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A MAGNETORESISTOR GEOTILTMETER FOR MONITORING GROUND MOVEMENT

by

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ABSTRACT

A new type of a recording geotiltmeter has been developed at the Nordic Volcanological Institute. The instrument is based on a pendulum with a strong permanent ferrite magnet fixed in its lower end. The horizontal displacement of the pendulum is sensed by four magnetoresistors fixed in a rectangular array immediately below the magnet. The two crossing pairs of resistors are connected in measuring bridges, recording the displacement of the pendulum in two directions normal to each other. During a performance test in the tectonicly active Krafla caldera, N-Iceland, this magnetoresistor tiltmeter proved to be as reliable as a water tube tiltmeter operated at the same time.

INTRODUCTION

A geotiltmeter based on a magnetic pendulum and magnetoresistor sensors was developed at the Nordic Volcanological Institute. The instrument is compact and rugged, well suited for borhole installation.

The instrument consists of two aluminum tubes, an outer one and an inner tube housing a pendulum. The position of the inner tube is adjustable relative to the outer one as well as the height of the pendulum.

Operation of the tiltmeter is based on the response of the magnetoresistors to changing magnetic flux. Their distance from the permanent magnet of the pendulum and their positioning below it determines the sensitivity of the instrument. During performance test at the tectonicly active Krafla volcano N-Iceland the sensitivity of the instrument was found to be 0.14 mV/microradian.

The absolute resolution of the instrument is unknown at the present due to interference from microseismic activity during the test. Dynamic range is known to be at least $\pm$500 microradians.

CONSTRUCTION

The construction of the tiltmeter is shown in figures 1 and 2. The housing of the instrument is an aluminum tube (F in Fig. 1) with fixed bottom plate. Two brass pins are fastened in the bottom plate, one in the center acting as point bearing for the inner tube (G in Fig. 1) and another to prevent its rotation. Since it is impossible to install the instrument absolutely vertical in a borehole, the outer tube serves as an installation cover for the adjustable inner tube, housing the pendulum.

Two gears are fastened to the removable top plate of the outer tube (Fig. 1, Fig. 2) making fine adjustment of the inner tube possible from above after installation of the instrument. The horizontal adjustment screws (F in Fig. 2) counteracted by spring (C in Fig. 2) are moved with the aid of a worm drive (D in Fig. 2) accessible from above. One turn of the fine adjustment screw equals 0.06 mm lateral displacement of the top of the inner tube.

The fine adjustment assembly not only makes the relative positioning of the inner tube possible but also offers a simple way to calibrate the tiltmeter. Since the distance from the bottom bearing of the inner tube to its plane of motion is 1064 mm (Fig. 1) each turn of the fine adjustment screws simulates tilt of 56.4 microradians.

The pendulum (E in Fig. 1) hangs on a flexible wire (D in Fig. 1) inside the inner tube (G in Fig. 1). The permanent magnet (H in Fig. 1) is fixed to the bottom of the pendulum. The distance between the magnet and the sensors (I in Figs. 1 and 2) is adjustable by means of a screw (C in Fig. 1) without rotating the pendulum.

During calibration of the tiltmeter the rotation free adjustment of the pendulum eliminates errors due to assymetrical properties or position of the permanent magnet.

The magnetoresistor elements (I in Fig. 2) are glued in a rectangular array on the upper epoxy printed circuit board (I in Fig. 1) also supporting the fixed resistors of the measuring bridges. The amplifiers for the bridge outputs are installed on the lower circuit board (I in Fig. 1).

ELECTRONICS

The sensing elements of the tiltmeter are magnetoresistors. A magnetoresistor is an InSb semiconductor with oriented inclusions of NiSb needles. An external magnetic field lowers the conductivity of the resistor due to lengthening of the current path through the InSb crystal. In Fig. 3 the operating principle of a magnetoresistor is outlined.

A magnetoresistor is most sensitive to a magnetic flux normal to its surface so the sensors have to be arranged below the edges of the permanent magnet of the pendulum, where the vertical magnetic flux changes most drastically due to motion of the pendulum (Fig. 4).

The four sensors are arranged in two opposite pairs, sensing two dimensional displacement of the permanent magnet (Fig. 4). The two crossing pairs of sensors are connected with fixed resistors forming two measuring bridges. The sensor pairs are matched in order to ensure comparable sensitivity in both directions. The measuring bridges as are shown in Fig. 5. The nominal resistance of each sensor element is 200 ohm. The power dissipation of each sensing element is 31 mW with a bridge voltage set at 5 volts.

The magnetoresistors used have a temperature coefficient dR/dT = ÷ 0.16%/°C (ref.1). Using fixed resistor with temperature coefficient of 50 ppm/°C in the other half of the bridges, the error voltage due to temperature variation depends on the magnitude of bridge imbalance. At an imbalance of 12.5 mV corresponding to ground tilt of 89.3 microradians at 0.14 mV/microradian sensitivity the error caused by 20°C temperature variation is 0.8% of the tilt value.

