A Theory on Interpreting Engine Noises

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A THEORY ON INTERPRETING ENGINE NOISES

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PREFACE

Mechanics have always used sounds to "trouble shoot" an engine. To a trained ear, each sound is different. Since an ear can be this sensitive, this paper will attempt to prove that electronic equipment can be considerably more accurate in detecting engine problems.

The writer of this paper has attempted a project in which he hopes to prove that valve and bearing problems can be located by studying oscilloscope displays. These displays would picture the sound frequencies of valve and bearings in operation. The writer assumed that a comparison could be made of the displays of a normal engine operation and an abnormal engine operation, and an observation of any variance in the frequencies or wave forms could be identified.

The writer wishes to acknowledge the help given to him for this project. The following proved extremely valuable as resource persons:

DR. WILLIAM LUCK, in helping to clarify the study and for the use of his car for testing purposes;

DR. DALE OLSON, for advice concerning scope characteristics;

Mr. RICHARD KRAEMER, for his suggestions on how to photograph an oscilloscope display;

MR. TERRENCE MURRIN, for the use of his car for testing;

DR. RUSSELL HANSEN, for the use of his Polaroid camera;

MR. CHARLES LUNDEEN, for his help in collecting data; and

MR. CHARLES KRAEMER, for his help with developing necessary equipment.

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INTRODUCTION

From the beginning, the proverbial auto mechanic has listened to the engine to give him some clues to diagnosing problems. One step to advance this idea was a stethoscope which was similar to those used by doctors. This instrument mechanically amplifies the vibrations and sounds for a clue to a problem.

Modern trouble shooting instrumentation involving electronic vibration pickups are available from at least two companies: Kistler Instrument, and Techntronic Instrument Company.

So far, a review shows none of these companies has any device displaying an oscilloscope signal of mechanical problems which relates the frequencies for specific problems. For instance, if an engine has a knock, the sound emitted by the knock has a specific frequency by which the problem may be identified. Possibly, the frequencies emitted by an engine can be analyzed by investigation and the specific problems checked without dismantling the engine.

It is the purpose of this study to attempt to use certain available equipment and develop other equipment not available to experiment with the theory that sound and frequency variations may aid in determining and locating automotive mechanical problems.

DESCRIPTION OF APPARATUS TESTED

The valve overlap and frequency tests were conducted on a 283 cubic inch Chevrolet V-type eight-cylinder engine, with overhead hydraulically operated valves. This engine is stock production 1964 series with a two-barrel carburetor. The valves of this engine were adjusted to manufacturer's specifications before the test to eliminate interference between valve patterns.

