Paper 26

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MEASUREMENTS ON ROTATING TURBOMACHINERY ELEMENTS USING A TELEMETRIC SYSTEM DEVELOPED IN THE INSTITUTE OF THERMOMECHANICS

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Measurements on Rotating Turbomachinery Elements Using a Telemetric System Developed in Institute of Thermomechanics

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A special device to measure strain on blades in rotating turbomachinery has been developed in the Institute of Thermomechanics (IT AS) and applied to rotor blades of the last low pressure stages of 110 to 1000 MW steam turbines. These blades are exposed to extreme conditions, such as the field of strong centripetal acceleration and external dynamic forces from wet steam flow, which make the mathematical modelling of the fluid-structure interaction difficult. Therefore, in the design and development of new blades, where high aerodynamic efficiency is required, measurements on rotating blades under operational conditions play an important role /1/, /2/. Namely the knowledge of the basic stresses due to centrifugal forces and especially the dynamic, time dependent stresses in the blades are necessary. Since the blades can work under the different operational conditions and can be influenced by the corrosion during service, the behaviour of blades has to be monitored in the full range of operational conditions during the whole life time, and not only at the early stages.

Equipment for service measurements is mostly produced directly by the steam turbine manufacturers /3/. Several years ago the only telemetric equipment available was ACUREX. It could be used on rotors with a small diameter. Transmitters operated in frequencies from 88 to 108 Hz, and the corresponding antenna length was less than 0.75m. However, such an antenna is insufficient for the use in steam turbines with power above 110MW and diameter greater than 0.6m, because standing waves will arise in the antenna. Apart from this, this equipment was not universal enough for our purpose, because of the rotor had to be adopted for it. Furthermore, its price was quite high. This was the reason why, in 1976 development of a new equipment started with the demand to monitor bending and torque stresses in a frequency band from 0 to 1000Hz, in a field of centripetal acceleration 10^5 ms^{-2}, in wet steam with 100% humidity and temperatures up to 150°C. Further demands concerned the instalation of the equipment, namely certain flexibility in fixing it to the rotor. To meet these requirements two types of this equipment were developed. They differ from each other by the transmission of the signal from the rotor to the stator. The first equipment has the slip ring transmission, while the other is based on radio-telemetry.

The equipment with the slip ring

The strains in rotating and vibrating blades are picked up by metal, silicon or piezo-resistant strain gauges. In Fig.1 is an example of semi-bridge connection of the strain gauges of type n and p for measurements of static and dynamic stresses. The signal from the strain gauges is amplified by the amplifier to the values up to 1V. The strain gauges and gains are chosen according to measured relative deformations. The strain ranges are three: 100, 500, 5000 microstrains. The gains in the ranges 1, 10, 100 or 1000 can be set up from outside to obtain about 1V on the output of the amplifier at the slip rings. By the technology of hybrid circuits the designed circuits was miniaturized to a small plate (20x25mm), which was covered by the stainless sheet and then welded to the turbine wheel. The whole circuit, including strain gauges, has a power supply of 12V either from a battery or a generator. The advantage of this equipment is a simple and cheap design and a high accuracy. The drawbacks are the demand on one uncovered end of the shaft and in case of the welded slip rings the maximum circumferential speed which should not exceed $90ms^{-1}$.

The radiotelemetric equipment

The signals from the strain gauges are transformed by differential amplifier and the voltage control multivibrator to the frequency modulated carrier frequency, which is brought to the plane transmitting coil after being amplified by the high frequency amplifier. The frequency modulated transmitters are placed on the disk of the rotor and they transmit high frequency signals with different carrier frequencies to the antenna placed on the stator. Maximum distance between the transmitter and the antenna of the receiver is about 40mm (Fig.3). In the Fig.4 the arrangement for parallel transmission of information from the transmitters to the receivers are shown. The transmitters are distributed along the circle the diameter of which corresponds to the dimension of the plane wide-band antenna of the receiver on the stator. The transmitters work at different carrier frequencies from f_1 to f_{10} in the frequency band 15-25 MHz. The channel frequency difference is 1MHz. The transmission of other channels can be solved by means of miniature transmitters working on the same bearing frequency and placed on the next concentric circles of the ring. The main problem was to miniaturize the transmitter and to guarantee its sufficient accuracy and reliability for the defined life time at the extreme conditions. The telemetric transmitter was realized as a hybrid integrated circuit and miniaturized to the plate with a dimension 25x35x4 mm (Fig.5). The plane transmitting coil is placed on the front side of the plate and the complete electrical circuit is on the reverse side. These transmitters are produced by the company HIO Jelen under the type number 394. Their technical parameters are summarized in the Table 1..

