von Karman Institute for Fluid Dynamics
Chaussée de Waterloo, 72
B - 1640 Rhode Saint Genèse - Belgium

Preprint 1991-17 February 1990

DEVELOPMENT OF A HIGH SPEED ROTATING PROBE TRAVERSE SYSTEM USING OPTO-ELECTRONIC DATA TRANSMISSION

C.H. Sieverding; C. Vanhaeverbeek; G. Schulze; T. Angeli

paper presented
10th Symposium on Measuring Techniques for Transonic and
Supersonic Flows in Cascades and Turbomachines
von Karman Institute, Sept 1990

Paper 26

Session 8 - Measurements in Short Duration Wind Tunnels

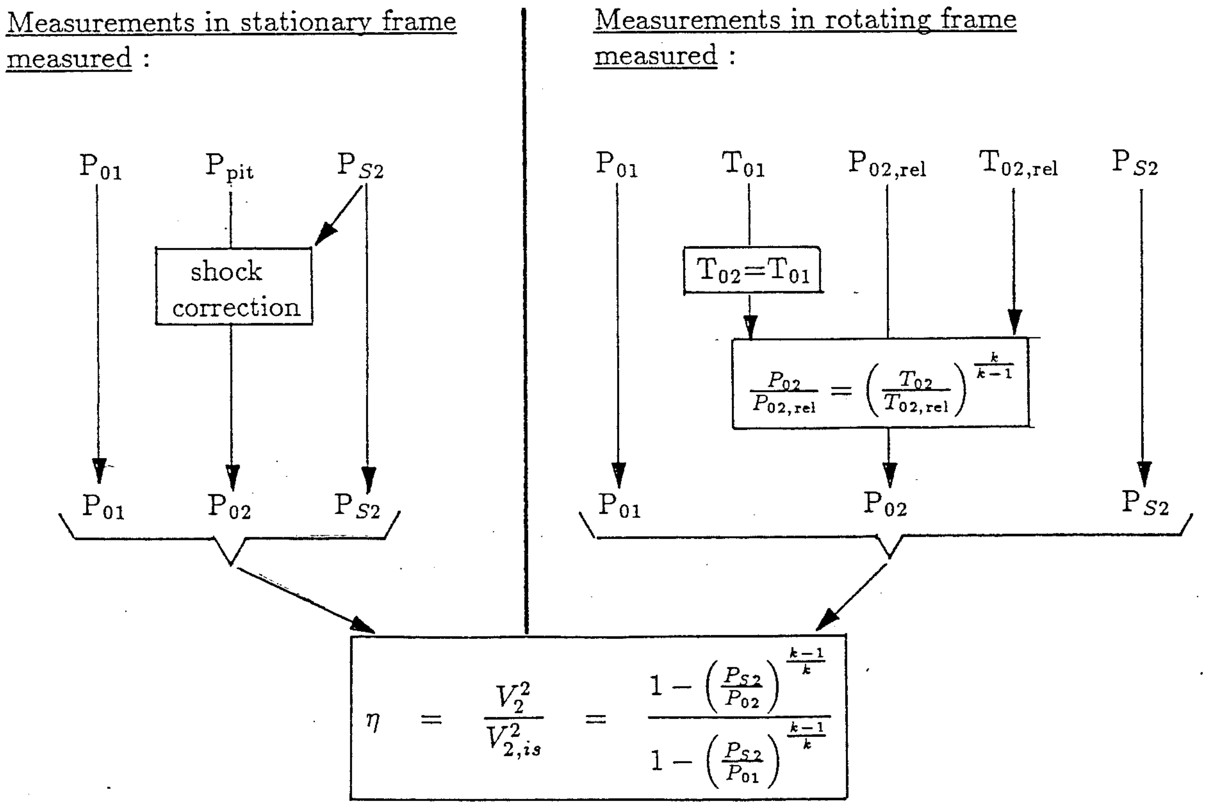
DEVELOPMENT OF A HIGH SPEED ROTATING PROBE TRAVERSE SYSTEM USING OPTO-ELECTRONIC DATA TRANSMISSION

C.H. Sieverding, C. Vanhaeverbeek, G. Schulze, T. Angeli

Turbomachinery Laboratory
von Karman Institute, Belgium

INTRODUCTION

The immersion of a probe into a transonic or low supersonic flow inevitably alters the local flowfield conditions due to the blockage effect of the probe, in particular of the probe stem, if this stem is directed normal to the flow, which is typically the case when testing annular cascades. To minimize the blockage effect it is proposed to put the probe into rotation, at a speed sufficiently high to reduce the relative velocity with respect to the probe to subsonic velocity. In addition to reducing the blockage effect, a second advantage of a rotating probe would be that the total pressure measurement would not need any more to be corrected for pitot probe bow wave shock losses. However, the rotating probe measures a relative total pressure and additional information is needed to evaluate the absolute total pressure. One possibility is to measure the relative total temperature in addition to the relative total pressure. The calculation of the blade efficiency for both types of measurements is compared below :



The performance of the blade is expressed either by the blade efficiency η or by the kinetic energy loss $\zeta = 1 - \eta$.

An error analysis shows that for the rotating measuring system errors in the relative total temperature are expected to present the biggest contribution to the uncertainty in the blade efficiency, while for the stationary measuring system the error in the static pressure plays the major role at high Mach numbers.

In addition to the problem of accurately measuring the total temperature, the problem of the data transmission from the rotating to the stationary frame must be solved. The following chapters briefly describe the rotating probe traversing mechanism, the design and construction of an opto-electronic data transmission system and preliminary results obtained with this transmission system.

