NORSAR ROYAL NORWEGIAN COUNCIL FOR SCIENTIFIC AND INDUSTRIAL RESEARCH

Internal Report No. 7-73/74

INSTALLATION AND CALIBRATION OF KIRNOS INSTRUMENTATION

by

R. Pettersen and P. W. Larsen

Kjeller, 1 March 1974

F44620-74-C-0001

INSTALLATION AND CALIBRATION OF KIRNOS INSTRUMENTATION

by

R. Pettersen and

P.W. Larsen

NTNF/NORSAR
Post Box 62
2310 Stange
Norway

1 March 1974

Internal Report No. 7-73/74

The NORSAR project was sponsored by the United States Air Force and monitored by the European Office of Aerospace Research and the Air Force Office of Scientific Research, Air Force Systems Command under contract number F44620-74-C-0001 with the Royal Norwegian Council for Scientific and Industrial Research.

SUMMARY

This report covers the installation and calibration of the Nordic Kirnos project equipment at subarray 04B. Measurements and calculation of all constants are included. Regular operation started 17 Dec 1973.

1. INTRODUCTION

The background and early preparation for this project are discussed in Internal Report No. 4-73/74. (Report on a visit to Finland related to the Kirnos Project at NORSAR Data Processing (NDPC).)

As the instrumentation involved was unfamiliar to the NORSAR Maintenance Center (NMC) staff, some problems have emerged. However, they were all solved in due time, and the proposed time schedule has been met.

2. LOCATION

The station is located at subarray 04B, some eight kilometers south of NMC, where access is convenient throughout the year. The geographical coordinates are: 60°40'25". 7531 North, 11°11'17".2079 East.

3. INSTALLATION

All equipment, except for the seismometer, is installed in a rented mobile hut erected close the the Central Terminal Vault (CTV) (see Fig. 1).

3.1 Seismometer

The Kirnos vertical component broadband instrument is installed in the subarray's Long Period Vault (LPV), with insulating cover, heating and heating control for 15°C environmental temperature. Fig. 2 shows the instrument with the cover off.

3.2 Galvanometer

The galvanometer with the light intensity control and light source is installed in the recording hut on a solid workbench, ref. Fig. 3.

3.3 Recording Drum

The recording drum is installed on the same workbench as the galvanometer. The drum is driven by an electrical motor which runs on 220 VAC and is synchronized to the net frequency of 50 Hz. Recording speed is 3 cm/min, and one seismogram contains 24 hours of data. Fig. 4 shows the recording drum.

3.4 Timing Unit

A timing source was not included in the equipment received from the University of Helsinki; therefore it was necessary to design and build a digital clock. This work was accomplished by field technician K. Falch (see Fig. 6, principal diagram of digital clock and time marker).

The clock runs on 5 VDC, and is directly connected to the back-up power batteries in the CTV. This was done to prevent time jumps in case of main AC failures. The clock is synchronized through the 2400 Hz oscillator in the CTV modem, which again is synchronized with data words zero crossings from NDPC. In this way the local timing is controlled by the main computer system timing. A delay of 150 sec (fixed) is introduced to the timing unit by the SPS at NDPC and communication equipment. This is taken into consideration and marked on the records.

The clock is supported by a commercial receiver for local control of the timing.

The time marks are introduced on the records through a relay which disconnects the light source (collimator) for 2 seconds every minute and 4 seconds every hour. Fig. 5 shows the radio receiver and digital clock.

4. CALIBRATION

The calibration procedures are explained in the Kirnos manual: General type seismographs of SKD system, Description and operating instructions. This section is therefore limited to formulae, computations and calibration constants. The test panel is shown in Fig. 7. Fig. 8 shows the overall system diagram.

4.1 Seismometer

4.1.1 Glossary of Terms

ℓ, reduced pendulum length = 0.497 m

k, moment of pendulum inertia (0.366 kgm^2)

T, pendulum period

D, pendulum damping

σ^2 coupling coefficient between seismometer and galvanometer

G_{11} the electromagnetic constant of the damping coil

G_{12} the electromagnetic constant of the pendulum working coil (data coil)

D_{10} mechanical damping of pendulum

D_{11} part of pendulum damping provided by damping coil

D_{12} part of pendulum damping provided by data coil

I" current through damping coil

I_{ac} current through data coil

a_{11} coefficient of electromagnetic attenuation of pendulum (damping coil)

a_{12} coefficient of electromagnetic attenuation of pendulum (data coil)

M, the constant strength moment

m, weight (10 g)

L, the distance from rotation axis (14.6 cm)

g acceleration of gravity (981 cm/sec^2)

n, circular freq. of natural period of the pendulum

R_D damping resistance

$\overline{V}$ magnification coefficient of the seismograph

4.1.2 Measurements and calculation

$$T_1 = \frac{60\ \text{sec}}{4\ \text{periods}} = 15\ \text{sec}$$

$$G_{12} = \underline{1.324 \cdot 10^8\ \text{CGSM}}$$

$$M_1 = m_1 \cdot g \cdot L_1 = 10 \cdot 981 \cdot 14.6 = \underline{1.43 \cdot 10^5\ \text{CGSM}}$$

$$I_{ac} = \frac{M_1}{G_{12}} = \underline{10.8\ \text{mA}}$$

$$a_{12} = \frac{G_{12}^2}{2 \cdot K_1 \cdot n_1} = \frac{(1.324 \cdot 10^8)^2}{2 \cdot 3.66 \cdot 10^6 \cdot 0.419}$$

$$= 0.572 \cdot 10^{10}\ \text{CGSM}$$

$$= 0.572 \cdot 10^{10} \cdot 10^{-9}$$

$$= \underline{\underline{5.72\ \text{ohms}}}$$

$$I_{11} = \underline{9.05\ \text{mA}} = 9.05 \cdot 10^{-4}\ \text{CGSM}$$

$$G_{11} = \frac{\overline{M}}{I_{11}} = \frac{1.43 \cdot 10^5}{9.05 \cdot 10^{-4}} = \underline{1.58 \cdot 10^8\ \text{CGSM}}$$

$$a_{11} = \frac{G_{11}^2 \cdot T_1}{4\pi \cdot K_1} = \frac{(1.58 \cdot 10^8)^2 \cdot 15}{4\pi \cdot 3.66 \cdot 10^6} = \underline{0.814 \cdot 10^{10}\ \text{CGSM}}$$

$$= 0.814 \cdot 10^{10} \cdot 10^{-9}$$

$$= \underline{\underline{8.14\ \text{ohms}}}$$

$$D_{12} = \frac{a_{12}}{r_g \cdot R_{s12}} = \frac{5.72}{79.5} = \underline{\underline{0.072}}$$