The bridge power supply has to be well regulated and insensitive to temperature variations, since changes of bridge voltage change the tilt value proportionally.

When the instrument is installed in a borehole the temperature variations will be much smaller in the hole than at the surface. Since the power supply is operated from the surface, its temperature coefficient has to be as low as possible. Using an integrated regulator (Ca 3085, ref.1) with a temperature coefficient of 35 ppm/°C, 20°C temperature change will cause a voltage change of 0.07%.

The sensitivity of the tiltmeter is adjusted by varying the height of the pendulum. Where resolution below 1 microradian is needed at bridge output adjusted to 0.14 mV/microradian, the signal needs to be amplified. Since operation amplifiers usually have a temperature drift exceeding 1 microvolt/°C, the amplifying circuit is located at the bottom of the tiltmeter to reduce temperature fluctuations. This amplifying circuit serves as a preamplifier for subsequent signal processing. The selected preamplification is a compromise between resolution and dynamic range.

PERFORMANCE TEST

The prototype of the magnetoresistor geotiltmeter was installed in August 15th 1977 at the tectonicly active Krafla caldera N-Iceland. The present surface deformation at Krafla is caused by inflation and deflation of magma chambers at about 3 km depth (ref.3). The meter was installed in N-S/E-W orientation in an underground cellar of reinforced concrete about 15 m west of the Krafla power house (Fig. 6). This location was selected to compare the results of the new tiltmeter with those of the water tube tiltmeter previously installed in the power house (Fig. 6).

During the performance test the signal from the magnetoresistor tiltmeter was continuously recorded. On September 8th 1977, a deflation event occurred a few km north of the Power Station followed by an eruption. Fig. 7 shows the recording of the N-S component during the beginning of the subsidence event. This shows that short term tilt fluctuations are easily monitored by the magnetoresistor tiltmeter.

The recordings of the new tiltmeter are compared with the water tube tiltmeter in figure 8. This shows a good correlation between the two tiltmeters although a slight long term deviation is indicated. At this stage the origin of this deviation is not known. Possible causes include:

a) Different absolute tilt at the two sites of observation and/or slightly different directional alignment of the two instruments.

b) A slight mechanical deformation.

c) A slight long term drift in the amplifying circuit or the sensors.

It is hoped that further tests and development will clarify the cause of this slight discrepency.

In conclusion the magnetoresistor geotiltmeter can be said to be an excellent monitor of short term tilt variations, and a promising instrument for monitoring of long term tilt deviations.

ACKNOWLEDGEMENT

The use of magnetoresistors as sensors was suggested by Mr. Ævar Jóhannesson, who is also thanked for fruitful discussions at various stages.

REFERENCES

1. SIEMENS, 1966. Galvano magnetic Devices. Siemens Aktiengesellschaft, Berlin.
2. R.C.A. Corporation, 1976. Integrated Circuits, N.J. U.S.A.
3. Björnsson, A. et al., 1977. Current rifting episode in North Iceland. Nature 266, pp. 318-323.

