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Unsteady aerodynamic pressure measurements on rotating lifting systems(*)

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A SPECIAL experiment has been carried out to study the problems of measuring an unsteady non-harmonic pressure in a rotating system. The experimental details are described and the results are discussed.

Dla określenia eksperymentalnie w układach wirujących niestacjonarnego, nieharmonicznego ciśnienia gazu wykonano specjalne urządzenie badawcze. W pracy opisano szczegółowo budowę i działanie tego urządzenia oraz przedyskutowano wyniki badań.

Для экспериментального определения во вращающихся системах нестационарного, негармонического давления газа изготовлено специальное исследовательское устройство. В работе описаны подробно строение и действие этого устройства, а также обсуждены результаты исследований.

Nomenclature

B	amount,
c_B	transfer coefficient,
c_{Ph}	transfer coefficient,
F	area,
f	frequency,
h	pressure ratio,
m	mass,
p	pressure,
$\mathfrak{R}$	specific gas constant,
r	radius,
T	temperature,
U	circumference velocity,
V	velocity,
Z	centrifugal force,
β	angle of inclination,
ξ	angle ($\xi = 4\psi$),
φ	phase angle,
ψ	cylinder coordinate,
ϱ	density,
φ	angle.

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1. Introduction

IF ONE wishes to study the local aerodynamic problems of a rotor or a propeller, then, one has to measure the unsteady pressure distribution. But to measure a time dependent pressure signal in a rotating system leads to many problems. Some of these will be discussed presently.

Recently, we had to measure the local pressure distribution of a ship propeller. Since a ship propeller is highly affected by the characteristic rear body flow of the ship hull, the pressure on the propeller becomes non-harmonically unsteady. More than two hundred different measurement points on a blade were required for a tubing system with Scanivalves and a pressure transducer near the hub was used.

2. Method of measurement

The use of a pressure pipe in unsteady pressure measurement requires the consideration of the transfer function of the tubing system. This behaviour is shown in Fig. 1. There is a time lag between the signal at the inlet of a tube on the surface and the end of the tube at the transducer

$$c_{Ph} = \varphi_E - \varphi_I. \tag{2.1}$$

There is also a certain ratio of the amplitude of the signals

$$c_B = \frac{B_E}{B_I}. \tag{2.2}$$

Since these transfer characteristics depend on the frequency, knowledge of the transfer function is required for all frequency parts which are included in the signal or which one has to take into account.

For this reason an Analog Fourier Analysing System (AFAS) was developed which measures the real and imaginary parts of the first six harmonic parts of a periodic signal. A typical result of the AFAS is shown in Fig. 2. The single frequency parts are already

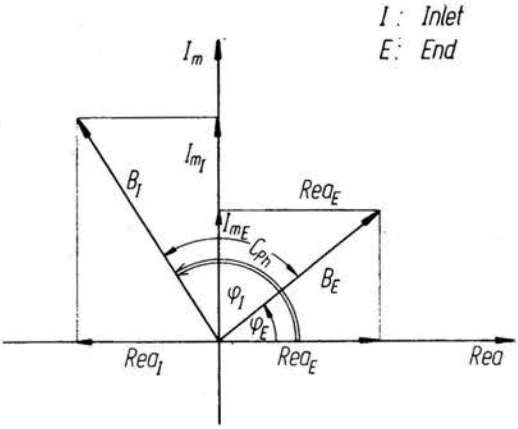


FIG. 1. Transmission characteristics of a tube.

corrected relative to the transfer function. They are put together at the bottom of the figure. This is the measured signal without the higher harmonic parts, higher than the first six ones.

