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41. *Improvements of Ocean-Bottom Seismograph— Construction of a Long-Life Magnetic Tape Recorder.*

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1. Introduction

In order to improve the resolving power for measuring $S-P$ time of micro-earthquakes and also for obtaining spectrum structure of earthquakes which will be observed at the ocean floor, a long-life magnetic tape recorder was constructed for ocean-bottom seismograph. At the same time several improvements were added to the instruments and system of the ocean-bottom seismograph which were reported in the previous paper.[1]

This paper will describe the construction of some of these instruments. The results of experimental observation at sea-bottom by this new magnetic tape system will be reported in the accompanying paper.[2]

The main improvements are as follows. A magnetic tape recorder was designed and constructed for use as a recording instrument. Transistors in the previous amplifier were changed to silicon transistors. A leveling device was added to the horizontal component of a seismometer. The main buoy and light buoy of the mooring system were improved and made convenient and safe. A system of data processing of recorded tape was developed.

1) S. NAGUMO et al., *Bull. Earthq. Res. Inst.*, **43** (1965), 671-683.
2) S. NAGUMO et al., *Bull. Earthq. Res. Inst.*, **46** (1968), 877-888.
3) J. T. THOMSON, W. A. SCHNEIDER, *Proc. IEEE*, **53** (1965), 2209-2216.
4) R. ARNET and T. W. NEWHOUSE, *Proc. IEEE*, **53** (1965), 1899-1905.
5) T. ASADA, lecture at the spring meeting of the Seismological Society 1966.
6) M. OHTAKE et al., *Bull. Earthq. Res. Inst.*, **45** (1967), 862.
7) R. S. REYNOLDS, *Proc. IEEE*, **53** (1965), 1890-1899.
8) H. BRADNER et al., *Proc. IEEE*. **53** (1965), 1906-1908.
9) Precision Instrument, *Bull.* **126**, 1964.

2. Magnetic tape recording system

Tape speed and modulation system

Several magnetic tape recording systems have already been reported for long-time recording of earthquake observation.[3–9]

However, there are several special requirements for a magnetic tape recorder which will be used for ocean-bottom seismograph. The size should be small so as to be placed in the pressure vessel, the power consumption should be as small as possible, and the recording time should be as long as possible. Therefore, it is very difficult to use a ready-made magnetic tape recorder, which is designed for land operation, in the ocean-bottom seismograph. A special design is always required corresponding to the type of pressure vessel.

First, we have to determine the tape speed and modulation system of the recording instrument. In order to extend the recording time, the tape speed should be lowered. When the tape speed is lowered, however, the quality of record-reproducing characteristics decreases in the high frequency region. As is well known, the high frequency limit of recording is proportional to the tape speed. Therefore, when the value of high frequency limit is selected, the required tape speed is naturally determined. The speed, however, differs according to the modulation system. In the system of amplitude modulation or direct recording, the high frequency limit of the information is much higher, say about 5 times, in AM than in FM in a given tape speed. Therefore, for a given high frequency limit, the tape speed of AM can be lowered to about 1/5 of that of FM, and the recording time in AM can extended about 5 times longer than FM.

On the other hand, however, the fidelity of reproduction of original wave form is generally much better in FM than in AM, especially in the low frequency region. Since high fidelity is required for the spectrum analysis of earthquake wave motion, FM system is usually favoured for that purpose. This time, it was decided to adopt the FM system sacrificing recording time.

The selection of frequency response of seismograph is always one of the essential problems of earthquake observation, and it depends upon the purpose of observation and the nature of earthquakes. As Asada[10,11] has reported about ten years ago, the micro- and ultra micro-

10) T. ASADA, *J. Phys. Earth*, **5** (1957), 83-113.
11) T. ASADA et al., *J. Phys. Earth*, **6** (1958), 23-33.

earthquakes contain plenty of high frequency components extending over some several ten cycles per second. The higher frequency component is very important for identifying the arrival times of P and S phases. In the present design, as a compromise between the high frequency characteristics and recording life, the value of the high frequency limit is selected at 20 cps. This choice is based upon the interest of covering the predominant part of wave energy of micro-earthquakes. The validity of this choice will be, of course, a matter of further investigation.

Thus, the carrier frequency of FM is determined as 80 cps. The necessary tape speed is determined as 0.06 inch/sec. The recording time is about 100 hrs by a tape 1,800 ft long in a 7 inch standard reel.

