# 27. *Triggered Magnetic Tape Recorder for Routine Seismic Observations.*

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## 1. Introduction

Until recently, mechanical recording system using a smoked paper has been prevailingly adopted in most Japanese seismological stations, owing to its simple treatment and its cheap expense for routine operations.

As it became more necessary to have sensitive seismographs and to put more accurate timemarkings on the record, optical recording systems had to be introduced also in our routine observations. Needless to say, high sensitivity is easily obtained by using the mechano-optical seismographs, and much more higher sensitivity is attained by electro-magnetic and electronic seismogaphs with oscillograph recorders. By means of these systems, it is expected that much more informations on the nature of earthquake motions can be obtained than by the former methods of recordings.

However, large amount of photographic films or bromide papers must be consumed when these methods are introduced in the routine observations. Of course, some techniques can be introduced to minimize these defects by focussing the light spot on the film as sharply as possible and recording it on the standard film of 35 mm width. T. Hagiwara and his collaborators have already succeeded in developing this standard film recording device in their routine observations.

On the other hand, also for the purpose of economizing the expense of bromide papers, it is suggested to introduce the trigger device in the recording system. But by the ordinary way of recordings with a starter attached to the seismometer, it is inevitable to miss the very beginning part of the earthquake motions, even if the sensitivity of the starter may be extremely sensitized. These disadvantages will be put aside if we introduce a memory device in the recording of earthquake motions. Since 1949 we have adopted the idea of taking up the commercial magnetic tape recorder for the triggered seismograph.

This method has more excellent characteristics than the mechanical and mechano-optical recording method. Mechanical seismographs heretofore in use were limited either in their frequency ranges capable of being registered or in their amplitude ratio of the smallest to the largest. The electro-magnetic type seismographs were somewhat improved in these characteristics, but anyhow these seismographs heretofore in use can supply only a record which was almost irrepeatable. As compared with these circumstances the case becomes quite different if we use the magnetic tape recorder as a new means for the registration of earthquake waves. Magnetic recordings can cover these defects by storing the seismic energy in broad-band frequency ranges, and by playing back the recorded tape we can have a nearly perfect facsimile of the seismic signals repeatedly.

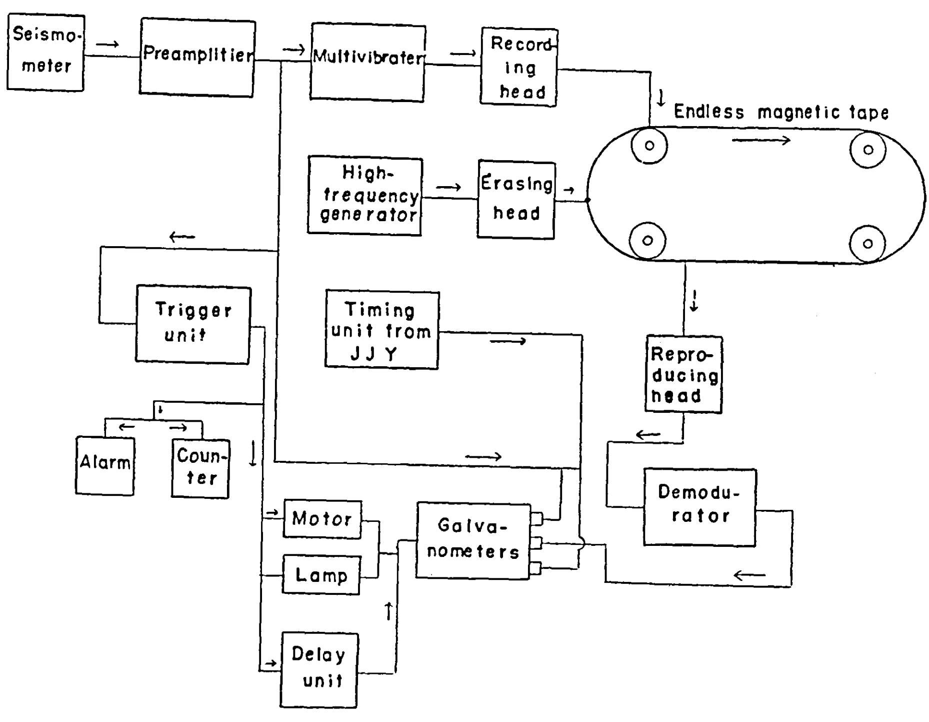


Fig. 1. Block diagrams of the equipment.