ROTATING PROBE TRAVERSING MECHANISM

Figure 1 shows the probe traversing mechanism of the VKI Compression Tube Annular Cascade Facility CT3. The downstream hub endwall is divided into a small fixed (immediately behind the cascade) and a large rotatable part. The probe moves with the rotatable part avoiding thus any probe traverse slot in the hub endwall. The probe nose extends upstream of the moving endwall which contributes further to minimize the flow perturbations in the measurement plane due to the probe traversing mechanism. The position of the measurement plane can be changed by adding spacer rings to the fixed part of the hub endwall. The probe carriage is fixed to the disc carrying the endwall. The disc is mounted on a shaft set in two ball bearings. The shaft is driven by an air motor to maximal 4000 RPM. The shaft is hollow to allow the installation of the electronic cards for signal amplification and data transmission. The optical transmission unit is placed between the second bearing and the air motor.

DESIGN AND CONSTRUCTION OF AN OPTO-ELECTRONIC DATA TRANSMISSION SYSTEM

The development of a high speed rotating probe traversing unit implied the use of an appropriate data transmission system to transfer the data from the rotating to the stationary frame. This system has to meet the following requirements :

a) transmission of an analog signal of 3 to 4 KHz, requiring a bandwidth of about 30 to 40 KHz;

b) operation in a low density environment with pressure levels down to 0.05 to 0.1 bar; (condition in test section before test run)

c) a high signal to noise ratio;

After a survey of existing data transmission techniques and their costs, it was decided to develop inhouse an opto-electronic data transmission system based on the use of infrared diodes. The system is shown in form of a block diagram in Figure 2.

<u>Components in rotating frame</u> :

- measurement device (e.g. Kulite pressure transducer) with a voltage output range from 0-50 mV;
- an amplifier with a gain of ~ 100;
- a V/F converter transforming the analog signal into a frequency between 500 KHz

and 1 MHz;

- a circuit with a second amplifier driving the infrared diodes;

Components in fixed frame :

- a receiver diode with a very high impedance input pre-amplifier and an operational amplifier;
- a frequency to voltage converter integrated in a PLL circuit;
- a low passfilter used to filter the residual frequencies of the PLL.

Figure 3 shows the emission angle curves of 3 respectively 4 emitting diodes of the type LED 1939 from Hamamatsu, mounted on a rotating shaft of 37 mm ϕ. The curves present the distance of equal power with respect to the power at 0-degree emission angle. The distance of 90 mm corresponds approximately to the maximum distance between emitting and receiving diodes. The diagram shows that a system with one simple receiver diode can operate in the following limits :

Emitting Diodes	Receiving Diodes	
	Min. distance	Max. distance
3	17 mm	72 mm
4	7 mm	75 mm

The system under development at VKI uses 4 emitting diodes.

The arrangement of the emitting diodes on the circumference of the rotating shaft allows simultaneous transmission of several channels by fitting a corresponding number of rows of emitting diodes on the same shaft. Of course, provision must be made that each receiver diode captures the light pulses only from 1 row of emitting diodes.

In a first step, a one-channel prototype was designed, built and tested with both the emitter and receiver optics in fixed positions facing each other. The first prototype had a maximum bandwidth of 110 KHz (response of the circuit to a square wave signal with an acceptance of a signal attenuation of -3 dB). However, because of a signal amplification of +2 dB at around 50 KHz a second prototype was built with improved overall response characteristics but a slight drop of the frequency band width to 100 KHz, Figure 4. DC signals were transmitted by both prototypes with an accuracy of ± $1^o/oo$.

PRELIMINARY TEST RESULTS WITH OPTO-ELECTRONIC TRANSMISSION SYSTEM

A small test rig was built to test the transmission system in rotation. Figure 5 shows the design of the model. A fast response total pressure probe (Kulite transducer) is rotated through 5 air jets exiting from 5 small (10 mm ϕ), closely spaced nozzles, arranged circumferentially on a circle of 300 mm ϕ in the rear wall of an annular settling chamber. The probe is attached to a disc mounted on a shaft, which, in its central part houses the electronics for signal amplification and transmission. The voltage supply for transducer and electronics (transmission via ordinary coal brushes), the emitting infrared diodes and the electric drive are arranged on the right end of the shaft. The photograph in Figure 6 shows the complete setup including the data acquisition unit.

Figure 7 shows (a) a complete pressure trace for one revolution, acquisitioned at $\sim$ 1000 RPM with a sampling rate of 1 MHz and (b) the corresponding trace for the traverse through the 5 jets only. The traces show clearly the pressure pulses due to the jets but superimposed to it appears a high frequency noise. Expanding the time scale further, it becomes evident that the noise is predominantly composed of periodic fluctuations with a frequency of 94 KHz which points to the resonance frequency of the diaphragm of the pressure transducer, Figure 7c. This is particularly clear when inspecting the data string in between two jets, see Figure 7d. The problem of eliminating the fluctuations due to the vibration of the transducer diaphragm can be easily solved by using a numerical low pass filter with a cut-off frequency of 40 KHz. The result of the filtered signal is shown in Figure 8. The remaining noise in the air jets is most probably due to the turbulence in the jet.

In the compression tube annular cascade facility, the test section is depressurized before the test to a pressure level of about 0.15 bar. To control the proper functioning of the electronics under these conditions, the complete transmission unit was tested in a scaled reservoir. Depressurizing the reservoir down to 0.15 bar did not show any noticeable effect on the signal transmission. To check the temperature rise of the electronic parts, a thermocouple was attached to the voltage regulator of the emitter part. The temperature rise was of the order of 10° only.

Based on these encouraging results, the system is extended at present to four channels and will be tested end 1991 in the VKI Compression Tube Annular Cascade Facility.

