AN AUTOMATIC TRAFFIC SPEED RECORDER

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SYNOPSIS

This paper is a report of one of the co-operative investigations of the Joint Highway Research Project, Purdue University. The two main purposes of the report are to review some of the methods used in measuring speed, and to present a description of an economical and accurate apparatus for obtaining acceleration patterns (both positive and negative accelerations) and measuring "spot speeds"

Methods of measuring the speed of an observed vehicle depend upon fundamental time-measuring instruments which consist of detecting, timing, and recording units Several of the existing methods are discussed with brief comment about certain characteristics that restrict their general adaptability The new "Automatic Speed Recorder" (Photo-Velaxometer) is described as an instrument designed to measure and record accurately small time intervals, or a sequence of small time intervals The standardizable speed recorder operates on the principle of photographing the moving hands of a synchronously-driven precision clock

The performance characteristics and recommended standard operating procedures are discussed Certain alternative control and calibration methods are presented

The underlying principles of the Photo-Velaxometer as a means of obtaining acceleration patterns and "spot speeds" are sound. Its many thousands of recordings, without mechanical or electrical failure, indicate that the design is adequate, easy to use, and the data are obtained rapidly. The equipment is equally adaptable for recording "successive spot speeds," as well as "spot speeds" In addition, the instrument incorporates portability, standard parts in construction, ease of operation, precision measurements, and provides permanent records which are economical to obtain

NEED FOR SPEED MEASURING DEVICE

In the United States today there are thousands of miles of highways that are not adequately designed for modern traffic. The development of the automobile has been so rapid as to outmode the system of highways, laid in previous years, that have existent hazards such as narrow bridges and short sight distances. Even new roads must, for economic reasons, be constructed with some hazards such as grades, curves, and intersections. The motorist's reactions to these factors place certain responsibilities upon him. To assist him in his driving performance, by forewarning him of such hazards, highway engineers have performed laboratory experiments (1)[1] and field tests of his reactions. Such reaction can best be measured in terms of a change in driving speed.

Speed has been one of the more important causal factors of our ever-increasing highway accident record. The accurate and economical measurement of speed has long been a proper subject for investigation. Many significant advances in the technique of recording traffic movement have been made in the past few years. New devices have made possible the collection of field data that opened entirely new fields for the study of the requirements for safety, utility and mobility of traffic.

These devices, in general, measure "spot speeds" and do not give a complete acceleration pattern of the reaction of the motorist. (Note: The term acceleration as used in this paper includes positive and negative acceleration) There has been a need for speed measuring devices which

[1] Figures in parentheses refer to list of references at end

will measure not only "spot speeds" but give a complete acceleration pattern of the automobile as it passes through several successive "speed traps." In addition, such a device should incorporate portability, standard parts in construction, ease of operation, precision measurements, and provide records that are economical to obtain. The two main purposes of this report are to review some of the common methods used in measuring speed and to present a description of an instrument that incorporates these qualities

SPEED MEASURING DEVICES

Practically all methods of measuring the speed of an observed vehicle depend upon a fundamental time-measuring instrument consisting of detecting, timing, and recording units The speed of observed vehicles is measured by recording the time it takes them to traverse a known "speed-trap" distance. Distances varying from a few inches to several miles have been used as "speed-trap lengths."

Clocks, pocket watches, stop-watches, mechanical and electrical devices have been used to measure a time interval or successive time intervals. Electrical measuring devices have been used both with and without electronic tube equipment. Visual observations, including the Eno Speed Recorder (2), depend upon observing the instant at which a vehicle enters and leaves a "speed-trap" of known distance. As the length of the speed-trap is decreased, the opportunity for greater error increases, and need arises for detecting units such as mechanical tripping devices, electronic tubes, metallic road contact strips, or pneumatic tubes to actuate the mechanisms which record the time of the vehicle's entry and exit from the "speed-trap."

An air-switch actuated by a pneumatic rubber tube has been used with considerable success by the Public Roads Administration (3). The direct contact type which is made up of two strips of metal separated at intervals by an insulating material has been in use by the Illinois State Highway Department. Electronic tubes have been used by the Washington State Highway Department (4). A similar detecting device has been used by the South Carolina State Highway Department (5) A mechanical tripping device has been used successfully as a detector for a speed recorder in operation by the Ohio State Highway Department The detecting unit of a pneumatic type seems to be superior to the other types mentioned from the standpoint of operation, portability, cost, ease of installation, and durability (6).

