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25. *A Seismographic Starter Using a Phototransistor.*

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1. Starters of recording apparata for seismic observations have frequently been used since early times for the purpose of saving the care and expense of continuous observations. Recently demands for seismograms rendering detailed analyses of earthquake motions have been made by both theoretical and practical workers. To cope with this demand, fine recording or high speed drivings of recording papers and films have been introduced in earthquake observations. But for engineering purposes, it has been realized that motions of twenty cycles or more per second must be made legible. This raised a new problem, since continuous observation on photographic paper driven with such a high velocity involves technical difficulties in addition to the high expense. If we are to use a revolving drum type record receiver, it is very difficult to obtain a light spot bright enough to leave its trace, in high frequency oscillations, on the photographic paper without fogging the background in the course of the long exposure. These circumstances compel us to use a recording apparatus equipped with a starter. The light source may then be made bright enough, and the recording paper may be driven fast enough to make the record of high frequency oscillations easily legible.

Although we cannot but lose initial portions of seismograms if we use a starter, the amplitudes of P-phases are usually small in comparison with those of S-phases, and the loss is of no vital consequence from the engineering point of view. With these facts in mind, a number of starters have been made and used practically. All of them have their respective merits, but some are of too low sensitivities as they only are set free by a strong earthquake or by an earthquake strong enough to be felt by unaided human senses, while others are made very sensitive by means of electronic amplifiers, and are safely used only by trained operators. These disadvantages make it difficult to use them in an area of low seismicity or in rural districts where trained operators are not easily accessible. Additional difficulty may also be found in areas where no commercial AC power supply is available.

But recently phototransistors with sensitivities as high as 10,000 times of the photocells have been made and used in various fields. If we use one in our starter, the use of a delicate electronic amplifier and the need of a trained operator may be dispensed with. With this in mind, we have made a starter for a seismograph using a phototransistor. In it, the transistor is illuminated continuously by the light from a lamp after being reflected by the mirror of a galvanometer, which is connected to a pickup. The sustained collector current of the transistor keeps, by the first relay, breaking the circuits to operate the record receiver. By the onset of an earthquake motion with an amplitude larger than a prescribed limit, the light on the phototransistor is deflected to nullify the collector current, and the record receiver may begin its function.

This starter may also be used where no AC power supply is available, and it has a tolerable sensitivity without using an electronic amplifier. The reason for not using the usual mechanical starter is the difficulty of obtaining a sufficient sensitivity by such means. But our new device is not without drawbacks, because the use of a phototransistor makes it necessary, as we have mentioned, to constantly illuminate the transistor. This will necessitate special consideration for minimizing the required power supply to the light source. We have endeavoured to do so, and have been able to make two storage batteries maintain the necessary power for half a month without recharging, which we will explain further later. Other points provided for in the construction of our starter are as follows:

a) It is stably responsibe to high frequency oscillations up to at least 30 cycles per second, with a prescribed threshold amplitude of the element of the ground motions.
b) It dispenses with a dummy pickup, and uses in its stead the same pickup used for the observation also for the starter.
c) It avoids the trouble encountered in emergencies such as breaking of the filament of the lamp or permanent deflections of the light of the lamp which is illuminating the phototransistor in too strong an earthquake.

2. The final model is described schematically in Fig. 1. It's function will be explained briefly as follows. First the galvanometer for the starter is connected through the relay R2 to the pickup, and the