If one changes the choice of the value of the highest recording frequency to 10 cps, the recording life will be extended to 200 hrs by the same tape with tape speed of 0.03 inch/sec with carrier frequency of 40 cps. If one is satisfied with AM system, it will be possible to extend the recording life by about five times, that is 500 hrs for 20 cps, and 1000 hrs for 10 cps by a tape 1800 ft long.[12]

System of recording and playback

The recording instrument which will be used in the pressure vessel is separated from the playback machine which will be used in the laboratory. The recording instrument is designed as simply as possible in function so as to reduce the geometrical size, power consumption, and possible trouble.

The system of recording and playback is shown in Fig. 1. Record-

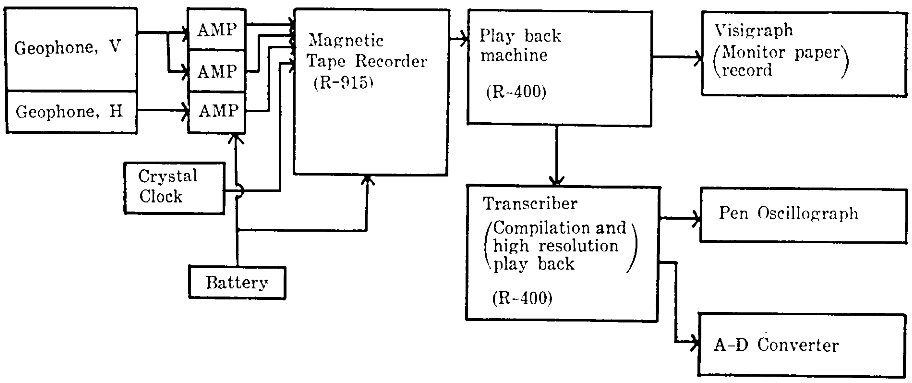

Fig. 1. System of ocean-bottom seismic recording and play-back.

12) *loc. cit.*, 3).

ing of seismic data is done automatically and completely in a pressure vessel which will be placed upon the ocean floor. Earthquake motions are detected by seismometers, one vertical and one horizontal, and are fed to the amplifiers. The outputs of amplifiers are fed to the magnetic tape recorder. The timing signal of every second, minute and hour from the crystal clock (SEIKO, QC 592 TF-7) is also fed to the tape recorder. The tape recorder is a 4-track recorder on 1/4 inch wide tape. The vertical component is recorded on two tracks with different magnification so as to increase the dynamic range of recording. The main specifications of the recording instrument are listed in Table 1. Both

Table 1. Main specifications of magnetic tape recorder R-915.

Modulation	FM
Carrier	80 cps
Tape speed	0.06 ips
Reel	7 in. in dia.
Tape	1/4 in., 1800 ft
Recording time	100 hrs.
Track number	4
Frequency response	0.2–20 csp
S-N ratio	30 db
Input voltage	± 1 Vpp
Input impedance	10 kΩ (unbalance)
Power	DC 12 V, 150 mA
Dimensions	$220 \times 500 \times 150$ mm
Weight	15 kg
Playback	By R-400, tape speed 6 (or 3) ips

magnetic tape recorder and amplifier are operated by the batteries of Nickel-Cadminium-Alkali cells, of which total capacity is $12\,V \times 39$ AH.

The playback of the recorded tape is done by a commercial magnetic tape recorder (TEAC, R-400). As regards data processing, first of all, a visible paper record for monitoring the content of the tape is made by optical oscillograph (SANNEI, VISIGRAPH FR-301). Since the playback tape speed is 50 times that of the recording tape speed, the original frequency range of information $0 \sim 20$ cps is changed to $0 \sim 1000$ cps, and it takes two hours to reproduce the 100 hrs record. As for detailed inspection of each earthquake, another paper record is made by an ink recorder (SANNEI, RECTIGRAPH) by the following procedure. In order to obtain proper playback tape speed for using the ink recorder, the original tape is first transcribed to another 10 tapes at the 10 times faster tape speed (30 inch/sec). The transcribed tape is then reproduced at the normal tape speed (3 inch/sec). Since the playback speed of the original tape is 50 times that of the recording speed, the ratio of original tape speed to final reproducing tape speed is $1\times 50\times 1/10=5$. Namely, the original frequency range of information $0\sim 20$ cps is changed to $0\sim 100$ cps. which is almost suitable for driving the ink recorder. The handling of frequency during transcription and reproducing is shown in Fig. 2. The output of playback of the transcribed tape is also fed directly to the A-D converter when the spectrum analysis is needed.

	Recording (R-915)	Play back (1) (R-400) Monitor and Transcription	Play back (2) (R-400)	
			Compilation	High resolution play back
Tape Speed	0.06 ips	3 ips	30 ips	3 ips
Signal Frequency	0.3-20 cps	15-1000 cps	15-1000 cps	1.5-100 cps
PM Carrier Frequency	80 cps	4000 cps	4000 cps	400 cps

Play back (1) → Monitor optical record

High resolution play back → Pen record / A-D Converter

Fig. 2. Handling of signal frequency and tape speed during data processing.