Brief descriptions of some of the methods used to measure the speeds of motor vehicles are given as follows:

Stop-watches are often used in visual observation. Undoubtedly this is the most common method A stop-watch will measure a time interval as short as one-tenth of a second or less, but the human error involved may be sufficient to make such data of little value. This is especially true when the "speed-trap" is short and the time interval is small (7) A review of the literature will indicate many ways of using a stop-watch in connection with speed surveys. For example, a vehicle's passage over a measured course has been observed with a surveyor's transit telescope, and the time interval measured with a stop-watch. The ends of the measured course are marked with flags and the transit is set back several hundred feet from the road on a line perpendicular to the highway centerline at one of the flags; the transit-operator starts the watch as a vehicle passes a line between him and the near flag, then look through the transit telescope and stops the watch as the vehicle crosses the line of vision.

Some investigators have felt that the visual observation of a light or the audible signal of a bell or buzzer is to be preferred to the direct observation of the vehicle's passage through the "speed-trap." This has resulted in the use of four types of detectors placed across the highway: namely, wires stretched across the highway connected to a mechanical switch, direct metallic contacts, pneumatic detectors, and the photoelectric circuit. Time intervals are measured by starting or stopping the watch as the visual or audible signals of the vehicle's passage are given. The use of solenoid-operated mechanisms to start and stop the watch is an added refinement that eliminates the human element. Such a device was demonstrated at the meeting of the National Safety Congress in October, 1940.

The L-shaped mirror box or Eno Speed Detector (2) has had wide use in observations of motor vehicle speeds. The detector consists of an open-ended L-shaped box mounted upon a tripod. A mirror, set at an angle of 45 deg. in the corner of the box, enables the observer to look down the road into the open end of the box and see across the road at that point. When two box detectors are used, the observer usually stations himself approximately halfway between the two detectors A vehicle passing the detector makes a distinct flash which can readily be observed. The use of the two Eno boxes is preferable to one because the observer can control the use of the stop-watch to better advantage if the starting and stopping signals are flashes. One flash and one direct observation tend to confuse the observer.

The use of either the transit telescope or the Eno speed recorder has certain disadvantages. It is conceivable that the motorist may react to the instruments and to the observers. Another disadvantage is that the observers can get only a relatively small proportion of the traffic flow unless the volume of flow is light. The human error in using the stop-watch makes it necessary to have a long speed-trap. The Texas Highway Department used a speed-trap length of 352 ft. (2). Their prime purpose in using a base line or speed-trap of 352 ft. was to facilitate office computation If the number 240 is divided by the time in seconds to traverse the 352-ft. speed trap, the answer is direct in miles per hour.

The utilization of electrical speed-indicating meters is a logical development which makes it possible to measure short intervals of time with greater accuracy. Such a circuit was devised by Mr. Eric A. Walker of the University of Connecticut (8). This device has many laboratory uses in measuring the timing of relays or circuit breakers, or even for measuring reaction times of individuals in psychological studies.

Other electrical speed measuring devices have been developed employing a similar electronic timing unit based upon the principle of the vacuum tube voltmeter. This consists of a charged paper condenser biasing the grid of a vacuum tube. When a vehicle actuates one of the switches of the detecting unit, the charged condenser begins to discharge through a resistor. The second switch in the detecting unit, upon being actuated by the vehicle, stops the discharge. The amount of discharge is dependent upon the time consumed by the vehicle in traversing the speed-trap distance. The remaining charge on the condenser causes a definite measurable current to flow through the vacuum tube.

The reading on the vacuum tube voltmeter is proportional to the length of time, and oftentimes the scale is calibrated to indicate the speed directly in miles per hour.

Dr. Bush of the Massachusetts Institute of Technology, in connection with the Massachusetts Highway Traffic Research Project, developed a speed meter similar to the one just described (9). A more elaborate electronic speed meter was developed at the University of Illinois by Professor Reich and Mr. Hershel Toomin, and has been used successfully by the Illinois State Highway Department and the Minnesota State Highway Department (10). The early model reported in *Review of Scientific Instruments,* December, 1937, has been revised considerably.