The power supplies to the transmitter can be:

- the lithium cell of type CR2430 switched on by a ray of light;
- the generator supply consisted of permanent magnets placed on the stator and a coil with a rectifier circuit and voltage stabilizer on the rotor; the permanent functioning of this supply is guaranteed from the rotational speed about 150rpm to 3600rpm, provided the distances between the coil and the magnets are about 10mm.

The transmitted signal is received by the antenna placed on the stator. The active wire antenna consisted of two parts for the upper and bottom lids of the turbine stator. Both input signals are led through the duct to the high-frequency synthesizer, where the signals are summed up and amplified for the connection of the coaxial cable of length 60m, which brings the signals to the six-channel receiver. The AFC superhet receiver has an automatic frequency tuning within ± 250kHz. In the receiver the input frequency modulated signal is demodulated so that the signal coming out from the receiver is directly proportional to the measured strain on the blade.

To keep the radiotelemetric transmission in the linear range, the maximum admissible change of the carier frequency must be in the band ±20kHz and the voltage of the output should be

1V after demodulation. This voltage level is set up by the comparison with the a reference wire strain gauge (K=2). The gains of amplifiers are set up on both the transmitter and the receiver so that the voltage/strain characteristics be linear in whole range of the operation of the apparatus.

This radiotelemetric apparatus was applied in the last years in the low pressure stage of the 110 MW turbine in a power plant, and was used for the monitoring the amplitude-frequency characteristics of the long blades rotating in vacuum. The site to the telemetric apparatus installed in the 110MW steam turbine is in Fig.6.

During the service measurements the strain signals from the blade are monitor on the oscilloscope, evaluated on-line by a two-channel analyzer BK 2034 and recorded on the tape recorder for the additional PC-evaluation. From the time dependent characterictics of the strains and their spectral analysis (Fig.7) it is possible to find the maximum strain. An example of the amplitude-frequency characteristics, evaluated from strain measurements of the blade in the range 1580 - 3230 rpm, and at the centripetal acceleration up to 10^4 G's is in Fig.8.

The experimental research on rotation turbomachines requires highly qualified and experienced staff and the Institute of Thermomechanics contributes substantionally to its training by specialized courses and also by the cooperation with Universities. A high reliability of these apparatuses is guaranteed by the specialized manufacturer HIO Jelen who also participates in the service measurements.

Acknowledgement

This theoretical research and evaluation of the measurements were done under the grant No.27-61-02 funded by the Czech Academy Grant Agency.

References:

1.Vaněk F.: Experimental investigation of flow in cascades of turbomachines, PhD Thesis, 1984, Prague.
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3.Hyrát J., Tomanec L., Vaněk F.: Experimental determination of stress of rotor blades of large capacity steam turbines. Škoda Review 3/1978.
4.Vaněk F., Pelc F.: Telemetric equipment for measurement of dynamic strains in steam turbine rotors, Proceedings of 1st Conference on Mechanics, AS CR Prague, 1987.
5.Vaněk F., Pospíšil K.: Micromechanic transducers of mechanical strain, Proceedings of EAN 90 Conference, Svratka, 1990.