Accomplishment of slow tape speed

The mechanism of slow speed driving of magnetic tape is one of the essential parts of a long recording-time instrument. As is well known, when the tape speed is lowered, the signal-to-noise ratio of record-reproduction also decreases. Therefore, in order to obtain high signal-to-noise ratio at slow tape speed, one has to be very careful in the design of the mechanism so as to avoid any possible undesirable noises which will be produced by the system of driving mechanism. The systems which are known at present are (1) the use of a high speed motor with speed change mechanism, (2) direct use of servo-motor to capstan,[13] (3) endless belt driving method.[14] The first method is used this time because it is most commonly used in magnetic tape recorders.

The required rotation of the capstan is about 5 rpm for 0.06 inch/sec

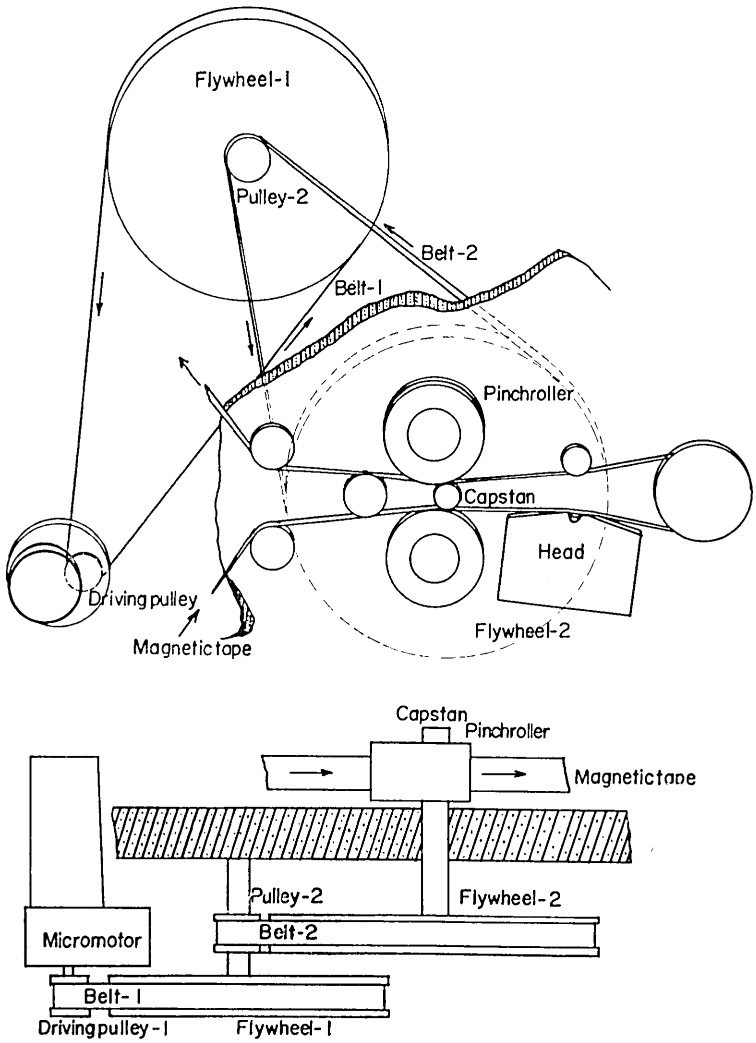

Fig. 3. Mechanism of slow speed driving.

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13) *loc. cit.*, 5).
14) *loc. cit.*, 6).

tape speed by 6 mm diameter capstan. The rotation of the high speed motor is 3000 rpm. Therefore, the required ratio of speed change is approximately 1/600. The schematic illustration of the mechanism of slow speed driving which is used this time is shown in Fig. 3, and the main specifications are listed in Table 2. From the high speed DC

Table 2. Main specifications of mechanism of slow speed driving.

Motor type	DC Micromotor (CLF-2A-300)
Operating Voltage	6 V
rpm	300
Driving Pulley Dia	8 ϕ
Flywheel-1 Dia	65 ϕ
Pulley-2 Dia	10 ϕ
Flywheel-2 Dia	77 ϕ
Capstan Dia	6.03 ϕ
Capstan rpm	4.83
$\frac{\text{Capstan rpm}}{\text{Gear Head rpm}}$	$\frac{1}{62}\left(=\frac{4.8}{300}\right)$
Tape Speed	0.06 ips (1.5 mm/s)

motor of 3000 rpm (JMM, CLF–2A), which is servo-controlled, the number of rotations is changed to 300 rpm through a gear-box which is mounted directly on the high speed motor. Then it is changed down to about 5 rpm of capstan by a two stage pulley-belt system.