FLOW FIELD MEASUREMENTS WITH
HIGH SPEED ROTATING PROBE

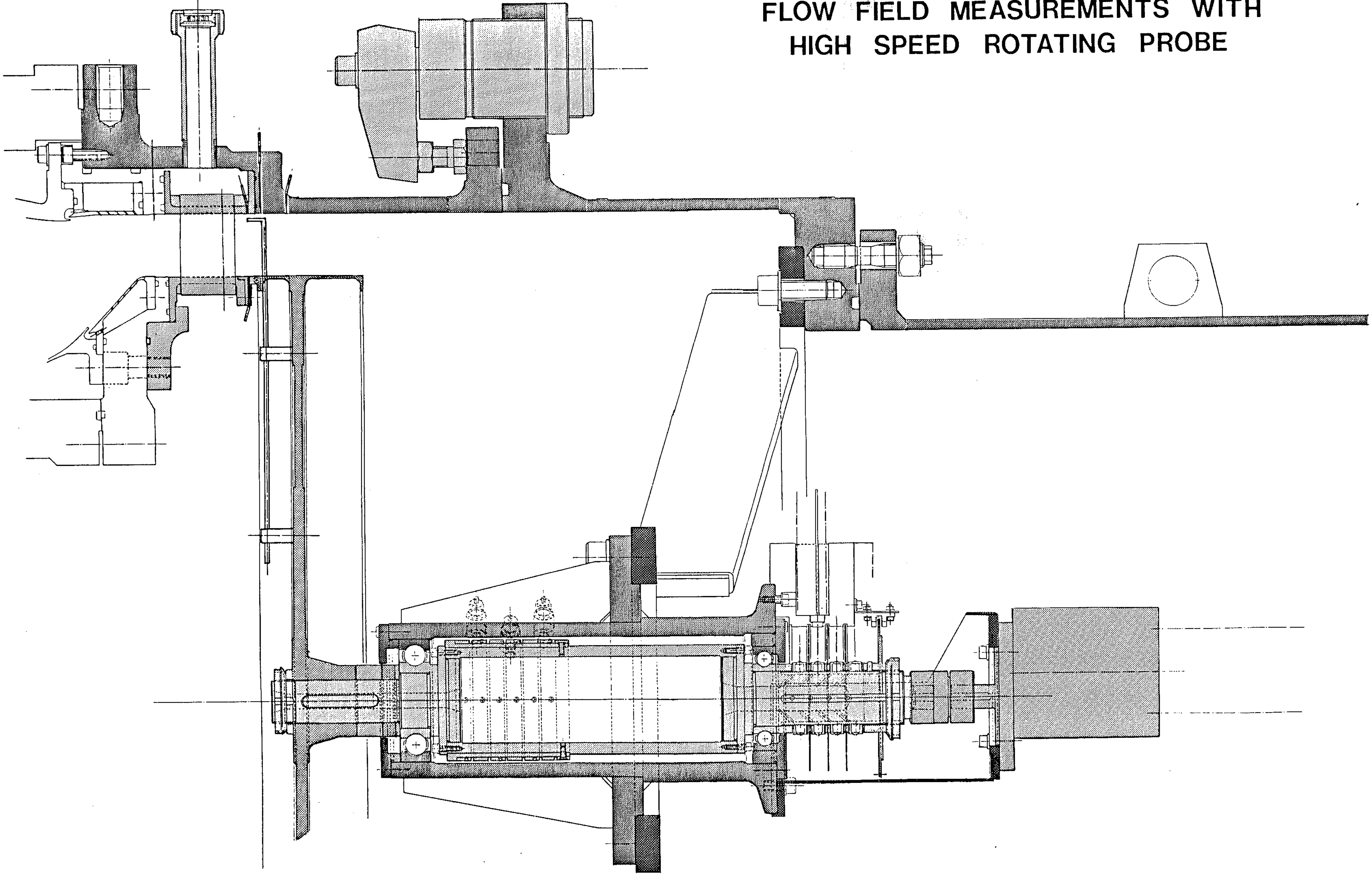


FIG. 1 - HIGH SPEED ROTATING PROBE SYSTEM