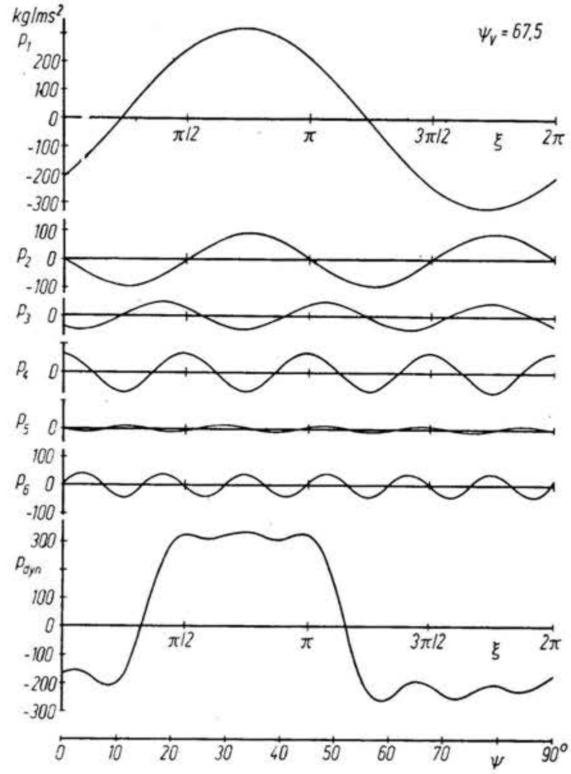


FIG. 2. Result of the harmonic analysing system.

But if one uses an outpiping pressure system in rotation, there is another problem as shown in Fig. 3. The centrifugal forces act on a volume element in the rotating pipe

$$dZ = \frac{dm \cdot U^2}{r} = 4\pi^2 F f^2 \varrho r\, dr. \tag{2.3}$$

With the equation of state this becomes

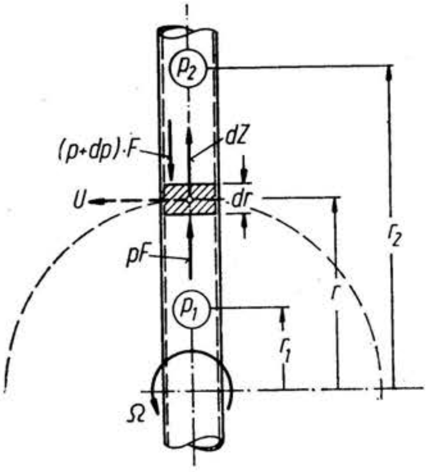
$$dZ = \frac{4\pi^2 F}{\Re T} f^2 p r\, dr. \tag{2.4}$$

The centrifugal force is in balance with the pressure and this leads to

$$\frac{dp}{p} = \frac{4\pi^2}{\Re T} f^2 r\, dr \tag{2.5}$$

with the solution

$$p_1 = p_2 \exp - \frac{2\pi^2}{\Re T} f^2 (r_2^2 - r_1^2). \tag{2.6}$$



$$p_1 = p_2 \exp - \frac{2\pi^2}{RT} f^2 (r_2^2 - r_1^2)$$

FIG. 3. Rotating pressure tube.

The measured pressure has to be corrected according to this equation. For the practical case of an experiment with $r_1 = 0$ this can be simplified by developing in a series. Then one gets only an additional term which is equal to the dynamic pressure based on the circumference velocity

$$p_1 = p_2 + \frac{\varrho}{2} U^2. \tag{2.7}$$

Together with the outlined measurement technology there are three questions:

Where is the limit for the AFAS which is restricted to the first six terms of a Fourier row?

Is it possible to apply the measured transfer function to the different frequencies in a rotating system?

Does the theoretical correction equation describe the real influence of the centrifugal force on the gas?

To investigate these problems a special experimental set-up was developed. The main idea was to produce signals of a well-known shape and to compare them with the result of the measurement method as mentioned before.

3. Experiment

One part of this set-up is shown in Fig. 4. There we have a special cover plate which is put into the stream of a wind tunnel. Some of the single plates are fixed and some are movable. Downstream of the cover plate we will get a radial similar flow field. The structure of this flow field depends on the angle between the fixed and the variable plate.

Figure 5 shows the whole set-up. The flow comes from the left hand side. Downstream of the stream modulator is a motor-driven arm with a carriage. This carriage can be moved in the radial direction and it carries a total pressure probe. The probe is connected to the pressure transducer which is in the axis of rotation. The distance between the tip of the probe and the rotating arm is large enough, so that we can assume the measured flow field not to be influenced by the rotation. With this arrangement we could measure the total pressure of the disturbed flow step by step in a stationary way and in rotation using the AFAS.

