Finally, although one cannot deny that nonstationary flow has an effect on the probe behaviour concerning the measurement of the total pressure, it seems that in our case, probably because of the small size of the tubes used, this influence was very small.

AKNOWLEDGEMENTS

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[2] Davis, W.R., Millar, D.A.J.: "Axial flow compressor using a matrix method" (Carleton University ME/A73-1)

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Analysis of the unsteady flow in a turbine stage with different methods

by

K. Einsfeld

On the turbine stage at the "Institut für Aerodynamik und Gasdynamik, Universität Stuttgart" there were at first made spatial and/or temporal integrating pressure measurements and high-speed Schlieren and interference measurements[1)] with high spatial and temporal resolution. The essential result was: the Schlieren and interference pictures show a highly complicated unsteady flow; the consequence is, the conventional integrating pressure measurements cannot describe satisfactorily the universal flow behaviour. Therefore other more informative time resolving measuring techniques were applied; techniques with less expense than by the optical measurements and more expense than by the pressure measurements. Integral forces effected on the profile were determined with semi-conductor strain-gages[2)] and velocity distributions with a hot-wire anemometer[3)].

The aim of all investigations is to analyse the unsteady flow through a turbine stage in detail and to study what is the consequence, if the highly complicated unsteady flow is treated as a simpler one.

1) Hahn, G.: Eine einfache hochfrequenzkinematographische Einrichtung bis 3,3 10^6 Bilder/Sek. für interferometrische Aufnahmen instationärer Strömungen.
Kurzzeitphotographie. IV. Internationaler Kongress. Köln 1958. Verlag Dr. Othmar Helwich. Darmstadt 1959. S. 257-266.

2) Einsfeld, K.: Vergleichende elektromechanische und hochfrequenzinterferometrische Messung instationärer Schaufelkräfte an einem durch ein Laufrad instationär beaufschlagten Turbinengitter.
Dissertation an der Universität Stuttgart, Nov. 1970.

3) This investigation is within the "Sonderforschungsbereich 85 Thermodynamische und strömungsmechanische Probleme der Luft- und Raumfahrtantriebe", sponsored by the Deutsche Forschungsgemeinschaft.

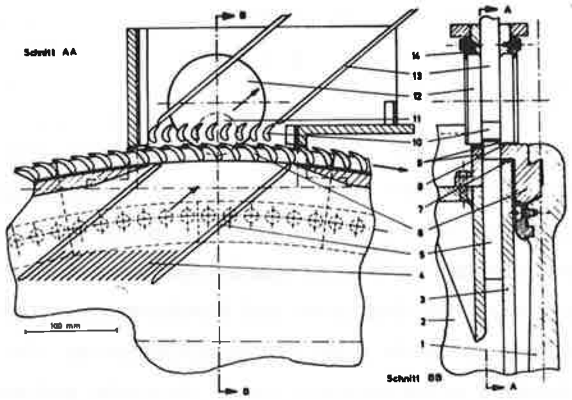


Fig. 1 Turbine stage test facility

In the following some substantial results are presented.

Fig. 1 is a sketch of the turbine stage. The kinematic is changed. The first lattice is mounted on a rotating motor-powered wheel with three hundred profiles and the socond lattice is stationary in the chamber with windows for optical measurements. The airflow is directed radial from the inner to the atmosphere.

The interference picture (Fig. 2) is one frame of a series of nine pictures, taken with a high-speed rotating mirror camera. The picture frequency was 50 kHz. In this picture the lines are the isocores of an unsteady transonic flow. It is to see the stationary lattice and one trailing edge of a moving profile. The interferogram was made with a Mach-Zehnder-interferometer. Significant is the shock in the gap between the two cascades. The shock is a combination of the trailing-edge

shock on the first profile and the shock in the local supersonic region on the second profile. The shock is moving and the interaction between the shock and the boundary layers gives rise to an essential unsteady non-periodical part of the flow.

This fact is demonstrated in Fig. 3. On one of the profiles in the chamber there was mounted a semi-conductor strain-gage. The length of the profile was so selected that the first inherent bending frequency was the same as the stimulating frequency of the rotating cascade. The amplitude of the profile vibration is traced against the total pressure ahead of the stage. Interesting is, that at first the amplitude rises nearly linearly to a maximum. In this region the upstream behind the first cascade is sonic. Then the amplitude decreases rapidly and the values are fairly fluctuating. This is the consequence of the fact, that the periodicity is reduced.