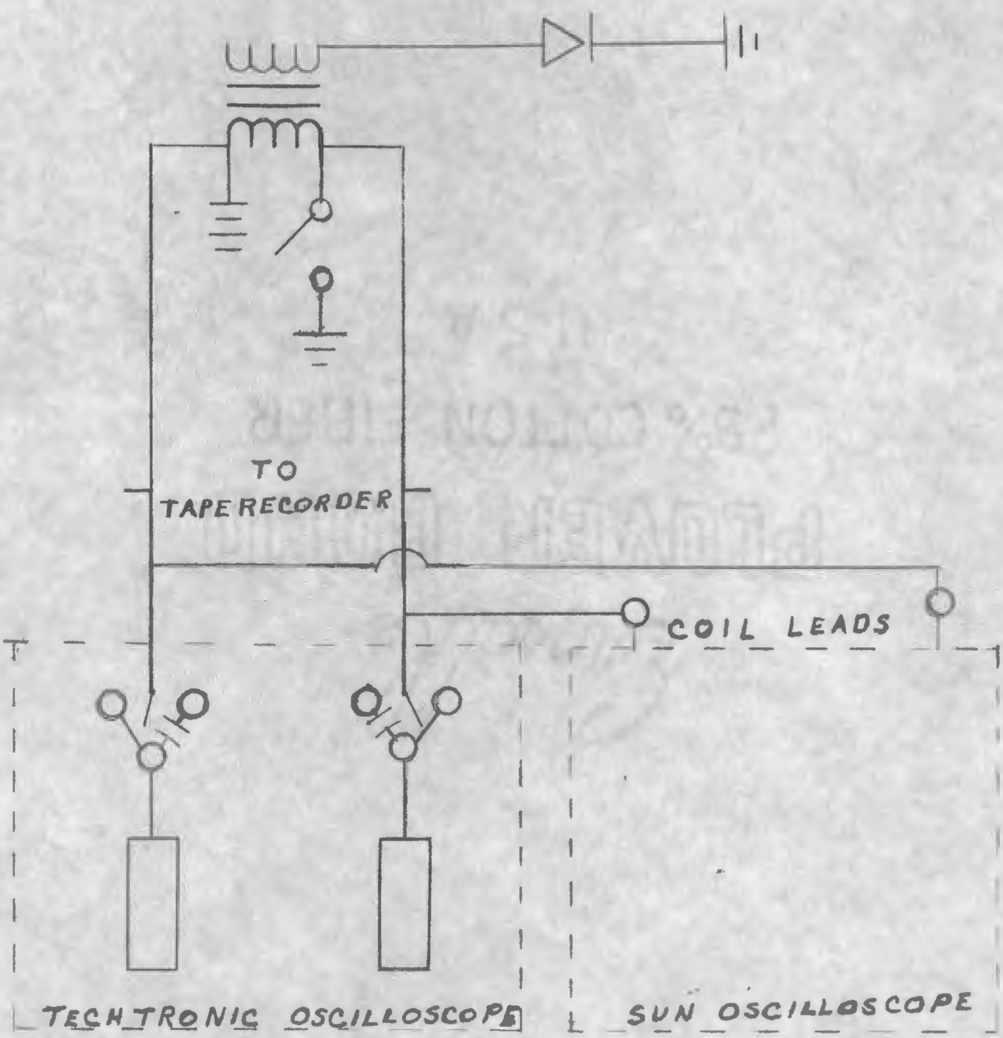
For generator noises, a Chrysler Corporation generator, No. 66W-6014A, was used. The back bearing measured .673 inches and the commutator shaft measured .668 inches. The bearing was then reamed out in steps to a final measurement of .723 inches. The front bearing was not measured or removed from the case

A valve test was run on a Chevrolet 6-cylinder, in line 235 cubic inch engine, Serial No. E59J 224-131. This engine was suspected of having a malfunctioning valve lifter, which was confirmed by an oscilloscope test. This engine is a production stock engine with 70,000 miles of service.

Two Ford transmissions were tested. One was a 1967 Mustang transmission and the other a 1967 Ford Fairlane with a three-speed synchromesh transmission without overdrive. The Mustang was scheduled to be disassembled for repair and the Fairlane was used to compare bearing

SKETCH OF CIRCUITRY

This sketch illustrates the wiring used to connect the components for this test. Refer to page 5 for further information.



displays with the Mustang.

OBJECTIVE

The objective of this test is to devise a system of existing equipment and to develop equipment to sense, record, display, and photograph sound frequencies emitted from valves and bearings of internal combustion engine parts. Then to analyze the photographs for frequency ranges and set up time bands of probable emission that are related to the seven hundred and twenty degree cycle of a four cycle internal combustion engine.

Equipment, Description, and Schematics:

A. A Sun Rastronic Engine Diagnosis Machine, Model 1120 oscilloscope will be used. This machine can be used to display a pattern from electrical impulses or signals. It is a single trace scope used to measure low and high voltages in the electrical system in cars. This instrument can be controlled to display a signal at an exact time, so time can be determined in order to calculate frequency.

B. A Sony Taperecorder will be used, which is a four track stereo tape recorder (Model No. TC500A). It has a built-in amplifier of excellent linear and response characteristics. A contact microphone will be used with this instrument. It has an amplifying power of 7 watts RMS per channel. It will also record the signals on tape for reproduction of the display on the oscilloscopes.