The play-back from the tape is electrical in form and can be led into the differential, integral, bandpath filter circuits or combinations of these circuits, and makes it possible for the analyst to repeat more detailed analysis.

In Johannesburg, South Africa, Gane and others[1] have devised and constructed a new equipment with a long endless magnetic wire as a delay unit. With this equipment they succeeded as early as in 1948 in getting a good recording of the earth tremors in the vicinity of Witwatersrand. In our country, Tomoda and Aki[2] have constructed a seismometer which can record earthquake motions on a magnetic tape by means of the area type recording device. We have constructed a seismometer that records on the magnetic tape by means of the density type recording device. It was possible for us to construct the equipment in portable size, because it used magnetic type, not wire. The equipment has been in use for more than one year smoothly, and it seems very adequate for the routine observations of earthquake motions. So somewhat detailed descriptions of the equipment shall be given here.

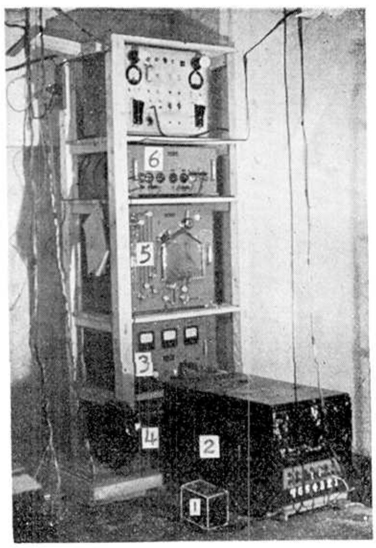

Fig. 2. General appearance of the equipment. 1, seismometer. 2, recording oscillograph. 3, power supply. 4, stabilizer. 5, endless magnetic tape. 6, preamplifier modulator and demodulator. 7, alarm and counter units.

## 2. Details of the equipment and its working characteristics

a. Introduction. The general idea of the equipment is illustrated schematically by the block diagram in Fig. 1 and its appearance is shown in Fig. 2. Input signals from a seismometer, being amplified by the preamplifier, modulate the frequency of the carrier waves of 800 c/s. Then the frequency modulated carriers are led to the recorder head. These signals are here recorded on the endless magnetic tape which runs with the velocity of 3.75 ips (9.53 cm/s). The tape that passes through the recording head reaches some times later to the reproducing head where the seismic

1) P. G. Gane, H. J. Logie and J. H. Stephen, *Bull. Seis. Soc. Amer.*, **39** (1949), 117.
2) Y. Tomoda, K. Aki, *Zisin* (*Jour. Seism. Soc. Japan*), [ii] **5** (1952), 132.

signals are picked up and led to the demodulation circuit. The circuit diagrams of these electronics parts are shown in Figs. 3–a, b, c. The demodulated current is conducted to a low resistance galvanometer, and rotates the mirror attached to the string of the galvanometer. Thus the record of seismic signals is reproduced on a photographic paper. The endless magnetic tape that passed through the reproducing