Fig. 1. <u>Mechanical parts</u>

A. Fine adjustment screw.

B. Aluminum profile L-20x20x4 mm.

C. Vertical adjustment screw (does not rotate pendulum).

D. Steel wire Ø 0.4 mm.

E. Aluminum pendulum L = 920 mm, Ø = 30 mm.

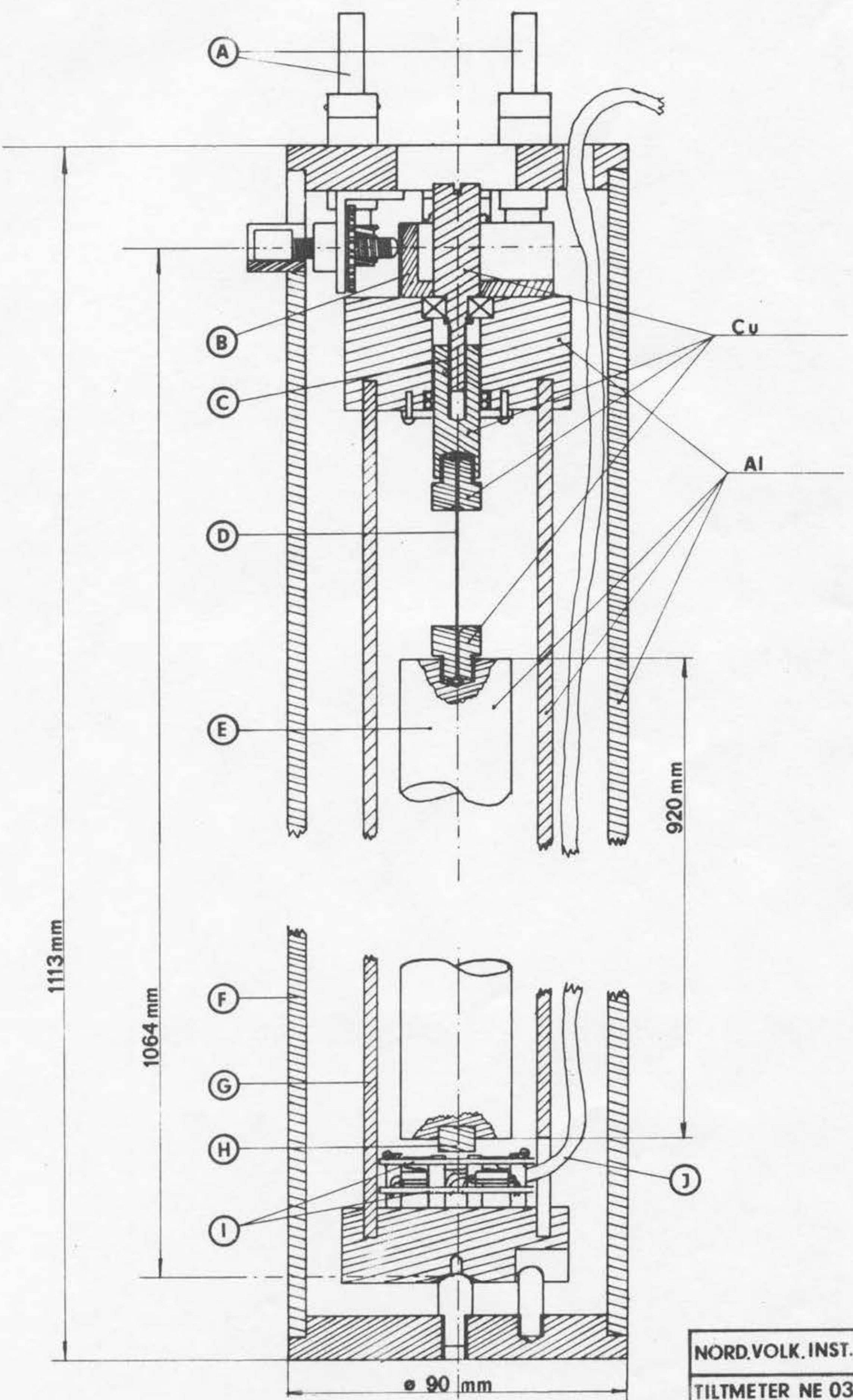
F. Aluminum cylinder OD = 90 mm, ID = 80 mm.

