed air of about 4bar flows through a perforated tube in the centre of this tank and sucks particles into the injection stream. The particles reach the main flow of the test stand through a 90° pipe bent.
To provide an intermitting stream of a distinct amount of particles, the quartz grains are loaded via a funnel directly into the sealed pipe bend, and are afterwards supplied into the main stream by short duration jets of pressurised air.
In both cases the main difficulty is the agglomeration effect of particles smaller than 20µm diameter.
The particle distribution observed near the leading edge is considerably influenced by the starting conditions of the introduced particles. The Laval - nozzle focuses the particles towards its axis, therefore most of them would hit the flat leading edge, and afterwards impact several times on the specimen surface. To force the particles to hit the surface directly behind the leading edge the seeding pipe bend was inclined -15° to the axial direction. Another severe effect for the radial deviation of the particles in the main stream is the different inertia force due to the acceleration within the sedding pipe which tended to deviate the particle sidewise. Nevertheless, the direction of the first impact on the surface do not differ very much from the axial direction.

LDA Measurements

For LDA measurements a two-dimensional DANTEC Fiber Flow system had been used together wit a DANTEC Burst Spectrum Analyser. For LDA measurements a DEHS seeding was used provided by a PALLAS-AGF particle generator in a droplet size below 1µm.

The velocity magnitudes 1.5 mm above the surface of the wedge starting at the leading edge as a comparison between LDA and calculation with FIRE show Fig.3.
For some positions along the flow direction two values have been analysed from the LDA-signal according to two distinct peaks which correspond to the fluctuating position of the unsteady second shock wave. The extensions of the recirculation zone on the Laval contour pulsates according to the unsteady change of the second shock wave position, which in some extreme situation reaches nearly the location of the first shock wave at the leading edge. These LDA measurements gave first velocity data on the main air flow. Due to the highly erosive effect of the quartz grains and the extended time of LDA measurements no solid seeding could be used for LDA measurements. For that reason we decided to set up a PIV recording of particle velocities.

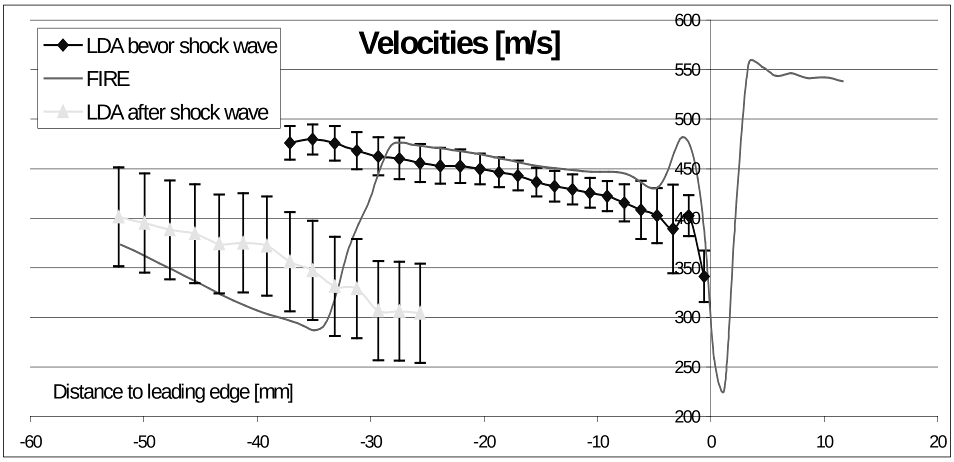

Fig.3 Comparison of LDA Measurement and CFD Calculation close to the wedge surface