Table 1. - Technical parameters:

Transmitter HIO 394	
Carrier frequency	15-25 MHz (1MHz is a channel difference)
Modulation	FM
Frequency deviation	±20 kHz
Sensitivity (gain x1, x10, x100, x1000)	0.1mV - 100mV/kHz
Input INV, NEINV, DIF 100kΩ	for strain gauges
INV 1MΩ	for piezo strain gauges
Frequency response	0-5kHz
Linearity	1% in the whole range
Temperature dependence of the carrier frequency	5kHz/°C
Temperature dependence of the sensitivity	±0.2%/°C
Supply	12V/20mA
Ambient temperature range	-20 - 125°C
Overloading	to 10^4G's
Dimension	25x31x3mm
Mass	7g
Mass with the sheet cover	about 18g

Generator supply HIO 294

Output voltage, max. current 12V; 30 mA

Input induced min. voltage from the coil is 14V in the field of magnets at the maximum distance 10mm from the coil

Dimension	∅26mmx3mm
Mass with the sheet cover	27g

Light switch HIO 194	
Time of activation by the infra LED	1.6s
Supply voltage, max. current	12V, 30mA
Dimension	28x9x3mm
Mass with the sheet cover	10g

Receiver HIO 006	
Frequency band	15-25MHz (continuous tuning)
Frequency deviation	±20 kHz
Frequency response	20Hz-4kHz
Sensitivity (26dB s/n)	100µV
Output voltage in band ±20kHz	±1V
Automatic frequency tuning	±100kHz
Supply	12V/250mA; 24V/5mA
Dimension of one channel	201x56x200mm (module unit)

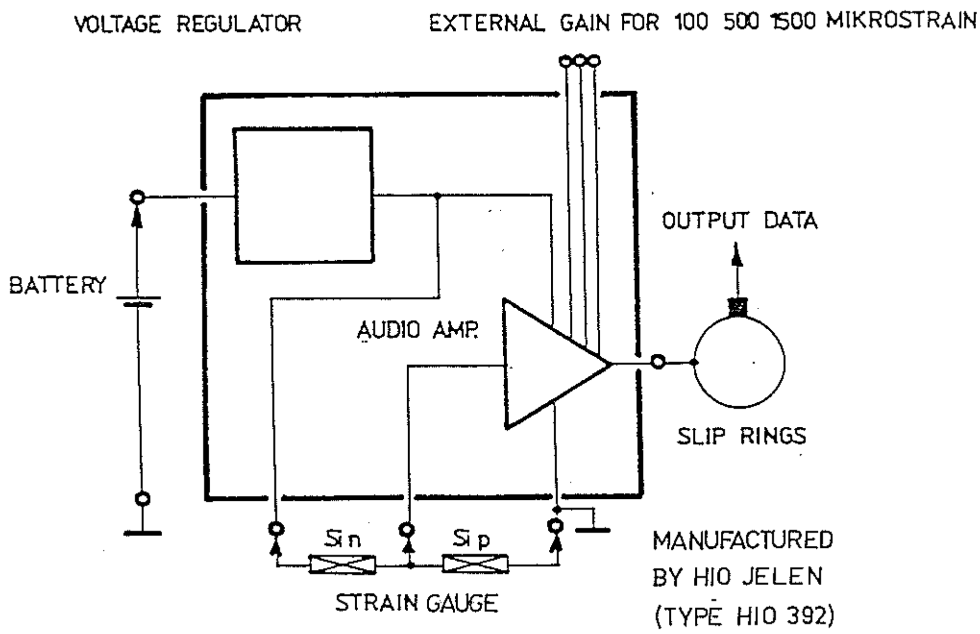
VOLTAGE REGULATOR
EXTERNAL GAIN FOR 100 500 1500 MIKROSTRAIN
OUTPUT DATA
BATTERY
AUDIO AMP.
SLIP RINGS
Sin
Sip
STRAIN GAUGE
MANUFACTURED
BY HIO JELEN
(TYPE HIO 392)