Any device for changing speed always produces some undesirable noises. At present the necessary frequency range of information which will be recorded on magnetic tape is, as stated before, selected as $0\sim20$ cps. Therefore, any undesirable irregularities of revolution should, at least, be avoided in this frequency range as far as possible. In general, the frequency f_n of occurrence of probable irregularities of revolution due to speed change is associated with the revolution of each rotating part of the system. When the number of rotations of a rotating body is r(rpm), and when such probable irregularity occures n time per revolution, the f_n is given by

$$f_n = n \cdot r/60 \qquad (1/\text{sec})\ .$$

Since the numbers of rotations of the gear head shaft, the first pulley and the second pulley are approximately 300 rpm, 37 rpm, and 5 rpm respectively, the associated f_n are $f_n = 5\,n$, $0.6\,n$, and $0.08\,n$ respectively.

It is seen that the most dangerous noise might originate from the gear box. In fact, this noise has limited the signal-to-noise ratio of the whole system.

As regards tape tension, the closed loop system is adopted.

The frequency responses of the magnetic tape recorder when played

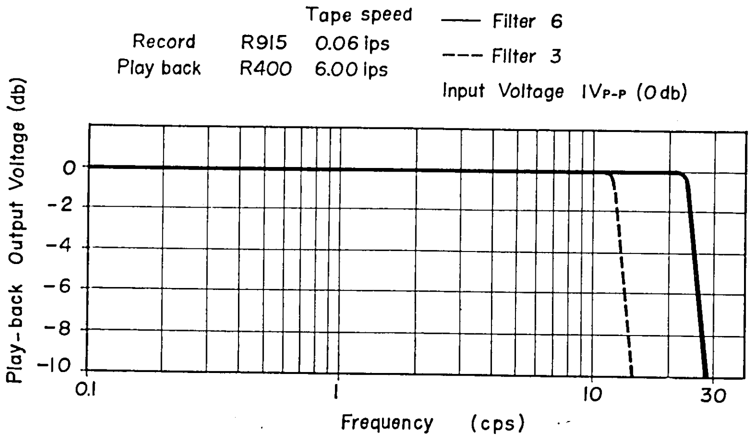

Fig. 4. Frequency response of record-reproduction, recorded by R-915, reproduced by R-400.

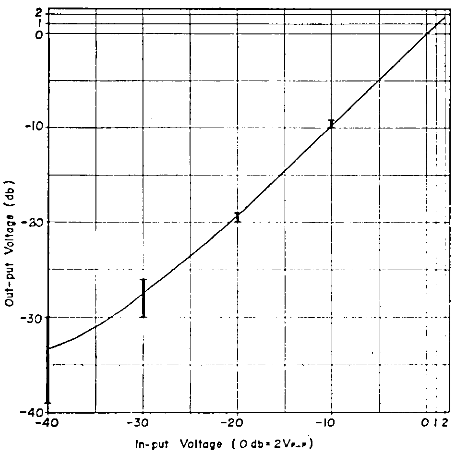

Fig. 5. Input-output characteristics of record-reproduction.

back by R-400, is shown in Fig. 4. The input-output characteristics are also shown in Fig. 5. The signal-to-noise ratio is a little above 30 db.

Amplifier and stabilizer

In order to reduce the power consumption and temperature effect to the gain of the amplifier, the transistors in the former amplifier were changed to silicon transistors, which are now common in the market. The frequency response of the amplifier is shown in Fig. 6, and the temperature effect to the gain is shown in Fig. 7.

Since the voltage of the battery varies from 13.5 V to 10 V during long observation time, it is necessary to use a stabilizer for the power

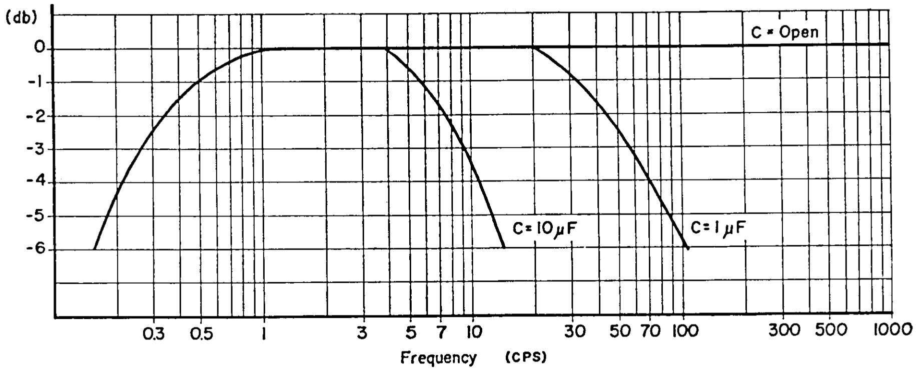

Fig. 6. Frequency response of amplifier.

