Technical Report Documentation Page

1. REPORT No.
M & R 636338

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
A High-Speed Profilograph

5. REPORT DATE
July 1969

6. PERFORMING ORGANIZATION

7. AUTHOR(S)
Nordlin, E.F., Kubel, L.G., and Chow, W.

8. PERFORMING ORGANIZATION REPORT No.
M & R 636338

9. PERFORMING ORGANIZATION NAME AND ADDRESS
State of California
Department of Public Works
Division Of Highways
Materials and Research Department

10. WORK UNIT No.

11. CONTRACT OR GRANT No.

12. SPONSORING AGENCY NAME AND ADDRESS

13. TYPE OF REPORT & PERIOD COVERED
Final Report

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT
The results of research conducted by the California Division of Highways on the development of a high-speed profilograph is reported. A description of the equipment used to measure road profile at high speeds between 50 and 65 mph is described. The goal of this project was to obtain a profile record of the road similar to the current records obtained by the hand push and motorized low-speed profilograph. A rotary potentiometer was used to measure the relative movements between an automobile's wheel and its chassis. An accelerometer was used on the automobile chassis in the proximity of the wheel frame to measure the absolute displacement of the automobile frame. The difference between these two movements was taken to be a representation of the road profile. A good correlation between current profile measurements and the high-speed measurements were made on relatively smooth road surfaces. Because of the slow response of the automobile wheel rapid differentials in the road surface were not detectable by this equipment.

It is the conclusion of this research that in order to detect pavement characteristics such as step-off it will be necessary to obtain detection equipment with a higher frequency response. Some form of contactless probe seems to be most promising for high-speed profilograph recording.

17. KEYWORDS
Pavement surfaces, profiles, profilometers, pavement smoothness, testing equipment, instrumentation

18. No. OF PAGES:
22

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1969-1970/69-23.pdf

20. FILE NAME
69-23.pdf

3791

HIGHWAY RESEARCH REPORT

A HIGH-SPEED PROFILOGRAPH

FINAL REPORT

DND

69-23

STATE OF CALIFORNIA

BUSINESS AND TRANSPORTATION AGENCY

DEPARTMENT OF PUBLIC WORKS

DIVISION OF HIGHWAYS

MATERIALS AND RESEARCH DEPARTMENT

RESEARCH REPORT

NO. M & R 636338

Prepared in Cooperation with the U.S. Department of Transportation, Bureau of Public Roads July, 1969

STATE OF CALIFORNIA—TRANSPORTATION AGENCY

RONALD REAGAN, Governor

DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS
MATERIALS AND RESEARCH DEPARTMENT
5900 FOLSOM BLVD., SACRAMENTO 95819

July 1969
Final Report
M & R No. 636338
D-1-1

Mr. J. A. Legarra
State Highway Engineer

Dear Sir:

Submitted herewith is a research report titled:

A HIGH-SPEED PROFILOGRAPH

ERIC F. NORDLIN
Principal Investigator

LESLIE G. KUBEL AND WILLIAM CHOW
Co-Investigators

Very truly yours,

JOHN L. BEATON
Materials and Research Engineer

REFERENCE: Nordlin, E. F., Kubel, L. G., and Chow, W., "A High-Speed Profilograph", State of California, Department of Public Works, Division of Highways, Materials and Research Department, July, 1969. Project Work Order No. M & R 636338.

ABSTRACT: The results of research conducted by the California Division of Highways on the development of a high-speed profilograph is reported. A description of the equipment used to measure road profile at high speeds between 50 and 65 mph is described. The goal of this project was to obtain a profile record of the road similar to the current records obtained by the hand push and motorized low-speed profilograph. A rotary potentiometer was used to measure the relative movements between an automobile's wheel and its chassis. An accelerometer was used on the automobile chassis in the proximity of the wheel frame to measure the absolute displacement of the automobile frame. The difference between these two movements was taken to be a representation of the road profile. A good correlation between current profile measurements and the high-speed measurements were made on relatively smooth road surfaces. Because of the slow response of the automobile wheel rapid differentials in the road surface were not detectable by this equipment.

It is the conclusion of this research that in order to detect pavement characteristics such as step-off it will be necessary to obtain detection equipment with a higher frequency response. Some form of contactless probe seems to be most promising for high-speed profilograph recording.

KEY WORDS: Pavement surfaces, profiles, profilometers, pavement smoothness, testing equipment, instrumentation.