Fig. 1

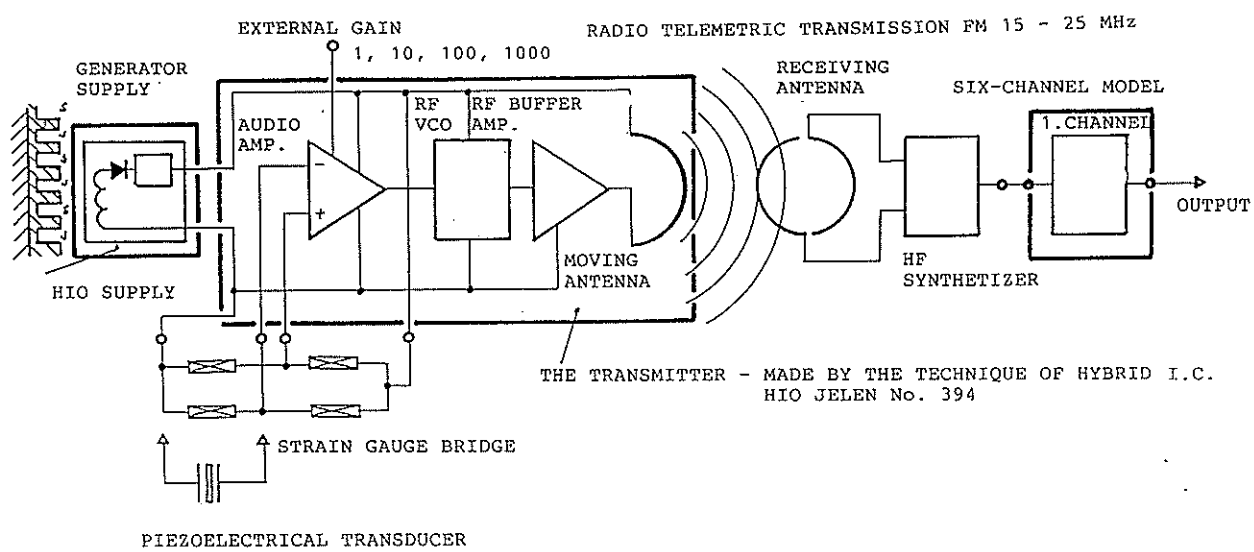
EXTERNAL GAIN
1, 10, 100, 1000
RADIO TELEMETRIC TRANSMISSION FM 15 - 25 MHz
GENERATOR
SUPPLY
RECEIVING
ANTENNA
SIX-CHANNEL MODEL
AUDIO
AMP.
RF
VCO
RF BUFFER
AMP.
1.CHANNEL
OUTPUT
MOVING
ANTENNA
HF
SYNTHETIZER
HIO SUPPLY
THE TRANSMITTER - MADE BY THE TECHNIQUE OF HYBRID I.C.
HIO JELEN No. 394
STRAIN GAUGE BRIDGE
PIEZOELECTRICAL TRANSDUCER

Fig. 2

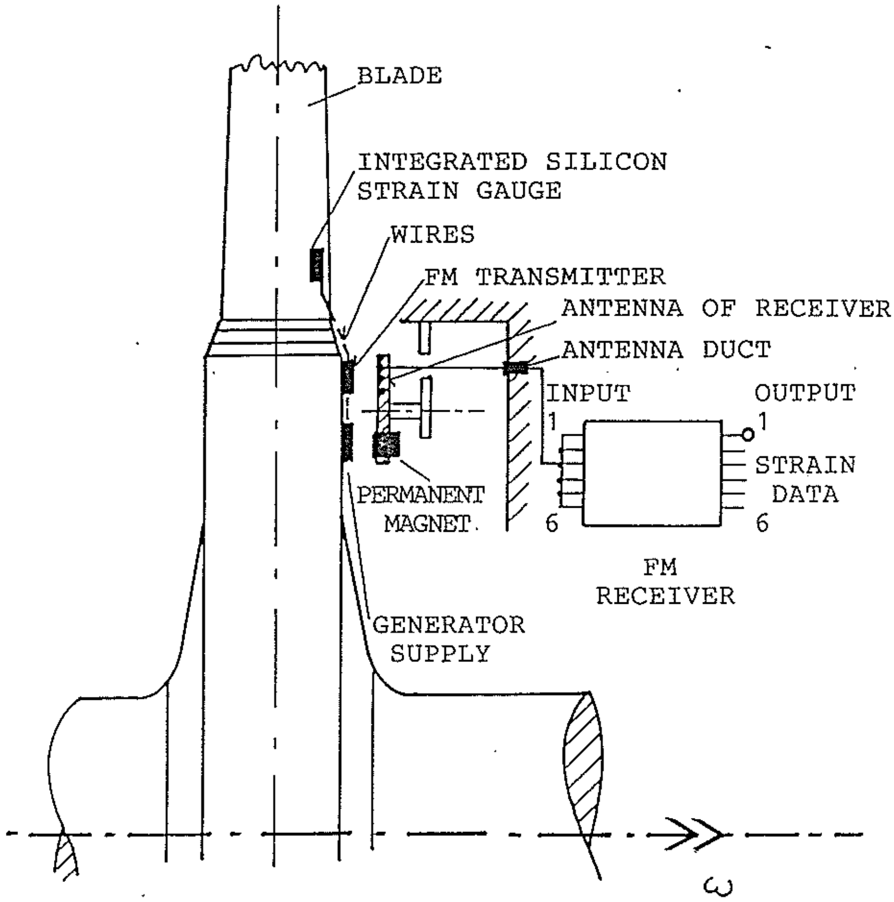
BLADE
INTEGRATED SILICON
STRAIN GAUGE
WIRES
FM TRANSMITTER
ANTENNA OF RECEIVER
ANTENNA DUCT
INPUT
1
6
OUTPUT
1
STRAIN
DATA
6
PERMANENT
MAGNET
FM
RECEIVER
GENERATOR
SUPPLY
ω