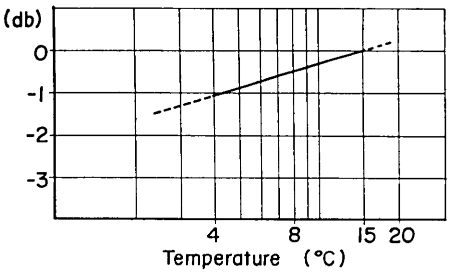

Fig. 7. Gain change of amplifier with temperature.

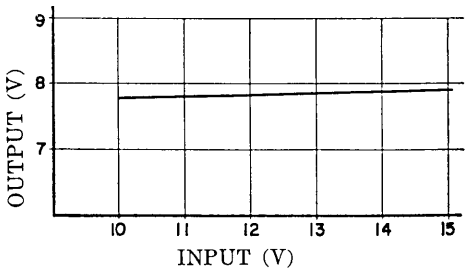

Fig. 8. Characteristics of stabilizer.

of the amplifier in order to keep the gain of the amplifier as constant. The characteristics of the stabilizer used in this amplifier are shown in Fig. 8. The total power consumption for both amplifiers and stabilizer is about 12 V × 40 mA.

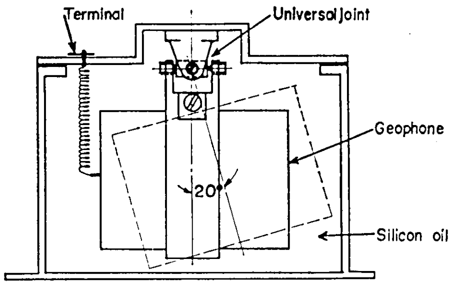

Fig. 9. A leveling device for geophone.

The maximum gain of the amplifier is 80 db. Specially selected 2 SC 369 is used for the first stage so as to reduce input noise level. The noise level equivalent to the input signal is about $2\,\mu V_{pp}$ in the frequency range 1∼20 cps. The equivalent input signal level, here, is defined as the one which increases the output of the amplifier to two times the noise output of the amplifier when the signal generator is inactive.

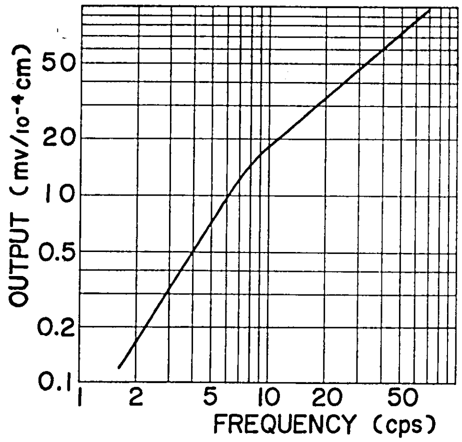

Fig. 10. Frequency response of geophone.

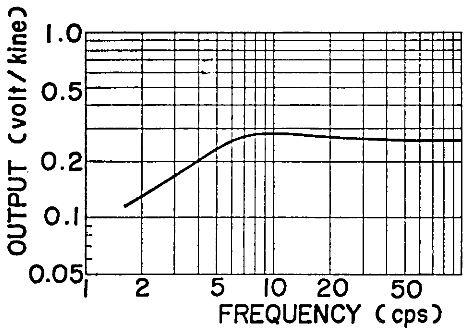

Fig. 11. Frequency response of geophone.

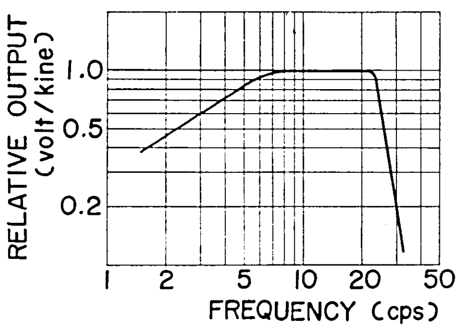

Fig. 12. Overall characteristics of record-reproduction of seismic motion.

Geophone and its leveling device

The geophones which are used in this ocean-bottom seismograph are (GEOSPACE, HS-1 and/or 8 D-L 4 B) which are commonly used in seismic prospecting. The natural frequency is 4.5 cps both for vertical and horizontal component. These geophones do not need an accurate leveling device for their operation. However, for the sake of safety operation, a simple leveling device is added to the horizontal component. As illustrated in Fig. 9, the leveling device is the suspension of the geophone by universal joint in a heavy viscous fluid, silicon oil of 10^5 poise. The allowable range of inclination is about 20°.