A portable Photo-Electric Speed Recorder has been developed by Professor Homer J. Dana, Assistant Director, Engineering Experiment Station, the State College of Washington (4)[2] in collaboration with the Washington State Highway Department. It consists essentially of two units, the transmitter and the receiver. The detector units, two photo-cell circuits, are spaced 24 in. apart and the record is made on a zero-center meter Accuracy is claimed to be within one mile per hour. Another detector of similar nature was developed by the South Carolina State Highway Department (5).

The Ohio State Highway Department has used a Precision Speed Recording Clock which starts when the first road contact is closed and stops when the second road contact is closed. The error is small because the synchronous motor runs constantly and the clutch action which operates the clock hands is positive The counter, or clock hands, have very little inertia, and will stop within about 1/100 of a second.

Another type of device records the number of cycles of an alternating voltage on a photographic film. This device is similar to one developed at Purdue University (11) which incorporates a lamp housing containing a 6-volt, 50-candle-power bulb, a Dorsey phonoelescope (incorporating the optical lever principle) actuated by a standard headphone unit, and an appropriate lens system for focusing a light beam on the recording paper.

All the aforementioned devices are used to measure spot speeds, that is, the time required for a motor vehicle to travel between two points. Such devices may suffice for "spot speed" studies, but are not adequate when the research problem involves acceleration patterns of successive speed patterns.

The Public Roads Administration has recently developed an Electro-mechanical Recording Speedmeter which is capable of measuring successive speed intervals (2). The timing unit makes use of an electro-mechanical stopping switch of the type employed in automatic telephony and known as the Strowger 50-point rotary switch. This switch consists of a number of wipers mounted on a shaft which is rotated by a pawl-and-rachet mechanism actuated by an electromagnet. The wipers are thus stepped around over a number of fixed contacts arranged in an arc. Since the wipers revolve at a definite speed, the amount of their angular movement is a measure of time. Operation of the Strowger switch is controlled by a set of quick-acting relays electrically connected to the road switches and actuated by the latter. Motion of the wipers is invariably arrested when one wiper is in contact with one of the 50 contacts on its corresponding level, and through the associated equipment a separate electrical circuit is closed to one of the many recording elements in the graphical recording unit. This apparatus has been used in many states and for many purposes such as passing studies, performance of trucks on hills, lateral position on highways, etc.

Compared with stop-watch equipment and other fundamental speed measuring devices, the electronic and synchronous motor clock speed recorders are very expensive. However, it is possible to measure the speed of practically every vehicle, even when the traffic volume is large. They have another advantage in that the observer and equipment may be placed in a vehicle parked off of the highway and out of view of the motorist. This is particularly true for all the devices except the apparatus using the photo-electric cell circuit as a means of detection.

[2] See the preceding paper by Homer J. Dana.

DEVELOPMENT OF THE PHOTO-VELAXOMETER

Purpose

The Photo-Velaxometer is designed to measure accurately and to record small time intervals, or a sequence of small time intervals. It has been built primarily to measure and record a series of successive time intervals which give an acceleration pattern of an automobile as it progresses along the "speed-trap" and to determine "spot speeds."

Description

The main unit of the apparatus consists of a light-tight box in which are mounted

Figure 1. A General View of Photo-Velaxometer Showing Operator Taking Direct Readings of Spot Speeds.

an electric clock of special design, two cold-cathode gas discharge tubes which act as a light source, an electrically operated counter, and a photo-electric cell. The lens of a 35-mm. camera is arranged in the light-tight compartment so that the clock face and the counter can be photographed by means of the light produced by a flash of the gas discharge or strobotron tubes. The 35-mm. camera is mounted so that it is an integral part of the light-tight compartment. The lens of the camera is projected within the light-tight compartment. The mounting of the camera is rigid and the camera is so placed that it is in fixed focus. The shutter is permanently fixed at the F-4.5 opening. On the outside of the light-tight compartment are mounted eight fast-acting relays, a vibrator type high-voltage power supply operated from a 12-volt battery, the control apparatus for the gas discharge tubes, a gas filled tetrode which is used in conjunction with the photo-electric cell, a signal bell, and various other circuit components. All of this equipment is included within the portable case as shown in Figure 1.

On the control panel of the unit (Fig. 2) are mounted all the necessary control switches, the checking voltmeter, and all the signal lights. Provision is also made on this panel for plugging in the source of voltage which is used to supply the necessary power for operation of the unit. The power supply consists of three 6-volt storage batteries. These are used as power sources because portability is a factor in the usefulness of the unit.