Fig. 3

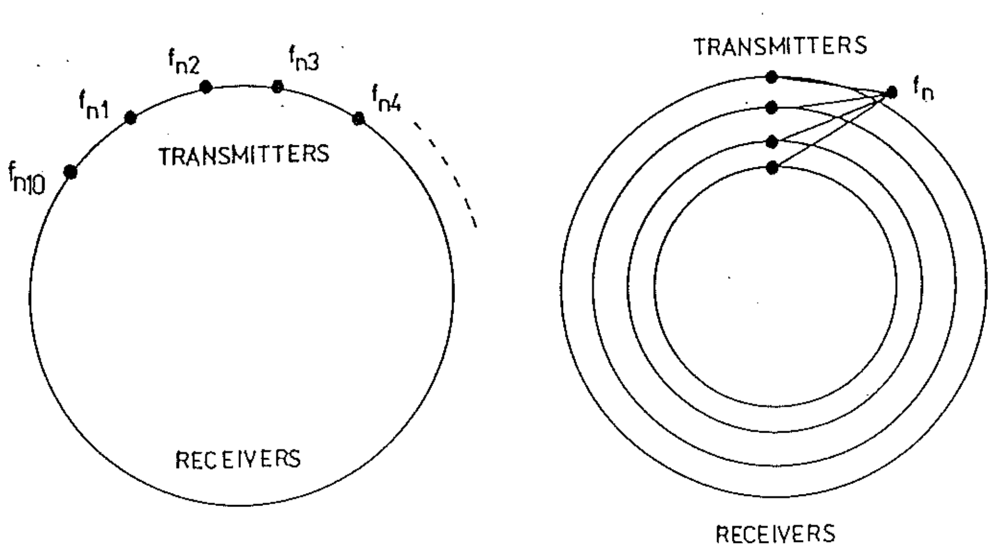
f_{n1}
f_{n2}
f_{n3}
f_{n4}
f_{n10}
TRANSMITTERS
RECEIVERS
TRANSMITTERS
f_n
RECEIVERS