ACKNOWLEDGEMENTS

This research was done in cooperation with the U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads (Federal Program No. HPR-1(2), F-1-1).

The opinion, findings, and conclusions expressed in this publication are those of the authors and not necessarily of the Bureau of Public Roads.

TABLE OF CONTENTS

I - INTRODUCTION AND BACKGROUND

Findings from Research Project M & R No. 61245-R dated August 17, 1964, "A Report on Vehicle Response to Pavement", were that a pavement ride-comfort index was difficult to attain. The outgrowth of the above research indicated that the relative motion between the car wheel axle and the car chassis frame presented a very good profile of the pavement surface. A new project, "Development of a High-Speed Profilograph", was submitted to the Bureau of Public Roads for their participation in its development. Bureau of Public Roads participation approval was given in April 1964.

Road profiles have been and are still being measured by the hand push profilographs and a motorized profilograph. The operations of these two types of profilographs are very slow since the speeds are limited to a man walking for the push units and 5 mph for the motorized unit.

Road profiles are unattainable with the present hand push or motorized units once a freeway is opened to heavy traffic because of the traffic safety aspects.

The method used to obtain road profiles at high-speed was dependent upon recording the relative movements between the car's chassis and its wheel in the form of an analog voltage. Simultaneously, an accelerometer attached to the car's chassis, near the wheel, recorded the absolute accelerations of the car chassis in an analog voltage form. These acceleration signals were then integrated twice to produce absolute chassis movements. The difference between the chassis movements and the wheel movements was considered to be the pavement profile.

II - CONCLUSIONS

The conclusions of this research are that this method of high-speed profile measurements shows great promise in the rapid recording of pavement profile, especially on high-speed roads where the low-speed profilograph presents a traffic hazard. Problems still exist in the measurement of rapid differentials of pavement surface at these high speeds. The inability of this device to measure rapid changes in pavement surfaces is due to the relatively low frequency response of an automobile suspension. An automobile suspension has the tendency to filter out the higher frequencies of relative motion producing a somewhat integrated picture of the pavement profile. Some preliminary investigations of contactless probes which would have a higher frequency response have been made. One of these probes is an eddy current sensor which can measure the displacement between two metallic surfaces. One obvious drawback of this system would be the necessity of spraying a light metallic surface on the road prior to measurement. A possible second approach to a contactless probe is the measurement of the back pressure experienced on a nozzle in close proximity to the road surface. The nozzle back pressure would be proportional to the distance between the road surface and the nozzle.

III - EQUIPMENT AND TEST PROCEDURES

Specifically, this project was to develop a high-speed profilograph which would alleviate the aforementioned shortcomings of the present profilographs. A successful high-speed profilograph would enable the measuring and recording of pavement irregularities and profiles. This information would enable standards to be set for maximum allowable pavement roughness and irregularities for both new and in-use pavements. Figure 1 is a drawing of the high-speed profilograph instrumentation setup in the car; Figure 2 is a line diagram of the instrumentation setup, and Figure 3 is a photograph of the instruments. A description of the instruments (numbers keyed to the photograph) and their functions in the high-speed profilograph project follows:

Helipot 10-turn Rotary Potentiometer (1)

As the car travels along the highway pavement, the pavement profile induces a changing vertical distance between the car chassis and its wheel. In this project the hypothesis was made that the aforementioned changing distance is analogous to the pavement profile. Therefore, a 10-turn rotary potentiometer was used to sense this change in vertical distance. A tension spring was attached to one end of a beaded chain; the free end of the chain in turn attached, in a vertical position, to the car wheel axle and the other end of the spring stretched and attached to the chassis. A sprocket gear was installed on the potentiometer shaft and "mated" to the sprocket chain; as the sprocket chain moved up and down because of the changing distance between the car chassis and its wheel axle, it caused the sprocket wheel to rotate and which in turn rotated the potentiometer. Thus, the chassis-axle relative motions rotated the potentiometer in a manner analogous to the pavement profile traversed.

Statham ± 2G Accelerometer Model A5a (2)

The aforementioned hypothesis was made that the up and down wheel motion was analogous to pavement profile. It was assumed that the traveling car chassis would provide a steady elevation platform from which to reference the vertical wheel motions. This proved to be a false assumption in actual tests. The car chassis undulations created a non-steady elevation reference platform so that the vertical wheel motions could not be referenced to it.