4.1.3 Test 1 - M

Ref. Fig. 9

v^3 med = 1.115

$$\lg v = \lg v^3 \text{med} \cdot \frac{1}{3} = \underline{0.0158}$$

$$D_{,}^{(1)} = \frac{0.733 \cdot \lg v}{\sqrt{1+(0.733 \cdot \lg v)^2}} = \frac{0.733 \cdot 0.0158}{\sqrt{1+(0.733 \cdot 0.0158)^2}} = \underline{0.01158}$$

$$D_{10} = D_{,}^{(1)} - \frac{a_{12}}{R_{SII} + R_1 + R_7 + \frac{r_7 \cdot r_g}{r_7 + r_g}}$$

$$= 0.01158 - \frac{5.72}{20.59 + 5.91 + 1516 + \frac{120.4 \cdot 53}{120.4 + 53}}$$

$$D_{10} = \underline{0.00796}$$

($D_,$ Selected to 0.4)

$\underline{\beta = 1}$

$$\sigma_,^2 = \frac{D_{12}}{D_,} = \frac{0.072}{0.4} = \underline{0.18}$$

$$R_D^{(1)} = r_4 = \frac{a_{11}}{(D_, - D_{12}) - D_{10}} - R_{SI}$$

$$= \frac{8.14}{(0.4 - 0.072) - 0.00796} - 24.94$$

$$= \underline{\underline{0.49 \text{ ohms}}}$$

$$\bar{V} = \frac{2A}{\ell_1} \sqrt{\frac{K_1}{K_2}} \cdot \sqrt{\sigma^2 \cdot \frac{D_1 \cdot T_2}{D_2 \cdot T_1}}$$

$$= \frac{2 \cdot 1}{0{,}497} \sqrt{\frac{3{,}66 \cdot 10^6}{4{,}351 \cdot 10^{-2}}} \cdot \sqrt{0{,}18 \quad \frac{0{,}4 \cdot 1{,}2}{8 \cdot 15}}$$

$$= \underline{989{,}1}$$

Fig. 10 shows the Kirnos seismograph response curve at full magnification (β=1).

Magnification $V = \bar{V} \cdot \bar{u}$ where $\bar{u}$ is frequency response.

$$u = \frac{\frac{2 \cdot D_2}{T_2}}{\sqrt{T_\omega^{-2} + a + BT_\omega^2 + cT_\omega^4 + dT_\omega^6}}$$

where

$$a = m^2 - 2p$$

$$B = p^2 - 2mq + 2S$$

$$c = q^2 - 2pS$$

$$d = S^2$$

$$m = 2\left(\frac{D_1}{T_1} + \frac{D_2}{T_2}\right)$$

$$p = \frac{1}{T_1{}^2} + \frac{1}{T_2{}^2} + \frac{4D_1D_2}{T_1T_2}(1-\sigma^2)$$

$$q = 2\left(\frac{D_1}{T_1T_2{}^2} + \frac{D_2}{T_2T_1{}^2}\right)$$

$$S = \frac{1}{T_1{}^2 \cdot T_2{}^2}$$

T_ω = period of ground displacement

<u>β = 2</u>

$$\sigma_2{}^2 = \frac{0,18}{2^2} = \underline{0.045}$$

$$D_{12} = \frac{a_{12}}{R_{s12} + R_2 + \dfrac{r_2 \cdot r_g}{r_2 + r_g}}$$

$$= \frac{5,72}{26,5 + 26,46 + \dfrac{53,07 \;.\; 53,0}{53,07 + 53,0}}$$

$$= \underline{0,07197}$$

$$R_D{}^{(2)} = r_5 = \frac{a_{11}}{D_1 - D_{12} - D_{10}} - R_{SI}$$

$$\frac{8,14}{0,4 - 0,07196 - 0,00796} - 24,94$$

$$= \underline{0,49 \text{ ohms}}$$

$$\overline{V} = \frac{2A}{\ell_1} \cdot \sqrt{\frac{K_1}{K_2}} \cdot \sqrt{\sigma^2 \cdot \frac{D_1 \cdot T_2}{D_2 \cdot T_1}}$$

$$= \frac{2}{0,497} \cdot \sqrt{\frac{3,66 \;.\; 10^6}{4,351 \;.\; 10^{-2}}} \cdot \sqrt{0,045 \;.\; \frac{0,4 \;.\; 1,2}{8 \;.\; 15}}$$

$$= \underline{\underline{494,6}}$$

4.2 Galvanometer

4.2.1 Glossary of terms:

A	optical arm, galvanometer - drum (100 ± 0,5 cm)
T_2	galvanometer period (0,9 - 1,3 sec)
D_2	galvanometer damping
r_g	internal resistance (53 ohm)
P_2	current sensitivity ($1-2 \cdot 10^{-8} \frac{A.m}{mm}$)
K_2	relativity of rotation axis ($4-5 \cdot 10^{-2}$ gsm^2)
r_a	external critical resistance (600 - 800 ohm)
D_{20}	mechanical damping of the galvanometer
a_2	coefficient of electromagnetic attenuation of the galvanometer
Y_a	successive two-way amplitude (test 3 - g)
I_a	current in amperes (test 3 - g)

4.2 Galvanometer

4.2.1 Glossary of terms:

A	optical arm, galvanometer - drum (100 ± 0,5 cm)
T_2	galvanometer period (0,9 - 1,3 sec)
D_2	galvanometer damping
r_g	internal resistance (53 ohm)
P_2	current sensitivity ($1\text{-}2 \cdot 10^{-8}$ $\frac{A.m}{mm}$)
K_2	relativity of rotation axis ($4\text{-}5 \cdot 10^{-2}$ gsm^2)
r_a	external critical resistance (600 - 800 ohm)
D_{20}	mechanical damping of the galvanometer
a_2	coefficient of electromagnetic attenuation of the galvanometer
Y_a	successive two-way amplitude (test 3 - g)
I_a	current in amperes (test 3 - g)