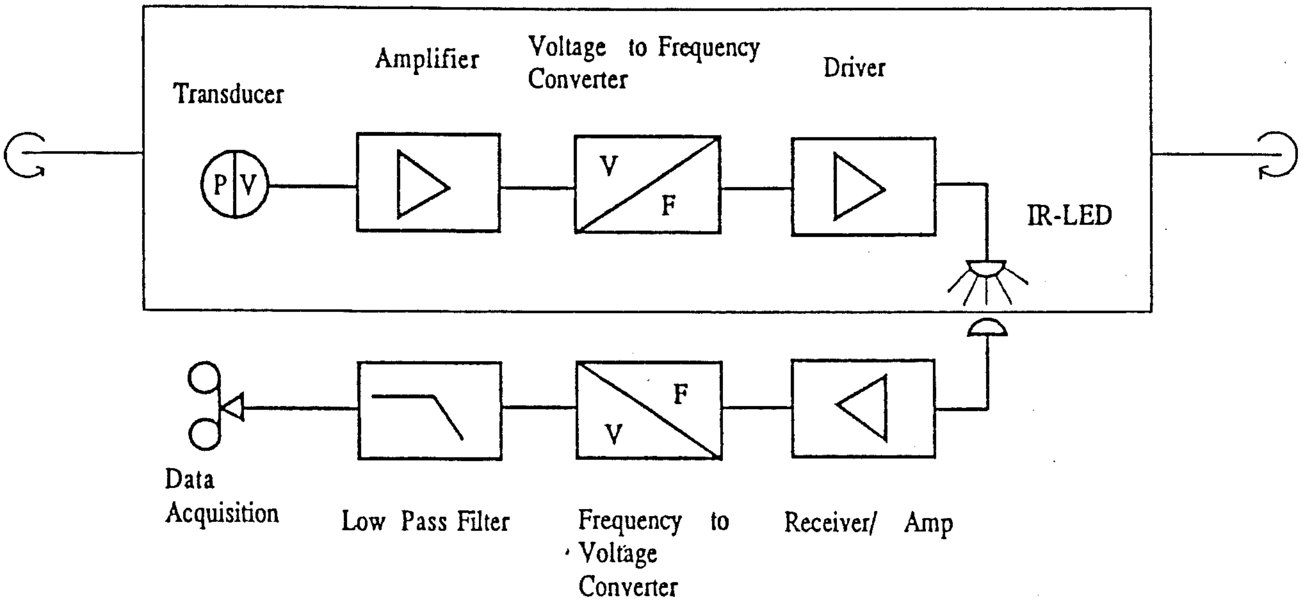


FIG. 2 - BLOCK DIAGRAM OF OPTO-ELECTRONIC DATA TRANSMISSION SYSTEM

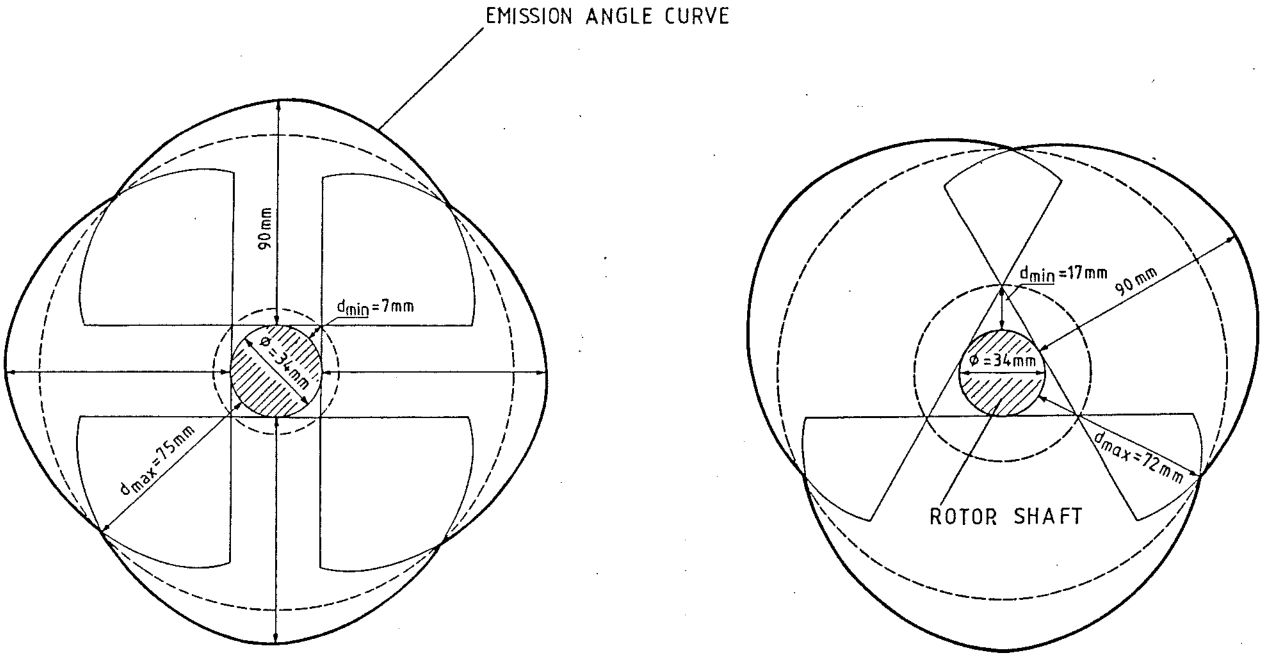