The auxiliary apparatus consists of eight air-operated electric switches of special design but similar in character to those used by the Public Roads Administration (12). These switches are air-compression operated and actuated by the passage of a vehicle across a rubber tube. The switches are connected to the unit by means of two shielded five-wire rubber insulated cables. One wire in each cable serves as a common return for the four switches. Leads which consist of a common wire and a separate lead wire are tapped off at 100-ft. intervals on each lead cable. These leads are attached to the several switches. Two five-wire cables are attached to their respective receptacles when the Photo-Velaxometer is in operation.

The operation of the apparatus can best be explained by describing the procedure for making an acceleration record of one vehicle. Pneumatic tubes, with switches and switch cables attached, are placed along the highway at 100-ft. intervals. The cables are then attached to the proper receptacles on the panel board of the unit.

The several operating switches are thrown to the "on" position to energize the various control circuits. (See top view of Photo-Velaxometer, Fig. 2.) This starts the clock motor, but not the hands of the clock, as they are clutch-operated. However, provision has been made by means of a control switch to permit the hands to rotate continuously while the clock motor is operating. When a car crosses the first tube, road switch Number one is closed. This in turn causes the first relay (Relay Number 1) to operate. (See wiring diagram, Fig. 3.) This relay is energized by means of an impulse of energy received from the high voltage power supply through the road switch. After the relay is energized, it is held in a closed position by the energy supplied from the twelve-volt battery (Batteries A and B). It will be noted that the original impulse comes from the high voltage source and a momentary impulse of current, provided as the capacitor C, essentially short circuits the current limiting resistor for an instant after the road switch is closed.

When relay Number 1 closes, it causes the clock clutch to be energized. This connects the hands of the clock to the motor, thereby starting the clock in motion. The closing of the relay also provides momentary (make-before-break) contact which actuates the gas discharge tubes. These tubes discharge the energy of capacitors C_2 through themselves, producing an almost instantaneous flash of light. This instantaneous illumination enables the camera to photograph the position of the hands of the clock at the instant of the flash. Relay Number 1 also closes the circuit for the coil of relay Number 2 so that it will be ready for operation before the vehicle closes road switch Number 2. The circuit is arranged in this manner in order that a record may be made of only one car as it passes through the "speed-trap," even though this car may be preceded or followed by other vehicles. The sequence of operation is much the same for the succeeding relays until Number 8 is reached. When this relay is operated, it stops the clock hands by disengaging the clock clutch.

The hands may now be reset to zero by pressing the reset push button. This procedure as outlined permits relay Number 1 to operate the clock clutch. Some error is induced because the starting of the clock hands is about one hundredth of a second. This error is overcome if the clock is allowed to run continuously.

The record obtained on the film is a multiple exposure of eight different positions of the clock hands. Since the sweep-hand of the clock completes one revolution per second and the other hand re-

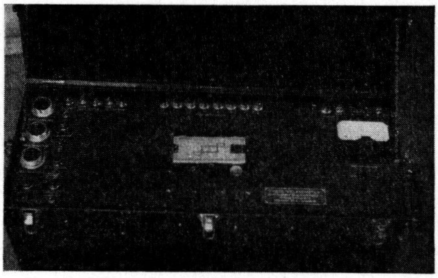

Figure 2. Top View of Photo-Velaxometer

quires 25 sec. per revolution, it is not difficult to interpret the time intervals between successive flashes. The photographic record is read by projecting an image on a small screen. Figure 4 gives a complete integrated acceleration pattern and shows the eight positions of the clock hands.

If spot speeds are recorded photographically, there are but two positions of the clock hands. The action of the photographing unit is dependent upon two road switches only. The actuating relays in this case are Number 1 and Number 2 and they perform the same functions as relays Number 1 and Number 8 if the control switch is placed in the "two-switch" position. Figure 5 shows a typical "spot