4.2.2 Measurements and calculations

$$T_2 = \frac{60 \text{ sec}}{50 \text{ periods}} = \underline{1{,}2 \text{ sec}}$$

4.2.3 Test 1 - g

Ref. Fig. 11.

$$v^{10}\text{med} = \underline{1{,}292}$$

$$\lg v^{10}\text{med} = \underline{0{,}11126}$$

$$\lg v = \frac{1}{10} \cdot \lg v^{10}\text{med} = \frac{1}{10} \cdot 0{,}11126 = \underline{0{,}011126}$$

$$D_{20} = D_2 \quad (1)$$

$$D_{20} = \frac{0{,}733 \quad \lg v}{\sqrt{1 + (0{,}733 \cdot \lg v)^2}}$$

$$= \frac{0{,}733 \,.\, 0{,}011126}{\sqrt{1 + (0{,}733 \quad 0{,}01126)^2}}$$

$$= \underline{\underline{8{,}155 \quad 10^{-3}}}$$

4.2.4 Test 2 - g

Ref. Fig. 12

$$v^3 med = \underline{2,9365}$$

$$lg\, v^3 med = \underline{0,4678}$$

$$lg\, v = \frac{1}{3} \cdot lg\, v^3 med = \frac{1}{3} \cdot 0,4678 = \underline{0,1559}$$

$$D_2^{(2)} = \frac{0,733 \cdot lg\, v}{\sqrt{1 + (0,733 \cdot lg\, v)^3}} = \frac{0,733 \cdot 0,1559}{\sqrt{1 + (0,733 \cdot 0,1559)^2}} = \underline{0,1135}$$

$$a_2 = (D_2^{(2)} - D_2^{(1)}) (r_g + r_{11})$$

$$= (0,1135 - 0,008155) (53 + 5980)$$

$$= \underline{635,55 \text{ ohms}}$$

4.2.5 Test 3 - g

Ref. Fig. 13

$y_a = \underline{95{,}5\ \text{mm}}$ $I_a = \underline{296 \cdot 10^{-6} A}$

$$P_2 = \frac{2_A \cdot r_{13}}{r_g + R_{13} + r_{13}} \cdot \frac{I_a}{y_a}$$

$$= \frac{2 \cdot 1 \cdot 0{,}99}{53 + 500{,}14 + 0{,}99} \cdot \frac{296 \ . \ 10^{-6}}{95{,}5} = 1.1075 \cdot 10^{-8}$$

$$K_2 = 3{,}23 \cdot 10^4 \cdot a_2 \cdot P_2^{\,2} \cdot T_2^{\,3}\ \text{kgm}^2$$

$$= 3{,}23 \cdot 10^4 \cdot 635{,}55 \cdot 1{,}1075 \cdot 10^{-8} \cdot 1{,}2^3$$

$$= 4{,}351 \ . \ 10^{-9}\ \text{kgm}^2$$

$$D_2 = D_{20} + \frac{a_2}{r_g + R_{S12}}$$

$$= 8{,}155 \cdot 10^{-3} + \frac{635{,}55}{79{,}5}$$

$$= 8{,}0$$

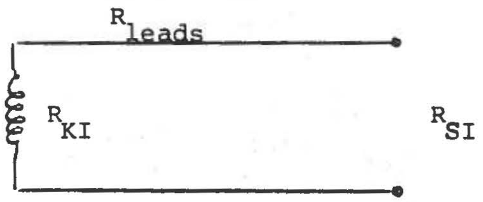
4.3 Data for test panel PRUOP-2M-I

Fixed values (ohms):

R_1 = 5,91
R_2 = 26,46
R_3 = 105,94
r_2 = 53,07
r_3 = 32,89

R_7 = 1516	r_7 = 120,4	r_8 = 119,92	r_9 = 179,51
R_{10} = 10644	r_{10} = 26,58	R_{11} = 1M	r_{11} = 5980
r_{12} = 4020	R_{13} = 500,14	r_{13} = 0,99	R_{14} = 5k
R_{15} = 4982			