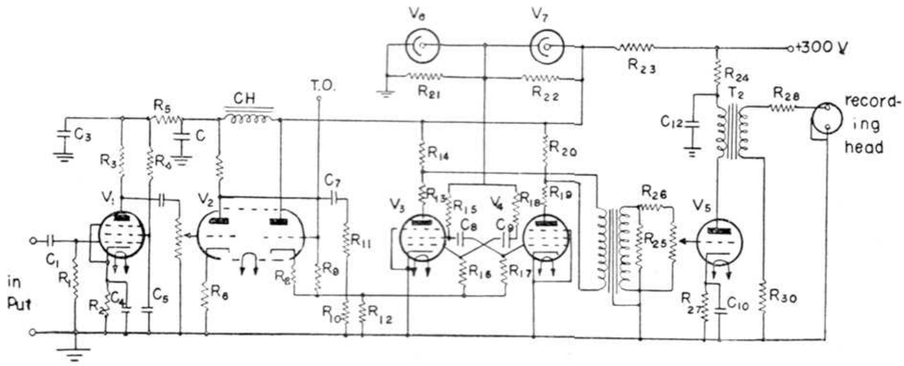


Fig. 3–a. Circuit diagrams of preamplifier and modulator.

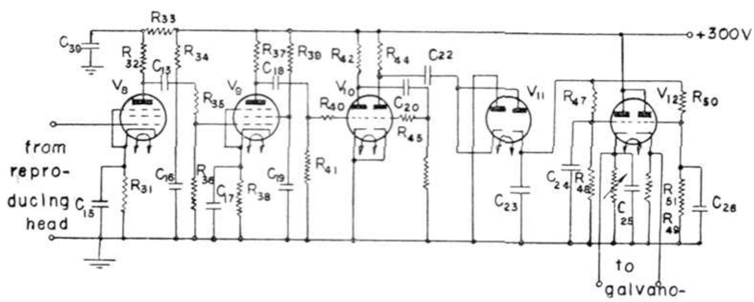


Fig. 3–b. Demodulation circuit diagram.

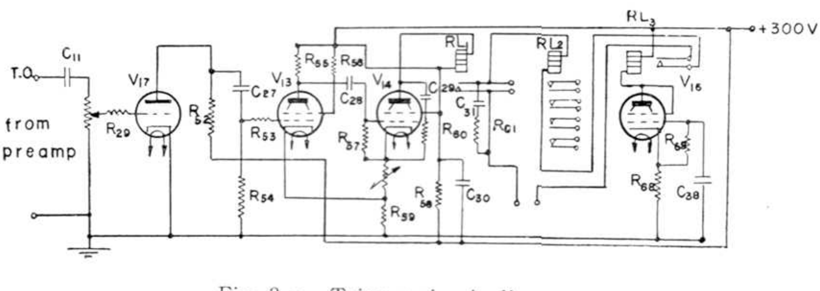


Fig. 3–c. Trigger circuit diagram.

head goes round and just before coming back again to the recording head, the tape passes through an erasing head where it is cleaned out and a new tape is supplied always to the recording head.

The galvanometer and recording camera assemblage is not in operation continuously. The trigger circuit which is connected to the preamplifier, is operated by the seismic signals and starts on one hand the driving of the recording camera, and on the other hand operates a delay circuit, which after a lapse of about three minutes, plays automatically the role of a stopper for the recording assemblage.

Thus the routine observations of earthquakes are carried on.

b. Preamplifier. As seen in Fig. 3–a, this part of the equipment is an ordinary low frequency amplifier, the characteristic curves of which are illustrated in Fig. 4. When a known voltage of a constant frequency is applied to the input of the preamplifier, the output current from it will deflect the recording galvanometer, provided the latter is directly connected to the former. In Fig. 4, which shows the relation between the input voltage and the amplitude of the deflection of the galvanometer, we see also that the difference of frequencies exerts little effect on the output amplitude within the range from 5 to 50 cycles.