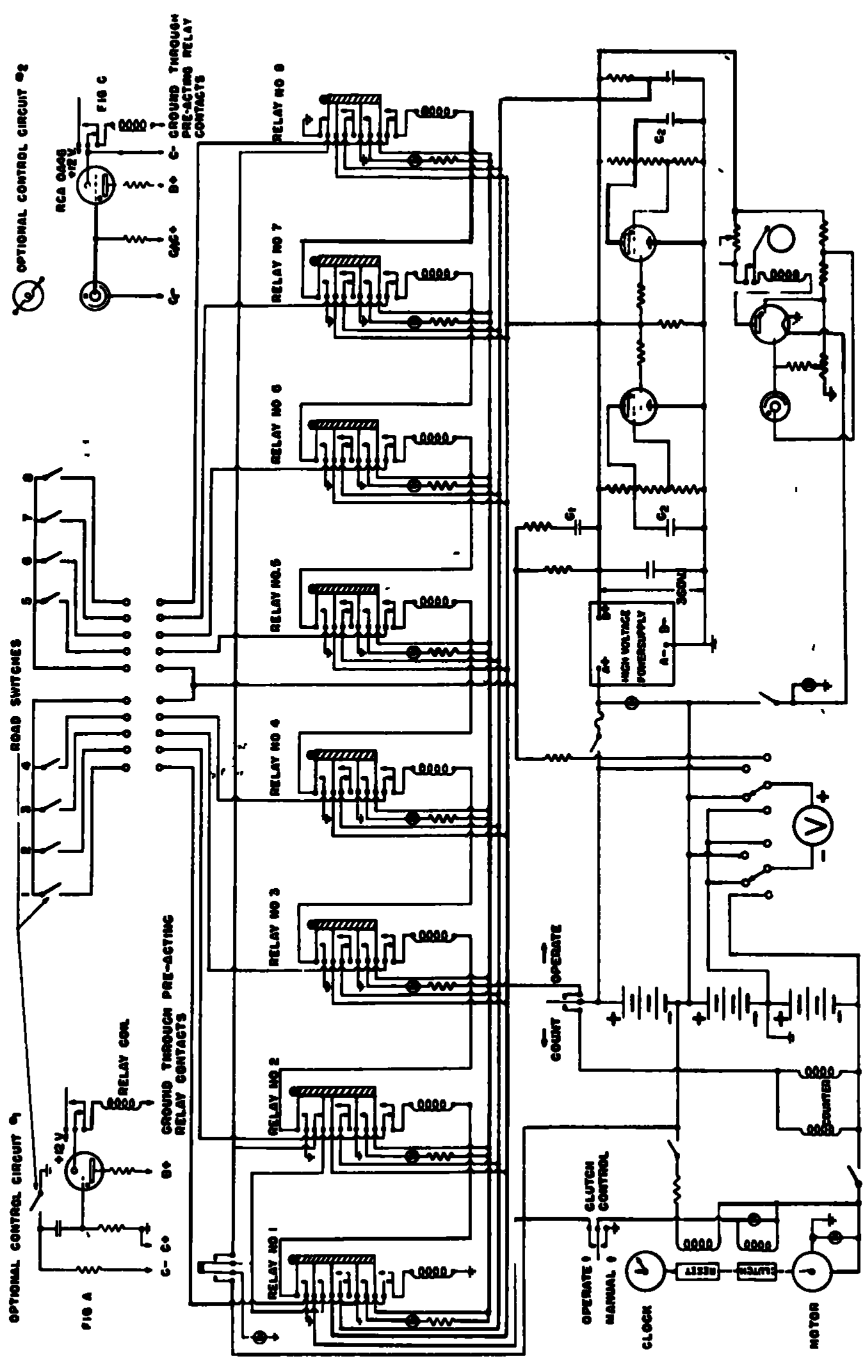

Figure 3. Photo-Velaxometer Wiring Diagram

speed" photograph. In general, it is much easier and more economical to read the spot speeds direct from the clock hands An experienced operator can read about 300 spot-speed records per hour.

The field operation of the machine for

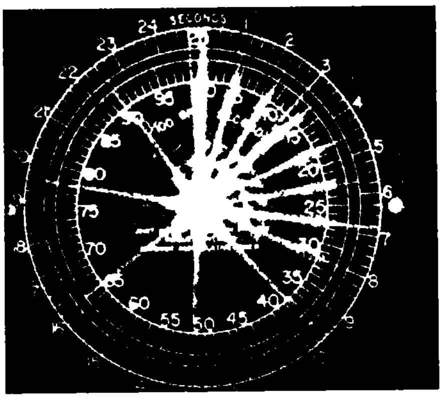

Figure 4. A Complete Integrated Acceleration Pattern Showing the Eight Positions of the Clock Hand.