G. Aluminum cylinder OD = 50 mm, ID = 43 mm.

H. Permanent ferrite magnet, cylindrical form Ø = 10 mm, L = 7 mm, $M = 0.12 \cdot 10^{-6}$ V·sec·m.

I. MR sensors (upper board) and amplifiers (lower board).

J. Screened cable.



NORD. VOLK. INST.	FIG. 1
TILTMETER NE 03	16.11.77

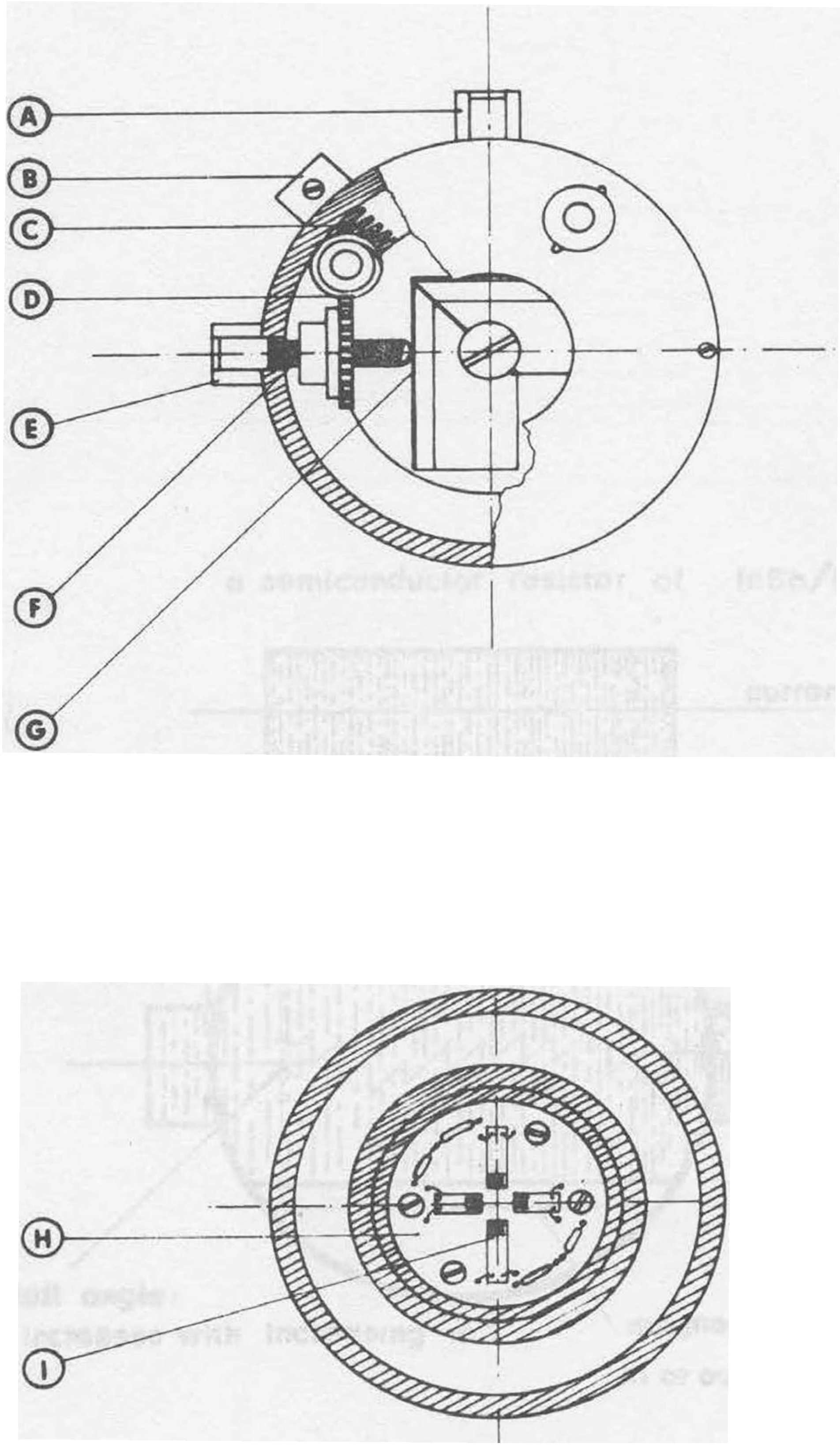
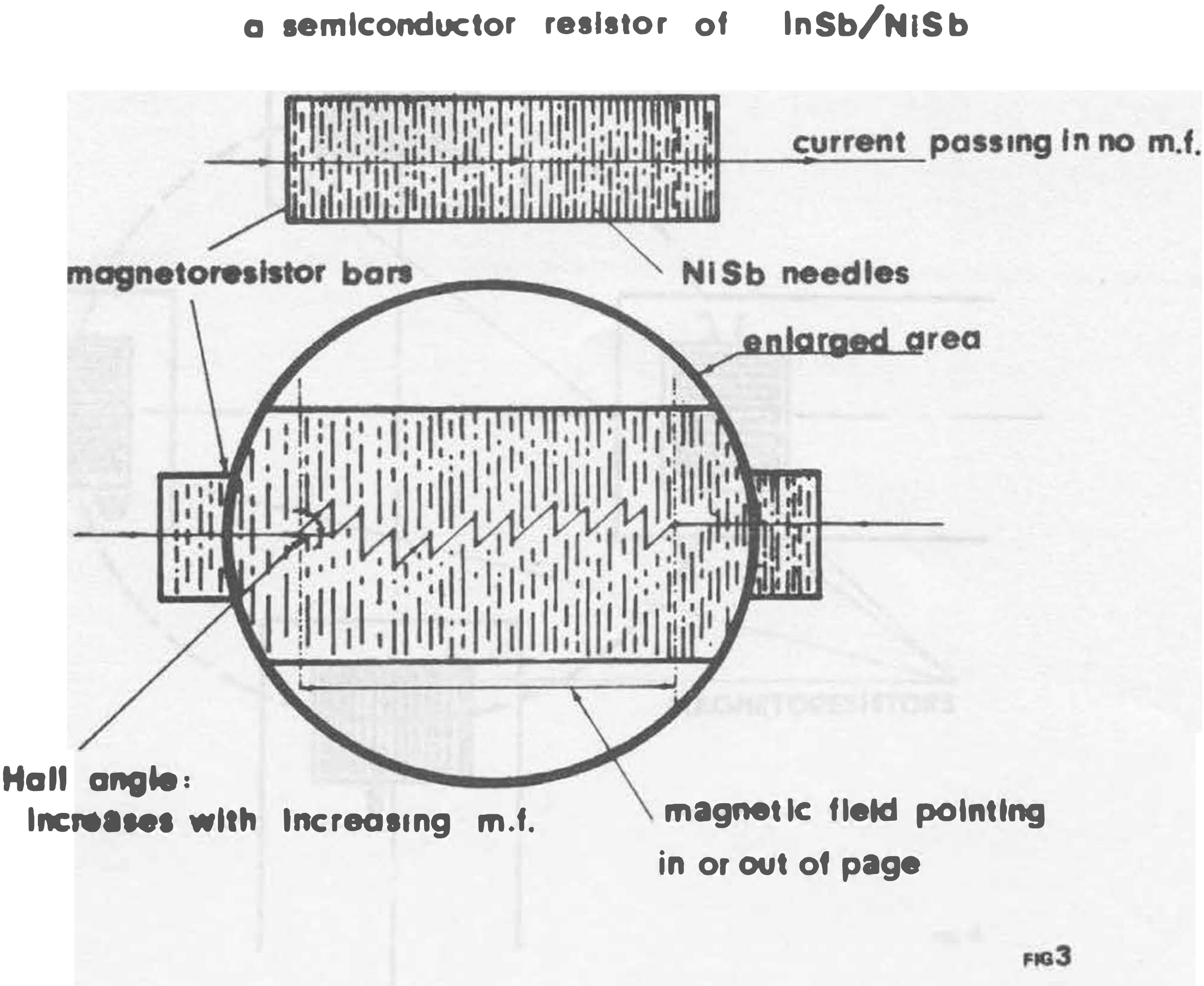