C. A techtronic Model 503 dual trace oscilloscope will be used. The dual trace can be used to superimpose two frequencies to look for similarities between them. Also, the Techtronic oscilloscope is more accurate and sensitive than the Sun 1120 oscilloscope.

D. A Pentax camera Model H3V single lens reflex camera will be used to record the data to compute the frequency. The camera has a shutter speed to one-thousandth of a second. Tri-X film will be used with an ASA of 400 to record the oscilloscope pattern.

E. A Polaroid Model 100 fixed lens camera with a close-up lens to operate in a focal range of 9-15". The Polaroid film has an ASA of 3000, which is fast enough for oscilloscope patterns.

DESCRIPTION OF METHOD

The Sony tape recorder was set up for operation. The microphone was placed in a receptacle for channel No. One. The auxiliary output for channel number One was connected to the coil primary leads on the Sun instrument. This allows a complete circuit form the tested engine through the tape recorder pre-amplifier and the amplifier to the tape head to be recorded and finally, to the auxiliary output and to the Sun scope, as shown on Electrical Wiring Diagram, page 2. After the power is turned on to the recorder and the Sun tester, the tape recorder is set to the amplifying position only and the microphone is placed near some noise. The controls on the scope are adjusted to produce the signal on the scope screen. The power switch is set on primary because this is the most sensitive signal of the scope. The primary voltage runs from seven to nine volts. The tape recorder has a power of seven watts which are close enough to give a display. The scale calibration is turned to variable while power is increased to the full limit. Next, the signal display is adjusted so the markings on the oscilloscope are fully displayed with all 720° on the screen. At this point, the Techtronic oscilloscope is connected to the tape recorder output leads in parallel with the Sun tester. The spark plug lead on the Sun tester is connected to the Number One spark plug to allow a reference position of the display relating to the position of the engine cycle. The tachometer will also be in operation when this basic electrical wiring installation is completed.

Before running the tests for the valve pattern on the Chevrolet engine, the ignition and valves were set to specifications. A baffle plate is designed to keep oil from being thrown from the rocker arms on the hot exhaust manifolds. The engine is started and each valve is

adjusted until clicking noise is evident. This required approximately one turn. The microphone is placed on each loose valve, one at a time, and the degrees are recorded when the noise begins and ends. Sometimes the noise will begin at the end of the display pattern and then appear at the beginning of the next triggering point of the oscilloscope. Valves offer a definite pattern on the screen. The frequency is much more difficult to pinpoint as the display tapers down to zero. The beginning of the display is very sudden and sharp. The beginning and end values are read on the bottom of the Sun scope. The degrees are measured only to 45 degrees for dwell and they are placed on the scope from right to left. The display is identified from left to right, thereby these figures are then subtracted from 45, and then multiplied by 16. This is because the full display is 720 degrees or two complete rotations of the engine and 45 goes into 720, 16 times. Each mark on the scale equals sixteen degrees of rotation. This allows for a certain amount of error to appear.
For further data, refer to the Valve Overlap Data page 9.
If instrumentation were designed for the specific problem a more accurate method would be available.

Photography also presented some problems. The ghost patterns on the Sun scope are so great that they interfere with the picture of the display. For this reason, the pictures were all taken on the Techtronic scope.

It is difficult to obtain good quality pictures of the oscilloscope display because of the fast film speed requirement. The Polaroid camera film offers a 3000 ASA rating.

This camera also gives instant results, thereby allowing poor pictures to be taken over immediately. The camera used in this test was a fixed lens camera and the shutter speed could not be adjusted freely. This would be a necessary requirement for deeper studies. The shutter speed should be set at a time of one cycle of the engine. If the engine were running at 600 RPM each cycle would be a full display and would occur in one-thirtieth of a second. This eliminates overlaps of displays to avoid confusion of the data. The Techtronic scope can be sequenced exactly with the camera time settings.

In testing the transmissions the same procedure is used as in the valve display tests except the car was jacked up and the microphone was placed at various parts of the transmission body to pick up the signals and record them. The microphone was placed on the front, middle, and end of the transmission housing. Tests were run on a 1967 Mustang that was to be dismantled for transmission repair. The 1967 Ford Fairlane was used to demonstrate a normal transmission pattern. For data, refer to the Transmission Bearing Data, Page 10.