FIG. 3 - AREA COVERAGE OF IR DIODE EMISSION ANGLES FOR 3 RESPECTIVELY 4 DIODES ON THE ROTOR SHAFT

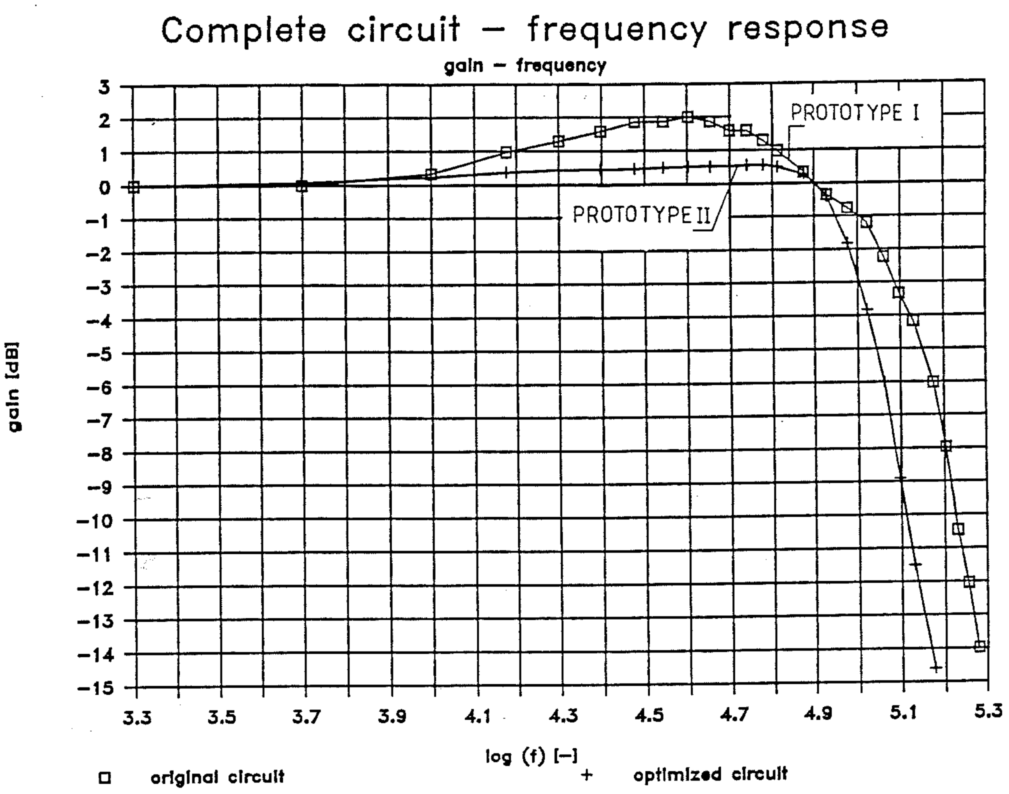