Fig. 2. A-(E). Flange for horizontal adjustment screw.
B. Spring holder.
C. Spring.
D. Worm drive gear ratio 1:8.33.
F. Horizontal adjustment screw, Ø - 5 mm threadings 2/mm (one turn .5 mm horizontal displacement).
G. Low friction surface (glass plate).
H. Epoxy printed circuit board.
I. Magnetoresistor element.



Operating principle of a magnetoresistor (m.f. stands for "magnetic field").

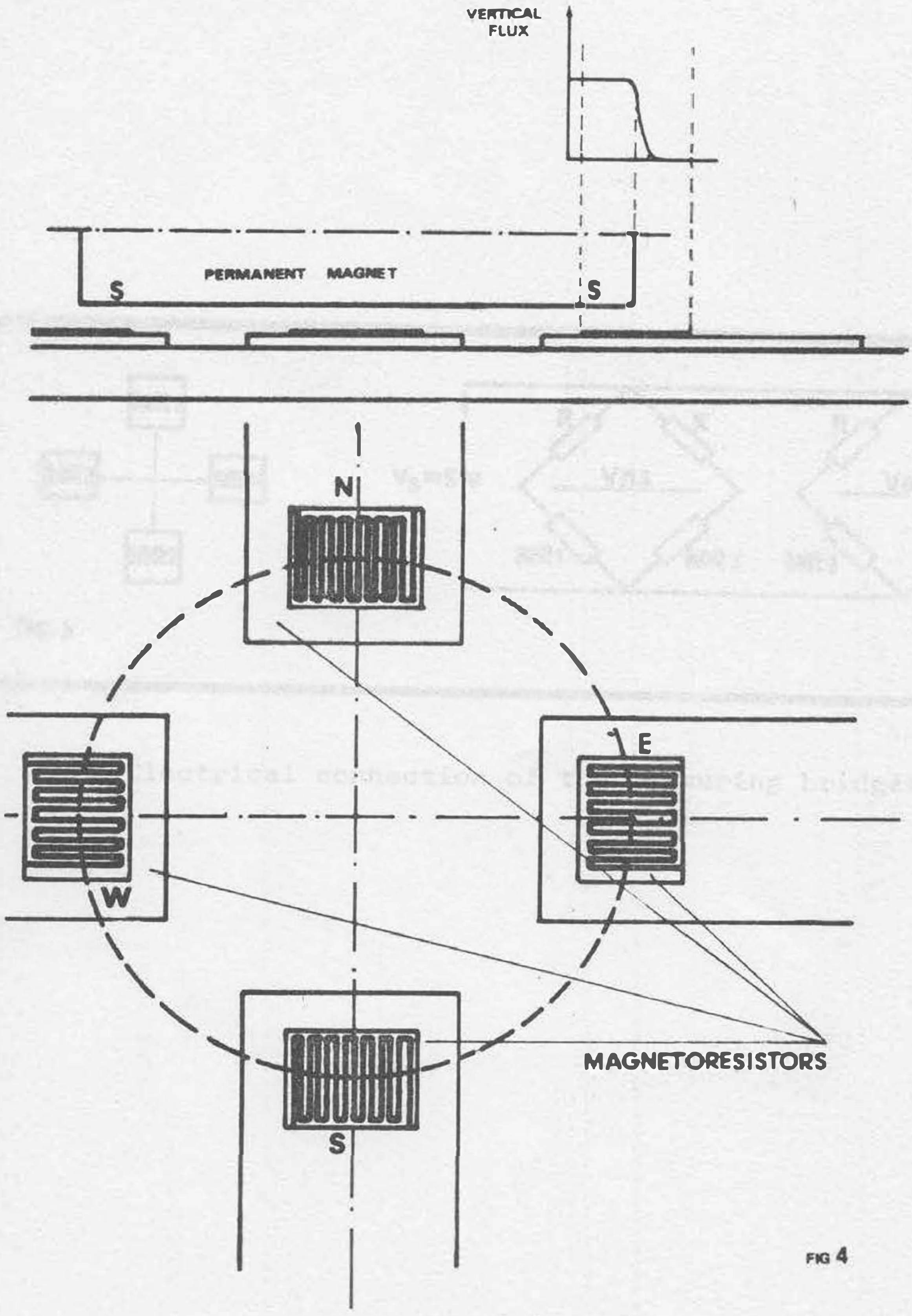


FIG 4

Alignment of sensors below the permanent magnet. The upper section of the figure shows the spatial arrangement of sensors and permanent magnet the change of the vertical magnetic flux is indicated on the diagram in the upper right corner of the picture. The lower part of the figure shows the arrangement of the measuring bridges.

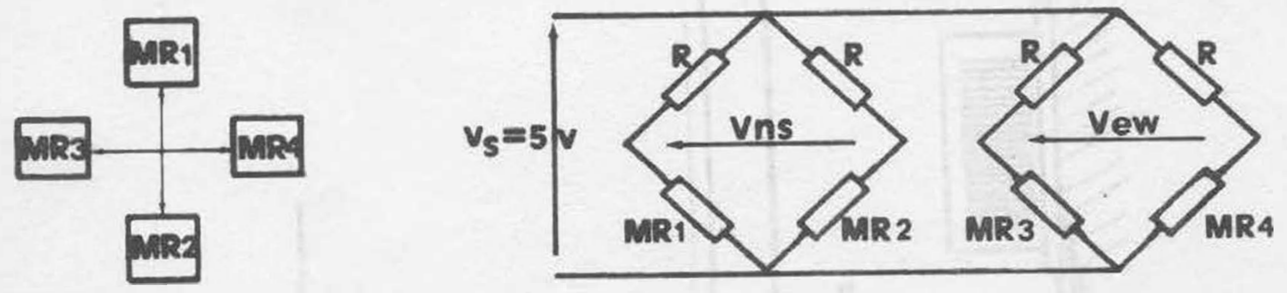


fig. 5

Electrical connection of the measuring bridges.