The generator bearing tests were conducted while mounted on the powersteering unit. The generator is mounted on in place of the generator pump. All mountings and belts are in their normal positions. The engine is to be run at 1750 RPM. The microphone is placed on the generators back bearing to pick up the signals. For the results, refer to the Generator Bushing Data, on page 11.

One method of determining the frequencies is to count the high peaks and determine this frequency against the time elapsed for those peaks. All the pictures are taken at a .020 second span. All the peaks are multiplied by 50 to find the number of peaks in one second.

VALVE OVERLAP TABLE

This data illustrates the position of No. 1 piston in degrees of rotation when each valve opens and closes for each of the eight cylinders.

Cylinder No.		Intake	Exhaust
1	Act.	716^{o}-342^{o}	128^{o}- 380^{o}
	Calc.	704^{o}- 352^{o}	160^{o}- 416^{o}
8	Act.	86^{o}- 432^{o}	218^{o}- 470^{o}
	Calc.	80^{o}- 448^{o}	208^{o}- 448^{o}
4	Act.	176^{o}- 522^{o}	308^{o}- 560^{o}
	Calc.	160^{o}- 528^{o}	320^{o}- 560^{o}
3	Act.	266^{o}- 612^{o}	398^{o}- 668^{o}
	Calc.	236^{o}- 624^{o}	400^{o}- 668^{o}
6	Act.	356^{o}- 702^{o}	488^{o}- 20^{o}
	Calc.	352^{o}- 720^{o}	512^{o}- 32^{o}
5	Act.	446^{o}- 72^{o}	578^{o}- 110^{o}
	Calc.	448^{o}- 80^{o}	576^{o}- 128^{o}
7	Act.	536^{o}- 162^{o}	668^{o}- 200^{o}
	Calc.	512^{o}- 176^{o}	672^{o}- 198^{o}
2	Act.	626^{o}- 252^{o}	72^{o}- 290^{o}
	Calc.	608^{o}- 256^{o}	80^{o}- 304^{o}

Act.: Actual Values

Calc.: Calculated figures

Firing Order: 1-8-4-3-6-5-7-2

Valve Frequency = 750 HERT

Reference Picture 25

TRANSMISSION BEARING TABLE

This table illustrates the frequency calculated from tests on the front and rear bearings of two Ford transmissions.

Picture No.	Car No.	Peaks	Frequency	Part
13	1	7	350 Htz.	B
16	2	10	500	B
17	2	10	500	B
15	1	9	450	F
14	2	10	500	F

Car #1: Ford Mustang

Car #2: Ford Fairlane

B: Back bearing

F: Front bearing

Period: .020 sec.

GENERATOR BUSHING TABLE

This chart illustrates the effect of bearing clearances and lubrication on the frequency of the sound emitted.

Bushing	Display	Picture	Lubrication	Frequency
.673"	.020 sec.	18	Dry	450 Hertz
.678	"	24	Dry	500 "
.678	"	23	Oiled	400 "
.683	"	22	Dry	600 "
.713	"	21	Dry	650 "
.723	"	20	Dry	650 "
.723	"	19	Oiled	550 "

RPM: 1725

Model:

Chrysler Corporation Generator

Shaft size: .668

Period: .020 sec.

CALCULATIONS

The valve overlap calculations are involved with converting the graduations to degrees of crankshaft rotation. The frequency calculations show a single method of calculating frequency from random displays. Both are offered as an explanation of the procedures in calculating data.

I. Valve Overlap:

A. The numbers from the Sun Tester are relative values in that they have to be processed:

1. They are subtracted from 45 to give the number of spaces from the left side of the screen where the display starts.
2. Multiplied times 16 converts the grid spaces to degrees. One space equals 16°.
3. The number of degrees from opening to closing is the duration:

#1 Grid Valves 35-19

$$\begin{array}{r} 45 \\ -35 \\ \hline 10 \end{array} \qquad \begin{array}{r} 45 \\ -19 \\ \hline 26 \end{array}$$

#2

$$\begin{array}{r} 10 \\ \times 16 \\ \hline 160^{\circ} \end{array} \qquad \begin{array}{r} 26 \\ \times 16 \\ \hline 416^{\circ} \end{array}$$

#3

$$\begin{array}{r} 416 \\ -160 \\ \hline 256^{\circ} \end{array}$$ duration.