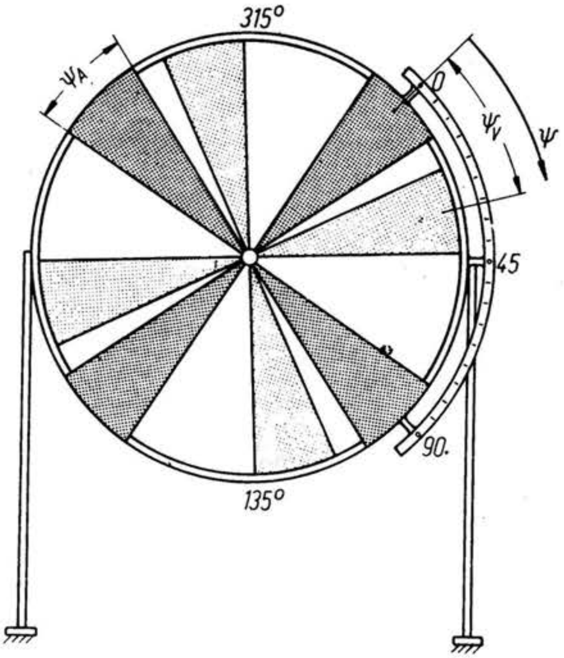


FIG. 4. Stream modulator.

But to measure the total pressure by a rotating probe leads to another problem, as shown in Fig. 6. The flow velocity is superposed by the circumference velocity so that there is an effective velocity under a certain angle of inclination.

The behaviour of the probe depending on the angle of inclination in the stationary case was measured. The result is given as a line in the figure. Then, the total pressure with the rotating probe in the undisturbed flow was also measured by varying the flow velocity V, the radius r and the revolutions per minute n. Similarly, the pressure reading is influenced by the centrifugal forces; the results were corrected according to the formula (2.6). The good agreement between the stationary and the rotating case gives us the following information:

The known dependences of the probe reading on the inclination angle enables us to measure the dynamic pressure of the incoming flow in rotation.

The agreement between the values of very large different centrifugal forces shows that the correction made eliminates this influence.

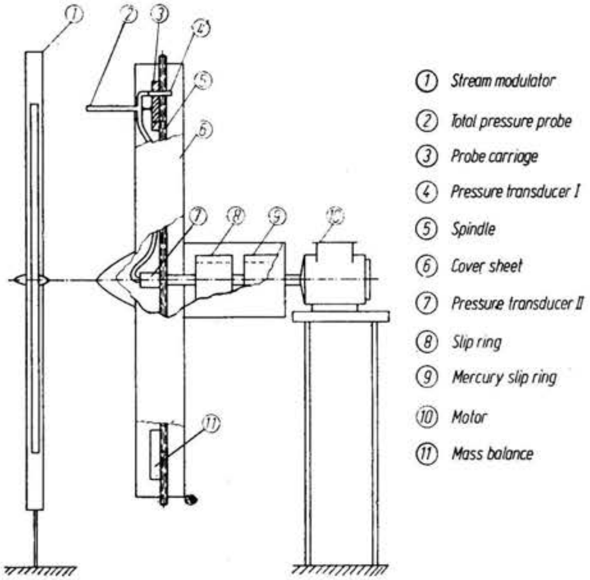


Fig. 5. Experimental set-up.

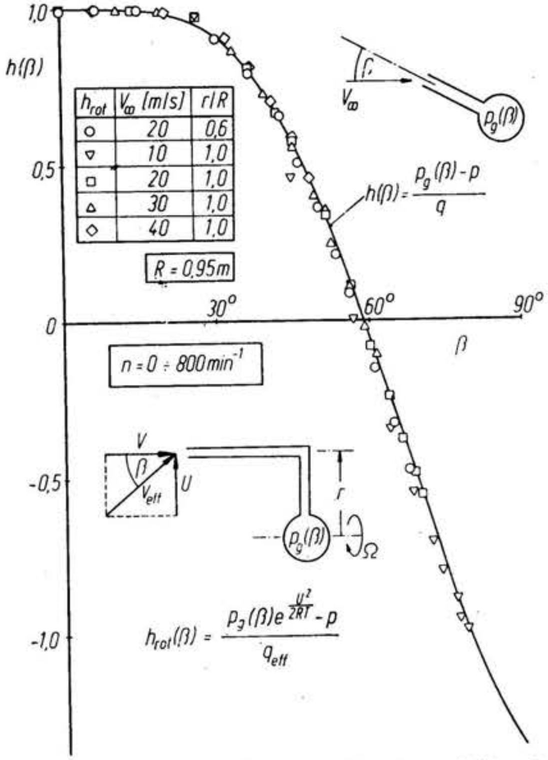


Fig. 6. Comparison of the steady and unsteady measured angle sensibility of a total pressure tube.