FIG. 4 - FREQUENCY RESPONSE CURVES OF PROTOTYPES I AND II

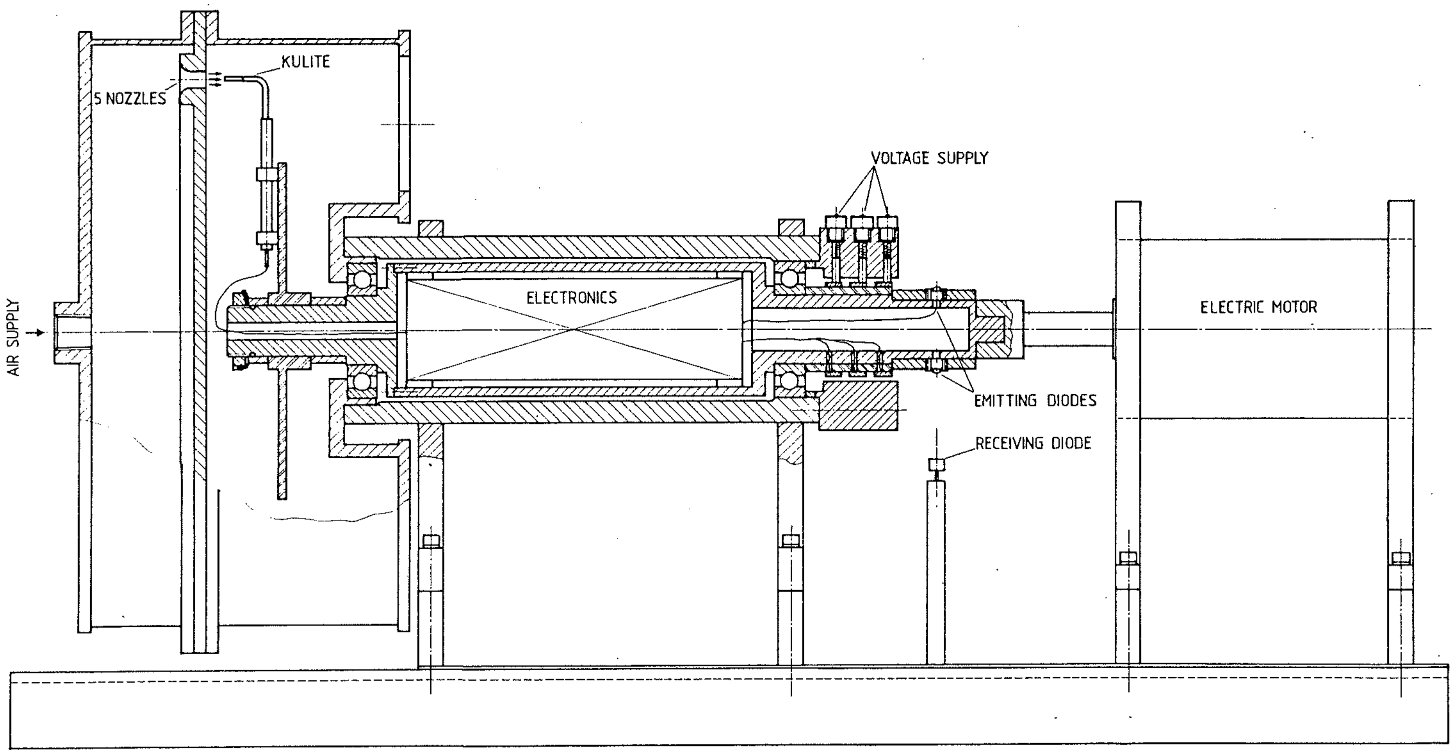


FIG. 5 - DESIGN OF MODEL FOR TESTING