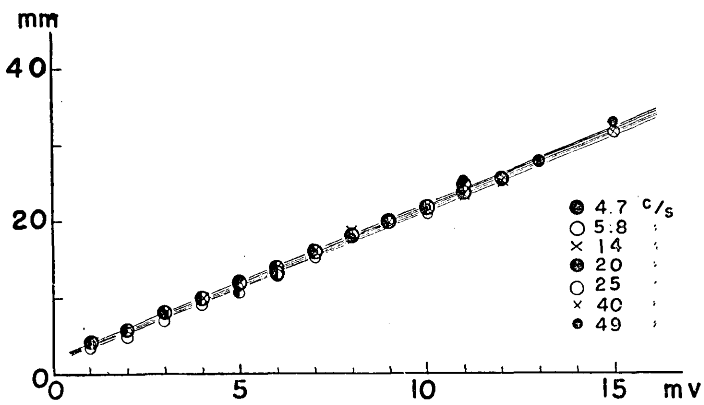


Fig. 4. Characteristics of preamplifier.

c. Modulation Circuit. As the frequencies of the seismic waves are extremely low, it cannot be clearly recorded directly on the magnetic tape, so we must introduce a system to modulate high frequency carrier waves by the input signals. As the frequencies of ground movement to be handled range from one to fifty cycles, the center frequency of the carrier wave was taken at 800 cycles. As seen in the circuit diagram in Fig. 3, 800 c/s carrier wave is generated by the $V_3$ and $V_4$ multivibrators and in turn the frequency of this carrier wave is modulated by the output voltage from the preamplifier that is led to $R_{12}$. The characteristic curve of this modulation circuit is seen in Fig. 5. We see from Fig. 5, that the input voltages less than 30 mV are modulated without distortion, and that the deviation of frequency that is deduced from the input voltage of 3 V to $V_2$ amounts to 200 cycles.

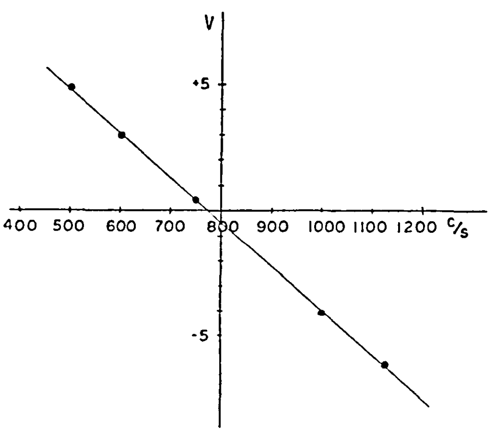

Fig. 5. Characteristics of modulator.

d. Recording Head and Reproducing Head. The carrier waves from the multivibrator are modulated in frequency by the signals to be recorded, and are recorded on the magnetic tape through recording head, then they are picked up by the reproducing head. With respect to these frequency modulation systems it becomes a factor of great importance to keep the speed of the tape constant and to make the speed of the tape that passes through the recording head strictly equal to the speed that passes through the reproducing head, because the constancy of the tape speed affects directly the accuracy of the form of reproduced seismic record.

e. Delay Unit. One of the greatest advantage of the magnetic tape recorder system is that high speed recording is easily obtained by the use of the memory capacity of magnetic tape. For the purpose of making accurate recordings of earthquake motions, two points have to be put into consideration. One point is that it is not known beforehand when an earthquake occurs. Thus, in the recording of earthquake motions everything has to be always in full preparation for recording. The second point is that the record of the earthquake motions has to be taken in a form fit for higher analyses. From this reason the paper speed of the seismic record becomes a matter of great importance.

In order to settle the first point, we adopted an endless tape system, in which the tape is running all day long and everything stands ready for the recording, and to settle the second point, the magnetic delay system was introduced. One of the final products of our system is a seismic record, photographed on a bromide paper that was driven at the highest possible paper speed. After the trigger operation of the trip circuit it takes only a few seconds for the whole apparatus to become ready for the recording, including the stationary running of a photographic paper. The next problem is to adjust the start of the trigger circuit. The very beginning part of the P waves is, in some cases, very small in their amplitude, so that if we adjust the trigger level so high as to start with the week beginning waves of P, a false start may frequently be caused by the ordinary background noises. To make them free from these false starts the trigger levels have to be made somewhat lower, but then it happens that the trigger circuit misses the week P and starts at the beginning of the large S phase.