The frequency characteristics of displacement and velocity of HS-1 are shown in Fig. 10 and Fig. 11. The damping is adjusted at about $h=0.7$ when it is fed to the amplifier.

Over-all frequency response

The over-all frequency response of record and reproduction of the whole system is shown in Fig. 12. The low frequency characteristics are determined by geophone, and the high frequency characteristics are determined by the tape recorder.

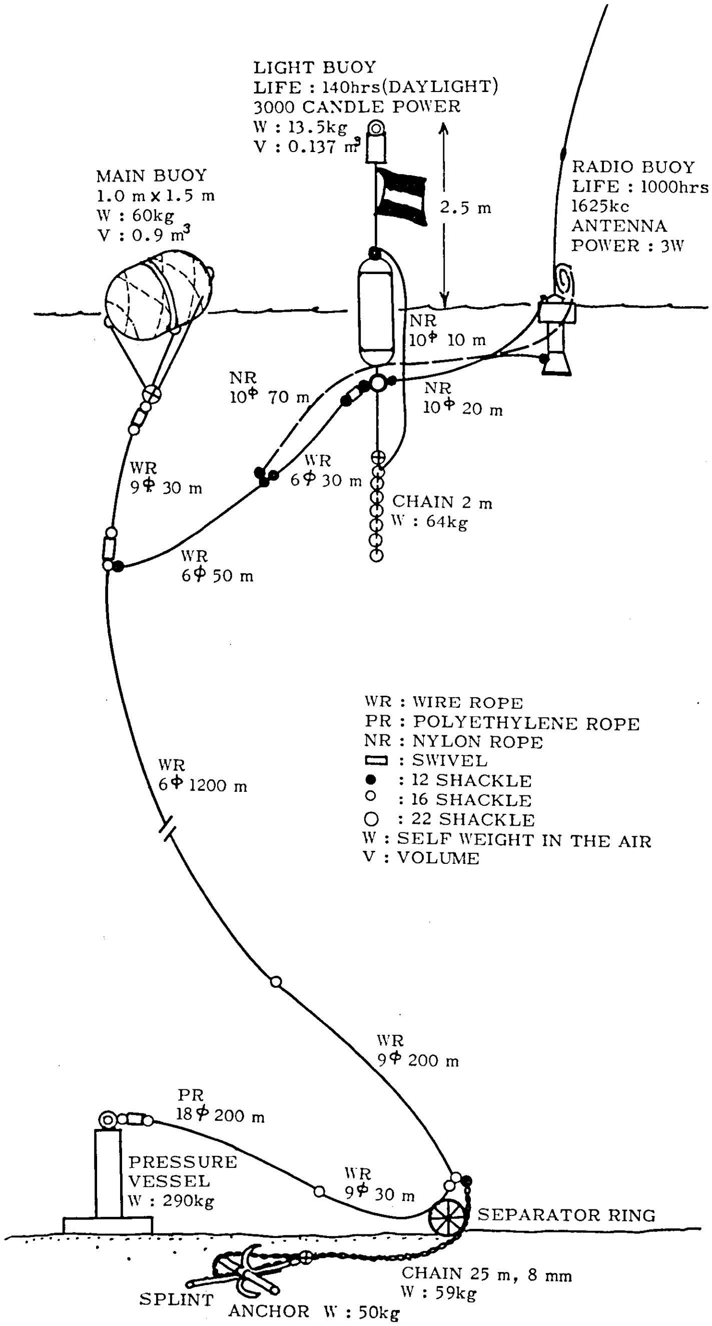

Fig. 15. A rope-buoy system for mooring ocean-bottom seismograph.

3. Mooring system

Several improvements were added to the rope-buoy system for mooring the ocean-bottom seismograph at the sea floor. For the main

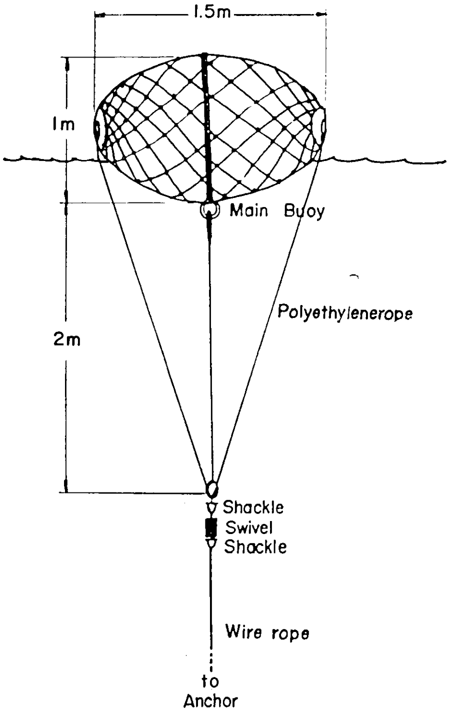

Fig. 13. Mooring buoy. Size: 1m×1.5m, weight: 80 kg, material: synthetic rubber, residual buoyancy: 820 kg.