Therefore, a Statham 2G accelerometer was mounted on the car chassis directly over the potentiometer-chain system. This accelerometer sensed the chassis undulations as varying accelerations. The varying chassis accelerations were electrically double integrated by an electronic system which produced an electrical signal equal to the chassis vertical motions. Subtraction of the chassis vertical motions from the chassis-wheel distance, measured by the potentiometer, provided the resulting wheel axle motions which is the road profile.

Video D.C. Amplifier (3)

The Video D.C. amplifier was used to amplify the Statham accelerometer signals to a level suitable for recording on the Pemco analog magnetic tape system.

Pemco PMR-500 Magnetic Tape Recorder (4)

The Helipot potentiometer signals and the Statham accelerometer signals were recorded on the PMR-500 analog magnetic tape recorder. The tape recorder is a 4-track machine. The Statham accelerometer and the Helipot potentiometer signals each occupied one track.

The third track was used to record "events" along the pavement by a hand operated switch. Because of the simplicity of the "event" marker, it is not shown in any of the figures.

The fourth track was used to record the pulses coming from the Electro Products proximity pickup. The pickup is not shown in the photograph but is shown in the drawings. A drive cable "T" was installed in the odometer outlet so that two drive cables were attached to it. The "extra" cable attached to one of the dual outlets was used to turn the 4-toothed gear. The proximity pickup sensed each of the teeth as it rotated past the pickup and the pulses resulting from the teeth passing the pickup were recorded on the magnetic tape's fourth track. These pulses represented distances traveled along the pavement.

In essence, this was the major instrumentation installed in the car for recording pavement profile and in the manner shown in Figure 1. Pavement profile magnetic tape recordings from the field tests were brought into the laboratory for subsequent analysis.

The following, keyed to the photograph, describes the laboratory in-house instruments used for the play-back analysis:

Pemco PMR-500 Magnetic Tape Recorder (4)

The Pemco was used in a dual function - to record pavement profiles in the car and to play-it-back in the laboratory for visual analysis.

Allied Audio Amplifier (5)

The proximity pulses, or one track of the Pemco recorder, were amplified by the Allied amplifier to provide adequate signal level to drive the Servo-Drive system.

Servo-Drive System (6)

The amplified proximity pulses were used to drive the stepping motor in the servo-drive system. The stepping motor in turn drove a Selysn which produced chart run-out in the Visicorder equal to 1" of chart paper equal to 25' of pavement traversed. This produced a chart run-out directly proportional to pavement traversed and independent of car speed.

Krohn-Hite Electronic Filter (7)

The accelerometer signals were filtered by the Krohn-Hite filter so that any questionable frequency component may be eliminated.

Honeywell Visicorder Oscillograph (8)

The oscillograph is a light-beam galvanometer oscillographic system wherein the pavement profile signal drives the galvanometer's mirror producing a swinging light spot, analogous to the pavement profile, on a photo-sensitive chart paper, for visual inspection.

All of the above described instruments were commercially available on the market. The only exception was the chart servo-drive system (Item #6 in the photograph). Commercially available chart drive system drives the chart paper out at a constant chart speed. The project needed a paper chart drive discharging paper in a proportional length to the pavement traversed and completely independent of time. The laboratory-built servo-drive system worked admirably for this purpose. The chart length (1" chart paper equals 25' of pavement traversed) was chosen to be identical, for ease of comparison, with the California Division of Highways low-speed profilograph. The servo-drive system functioned admirably by discharging the correct ratio of chart paper to pavement traversed at all different car speeds.

Project History and Findings

A 1960 Ford Ranchwagon was instrumented in September 1964 in the manner shown in Figure 1 but without the accelerometer. It was believed that the up and down motion of the car wheel axle relative to the car chassis would be analogous to the pavement profile. As previously explained in (1) above, the rotary potentiometer sensed these chassis-wheel motions. However, the chassis low frequency undulations and chassis bounce from pavement bumps contributed to the chassis-wheel relative motions. In addition, asphalt pavements with long wave lengths would set the car chassis into a slow oscillation. The above findings were the reason why the potentiometer, attached between the chassis and axle, did not produce a true road profile. The up and down motions of the car chassis created a non-constant elevation platform. Since a true road profile was contingent upon the vertical measurements referenced to a constant elevation platform, the measurements from the varying elevation car chassis gave an erroneous road profile.