Worth mentioning is another fact. On the rotating wheel three hundred profiles with equal pitches and with one differring pitch are mounted. This pitch is 1.5 the normal pitch and therefore the stimulation is shifted by hundred and eighty degrees after each revolution. The consequence is, that the amplitude of the vibrating profile increases slowly and then the amplitude decreases rapidly. That means, the decrease of the vibration energy is faster than the increase of vibration energy. This is shown in Fig. 4.

Another shorter profile with a strain-gage was used to measure the force effected on this profile. The first inherent bending frequency, about 7 kHz, was in the order of the stimulating frequency and the damping was small. This leads to difficulties.

The eclectrical signal in the oscillogram (Fig. 5) is a combination of the stimulated vibration and the natural vibration. Therefore the signal cannot be periodical. Its periodical part was deduced with a numerical procedure: the amplitudes and the phases of several harmonics.

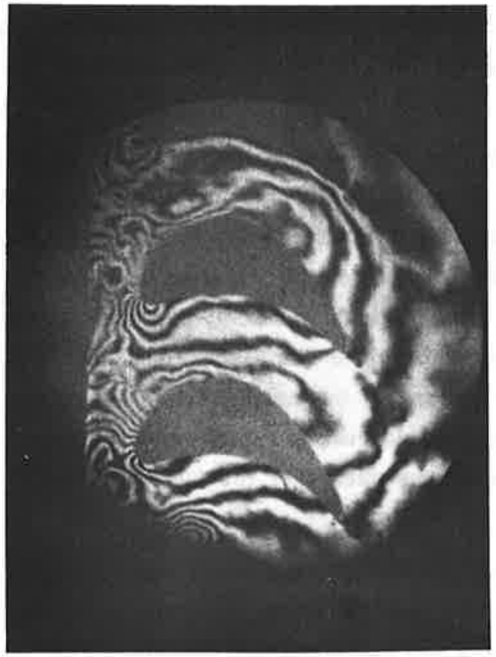


Fig. 2 Interference picture of the unsteady transonic flow through a turbine stage