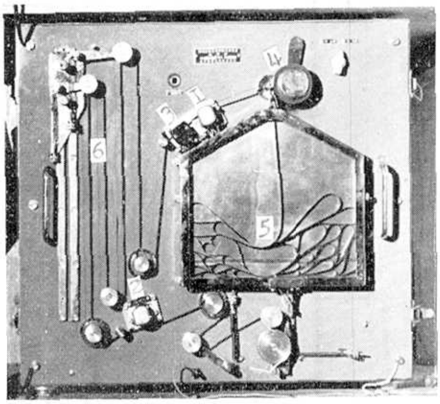

Fig. 6. Appearance of unit, driving the endless magnetic tape. 1, recording head. 2, reproducing head. 3, erasing head. 4, capstan. 5, tape storage. 6, endless magnetic tape.

In such cases the delay time is necessarily longer than the P–S duration time of the earthquake. As, at the first step of our experimental observations, we aimed at relatively near earthquakes, it was considered that one minutes and a half would be sufficient for such delay time. As is mentioned above, the tape speed is 3.75 in/sec (9.53 cm/sec) in order to give the delay time of 90 sec., it is necessary to have the store of the magnetic tape as long as eight meters.

To devise a mechanism capable of storing such a long tape was a difficult point. We succeeded in overcoming this difficulty by constructing a device as seen in Fig. 6. This is a box twenty centimeters square with a thickness of about one centimeter, that is to say, just a little wider than the width of the magnetic tape. As shown in the figure, this box, having its surface made of plane glass and facing vertically, has two slits, one at the upper side and the other at the lower side and through them the tape goes in and out. The magnetic tape that has passed through the recording head is driven into the box from the upper slit and goes down by its body weight piling up in the box as may be seen in the photograph in Fig. 6. The thickness of the box is so constructed as to be only a little wider than the width of the magnetic tape, so the tape piles up in good order and never becomes entangled in the box, going out in turn from the down (lower) slit very smoothly. In the box, the tape piles on succesively showing a natural curve as seen in the photograph, and through the lower slit the tape goes out from the box.

By means of this mechanism it is easy to store up a tape of more than ten meters.

f. Demodulation system. The output voltage picked up from the reproducing head is amplified by the square wave amplifier. Then passing through the differential circuit the numbers of waves are counted and thus the output current from the recording head is demodulated and as the time constant of the grid of $V_{12}$ is 0.5 sec. these demodulated current produces the deflection of galvanometer that is proportional to the output current from the seismometer. As is illustrated in Fig. 7, 200 cycles of deviation of modulated frequencies generates an output of 1.5 mA.

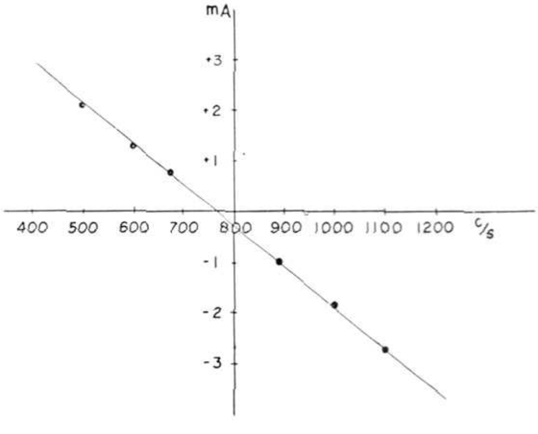

Fig. 7. Characteristics of demodulation circuit.

g. Overall Characteristics. Overall performance characteristics of the frequency modulated carrier recorder are illustrated in Fig. 8. As seen in Fig. 8, the output currents keep up a constant value irrespective of the difference of frequencies in the low frequency range, while they decrease in the somewhat higher frequencies.

h. Erasing circuit. After passing through the reproducing head the tape is erased at the erasing head that is placed just before the recording head. In this endless system of ours, the tape may be erased and re-recorded on each cycle and thus it can continue recording even if the duration of an earthquake motion happens to be longer than the whole cycle of the tape. Erasure is done magnetically.