Fig. 4

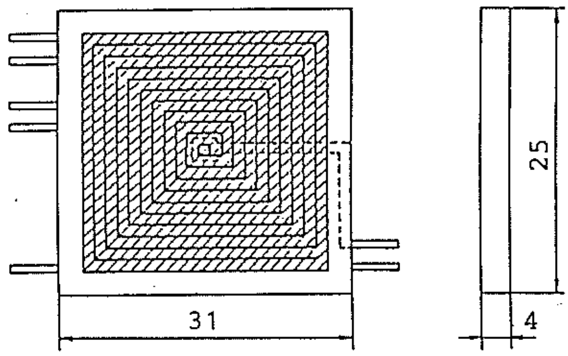

Fig. 5

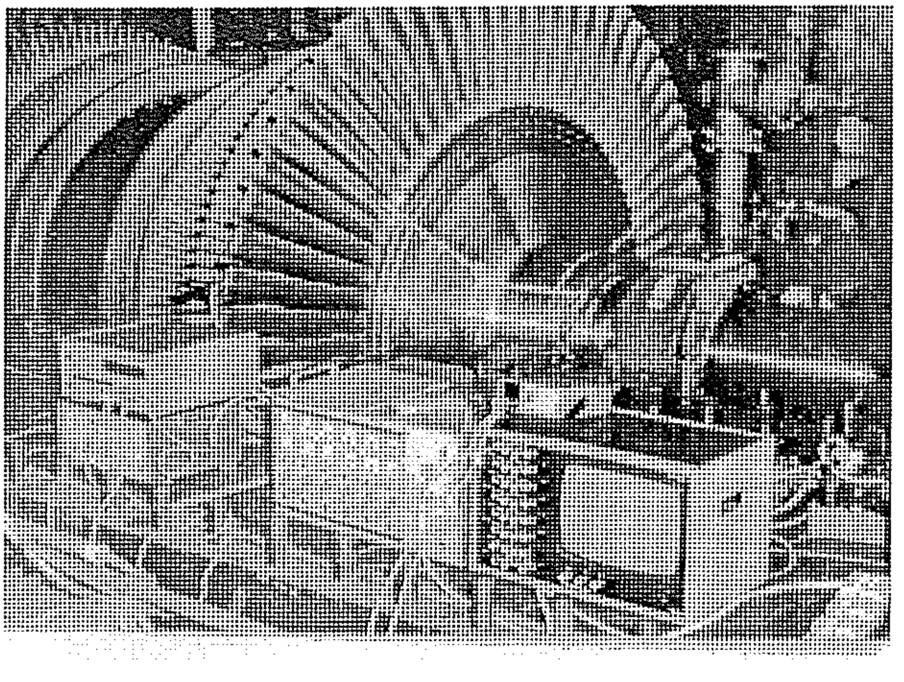

Fig. 6

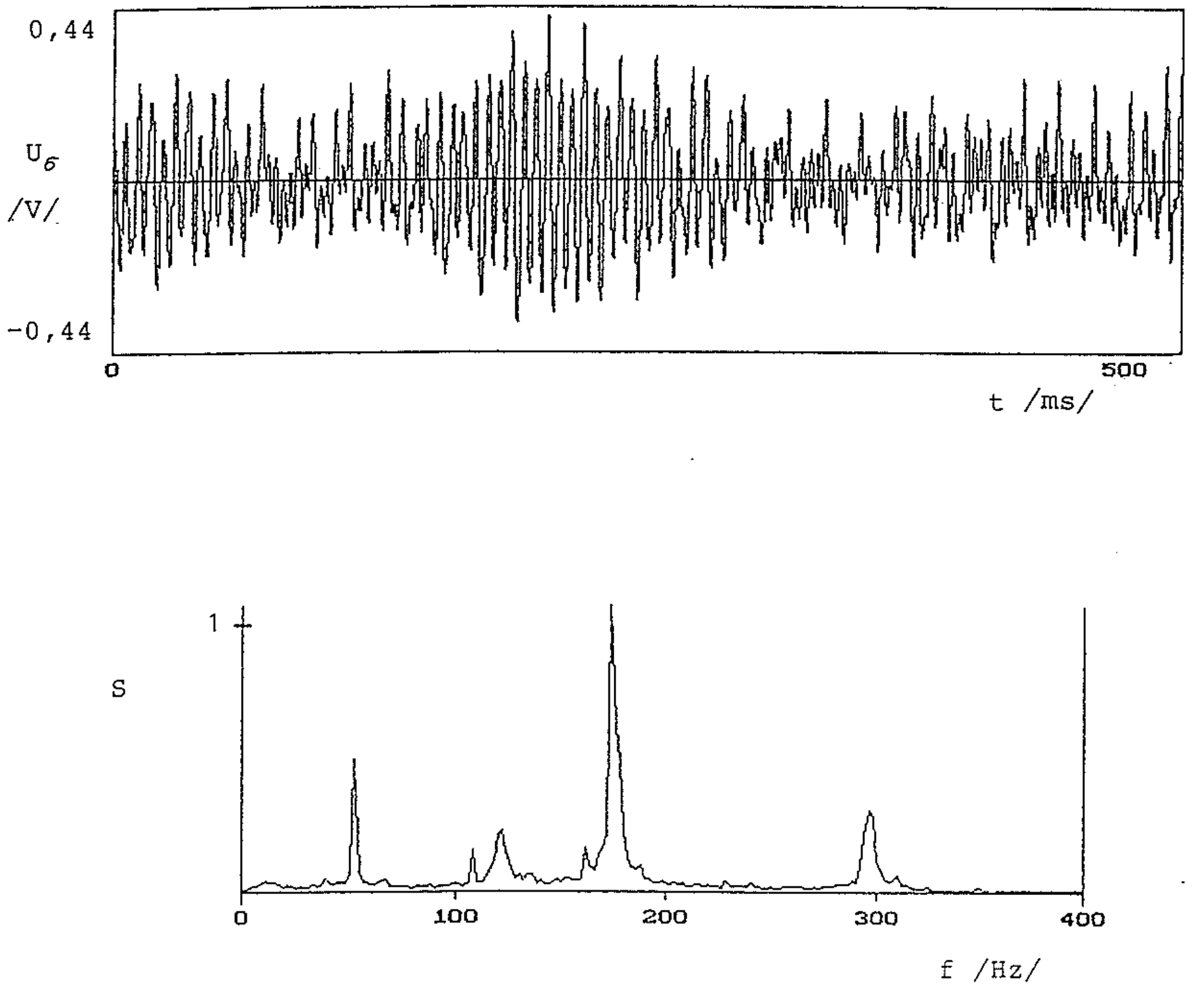
0,44
U_σ
/V/
-0,44
0
500
t /ms/
1
S
0
100
200
300
400
f /Hz/