In an effort to artifically create a non-varying elevation platform, the Statham 2G accelerometer was attached to the car chassis directly over the potentiometer system. The accelerometer sensed the accelerations resulting from the up and down motions of the car chassis. Recalling from basic physics that double integration of acceleration produces the resultant displacement, this physics principle was utilized to obtain an artificial stable platform. Therefore, the chassis accelerations recorded on the Pemco magnetic tape were double integrated in the laboratory to produce an electrical signal analogous to the up and down motions of the car chassis. The car motions were inverted (mathematical sign reversal for subtraction) and then combined (summation junction) with the potentiometer signal. The resultant signal was filtered by a Krohn-Hite filter to remove any high frequency extraneous signals such chassis or wheel shake. The final signal (shown on Figure 2) was reproduced on the Visicorder for visual observation and is the pavement profile.

By using various active band pass filters to filter out extraneous higher frequencies, the high-speed profilograph record, over the same stretch of pavement, very nearly matched the California low-speed profilograph record. However, the high-speed profilograph method could not pick up pavement faults or "step offs" across bridge or pavement joints. This turned out to be an inherent characteristic of a wheel rolling over a "step off" in which the wheel senses it as a rounded bump. Nevertheless, the method was quite successful as a high-speed profilograph except for the "step off" problem.

During this period General Motors was conducting a parallel development of a high-speed profilograph along similar principles and appeared to be ready to market it. The General Motors unit had the same drawback, i.e., not being able to record pavement "step offs". Therefore, laboratory efforts were redirected towards the development of a contactless probe to be incorporated into a high-speed profilograph. The efforts were limited to a literature and product research and a feasibility study only. The literature and product research revealed two approaches that may be feasible in sensing pavement profiles with contactless probes.

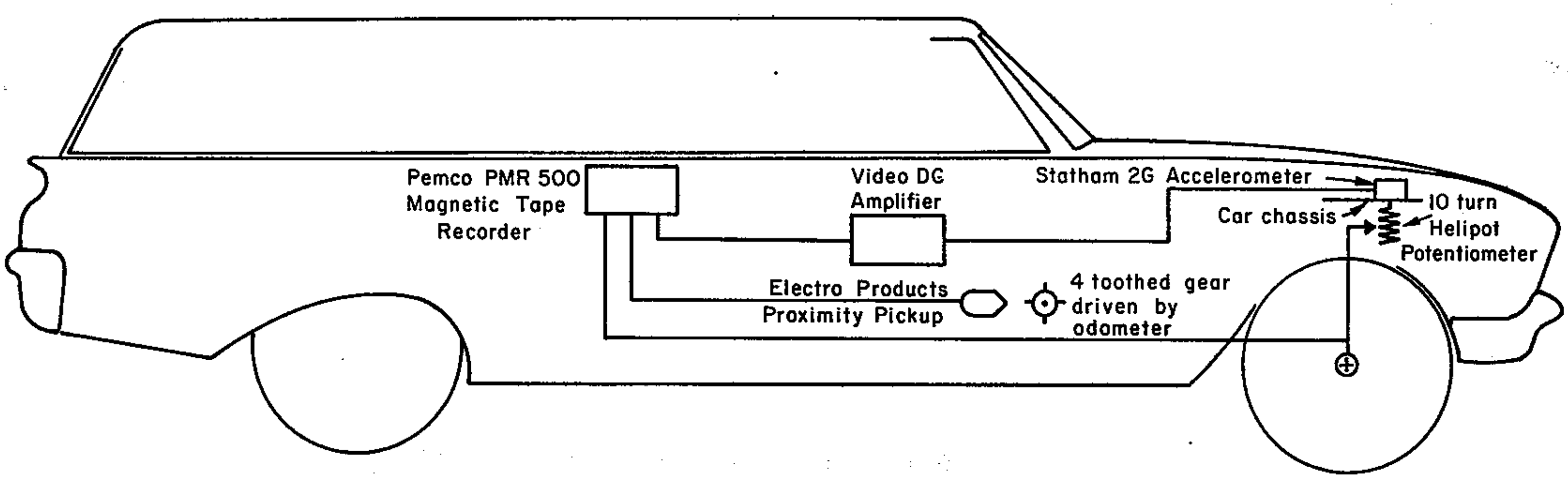
Kaman Nuclear Company of Colorado Springs, Colorado, manufactures an eddy current sensor which measures displacement between the transducer and an adjacent metallic surface. Since the system requires no mechanical connection (contactless) to the sensed metal object, it will make very high frequency response measurements and therefore it should be able to sense pavement step offs. The questionable drawback is that the sensed surface must be a metallic one so that eddy currents may be induced into it. In talking to Kaman Nuclear it was concluded that a metallic paint or liquid sprayed ahead of the sensing probe may provide an adequate eddy current conduction surface. However, this was not tried because of the "limited to a literature and product research" phase of this project.