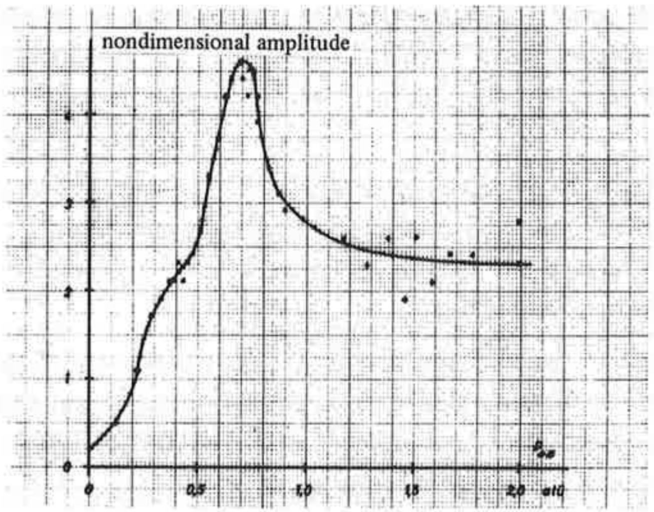


Fig. 3 Amplitude of profile vibration against total pressure ahead of the stage

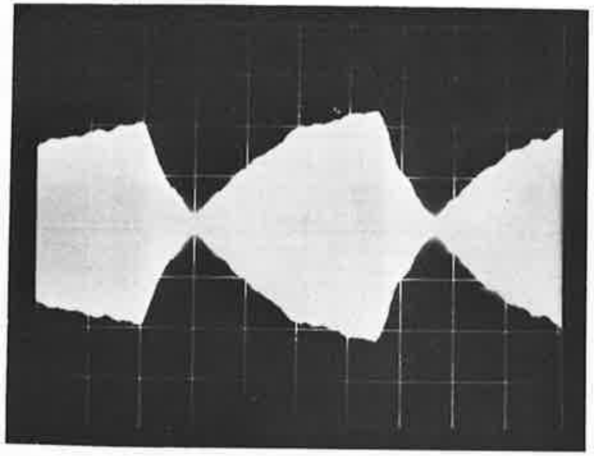


Fig. 4 Influence of an unnormal pitch on the amplitude of the profile vibration

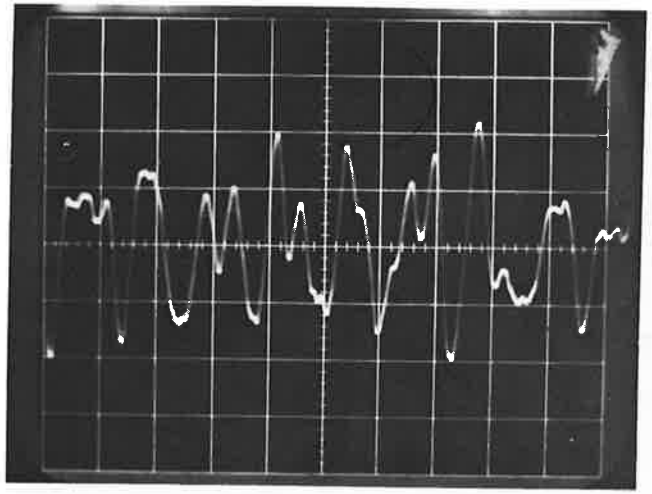
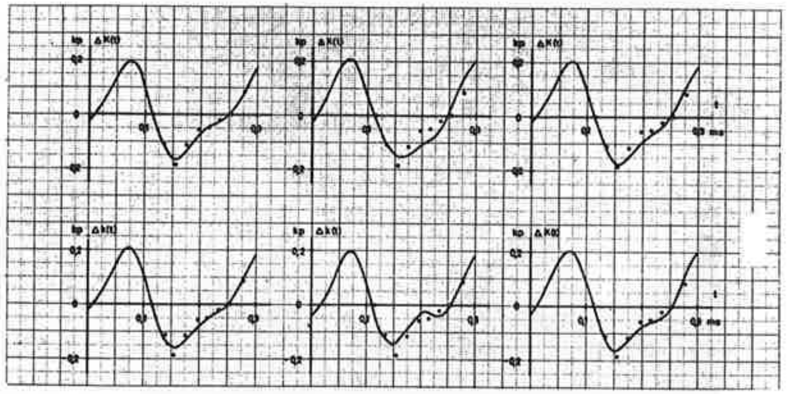


Fig. 5 Analogous electrical signal of the stimulated and natural profile vibration

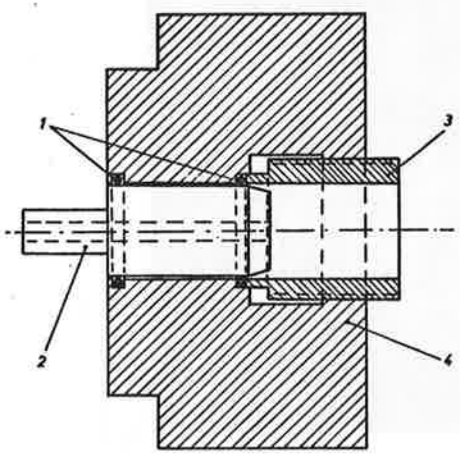


Periodic part of the force from strain-gage measurement

○ interferometry
– strain gage

mean value of force:
strain-gage measurement 1.26 kp
interferometry measurement 1.37 kp