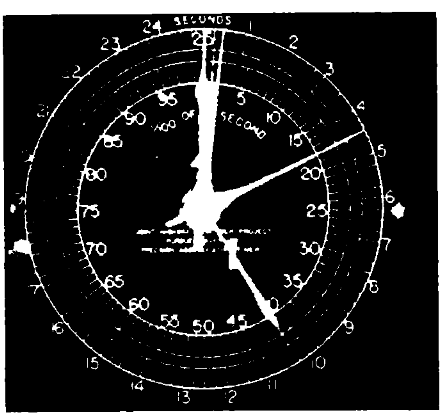

Figure 5. A Typical Spot Speed Photograph

making one complete record, after the road cables are in position, involves turning the camera one frame, pushing the reset button if the operator desires to have a zero position on the record, pushing the operate-count-switch to "count," and then back to "operate." This operation must be done for each observation.

Several checking features are provided as an aid in obtaining complete records. The operation of each relay is indicated on the control panel by a pilot light. Other pilot lights are used to indicate when certain units are functioning properly. These are shown in the circuit diagram and on the control panel (see Figs. 2 and 3). In order that the flashing of the gas discharge tubes within the light-tight compartment may be checked, a photo-electric cell used in conjunction with a gas-filled tetrode rings a bell with each flash. The two counters are synchronized: one is mounted on the control panel; the other

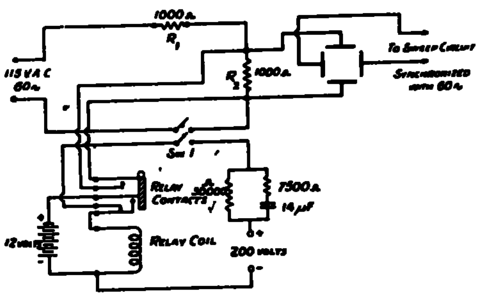

Figure 6. Circuit for Checking Time Required to Close the Relays After Impulse Has Been Placed on Road Switch.

is placed so it will be photographed. The photographed reading of the counter becomes a permanent part of the record. The operator records the exterior counter reading on his traffic log. The voltage of each battery and the high voltage power supply may be checked at any time by means of the voltmeter mounted on the control panel.

Calibration and Circuit for Determining the Closing Time of Relays

Checking the time interval required to close the relays after an impulse had been placed upon the road switch involved the circuit shown in Figure 6 (similar to cathode-ray oscillograph method used as a time indicator) (13). In the circuit, it is evident that when switch Number 1

(Sw -1) is closed the top contact of this switch closes the 115 volt A-C circuit and allows the voltage drop across R_2 to be applied to the vertical deflecting plates of a cathode-ray oscilloscope. Since a voltage from a linear sweep circuit, synchronized with the 60-cycle source, is already applied to the horizontal deflecting plates, the cathode-ray beam will begin to trace out a sinusoidal pattern of the 60-cycle voltage (Fig 7). This will continue until the top pair of relay contacts closes This short circuits the voltage applied to the vertical deflecting plates. The time interval between the application of voltage to the relay coil and the closing of the relay contacts is represented by a trace of a sine wave on the cathode-ray screen (Fig. 8). The duration of this trace may easily be measured by referring its length to that of a complete cycle, which in this case represents 1/60 of a second The projection of the curve-trace upon the horizontal axis for an average operating time of the relay gives a time interval of about 1/270 of a second This is a much shorter time interval than one division on the clock dial, which is calibrated in 1/100 of a second intervals. Therefore, the closing time of the relays has but little effect on the time interval measured.