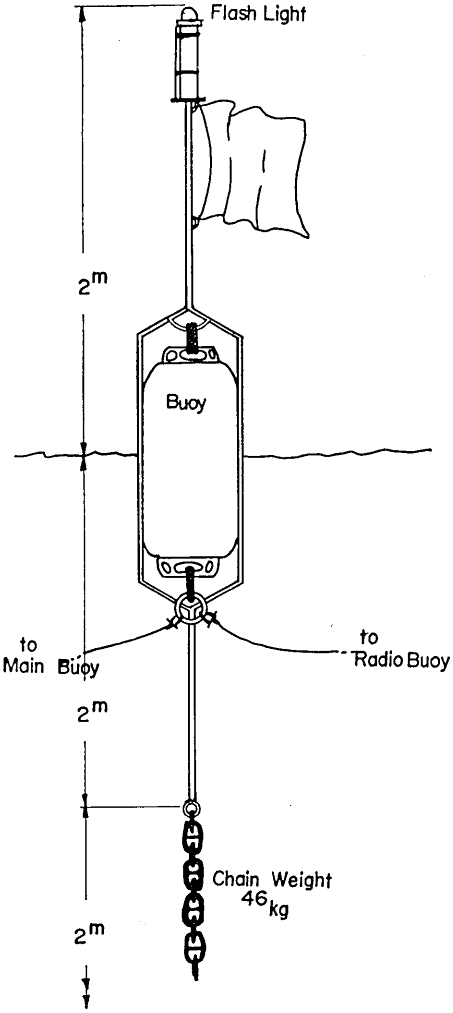

Fig. 14. Light buoy. Light brightness: 3000 candle, life: 140 hrs (excluding day-light time).

buoy, which is responsible for suspending the whole wire rope, a common fender was used. It is a rubber-made hollow oval ball, the size of which

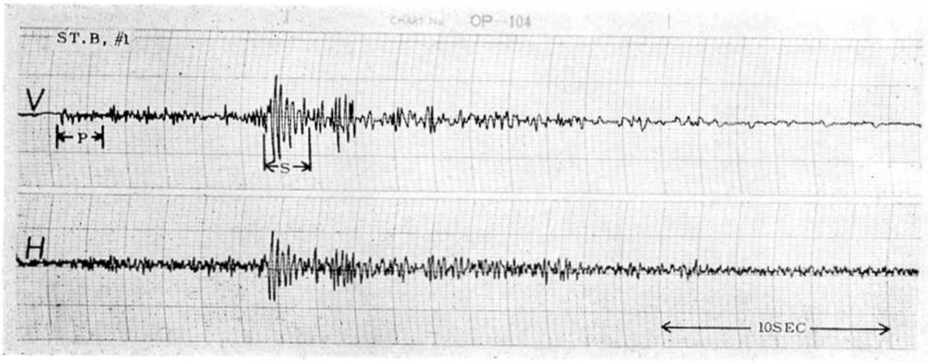

Fig. 16. Example of record.