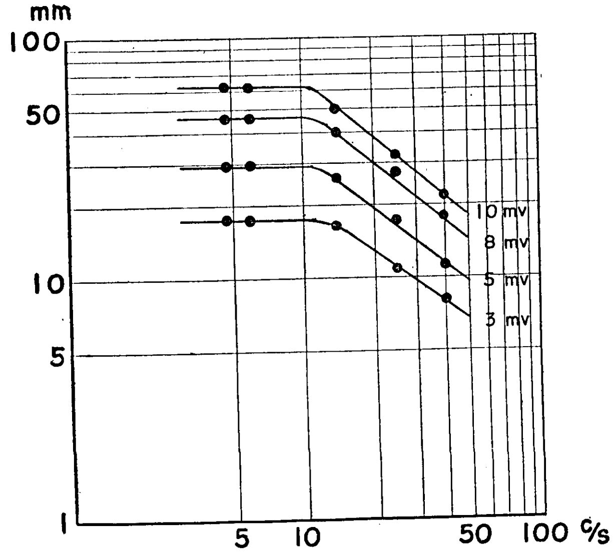


Fig. 8. Over-all frequency characteristics.

i. Trigger Circuit. A part of the output current of the low frequency amplifier is led to the trigger circuit. In Fig. 3–c, $V_{14}$ is normally conducting a current, while by the input signals from a seismometer, the plate current of the tube $V_{13}$ will be increased and this in turn causes $V_{14}$ to be cut off and at the same time this makes work the relay $RL_2$, which works on the recording circuit. The relay $RL_1$ will be reset in about 10 seconds. The sensitivity of the trigger circuit that makes the trip on will be adjusted by $VR_3$ as shown in Fig. 9. In the frequency range from 3 to 30 c/s, differences in frequency hardly affect the voltage that makes the trip on. The minimum input voltage for the trigger circuit is 0.5 mV.

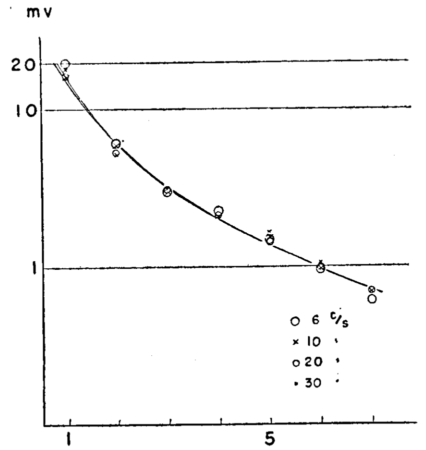


Fig. 9. Trigger current
Abscissa represents the scale number of the input dial plate of the trigger unit.

j. Timing. In the routine observation timing is an important factor. Our equipment is not yet constructed so as the time signals and seismic signals can be recorded on the tape simultaneously. One of the galvanometers of the oscillograph records the JJY time signals. This timing device will be improved in the near future.

k. Recording Devices. So long as we use the endless magnetic tape system, the informations of seismic signals will have to be preserved in some recorded forms. One device is to preserve them by means of the magnetic tape and another is to record them on the photographic paper. For the purpose of the former, we prepared one more magnetic tape recorder which is triggered by the seismic pulse and records the modulated seismic informations from the amplifier in Fig. 3-b. The duration of the operation time of this 2nd magnetic tape recorder is about three minutes and after that it stops operation automatically, and is reset for the next recordings. For the purpose of recording on the photographic paper we prepared three-element galvanometers. The sensitivity of the galvanometers is about $6.7 \times 10^{-6}$A/mm, the free oscillation period being 100 c.p.s. Of the three galvanometers one records the delayed seismic informations mentioned above, and the second galvanometer is connected directly with the output of preamplifier as shown in the block diagram in Fig. 1, and records the seismic waves that do not pass through the magnetic tape for comparison's sake, but of course the record of this second galvanometer lacks the beginning part of the earthquake motion. But the missing part is usually only a few seconds and we can compare the record that passed through the magnetic tape with the record that did not pass through it. As we have seen in Fig. 10 (Plate) the two is quite similar to each other and shows us that the magnetic tape does not distort the seismograms.