Fig. 7

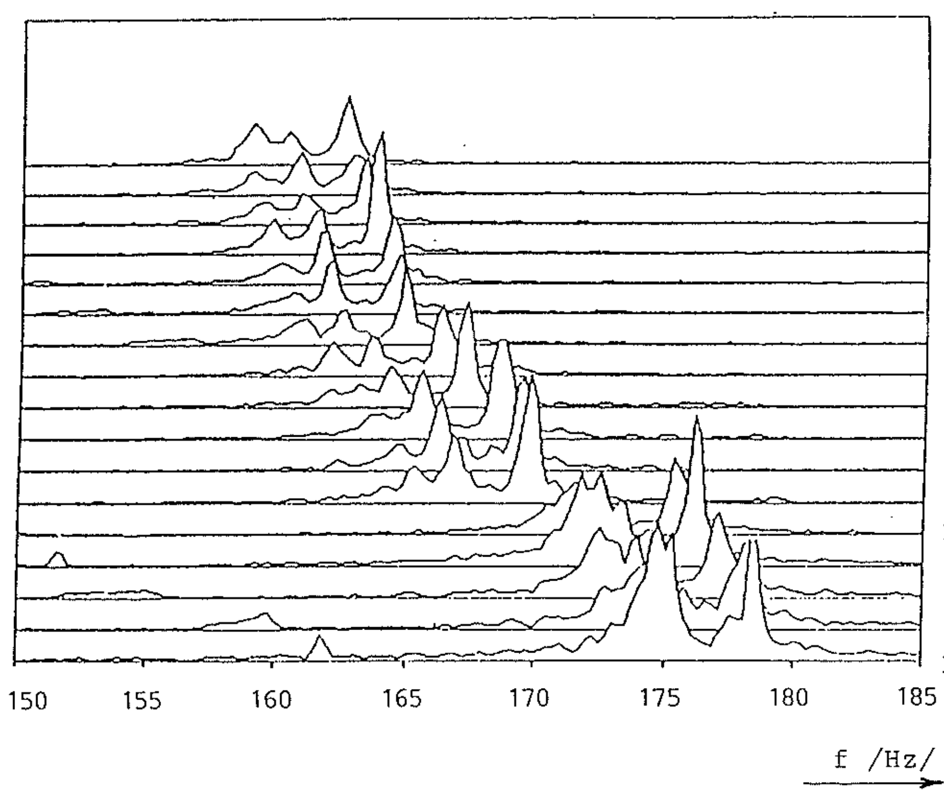
pm
1580
1780
2130
2930
3230
150
155
160
165
170
175
180
185
f /Hz/

Fig. 8