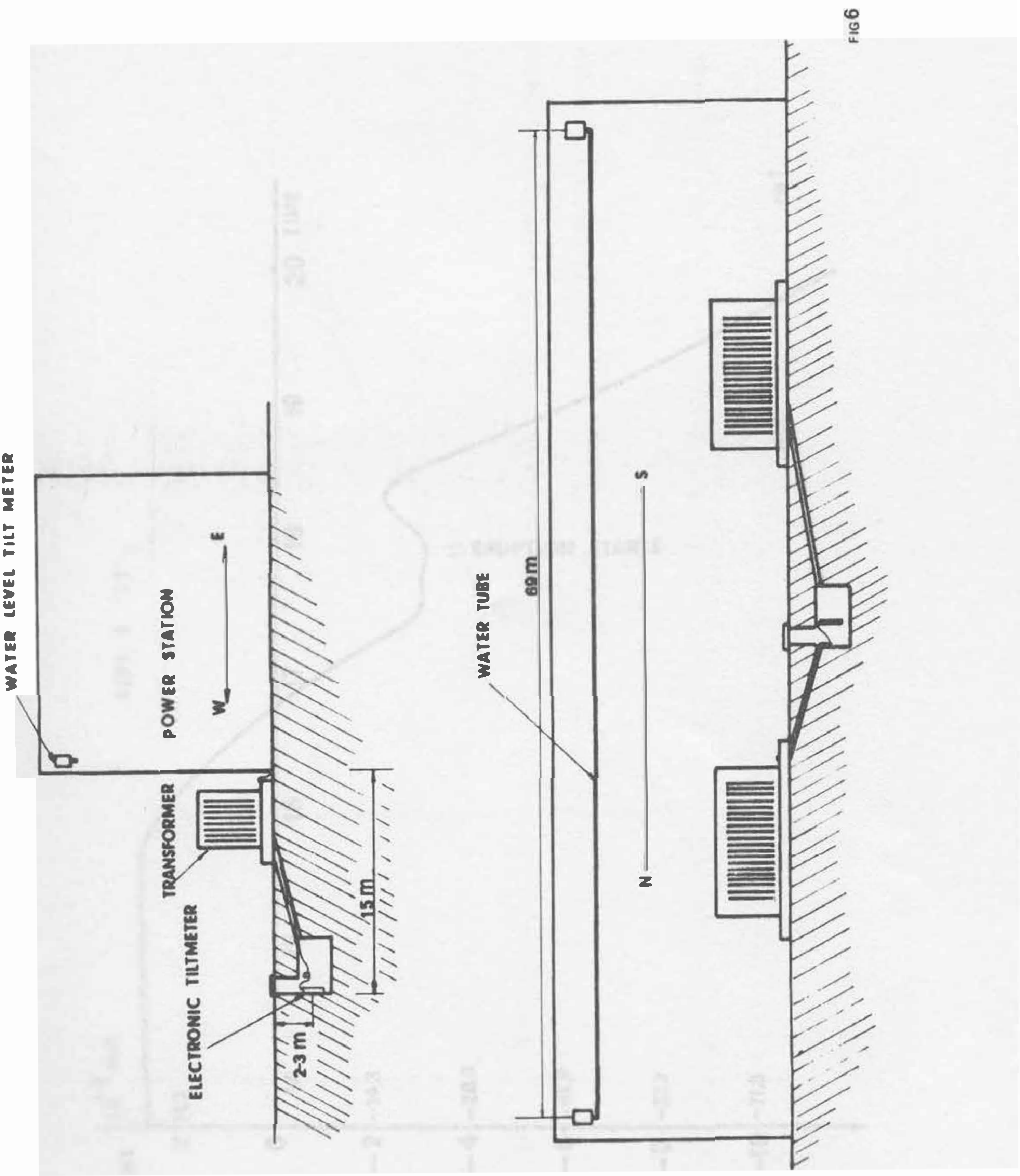


Fig. 6. Installation of the MR-tiltmeter during performance test and its distance relations to the water level tiltmeter.