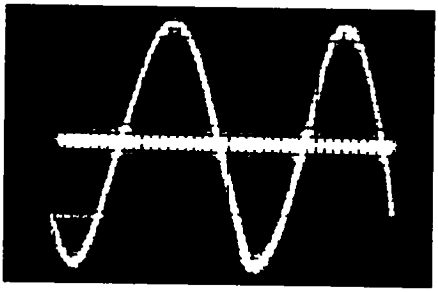

Figure 7. Sinusoidal Pattern of Complete Wave

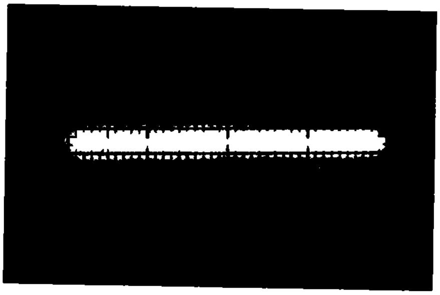

Figure 8. Typical Oscillographed Record Showing Closing Time of Relays

The 200-volt source and the resistance-capacitance network shown in Figure 6 are used as a means for quickly energizing the relay. When the lower contacts of switch Number 1 (Sw -1) are closed, the 14 microfarad condenser acts as a partial short circuit across the 30,000 ohm resistor. This permits a momentary inrush of current through the relay coil, which energizes it and operates the make-before-break contacts. These in turn connect the 12-volt source across the relay coil thus holding the relay closed. As can be seen from Figure 8, this method of operation closes the relay in a very small time interval.

Field checks were dependent upon the time required for a car to pass between two points varying from 100 to 700 ft. apart. As a check, a test car was driven at various constant speeds over the courses and clocked by means of a stop-watch and by means of the Photo-Velaxometer. There was some difference between the reading of the stop-watch and the unit when short speed traps were used, but when the long speed traps were used, there was no appreciable difference (less than one per cent). It is probable that the Photo-Velaxometer is more accurate than timing with a stop-watch, as the human element has been eliminated.

Optional Controls

There are many other suitable ways for obtaining the impulse provided by the road switch. An experimental circuit as shown in Figure C of the complete wiring diagram Figure 3 has been used successfully. Provision is made in this circuit for a photo-electric cell circuit and a light beam which can be interrupted Whenever the beam is eclipsed, the photo-cell will provide an impulse for a gas-filled tetrode which will produce enough power to close a relay. This circuit would provide an excellent means of obtaining an accurate road switch detector if the apparatus were to be set up permanently However, there are three disadvantages to this circuit; lack of easy portability, difficulty in obtaining power supply, and ease of detection by motorist.

Some optional circuits could be used for operating the Photo-Velaxometer A cold-cathode tube as shown in Figure A of the complete wiring diagram (Fig. 3) may be used to close a relay. The advantage of this method is that a closure of the detecting or initiating switch need be only in terms of micro-seconds to actuate the gas-filled tube. Also, this contact need not carry an appreciable current. This allows for maintaining a precise adjustment of the detecting switch contacts

Further refinement of the apparatus would involve placing a cold-cathode gas triode between the road switch and the relay circuit. If the clock were running continuously, then the flashing of the interior gas discharge tubes would be a function of the time required to fire the gas triode tube and would not depend upon the closing time of the relay. The time involved would be in terms of micro-seconds.

Another refinement that would make the apparatus practically automatic would be to replace the 35-mm. camera with an 8-mm. or 15-mm motion picture camera having a single frame exposure attachment. The attachment could be mechanically operated with an electrical solenoid serving as the power unit to pull one frame at a time Should the apparatus be used for spot speeds, the second flash of the gas discharge tube would provide the initial impulse to energize the circuit controlling the solenoid. The eighth flash of the gas discharge tubes could serve as the impulse for energizing the circuit controlling the solenoid in making a blank frame between records if acceleration patterns were being recorded.

Typical Uses

Figure 9 shows the compliance of motorists to a 40 M.P H speed zone sign These data were recorded as "spot speeds" in this study. Note the difference in direc-

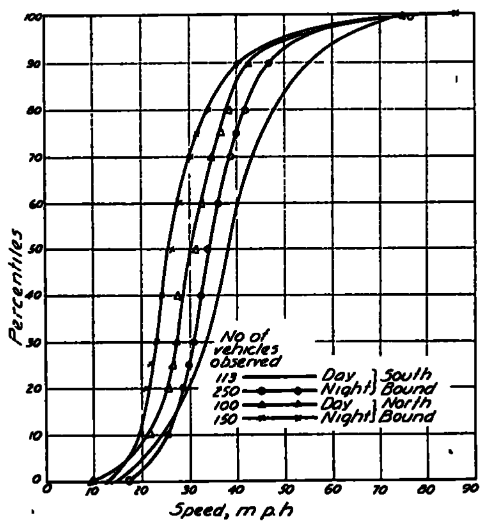

Figure 9. Spot Speed Study After 40 m.p.h. Speed Zone Signs Were Installed on Indiana State Route 100, Center Line Speed Trap 64 Ft. North of Center Line of Intersection of Raymond St. Field Data Recorded Sept. 6, 1941, Speed Trap Length 75.75 Ft., Weather Good.

tional speeds and the difference between day and night speeds In this particular study, outgoing city traffic moves at a higher rate of speed than incoming traffic. Likewise, daylight traffic moves somewhat faster than night traffic.