II. Frequency Calculations:

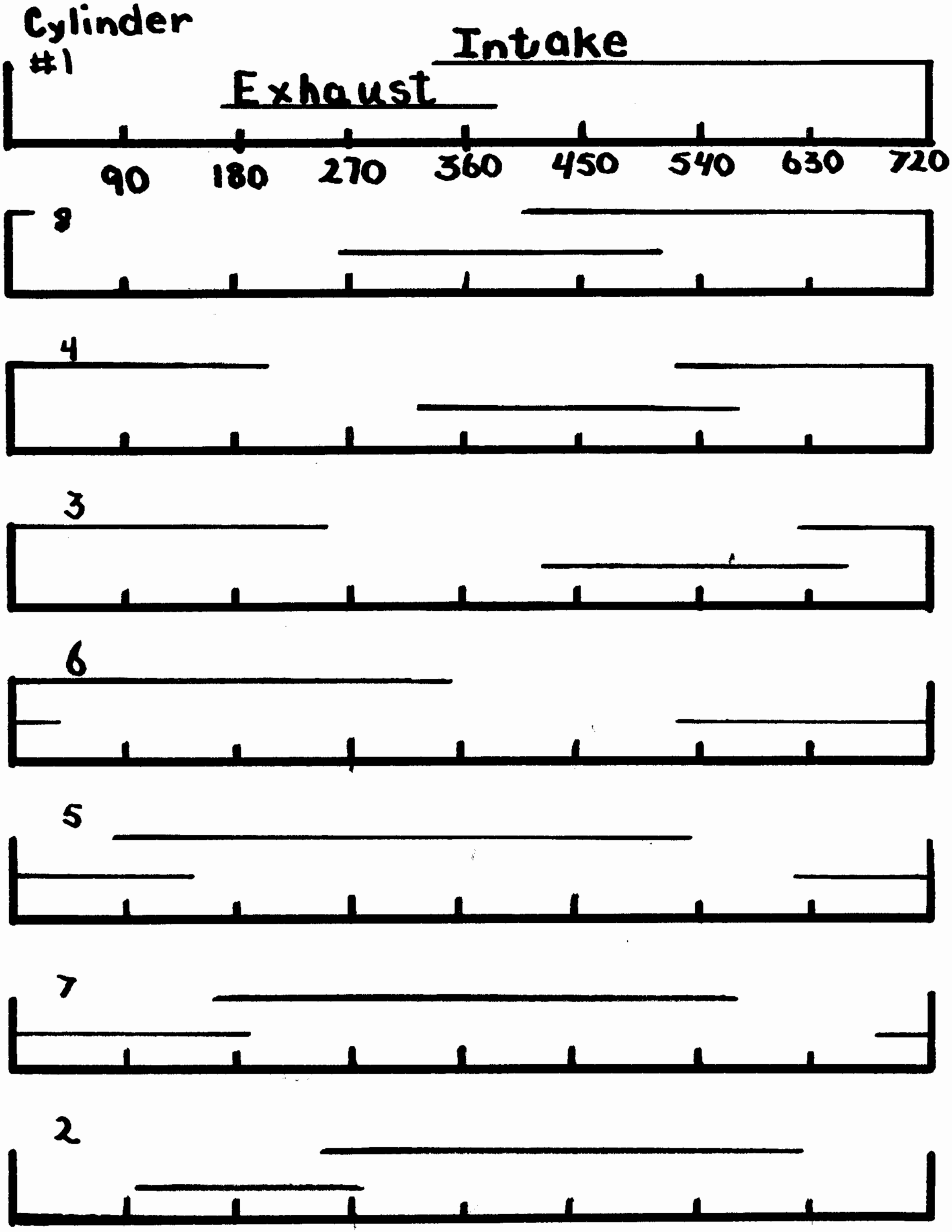
A. In one cycle of a wave there is one positive peak and one negative peak. To count either positive or negative peaks in .020 seconds, and multiply times 50 would give the number of peaks in one second or Hertz.