4.3.1 Damping Circuit

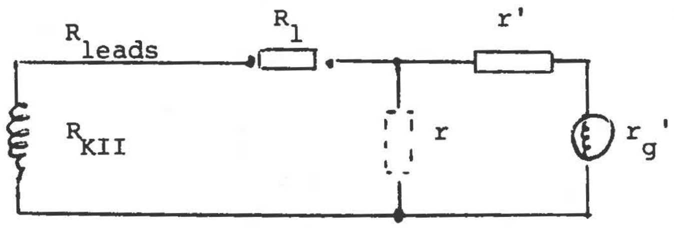


R_{KI} damping coil $= 23{,}39$

$+\ R_{leads} = \underline{1{,}55}$ ohms

$R_{SI} = \underline{24{,}94}$

4.3.2 Data circuit



R_{KII} data coil $= 19{,}33$

$+\ R_{leads} = \underline{1{,}26}$

$R_{SII} = 20{,}59$ ohms

$+\ R_1 = \underline{5{,}91}$

$R_{S12} = \underline{26{,}50}$

$r_g' = 50{,}1$ ohms

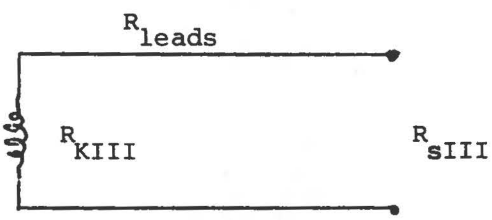
$r_g = 53 = r_g' + r'$

$r' = 53 - r_g'$

$r' = 53 - 50{,}1$

$= \underline{2{,}9 \text{ ohms}}$

4.3.3 Calibration Circuit



R_{KIII} cal coil $= 4{,}30$

$+\ R_{leads} = \underline{3{,}10}$ ohms

$R_{sIII} = \underline{7{,}40}$

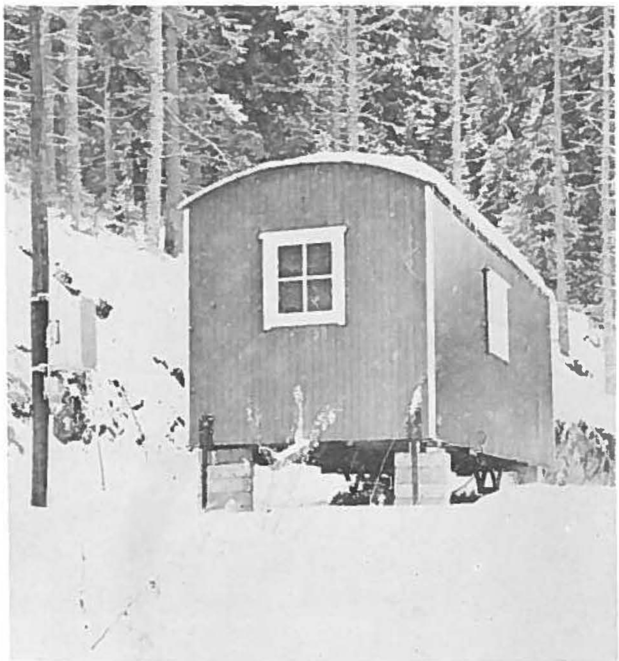


Figure 1. KIRNOS seismograph recording hut. (Electric power is acquired from the Central Terminal Vault located just behind the hut.)

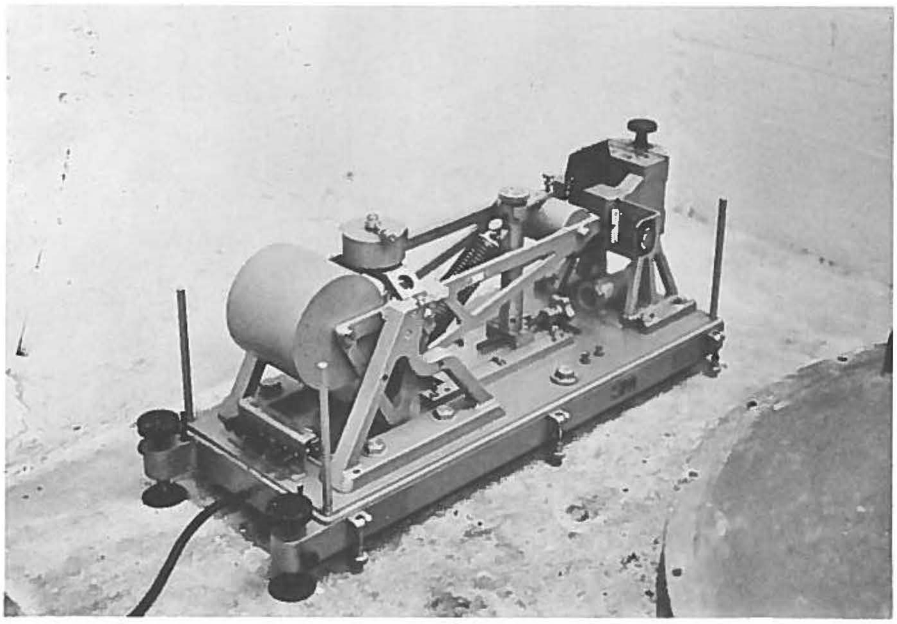


Figure 2. KIRNOS broadband vertical seismometer, type SVK-2.

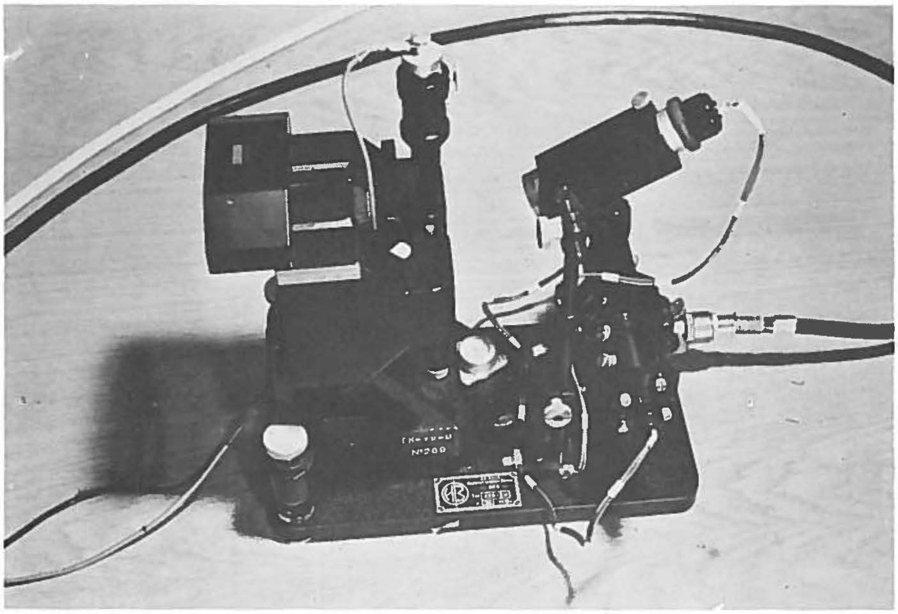


Figure 3. KIRNOS seismograph galvanometer, type GK-VII M.

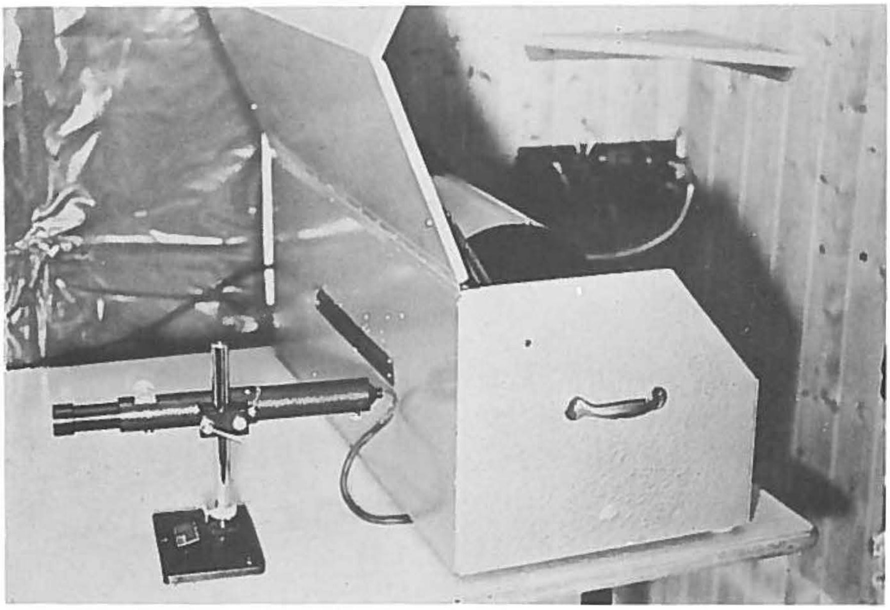


Figure 4. Recording drum (light source - collimator - in front).