PIV Measurements

For detailed evaluation of the erosion phenomena the impact velocities and impact angles of the particles are of special interest. Therefore, the very advanced PIV-method had been applied using a double pulse ruby laser. The laser is optically widened to a horizontal light sheet which is deflected via a mirror and a window in the lower LAVAL- contour part in the mid plane of the 2D channel. Particles moving along the light sheet deflect light in perpendicular direction where a camera is located to expose a photographic film. The ruby laser was double-pulsed with a pulse delay of 2 to 5µs, triggered by the particle seeding device. The recording were performed using a 35 mm photographic camera equipped with an exchangeable CCD-chip in the viewfinder of the camera [6]. This enabled optimal focussing of the light sheet. For purpose of electron-microscopic investigation of the erosion patterns on the surface of the specimen the surface had to bee highly polished. Due to this mirror-like surface nearly no light was reflected from the surface towards the camera.
The PIV-images were digitised afterwards for being used in an automatic analysis. For PIV-evaluation we applied AEA VISIFLOW software. An auto-correlation procedure computes the correlation values for every interrogation area subsequently for the whole PIV image. For this auto-correlation procedure the wedge surface itself had been masked. The program selected the three most probable correlation directions out of the correlation field. Fig.4 shows the result of such a procedure. In the center the auto-correlation spectrum is given clearly showing two auto-correlation peaks, one for the incoming particle flow, one for the reflected flow.

Results

From the difference in incoming speed and angle towards reflected speed and angle the energy loss due to impact was calculated. Together with a numerical flow analysis and an evaluation of penetration depth and width for different particle sizes using Scanning Electron Microscopy the average material loss due to single particle impact was studied ([7], see also Tab1).

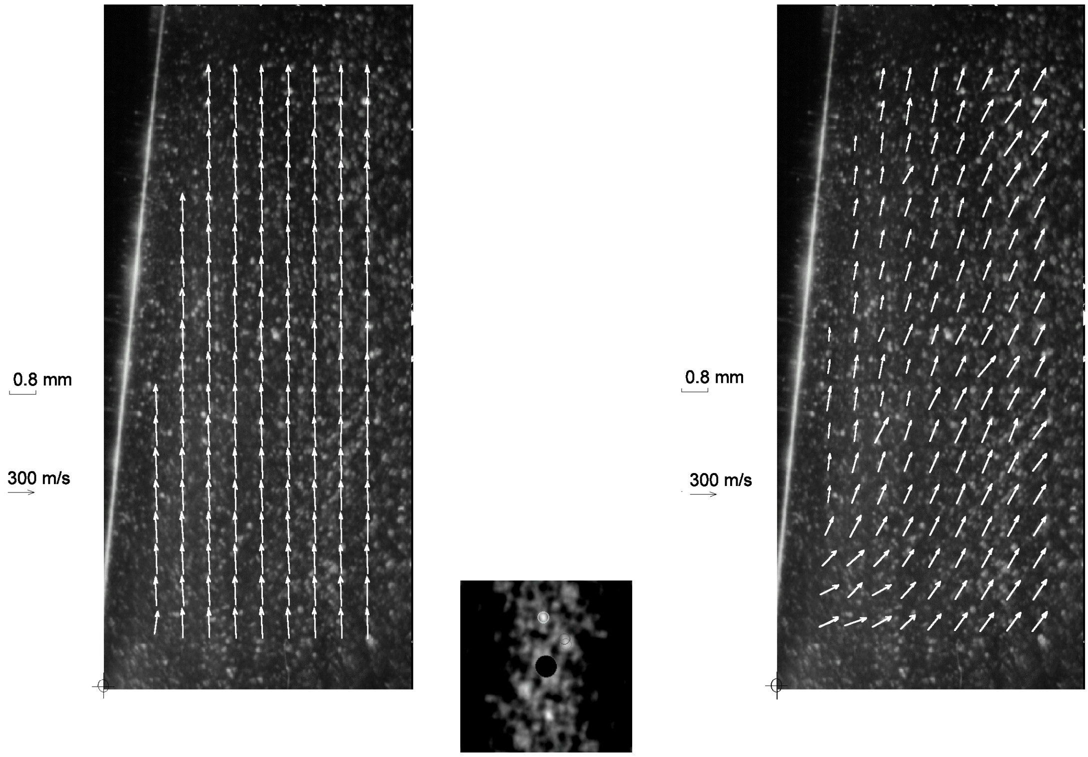

Fig.4 Solid particle impact on wedge surface. The leading edge is on the lower left. The flow direction is upwards. The auto-correlation spectrum (centre) for one interrogation area close to the surface shows two auto-correlation peaks, one for the incoming (left), one for the reflected (right) particle flow field.