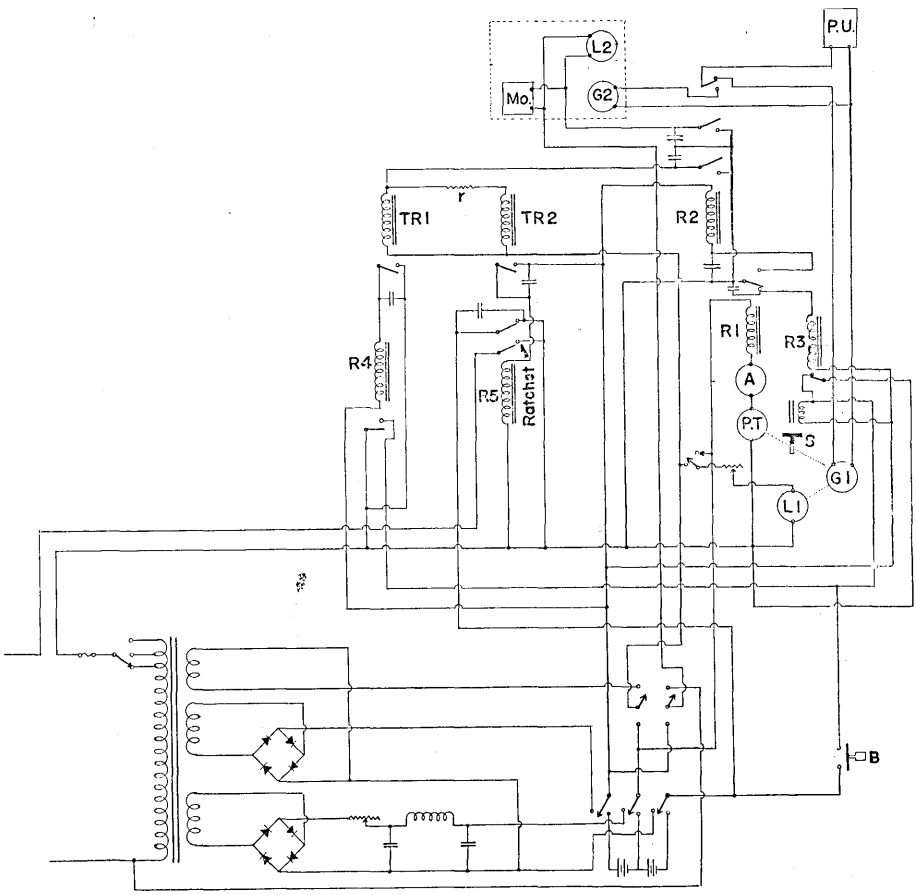

Fig. 1. Circuits of starter.

light from a lamp L1 is reflected by the mirror of the galvanometer G1, and illuminates the phototransistor P.T.. The collector current from the P.T. flows through the relay R1, by which action all functioning of the record receiver is kept in suspense. By the onset of an earthquake motion, the galvanometer mirror is rotated, and the light spot on the P.T. is deflected away from its sensitive area. The collector current will then be nullified, and the contact point of the relay R1 will go back and make the secondary circuit. The current will now flow through the coil of R2, and the magnet will pull the armature with three contacts. By the first contact the pickup P.U. (which has been connected to the galvanometer G1) is switched back to the galvanometer G2 in the oscillograph unit, and by the second contact the circuit to the oscillograph is made, and the motor to drive the record receiver is started, and at the same time, the light source L2 for the recorder is switched on, while by the remaining contact the stop mechanism begins its function and completes the action in a certain interval of time, as will be explained below.

In the precursory considerations, it seemed to us that these devices would be sufficient for a starter. But actual experiments proved them to be insufficient, because the starter as such does not respond to motions of high frequencies. It was found to be due to the inevitable time lags in the functions of these relays, especially to that of the relay R2. The relay R1 responds comparatively quickly in several milliseconds to the onset of an earthquake motion. But the power relay R2 is inevitably slow in the response and has a time lag amounting to a few tens of milliseconds. In case of the arrival of an earthquake motion of a high frequency, the armature of this power relay cannot acquire sufficient velocity to reach the magnet before the light spot returns to the sensitive area of the P.T. and the force acting on the armature of the R2 is reversed through the action of the relay R1. In this way the R2 does not respond to the quick vibrations of the ground if we do not cut the chain of process at some point. We have therefore introduced a light shutter S at a point before the transistor P.T..

This shutter is made of an iron piece, which is pulled up by the electromagnet magnetized by the current through the remaining branch of the secondary circuit of the relay R1. In this way the light passes to the P.T. until this circuit is broken by the motion of the armature of the R1 in response to the onset of an earthquake motion, as already stated. In such an event, the shutter is released and begins to fall. If the earthquake motion is of high frequency, the armature of the R1 returns to its original position quickly, and pulls up the falling iron piece of this shutter. But if the attraction of the electromagnet is adjusted to be not much stronger than the force due to gravity, the falling motion of the shutter which has started a moment ago can be made almost infallible. To test these circumstances, we experimentally connected an oscillator to the galvanometer G1 in our starter and the output voltage of the oscillator was very slowly increased until the amplitude of the light spot at the P.T. slightly exceeded the threshold value. In this way we could find that our starter functions very stably even by the oscillations of as high as 50 cycles per second. Part of provision a) mentioned above is thus fulfilled.

The rest of provision a) and provision b) is accomplished by the action of the second contact of R2, because we use in the starter a similar galvanometer to that used in the oscillograph unit, while the one pick-up used in the starter is switched over to the galvanometer G2 in the oscillograph without a changing. According, therefore, as the seismometer in use is designed to record the displacement, or the velocity or the acceleration of the ground motion, the same element of the ground motion actuates the starter when its amplitude exceeds the prescribed threshold value of the element.