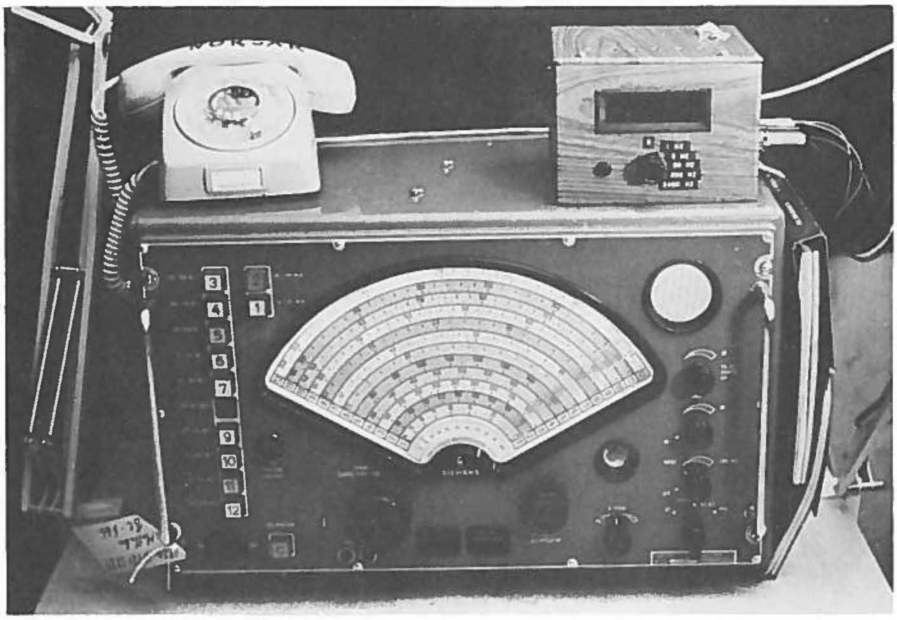


Figure 5. Radio receiver and digital clock.

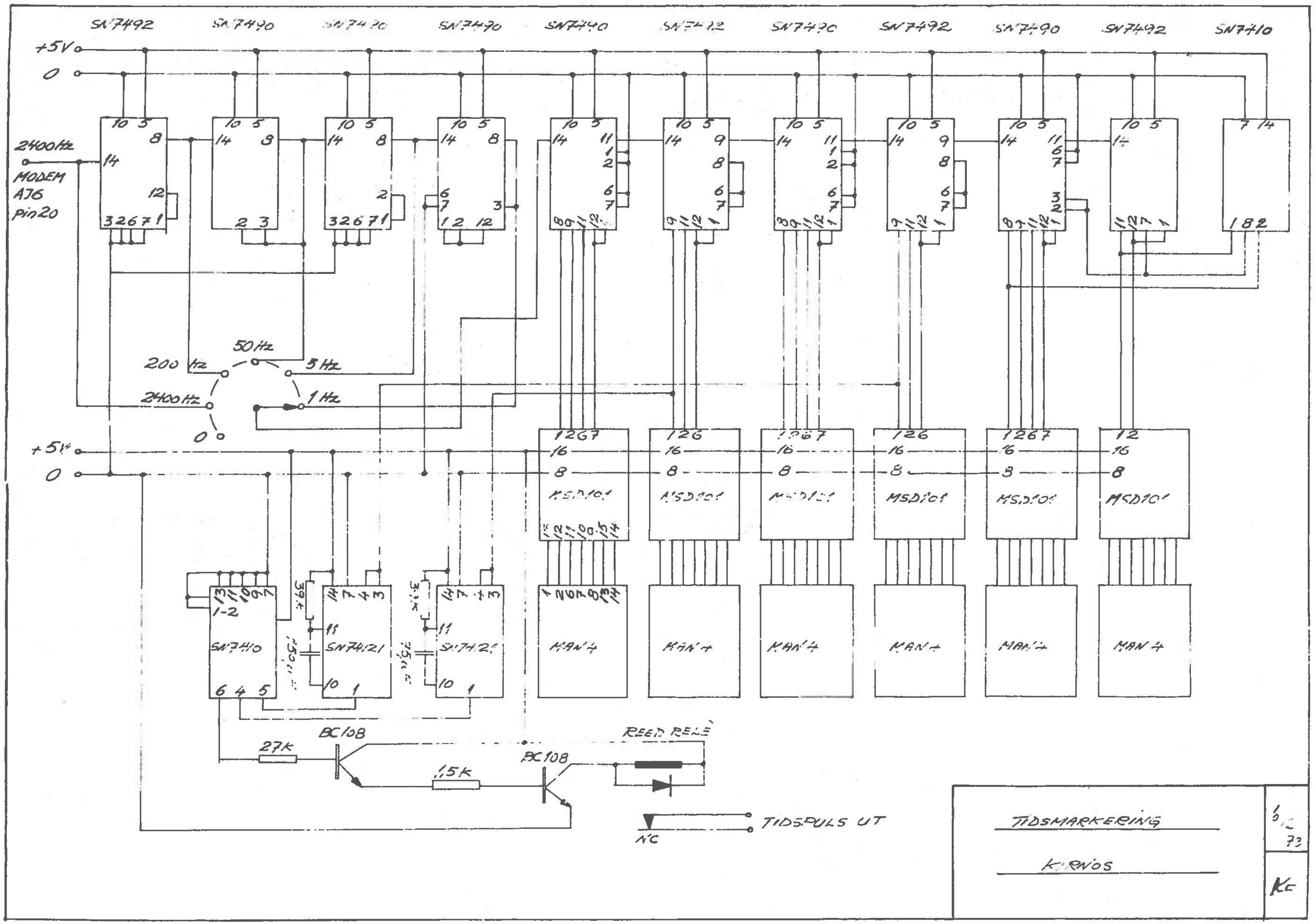


Figure 6. Digital Clock.