7 peaks in .020 seconds

7 peaks/.020 sec. x 50 = 350 hertz.

VALVE OVERLAP GRAPH

This graph illustrates the results of valve overlap table on page .



DISCUSSION AND CONCLUSION

Discussion of this project will include an evaluation of 1) valve data, 2) bearing data, 3) generator bushings, and 4) photography. The discussions of each of these areas will overlap to some extent.

Valve Data:

In order to analyze the problems of gathering data on the Sun tester, one must become familiar with the oscilloscope's grid. There are numerous horizontal lines which have value only for comparative purposes. At the bottom of the grid is a scale of 45 segments indicating swell degrees, as shown on Picture No. 1, page 21, Appendix A.

This scale will represent 720° in the cycle of an internal combustion engine, and each mark equals 16° in an engine cycle. Because the human eye can only detect 1/10 of a small space, it is impossible to evaluate the display to the nearest degree. This factor accounts for variation from true valve overlap diagrams published by the manufacturer.

Several degrees of variation will occur from one sweep to the next of the electron gun. In order to calculate an average reading, both extremes must be taken into account and averages; therefore, no attempt has been made to extrapulate to less than 16°.

By closely observing picture No. 1, the reader will notice a typical valve display in its beginning between 15° and 20° on the eight cycle scale. Note that it is very easy to observe where the opening begins, but it is difficult to pinpoint its end because the signal tapers off to zero.

The valve diagram data closely resembles the manufacturer's specifications, as shown on Valve Overlap Diagram, on page 14. The value of using this means of separating one valve from another has an application for noise or malfunctioning valve lifters. This equipment makes no distinction between a mechanical or a hydraulic problem. More sophisticated equipment may be able to accomplish this feat, as well as to evaluate valve seat condition and bushing clearances.

If more specialized equipment were to be designed for this application, a method of being able to divide the 720° display by two, four, or sixteen divisions, will allow the display to be read more accurately.

Because of the above stated information, no firm conclusions were made with respect to valve frequency relationships to problems.

Transmission Bearing Data:

The time element was not great enough to evaluate a number of transmissions with problems. More in-depth study is necessary to get a characteristic set of curves for each style of transmission and problem. It is felt that the general shape of the signal will closely simulate that of a sine wave as shown in Picture 18, page 22, App. A.

The more clearance there is in a bearing, the more spiked the signal form becomes with a higher amplitude as shown in Picture No. 14, page 21. Both pictures are signals of the Ford Transmission back bearing. The fact that the frequency is lower seems to indicate that the bearing and shaft are colliding less often in Picture 14, but with three times as much force as indicated by the amplitude.

The transmission which registered the highest peaks was disassembled and worn bearings were found both front and rear.

A more complete study would be necessary of each type and design of transmission in order to come up with a full array of frequency analysis.

Advantages of application for this type of analysis are unlimited. As a form of diagnosis, no disassembly procedure is necessary. A mechanic can quickly and easily perform this diagnostic test with a minimum of time and expense.

The limitations of this application are due only to lack of information and compiled data in this area.

<u>Generator Bushings Data</u>:

As a general statement and conclusion of the information shown on the Generator Bushing Chart, page 11, the frequencies emitted are proportional. The increase in frequency is caused by the bearing clearance as the drive speed was a constant 1/25 revolutions/minute. The frequency difference is very small for an increase of .050 inches in the bushing tolerance. Only 100 Hertz of variation is noted in the frequency range.

Every time oil was applied to the bearing the frequency and the amplitude was lowered. This indicated that less collisions were occurring between the shaft and the bearing. If bearing tolerance and the frequency of the bearing is known, lubrication problems can be diagnosed, provided the bearing clearance remains constant.