l. Alarm and Counter Device. It is also important to prepare such accessories as an alarm device and a counter device. There is of course a limitation to the volume of bromide paper the oscillograph camera can store, so that it would be effective to device a circuit indicating the number of times the trigger circuit had operated. Next, in case something is wrong with the equipment, the alarm circuit is deviced to operate at once, and all the runnings of the equipment is stopped automatically. With these devices we are able to continue the routine observation by this equipment.

m. Power Supply. Our equipment was designed and constructed to carry out the routine observation of earthquakes. Thus, excepting the galvanometers and their recording parts, all other parts, for examples, the driving part of endless magnetic tape, the low frequency amplifiers, the modulation and demodulation circuits etc., are in operation all day long unceasingly. It becomes a very important requirment to have a power supply without batteries. Needless to say it is very useful to have a battery as the heat source of the first-stage tube of the amplifier and some dry batteries as high-voltage sources, but the maintenance of these batteries is a troublesome matter. We constructed a power supply, fed wholly from the commercial AC current (50 cps, 100 volts). In the case when we use the AC 100 volts as a heater source of the tubes, however we may rectify them, some ripples remain and become the source of hums, and the fluctuations of the voltages of the source power generate some disturbances. We used balast tubes and other means to get rid of these undesirable effects as much as possible.

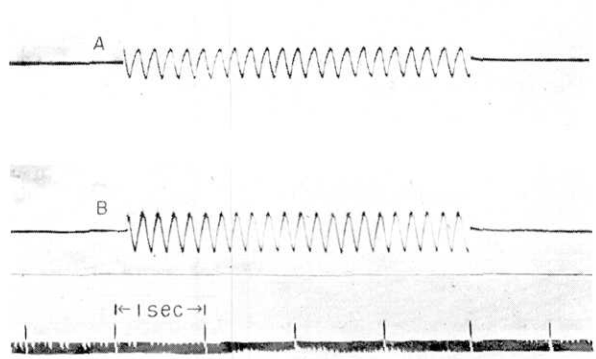

Fig. 11. Record showing the fidelity of the tape recorder system. An alternating voltage is applied to the seismometer terminal. (A) is a direct record through the preamplifier. (B) is a record passing through the entire channel, including the magnetic delay unit.

n. Recordings obtained. So long as we adopt the F–M system some distortions between the input and output wave forms is inevitable when the uniformity of tape seed is disturbed. To check this, the record of the constant input from an oscillator is shown in Fig. 11. In this figure, A is a record from the preamplifier and B is a record which passed through the magnetic tape. As may be seen in the figure two are very much alike. An example of the seismic record is shown in Fig. 10.

### 3. Concluding Remarks

We have described in this report a system that connects a seismometer and a magnetic tape recorder with electric cables. In the comming report the wireless linked systems will be reported.

The equipment here described is easy to maintain and the operating expenses are negligibly small, except for the bromide paper. Magnetic tape is replaced once a week but the expense is very light, the consumption of vacum tubes is negligible, the magnetic heads are not yet worn at all.

Through this mangetic tape recorder seismograph we obtain two sorts of records of earthquake motions. One is the magnetic tape in which the seismic signals are converted into the variation of the magnetic density of a layer of iron oxide on a recording tape, and the other is the bromide paper on which the seismic wave is photographed as an *oscillation curve*.

Setting aside the magnetic tape on which are recorded the seismic informations, it is still to the merit of this magnetic tape recorder seismograph that the photographic recording of the seismic waves is practicable at such low expenses, and while the paper speed is more than ten times faster than that of the ordinary photographic seismographs, the consumption of bromide paper is only about one tenth or even one hundredth.