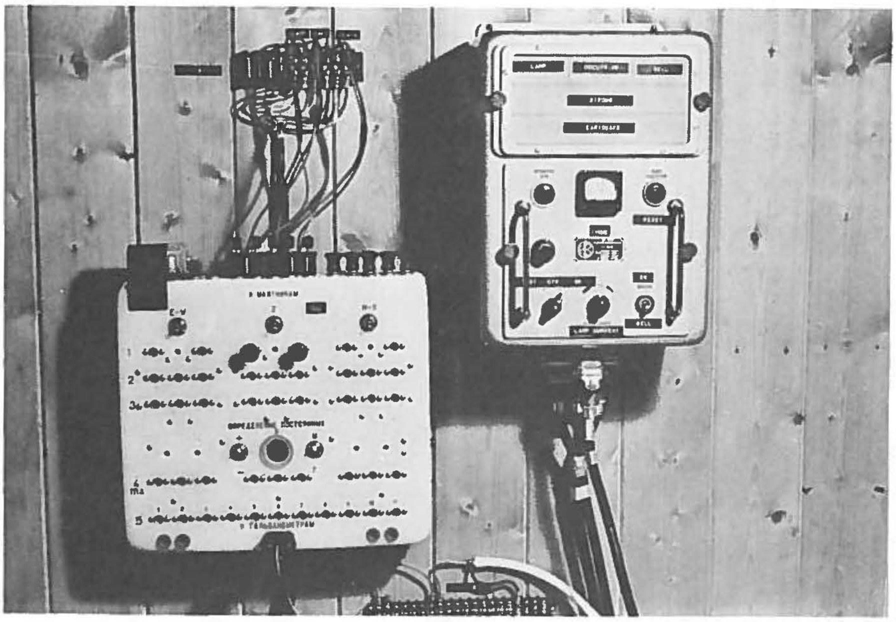
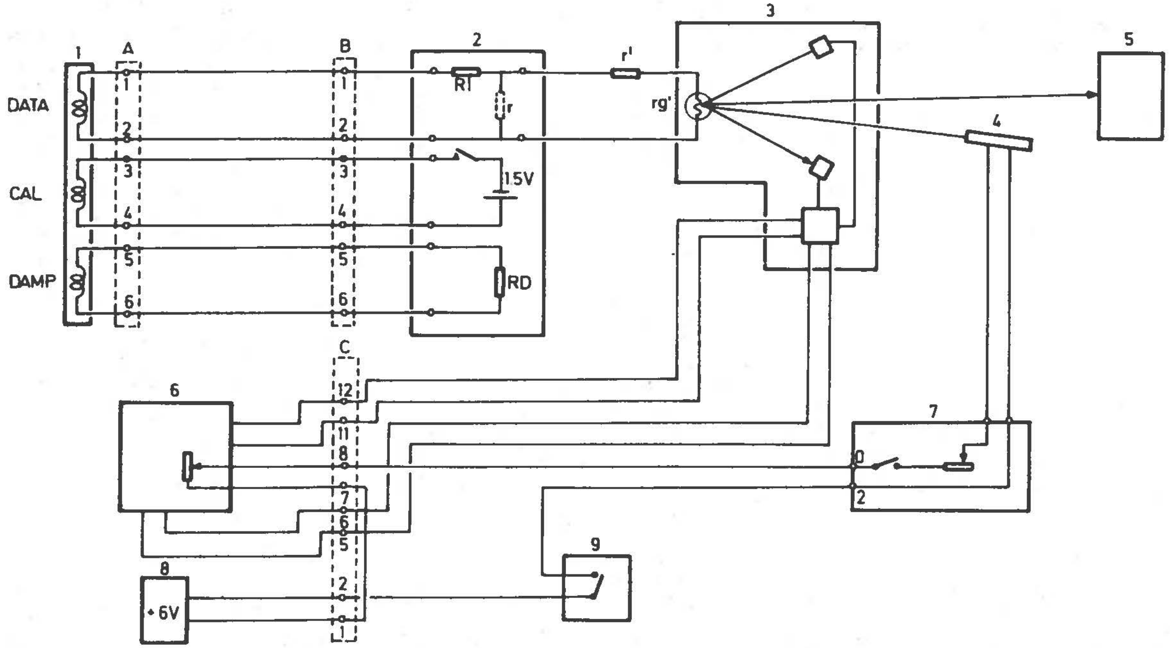


Figure 7. Test panel, type PRUOP-2M-I (left) and Automatic recording controller (automatic light intensity control and audio and light event detector).



1 PENDULUM
2 TESTPANEL PRUOP
3 PHOTO-OPTICAL UNIT WITH GALVANOMETER AND LAMP
4 COLLIMATCR (LIGHT SOURCE)
5 DRUM
6 AUTOMATIC RECORDING CONTROLLER AY3-IIM AUE-IIM
7 COLLIMATOR CONTROL UNIT
8 POWER SUPPLY
9 TIME MARKER (CLOCK)

Figure 8. KIRNOS broadband seismograph overall system diagram.