THE OPTO-ELECTRONIC TRANSMISSION SYSTEM

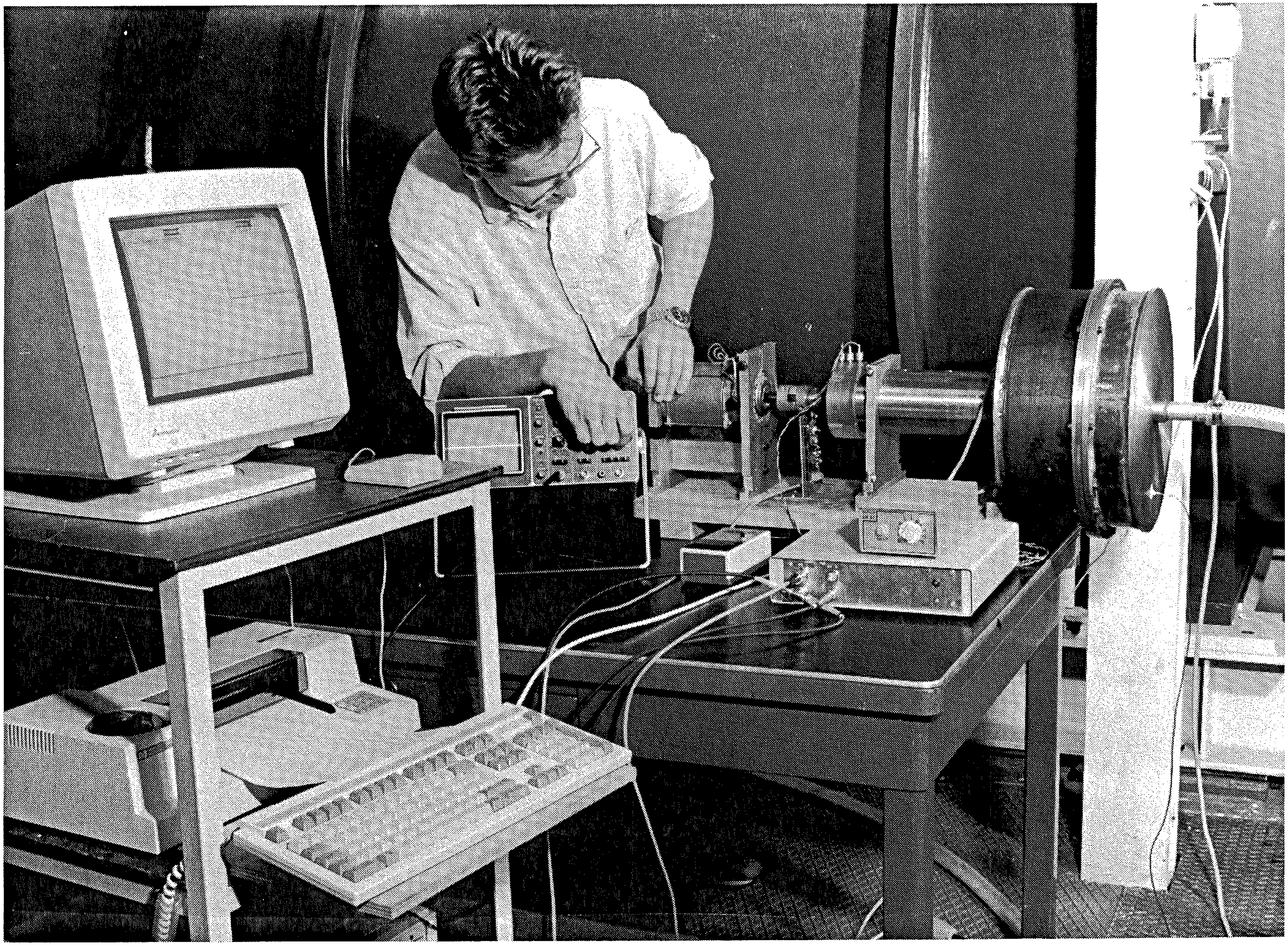
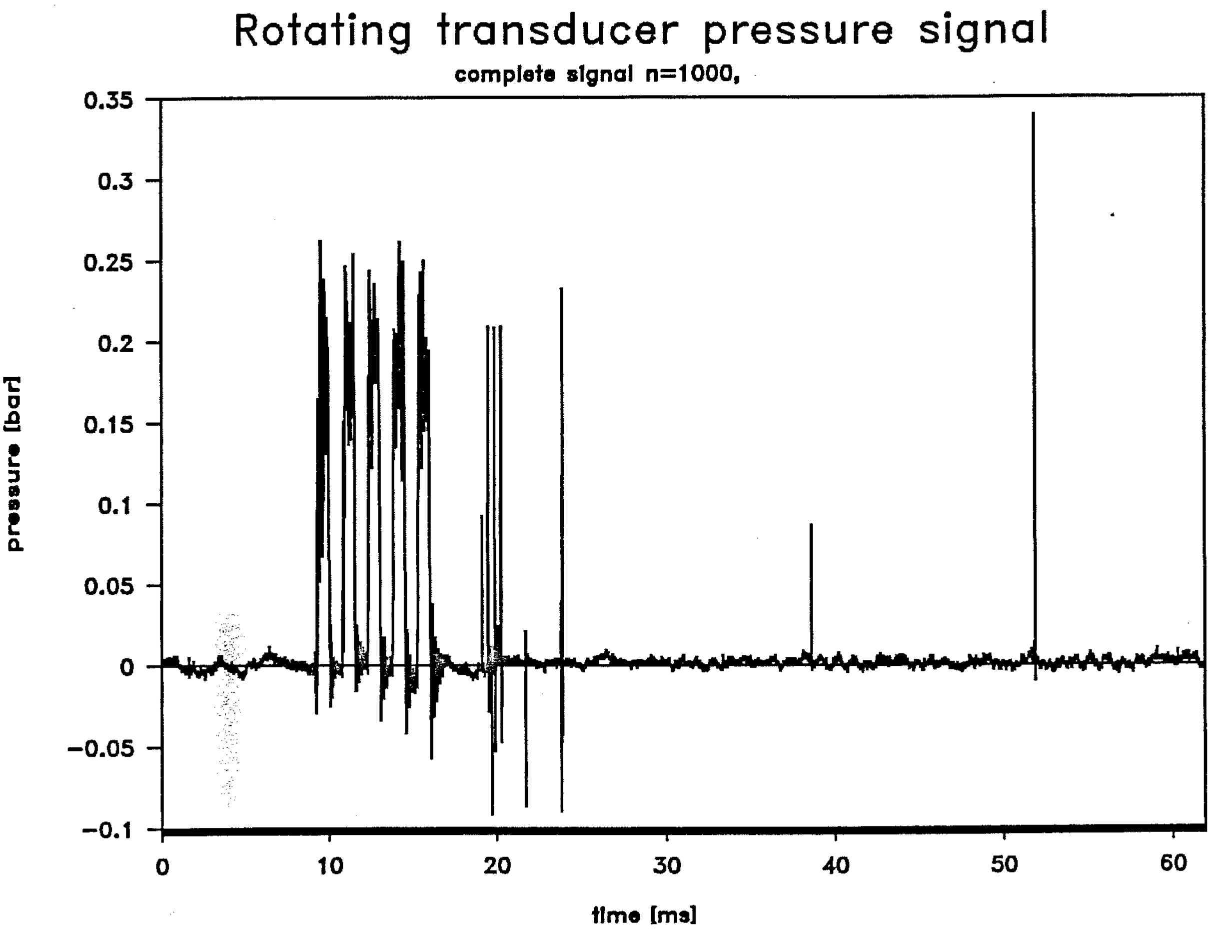
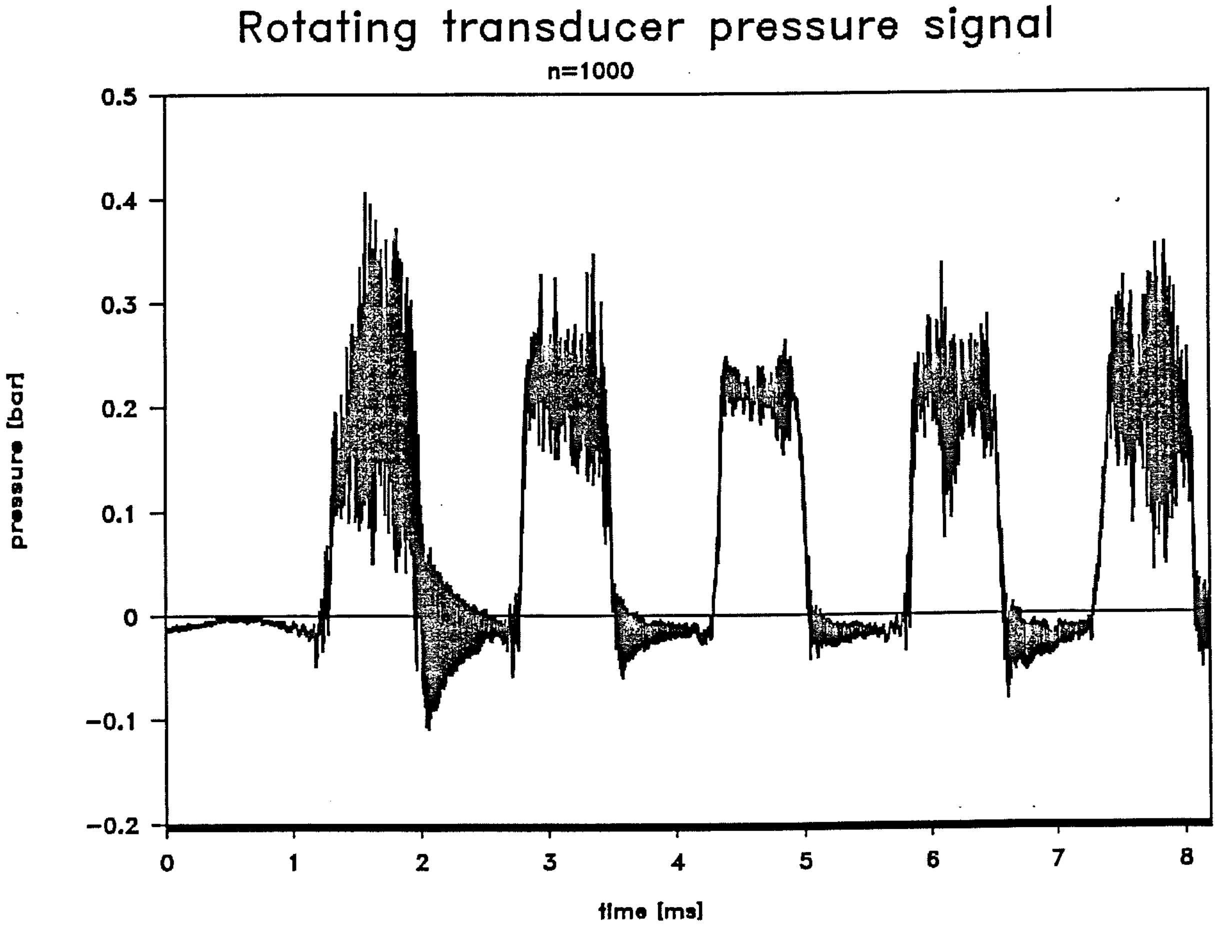