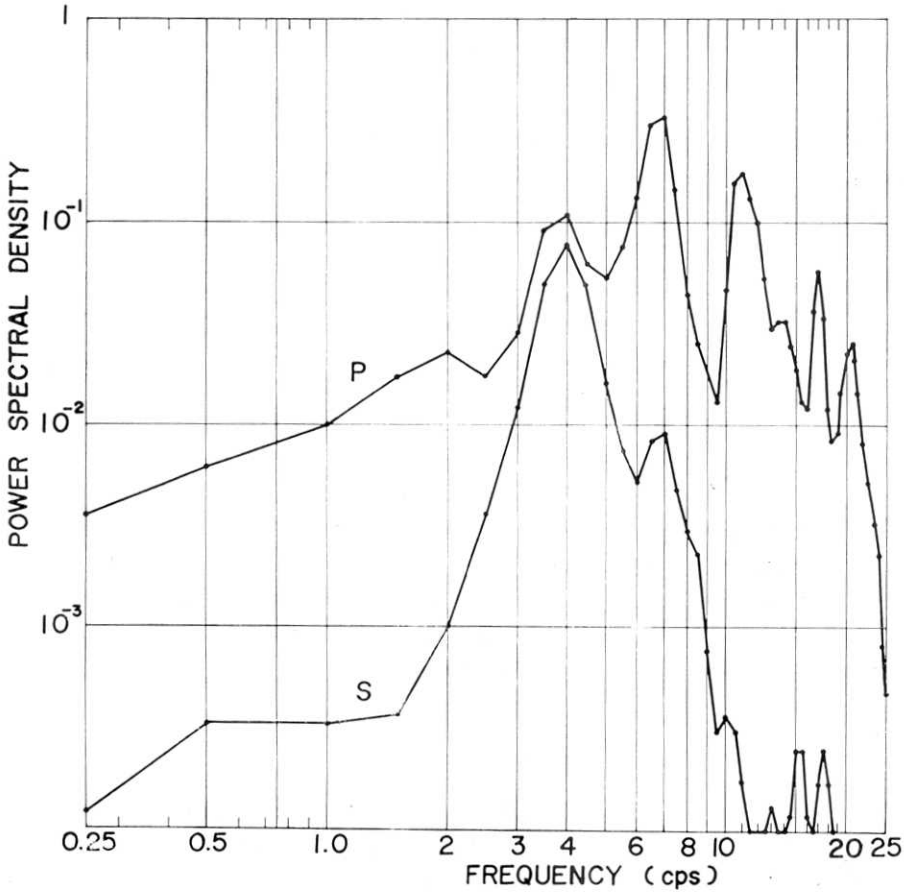

Fig. 17. Example of power spectral density of *P*-phase and *S*-phase.

is 1.0 m×1.5 m (Fig. 13). The use of this main buoy has greatly assured smooth and safety operation. The light buoy is also simplified. The sketch of it is shown in Fig. 14. The life of the radio-buoy has increased to 1000 hrs. The diameter of the main wire rope is changed to 6 mm, the former one was 9 mm. The improved rope-buoy system for mooring the ocean-bottom seismograph at about 1000 m depth is shown in Fig. 15.

4. Field test

By using the newly built tape recorder and improved rope-buoy system, field experiments have been performed at Sagami Bay in 1967 at the depth of about 1 km.

Some examples of earthquake records which were recorded by the new tape recorder at the sea-bottom and reproduced by R-400 in the laboratory are shown in Fig. 16. The record is the micro-earthquake of which $S-P$ time is about 9.2 seconds. The spectra of these earthquake motions are also illustrated in the Fig. 17. Further analyses of these earthquakes will be reported in other papers which will appear in forthcoming bulletins.

5. Summary and conclusion

Several improvements have been performed for ocean-bottom seismograph. The main improvements are, (1) construction of a long-life magnetic tape recorder for ocean-bottom seismiographic observation, (2) development of system of reproduction, (3) improvements of rope-buoy system for mooring ocean-bottom seismograph.

The magnetic tape recorder is 4-track FM recorder, of which recording time is 100 hours on 1/4 inch, 1800 ft long tape in a 7 inch reel. The frequency characteristics are flat from 0.2 to 20 cps. The $S-N$ ratio is above 30 db. This tape recorder enables us to obtain spectrum structure of earthquake motion.

Acknowledgement

The writers wish to express their sincere thanks to Professor T. Hagiwara for his encouragement throughout this study. They also wish to extend their hearty thanks to the staff of TEAC Corporation for their cooperation in making the proto-type tape recorder. They also express thanks to Captain H. Shimamune and the crew of M/S TANSEI-MARU of the Ocean Research Institute of Tokyo University and Captain M. Sato and the crew of M/S MEIYO of the Hydrographic Office, Maritime Safety Agency for their kind cooperation in the field test.

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41. 海底地震計の改良——長期間磁気テープレコーダの試作

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是沢定之

海底で観測される地震記録の初期微動継続時間の分解能を良くするために，また地震波のスペクトル構造を求めるために，海底地震計用の長期間磁気テープレコーダ方式の開発を行なつた．同時に先に報告した海底地震計および繋留装置 (*Bull. Earthq. Res. Inst.*, 43 (1965), 671-683) に幾つかの改良を加えた．この論文はこれらの計器の試作を記述したものである．観測実験の結果は次の論文に述べてある．

主な改良点は，(1) 磁気テープレコーダの設計試作，(2) 再生·解析方式の開発，(3) 増幅器のシリコントランジスタ化，(4) 水平動受振器の簡易水準装置の付加，(5) メインブイの改良，(6) ライトブイの改良等である．

磁気テープレコーダは 4 トラック，FM 方式，録音時間は 1/4 インチ幅 1800 フィートの長さのテープ (7 号リール) で約 100 時間である．録音再生の周波数特性は 0.2～20 cps で，$S-N$ 比は 30 db 以上である．