Table 1: Comparison of calculated and measured impact parameters

	PIV measurement					
particle size	**v_min**	**v_average**	**v_max**	**α_min**	**α_average**	**α_max**
µm	**m/s**	**m/s**	**m/s**	**°**	**°**	**°**
10-25	352	**388.7**	430	8	**10.0**	12
25-40	267	**292.8**	321	8	**11.0**	13
40-63	182	**222.5**	265	6	**9.0**	12
	Calculated Results (FIRE)					
5.0	441	**448.5**	454	6	**7.7**	9
10.0	415	**418.1**	421	11	**11.3**	12
17.5	368	**369.2**	371	12	**12.7**	13
25.0	333	**335.3**	338	12	**13.2**	14
32.5	306	**307.0**	309	12	**12.9**	14
40.0	284	**285.4**	287	11	**12.4**	14
51.5	264	**267.2**	270	10	**10.5**	12
63.0	240	**240.2**	240	11	**11.7**	12

Acknowledgements

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2) Planned future activities:

2.1) PIV investigation of two-phase flows
Institut für Strömungslehre und Wärmeübertragung

In future PIV activities we will focus on the investigation of droplet formation and motion in fluids consisting of low-concentration suspension in a liquid carrier phase. The formation of these droplets is of special interest and had been recorded previously in a more quantitative way. Using our PIV-system we intend to investigate the suspension flows in these droplets as well as in the carrier phase to better understand basic processes in these type of two-phase flows.

2.2) PIV investigation of flows in turbomachinery
Institut für Thermische Turbomaschinen und Maschinendynamik

Currently, a test turbine is set up at the institute. Beside probe , LDA measurements and flow visualisation we indent to perform PIV measurements of the main flow between stator an rotor within the next years.

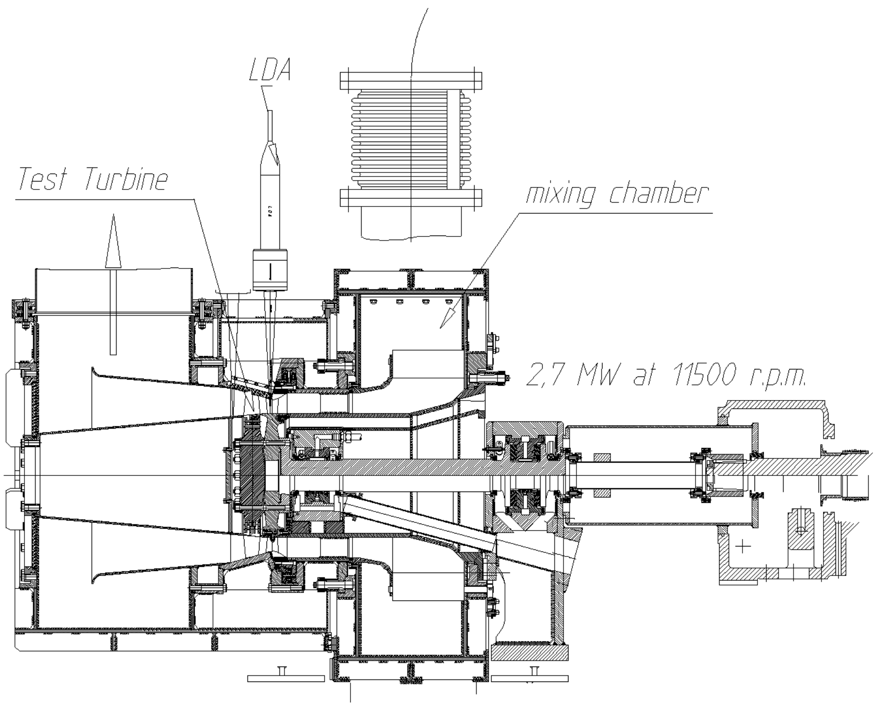

Fig.5 Test turbine design