FIG. 6 - PHOTOGRAPH OF MODEL SETUP

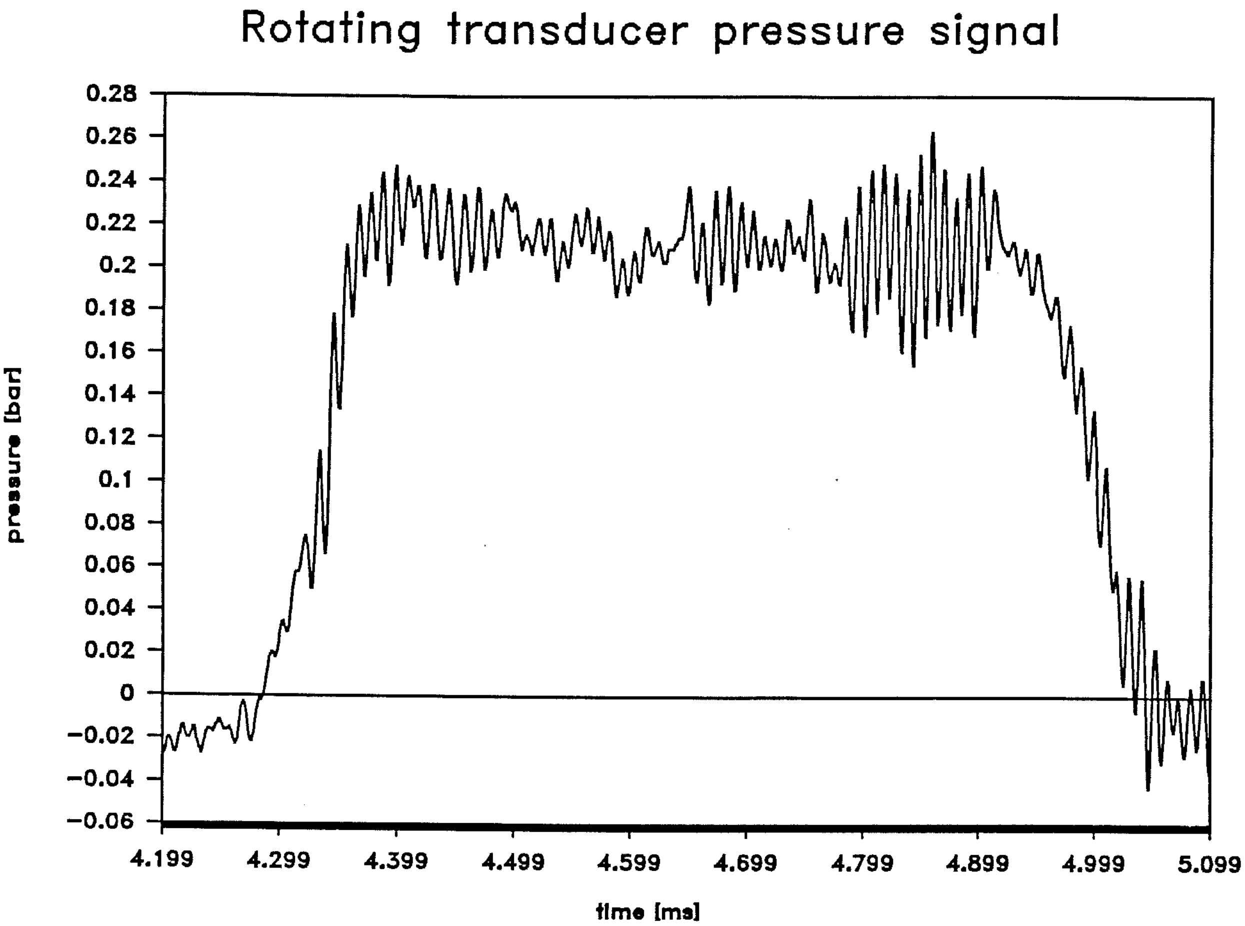


a) complete pressure trace over one revolution

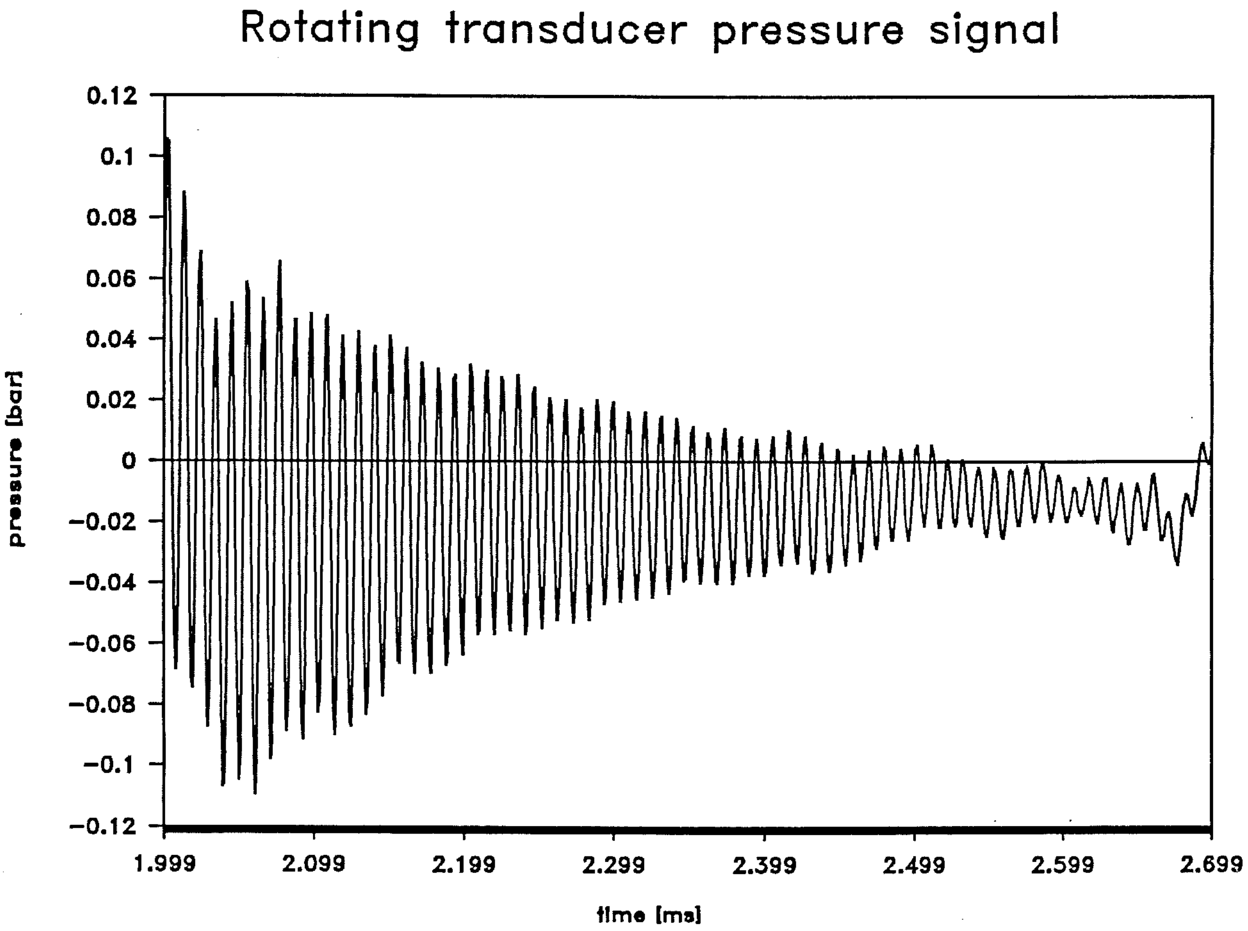


b) pressure trace through 5 air jets

FIG. 7 - TOTAL PRESSURE TRACE THROUGH AIR JETS



c) pressure trace of central jet



d) pressure trace in between jet 1 and 2

FIG. 7 - TOTAL PRESSURE TRACE THROUGH AIR JETS (Continued)