## 4. Acknowledgement

The authors wish to express their gratitude to Professor M. Hirata, Department of Physics, University of Tokyo for his kind advices and encouragements offered in the course of this study. Our best thanks are due to the Tokyo Tsushin Kogyo Co. Ltd. for the hearty cooperation given in the construction of this equipment. We also appreciate the valuable advices from Mrs. T. Asada and N. Den given to us in the course of this study. To Dr. N. Nasu and Dr. H. Tsuya, the director and the ex-director of our Institute our hearty thanks are also due for their encouragements. A part of the expense of the present study was defrayed from the budget of the Observation Branch of our Institute, and we express our indebtedness to Professor Takahiro Hagiwara, the Head of this Branch. The other part of the expense of the present study was defrayed from the Fund of the Experimental Scientific Research from the Ministry of Education.

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## 27. 地震観測用磁気テープ利用ひきがね式遅延記録装置

地震研究所 表 俊 一 郎
宮 村 摂 三
山 崎 良 雄

南アフリカの GANE らが Witwatersrand の rock-burst を研究するために長い磁氣録音鉄線の無終端ループをはりめぐらして，ひきがね式の遅延記録装置をつくり，無線方式による遠隔記録をもちいて，画期的な局地的地震観測網の運転に成功したのは数年前のことである．われわれも時をおな


Fig. 10. An example of the typical seismogram. (A) is a direct record through the preamplifier, (B) is a record passing through the entire channel, including the magnetic delay unit, (C) is a timemarking from the JJY time signal. (1/2 the actual)

じくして，同様の方式により観測装置の研究をはじめたが，ここには無線及び有線搬送による遠隔記録の部分は，別に報告することとし，約1年あまりまえから常時的観測業務にたえる装置として働くようになつたひきがね式遅延記録装置の部分についてその大要をのべることとした.本装置がGANEらのものとことなる要点は，磁気録音鉄線の長いループをはりめぐらす代りに，市販の磁気録音テープを無終端のループとして小さくまとめ，箱の中にためてうまく流し，遅延の目的を達するようにして全体を可搬型にしたことにある．遅延時間の調整もある程度自由に出来て便利になつている．また地震計としてはGANEらが容量変化型の換振器をもちいているのに対し，可動線輪動電型換振器をもちいているので，低周波増幅部はおのづからことなつている．録音方式は，補助搬送波 800 c./s をもちいて，ほぼ同様の回路によつている．

装置の構成は第1図の模式図にまたその外観は第2図の写真にみられるとおりである.磁気テープの速度は 3.75 i.p.s.，遅延時間すなわちテープが録音ヘッドと再生ヘッドとの間を通るに要する時間は 30 秒から 90 秒まで自由に調節できるので希望の遅延時間を与えて観測を行いうる．

ひきがね式遅延記録装置の地震観測装置としての特徴は，記録紙速度のはやい，従つて時間精度のすぐれた記録を経済的にとることができることであり，又特に本機においてはたとえ $P$ 振巾が小さくて $S$ あるいはその他かなり大きい振巾の位相の地動で始めてひきがねがひかれても，その地震動の $P$ が始まる少しまえからの記録がとれるので，一定の規準以上の振巾のものだけを記録することが出来るという便がある．本所において1954年3月以降ほぼ連続運転しており，記録の1例は，第10 図の写真にかかげてある．

本装置の開発については，東京通信工業株式会社の努力におうところが多いので，特にしるして感謝の意を表したい．また東大地球物理教室浅田敏，田望両氏にも御協力を得たので感謝する．本装置試作の経費は主として (1) 筆者らに与えられた文部省試験研究費および (2) 地震研究所に対する国際的地震観測網に寄与する特別事業の施設整備費によるものであり，前者については東大理学部平田森三教授，後者に関しては本所観測部長萩原尊礼教授に対し厚くその御配慮を感謝するものである.なお，終りに本研究に対し終始支持と激励を与えられた那須所長および津屋前所長に感謝する．