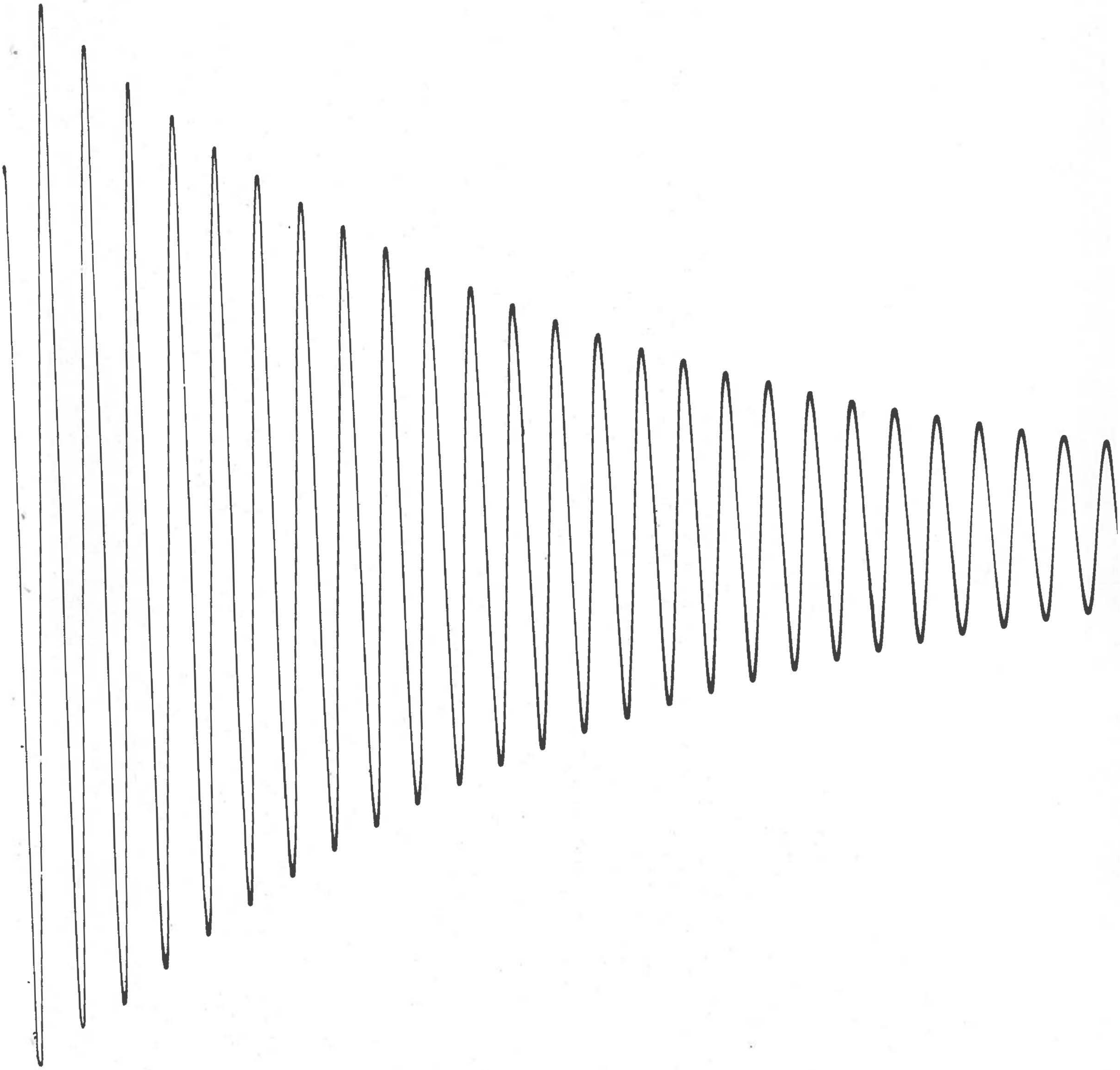


Figure 9. Pendulum, Test 1 - M.

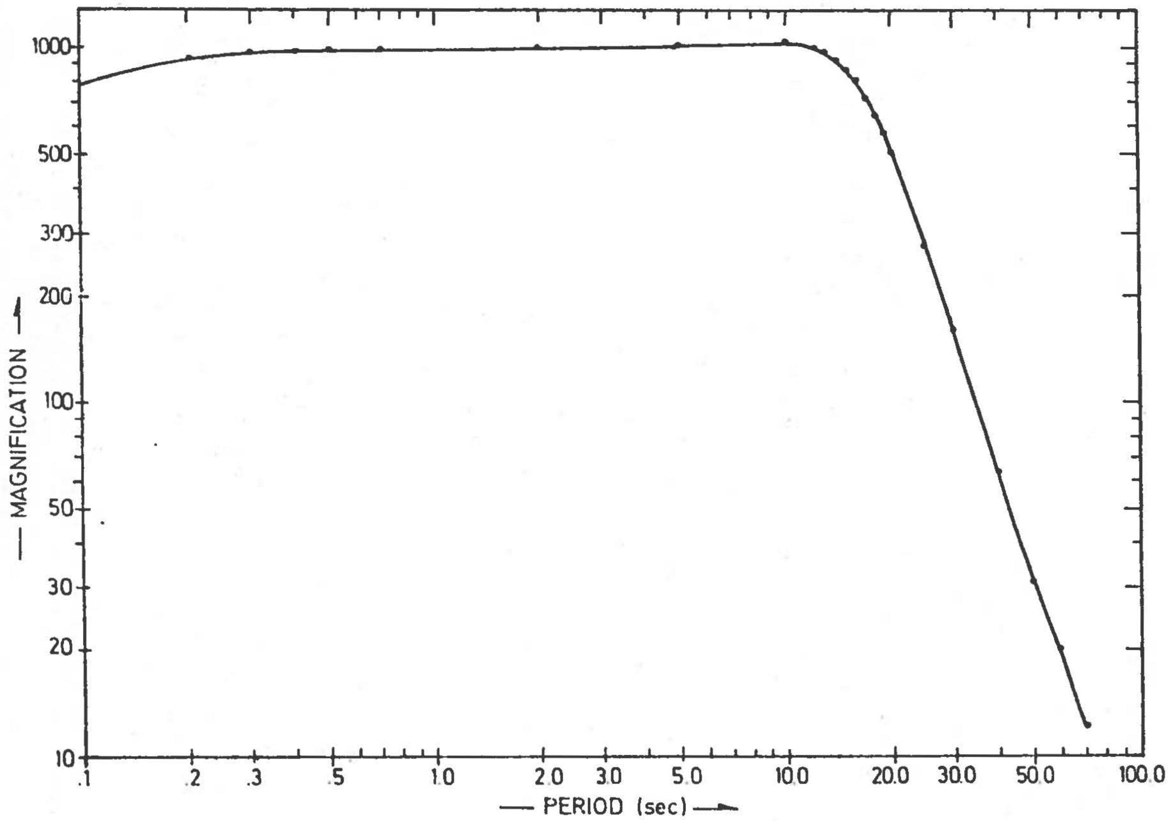


Figure 10. KIRNOS seismograph response.