4. Results

Figure 7 shows a flow profile measured in two different ways. The experimental conditions are given in the figure. The dotted line is the result of a stationary measured profile, measured in 90 points. The solid line is the result of the AFAS measured on the basic frequency 14 Hz. This result includes six frequency parts up to 84 Hz. This result was corrected due to the transfer function, the centrifugal forces and the dependence on the inclination of the probe.

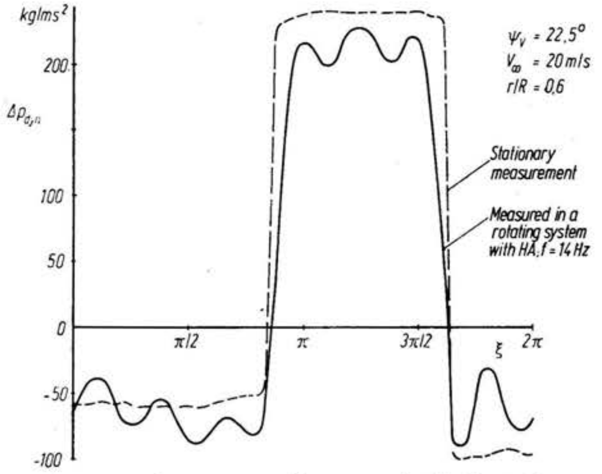


FIG. 7. The unsteady measured pressure profile compared with the stationary measurement.

Both signals have exactly the same position. Because of this and the symmetrical shape of the time-depending result, one can conclude that the correction of the transfer function is quite good. Each error in that correction would lead to an unsymmetrical shape. Furthermore, the rectangular shape is found by the AFAS. This certain roughness is due to the absence of the higher harmonic parts. Also the pressure level in the stream and behind the plates is nearly correct. Figure 8 shows another case. Here, using the AFAS the po-

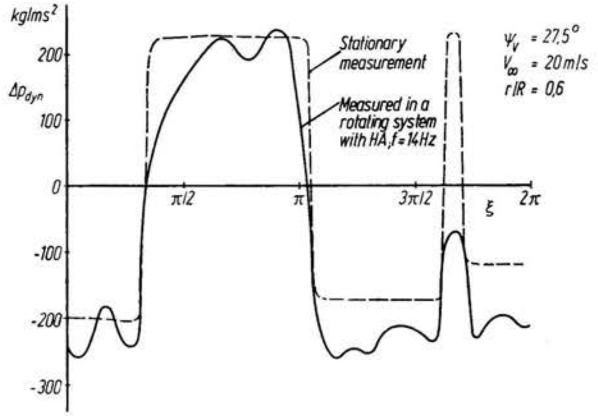


FIG. 8. The unsteady measured pressure profile compared with the stationary measurement.

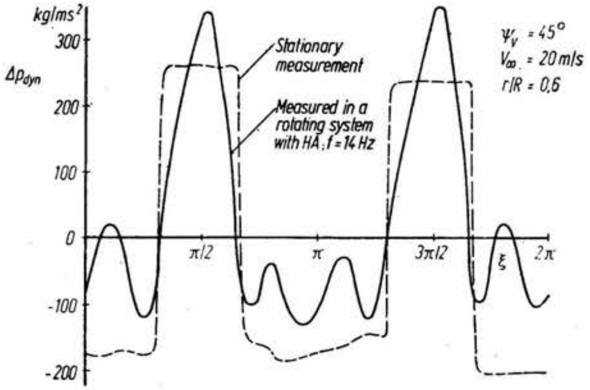


FIG. 9. The unsteady measured pressure profile compared with the stationary measurement.

sition of the second peak was found but the more complicated signal could not be produced as well as before.

In the case shown in Fig. 9 we have put two signals into one period. Thus the first, third and fifth harmonics were zero. This is the same if one uses three terms in the analysis. The result is as bad as one can expect. But also in this case the position of the signal is found quite well. A more detailed report is given in [1].

5. Conclusion

By summarizing the results we can draw the following conclusions from the experiment:

It is possible to measure a periodical signal by measuring the harmonics.

One is fully conversant with the necessary corrections by using a tubing system in unteady pressure measurement.

Reference

1. K. KIENAPPEL, *Untersuchung zur Messung instationärer Drücke in rotierenden Systemen.* DFVLR-AVA-Bericht 253, 77 J, 13, 1977.

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