The second approach which may produce a feasible contactless probe is based upon the principle of measuring the air pressure in a small nozzle as pressurized air is discharged from it. The air nozzle would be pointed directly at the pavement surface, perhaps within 1" and as the pavement changed in profile a pressure transducer would sense the changing air pressure being discharged by the nozzle. The changing nozzle discharge pressure would be analogous to the changing pavement profile. No actual work has been performed to determine the feasibility of this approach because of the aforementioned limited phase of this project.

Figure 1

HIGH-SPEED PAVEMENT PROFILOGRAPH

INSTRUMENTATION FOR THE ANALOGOUS RECORDINGS OF PAVEMENT PROFILES BASED UPON THE DIFFERENTIAL VERTICAL MOTIONS BETWEEN THE CAR CHASSIS AND ITS WHEEL AXLE.



1960 FORD RANCHWAGON

Figure 2

HIGH-SPEED PAVEMENT PROFILOGRAPH

Playback instruments used for reproducing pavement profiles in the laboratory from the magnetic tape recordings obtained in the field.

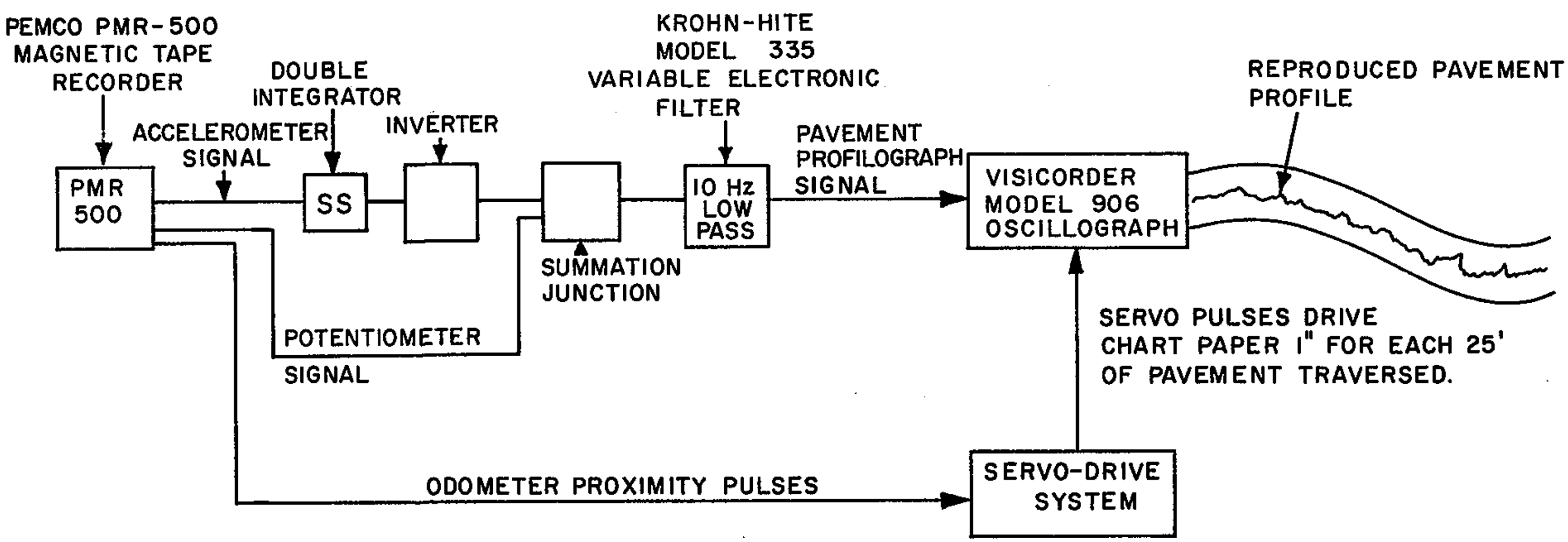


Figure 3

INSTRUMENTS FOR
HIGH-SPEED PROFILOGRAPH