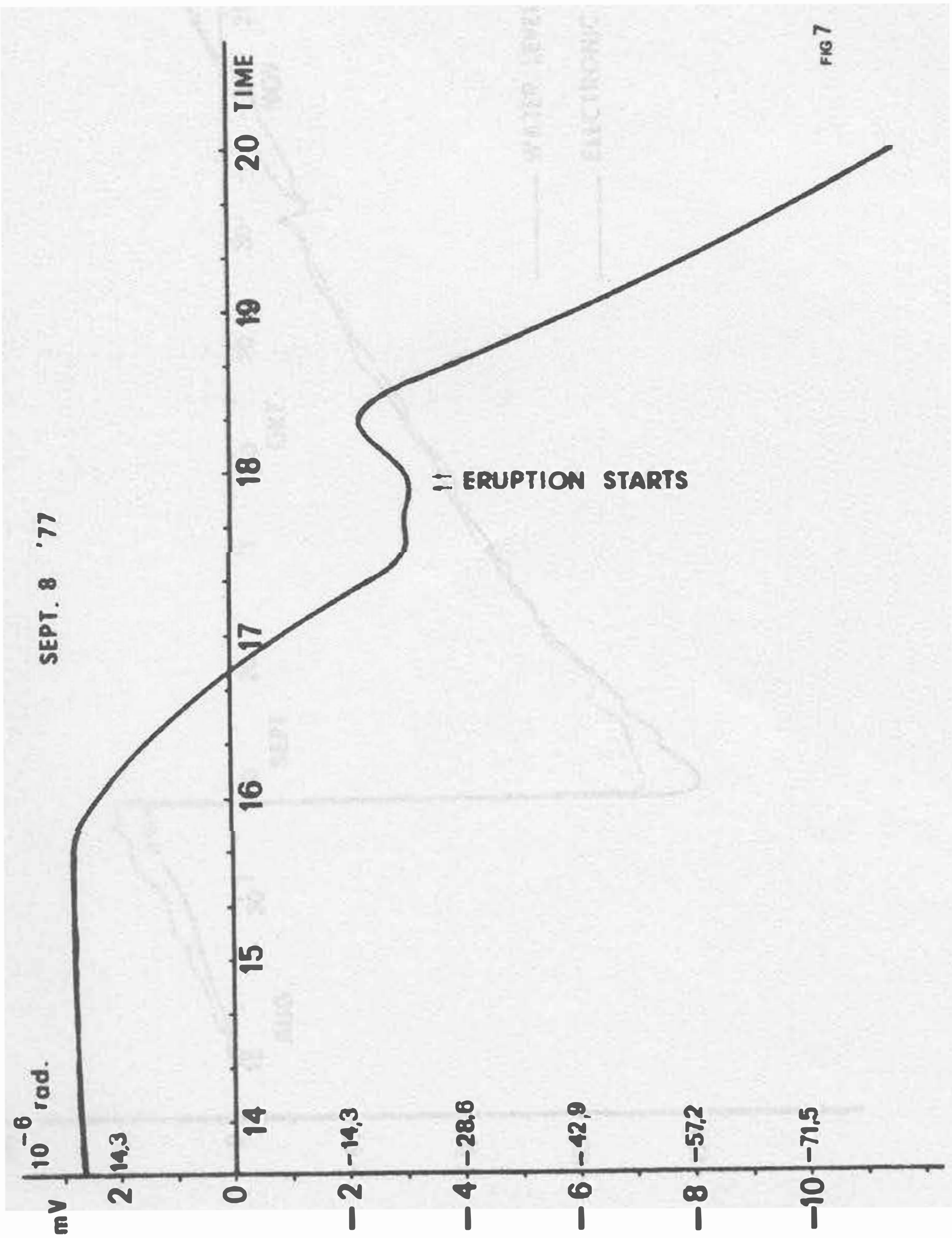


Fig. 7. Deflation event at the Krafla caldera September 8th 1977. North-south component.

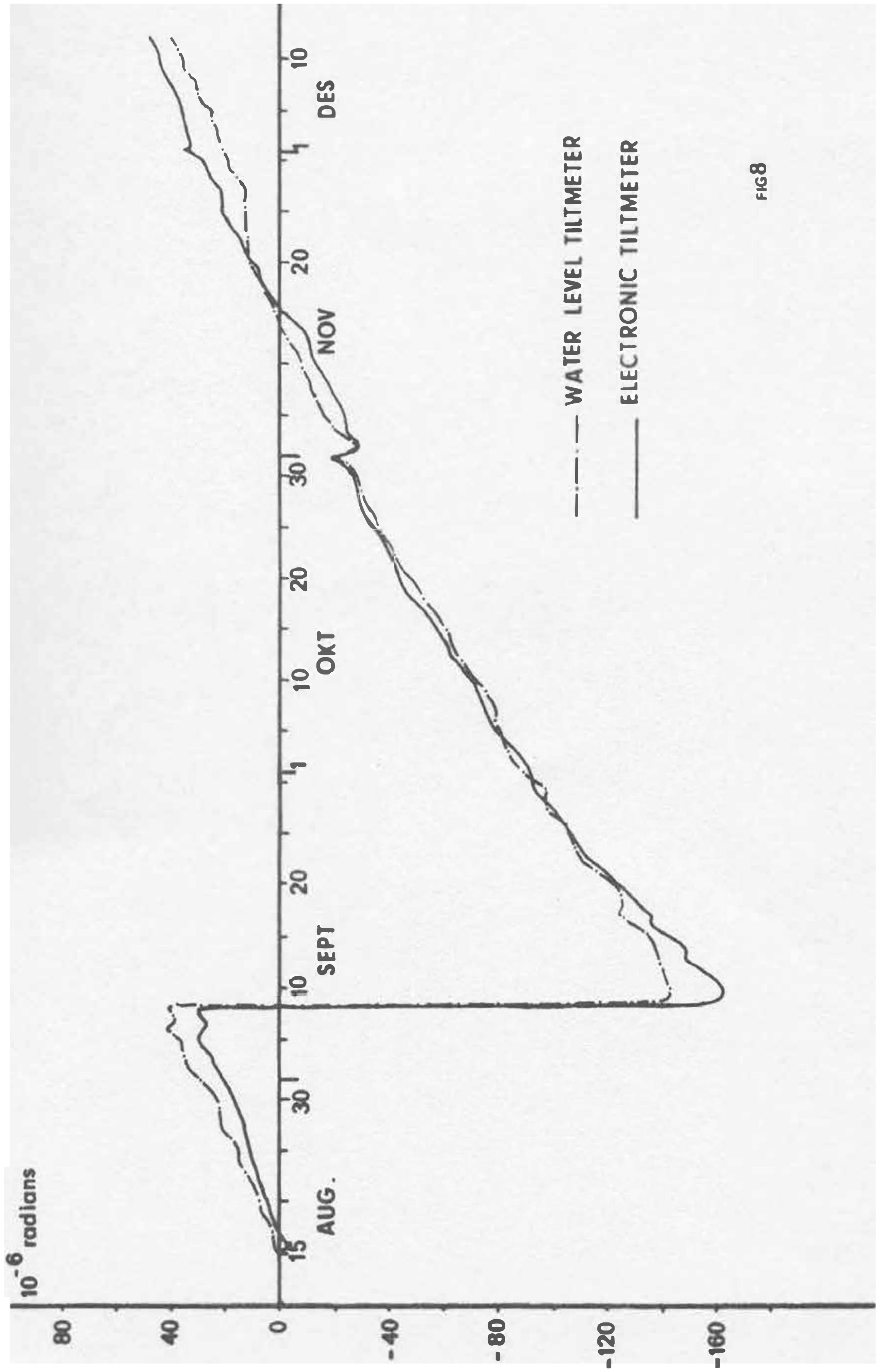


Fig. 8. Comparison between the magnetoresistor tiltmeter and the water tube tiltmeter during the time interval August 15th 1977 and December 10th 1977.