Fig. 6 Periodical part of the profile force against the time



Blade mounted with an oil layer between root of blade and support

1 = O-Ring
2 = Blade
3 = Tightening screw
4 = Blade support

Fig. 7 Measuring profile with very great damping

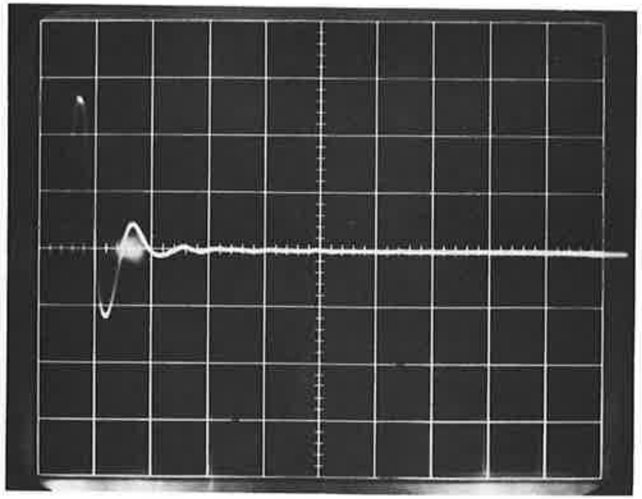


Fig. 8 Analogous electrical signal of the very damped natural profile vibration

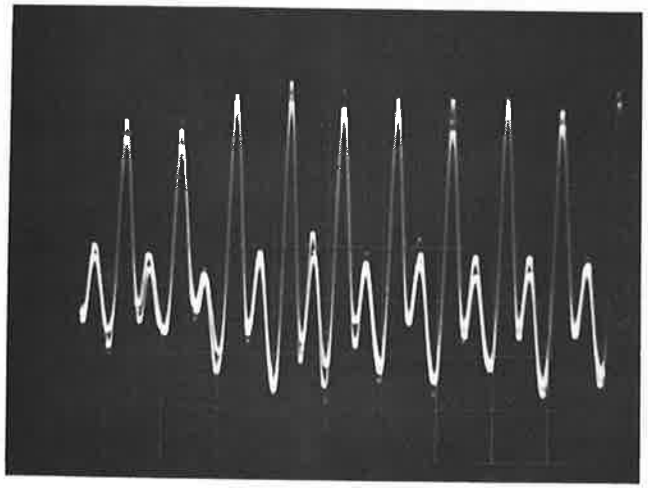


Fig. 9 Analogous electrical signal of the unsteady profile force

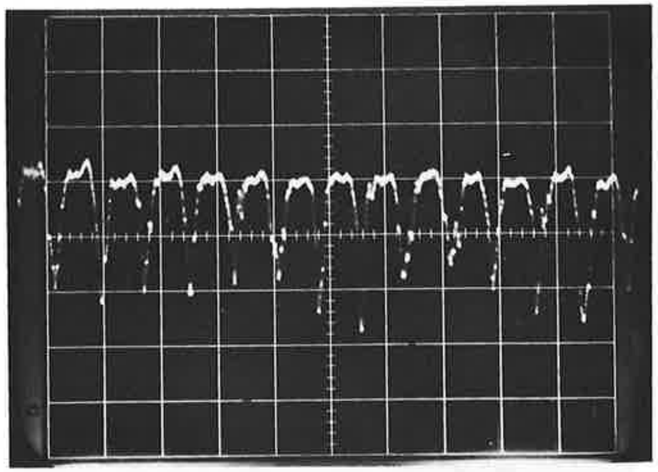


Fig. 10 Analogous electrical signal of the local velocity behind the rotating cascade against the time

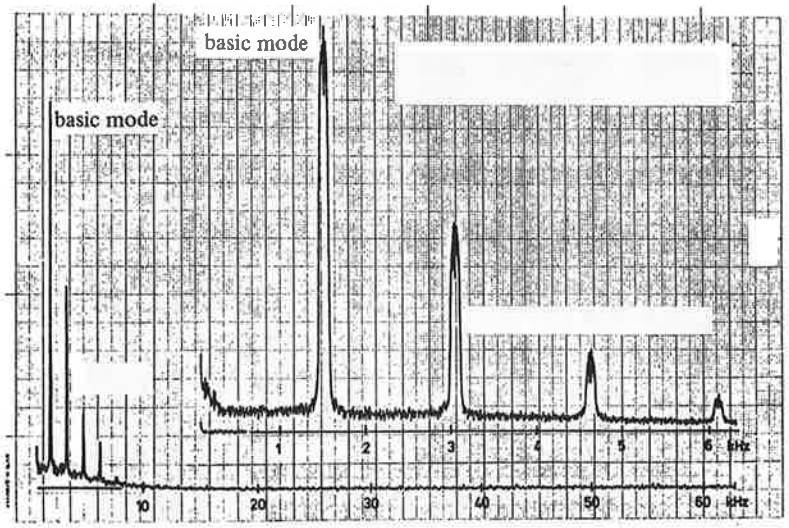


Fig. 11 Frequency spectra of the local unsteady velocity behind the rotating cascade

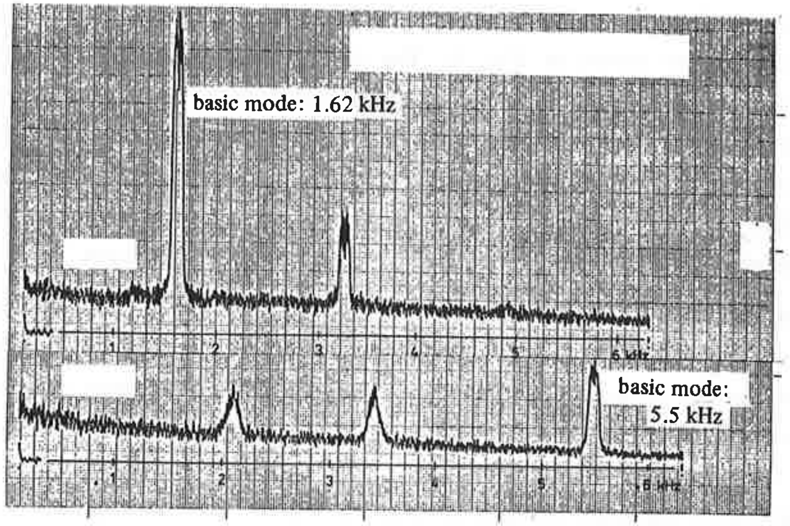


Fig. 12 Frequency spectra of the local unsteady velocity behind the stationary cascade