Now the function of the stopping mechanism will be explained. By the third contact of R2, the electric current begins to flow through the thermal relays TR1 and TR2. This current heats the bimetal strips each of which is provided with an electric contact. These bimetal strips will thus slowly be bent, and the contact point attached to the strip in the TR1 will touch another contact point in a certain prescribed time, say one minute, while the contact on the strip of the TR2 will touch the other in 65 seconds in our model. By these contacts, circuits are made to pull the armatures of the relays R4 and R5. Then by the relay R4 the electric current flows through the electromagnet to pull up the shutter, and the light of the lamp L1 is now able to illuminate the P.T.. The relay R1 and consequently all the other parts of our starter thus return to the original state, provided the light spot remains on the sensitive area of the P.T.. In case when the filament of the L1 would have been broken or the mirror of the G1 would have been shifted by too strong an impulse and others, the relay R1 begins its function and the record receiver starts over again. But as the thermal relays have already been heated and have no time to cool, the TR2, which has a longer time lag than the TR1 and has not yet made contact, now makes contact in an appreciably short interval of time, and the R5 will then be actuated to cut the main current flowing through the secondary circuits of this relay. And by this break of the negative side of all the circuits, all the function of the record receiver will be stopped. As a ratchet is provided to cramp the armature of the R5 the stopping action is securely maintained. It cuts the chain of infinite succession of the function of this starter, which might occur if it were not for the TR2, R5 and the ratchet. Thus provision c) is fulfilled.

In the event of such an emergency when the ratchet has caught the armature of the relay R5, we first examine the cause and eliminate it by changing the bulb L1 or readjusting the light spot coming from the mirror of galvanometer G1 etc.. And second we push the button B to raise the shutter S and then release the ratchet. If we can thus assure the collector current flowing through ammeter A we release the button B. Thus the state of perfect preparation is regained.

The resistance r is inserted in the primary circuit of the TR2 in order to prolong the time lag by several seconds as compared with that of the TR1, because it is necessary to resume the initial state of perfect preparation for the recording in case when all the recording system is in good condition. This state is easily verified by the needle of the ammeter A, which indicates the collector current of the phototransistor.

The capacities in Fig. 1 are used as usual to reduce the sparks in the gaps of the contacts in the relays and to suppress undesirable vibrations of the armatures which considerably retard the final touches of the contacts of the relays concerned.

3. The main drawback of our starter, as we have mentioned, is the constant power loss due to keeping the lamp L1 lit and keeping the shutter pulling up, so we endeavoured to minimize the necessary current. We selected a suitable bulb for the lamp L1 and introduced an appropriate optical lens system for that purpose. Fortunately the phototransistor has its maximum sensitivity for the infrared rays so that the filament voltage of the lamp can be lowered appreciably. We can safely drop the voltage as low as 2.5 volts from the normal 6 volts without dropping the collector current below the working level of 2 milliamperes of the relay R1. The necessary power supply is about 0.7 ampere in our lamp at that voltage, while the electromagnet operating the shutter S requires about 0.1 ampere, so that total current constantly needed is about 6 watts at maximum.

The necessary current to operate the oscillograph is 5 amperes at 12 volts. But as the working time is only 1 minute, this loss of power is almost negligible in comparison with the above mentioned constant consumption of 6 watts. If we use two batteries of 6 volts with a capacity of 200 ampere hours each, and exchange their line up at the end of one week, we can safely use the batteries another week more without recharging. Perhaps it will be wise to change one of the batteries every week alternately with a recharged battery.

In view of general usage of these recorder sets also at places where AC power supply is available, we have shown in Fig. 1 a line up of a model to be operated by AC as well as by DC sources. It is provided with a rectifier circuit and turn over switches from the DC storage batteries.

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25. Phototransistor を使つた Starter の試作

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Phototransitor を使用した Relay 回路による Starter を試作したが充分使用に耐えることがわかつた.

設計にあたつて特に注意したのは次の点である.

a) 交流 100 V, 50～60 サイクル或は直流 12 V 何れでも使用出来る.

b) 30 c/s 以下の周波数できめられた振巾(加速度, 速度, 変位, 何れでもよい)の地震動に対してはすべて安定に作動する.

c) Dummy の換振器は使用しない.

d) Lamp が切れるというような事故に対しては最小限に被害を喰いとめる様にする.

欠点は Lamp をつけ通して置かねばならない事で常時 6 W の電力を消耗する. このため直流を使用する場合には Battery の消耗に注意しなければならない. 例えば 6 V 200 A.H. の Battery 2 ケを使用し, Lamp に電力を供給する方の Battery を一週間で他方と交換すると, 充分充電してあれば 2 週間は連続観測することが出来る.