A second typical example of use is shown in Figure 10. An attempt is being made to determine the effect of bridge widths on both speed and transverse placement of the vehicle. The acceleration pattern shows the reaction of the motorist (during daylight and darkness) when approaching a narrow bridge that is 19 ft. between the parapet walls. The limited data show that passenger cars' acceleration patterns represent faster speeds during daylight hours than at night. The opposite is true for truck speeds. There is very little change in acceleration as the motorist approaches the narrow bridge. Furthermore, about one-third of the drivers changed their lateral position to a position near or across the centerline as they approached the narrow bridge. Thompson in his study, "Motor Vehicle, Driver Behavior Studied by New Methods" (14) makes a similar report as follows: "Although no general conclusion can be reached from the data applicable to this one bridge, it is of interest to note that its presence caused no significant change in speed but a pronounced shift of placement toward the center of the roadway."

SUMMARY

The Photo-Velaxometer which has been described is accurate and reliable. However, some changes in its construction would make it practically automatic. Some of these refinements have been discussed under Optional Controls. It is believed, however, that the underlying principles of the Photo-Velaxometer provide for an accurate and efficient means of measuring a series of successive "spot speeds" or "spot speeds." The former gives an integrated acceleration pattern recording. The apparatus is portable and stable in operation and has shown consistency in performance.

It would appear that there are several uses for this equipment in the field of traffic research. The apparatus has been used to record acceleration patterns of motorists when approaching narrow bridges, curves, stop signs, speed zone signs, and vehicle performance on hills. It has been used as an economical and

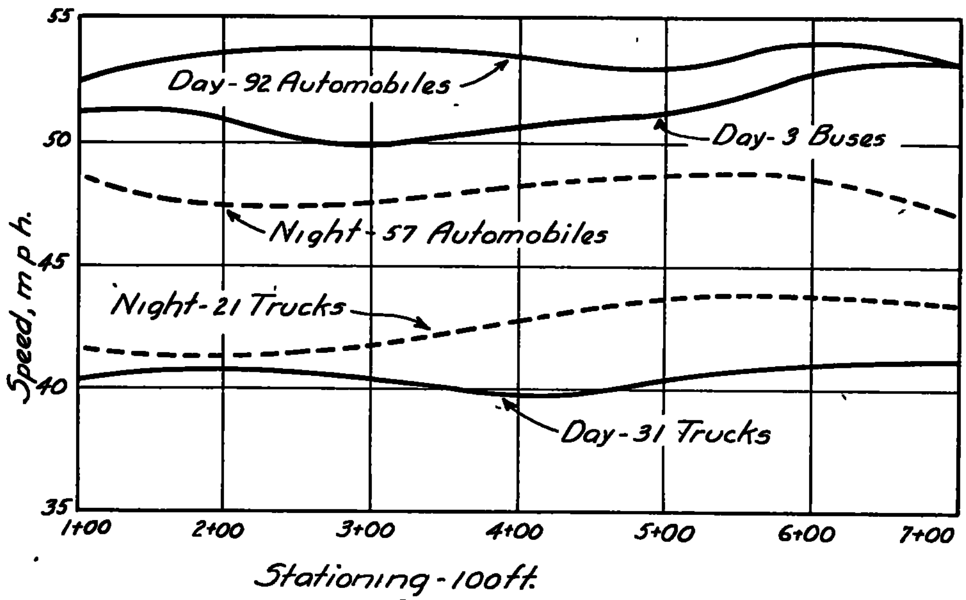

Figure 10. Acceleration Pattern Showing the Reaction of the Motorist to a Narrow Bridge. U. S. 52, Lebanon, Ind., Traffic Toward Lebanon. Sta. 7+00 Is 47.5 Ft. N.W. of Center of 65 Ft. Span, Width 19 Ft.

accurate means to measure "spot speeds." Many other driver reactions could be studied. In addition, the equipment could be used to measure the speed of falling bodies, to measure the speed at which air-craft "take-off" or "land," or to measure the speed at which air-craft are catapulted from the deck of a ship. Certain modifications of the apparatus could be used when other accurate speed checks are desired.

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