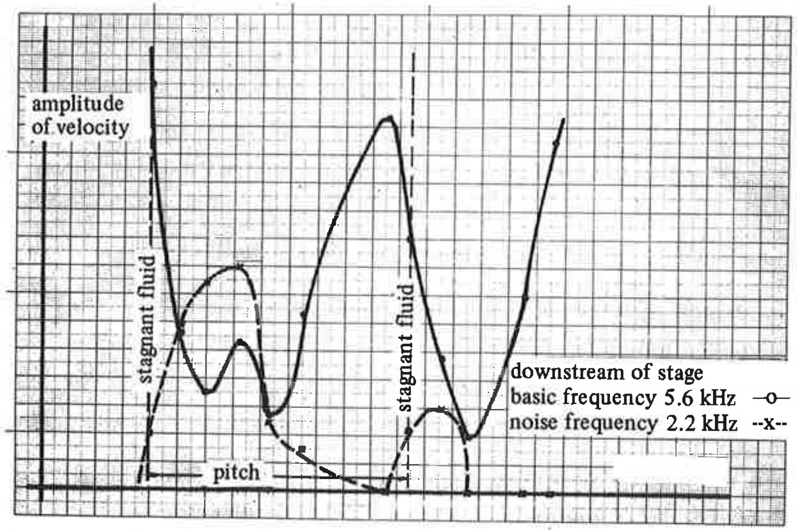


Fig. 13 Velocity amplitude of the first stimulated frequency against the circumferential direction

The results from six oscillograms, each taken at the same measuring conditions, are shown in Fig. 6. The periodical part of the profile force is plotted against the time. The points denote values from the interferometrical measurement. The curves differ slightly each from another. That means, the flow is not exactly periodical and the measuring time, about 8 periods, is too short to eliminate completely the non-periodical part. The amplitude of the unsteady force is about 0.15 the mean value.

To overcome the difficulties with the natural vibration a new shorter profile with very great damping was constructed. The profile has a cylindrical end which is supported in a very thin oil-layer (0.1 mm) and the gap is sealed with two O-rings. The semi-conductor strain-gage is applicated in a bore in the inner of the profile (Fig. 7). Fig. 8 represents the oscillogram of the very damped natural vibration. The consequence is, that in Fig. 9 the analogous electrical signal for the force is free from a part of the natural vibration. The picture is threefold exposed. The oscillograph was triggered external, coupled with the rotation of the wheel. So the flow past the same profiles is measured. The reproduction is good.

At present, the velocity field is measured with a hot-wire anemometer. Fig. 10 shows the local velocity behind the rotating cascade, periodical in time. From there the magnitude of the periodical parts and the amplitude of the non-periodical parts were determined with a frequency analyser (Fig. 11). The decrease of the amplitudes of the higher-harmonics is of the same order as with the strain-gage force measurements.

Two frequency spectra of the local flow behind the stage, that is, behind the stationary cascade, are represented in Fig. 12. Worth mentioning are two features. The decrease of the amplitudes of the higher harmonics is faster than in the gap between the cascades. That means, the higher harmonics are more damped during the passage through the second cascade. In Fig. 12b the first stimulated frequency is 5.5 kHz. Below this frequency there exist two other frequencies. They can be interpreted as a standing-wave phenomenon in the flow downstream of the stage. The peaks represent the third and the fifth harmonics of them.

The fourth and the sixth harmonics were detected at other flow conditions.

Another essential fact is, that the amplitudes of all harmonics vary considerably from point in a given test plane. Fig. 13 shows the velocity amplitude of the first stimulated frequency against the circumferential direction. In the wakes the amplitude is greater than in the potential flow. This fact must be important for the development of the boundary layer.

The aim of the measurements with the hot-wire anemometer is to study the relation between the periodical and the non-periodical parts of the unsteady flow.