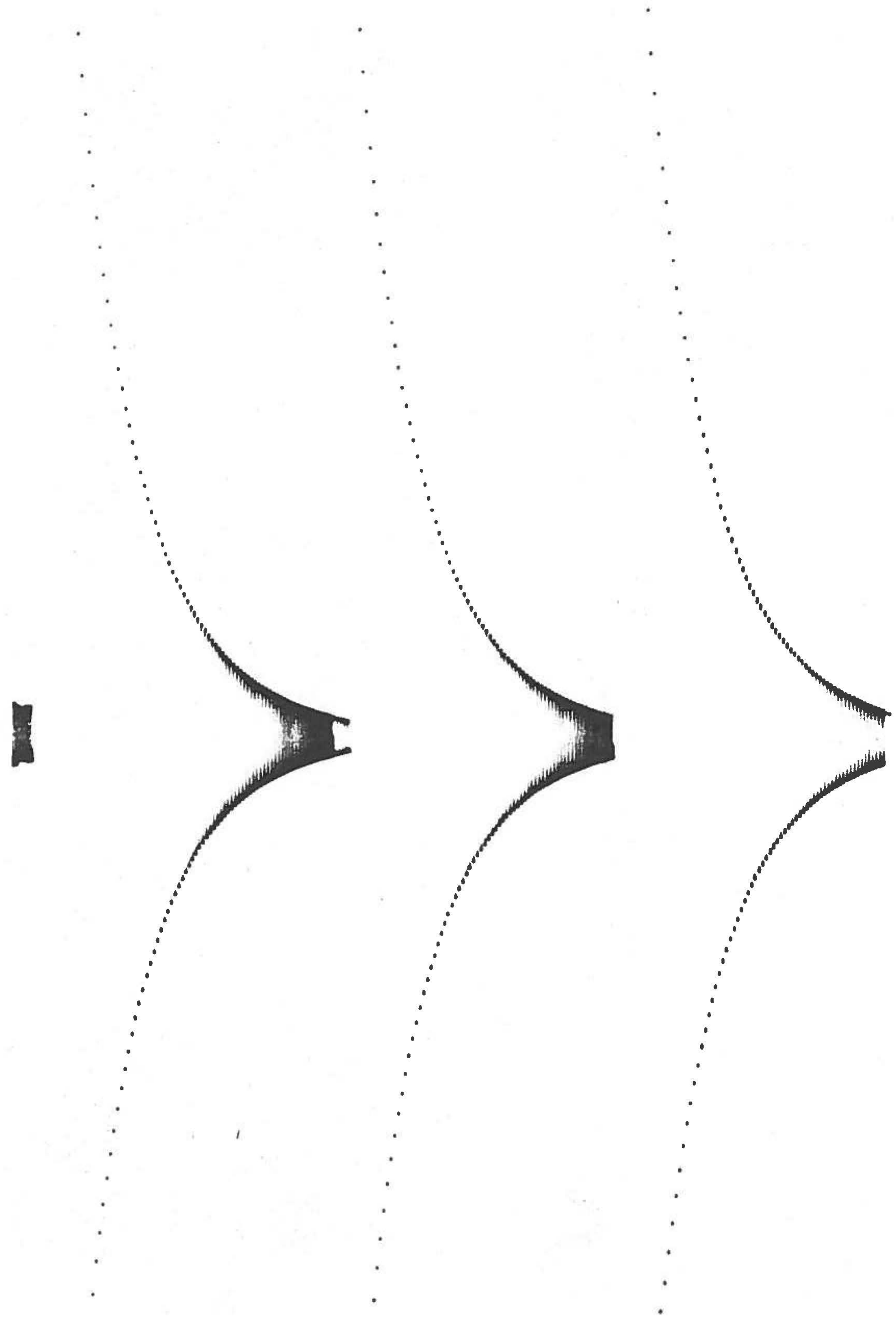


Figure 11. Galvanometer, Test 1 - g.

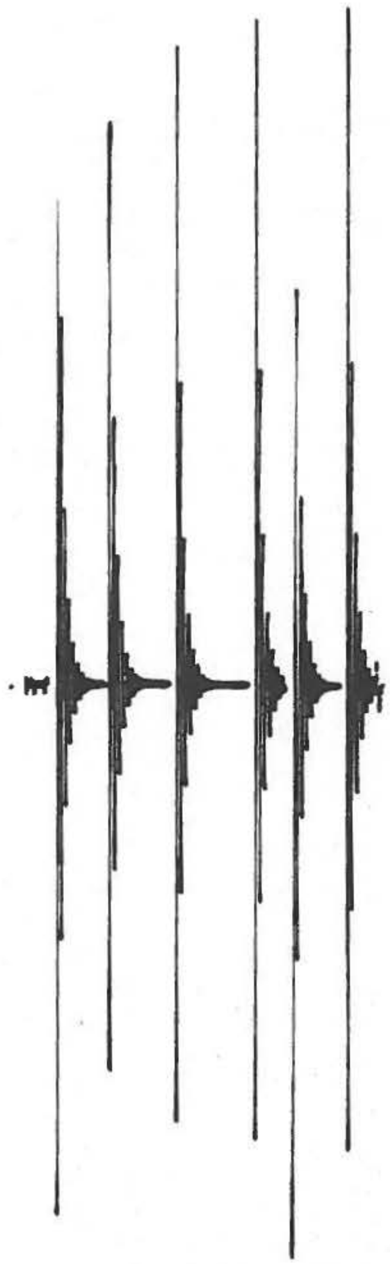


Figure 12. Galvanometer, Test 2 - g.

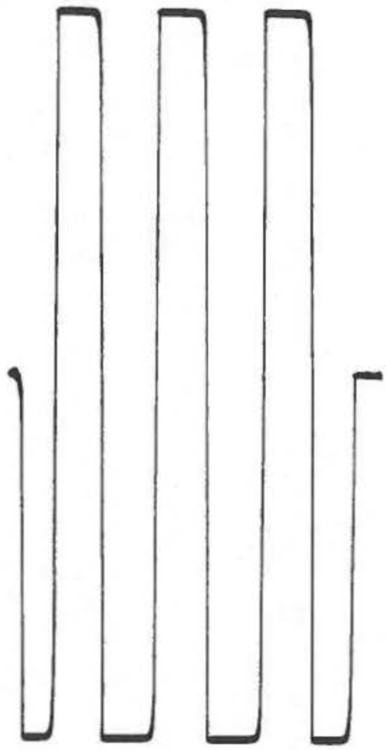


Figure 13. Galvanometer, Test 3 - g.