The generator bearing chart has no related value to the degrees of the engine cycles. This is a very elementary study of bearing characteristics similar to those that might be found in rod and main bearings. The rod and main bearing displays could be correlated to probable noise bands in the degrees of the engine cycle. Typical patterns could be set up similar to the Valve Overlap Diagram, page 14.

Photography:

The use of ASA 3000 film is necessary for taking pictures of the oscilloscope patterns. Since no other type of film can achieve this ASA rating economically, a Polaroid camera is needed. In addition, an adjustable shutter speed camera within range of .001 of a second to one second would be valuable. This would eliminate overlapping of frequencies as shown in pictures numbered 24 and 26, page 24, 25.

A necessary piece of photographic equipment would be an electronic trigger to operate the camera at specific times. This would allow taking pictures of segments of displays on the Sun tester. The ghost patterns would not affect these pictures as much because the shutter speed could be much higher and the intensity of the scope could be increased.

Failures of the first group of 35mm black and white pictures were due to film speed. They were taken at .001 of a second to .250 of a second. If the shutter speeds were left open any longer, the ghost pattern and the electron beam would overexpose the display pattern.

The photography was the ultimate factor in this project. The frequencies could not have been determined otherwise. Appendix A has all the pictures taken during the project with the 35mm Pentax camera. Appendix A has all the pictures taken by the Polaroid camera.

Conclusion:

The combined result of valve and bearing problems constitutes a large field of mechanical noises. By using the theories described in this paper, an in-depth study could be made of these areas to determine if interrelationships can be found. Once the frequencies are established, they could be used for all equipment using valves and bearings. The following example illustrates how a frequency range might be established.

The frequency spectrum could be divided into bands of specific problems. For example, the band of bearing frequencies might go from 450 to 550 Hertz. Valve frequencies might cover an area to possibly 500 to 1000 Hertz. A sensor could be placed on the engine and the signal sent to an amplifier. The amplifier should have a narrow adjustable band pass filter. This filter could be adjusted over a range of frequencies from 50 Hertz to well over the level of human hearing.

By studying the frequencies of the device and the pattern shapes, a full analysis could be made of an engine's problems. These frequencies could be programmed and interpreted by a computer, which would give technical information in a minimum amount of time.

One of the shortcomings of this test proved to be the omission of combustion frequencies. In this area, highly technical and costly equipment would be required.

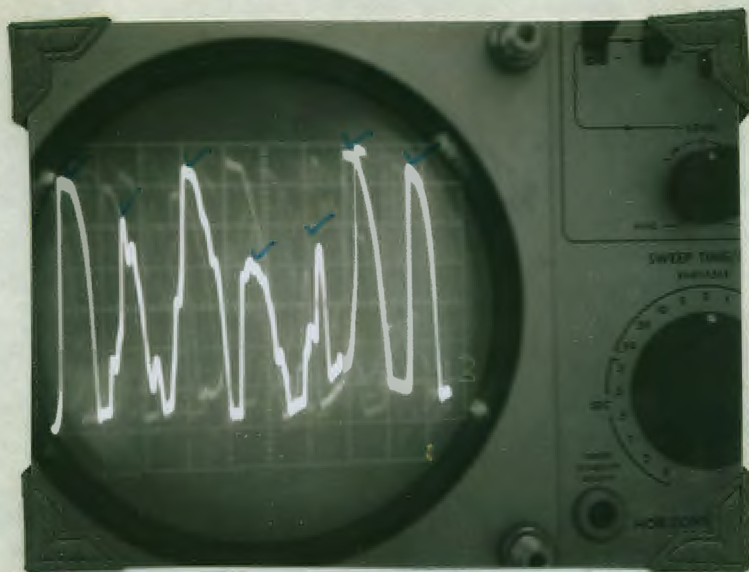
Another problem with this test was the time available to do an in-depth study. There was a limited field of experimental cars to be used for testing.

The writer's personal evaluation of this project is that it could be an area which could be expanded and applied in this age of complicated machinery. The use of the computer would make it highly adaptable for large industry.

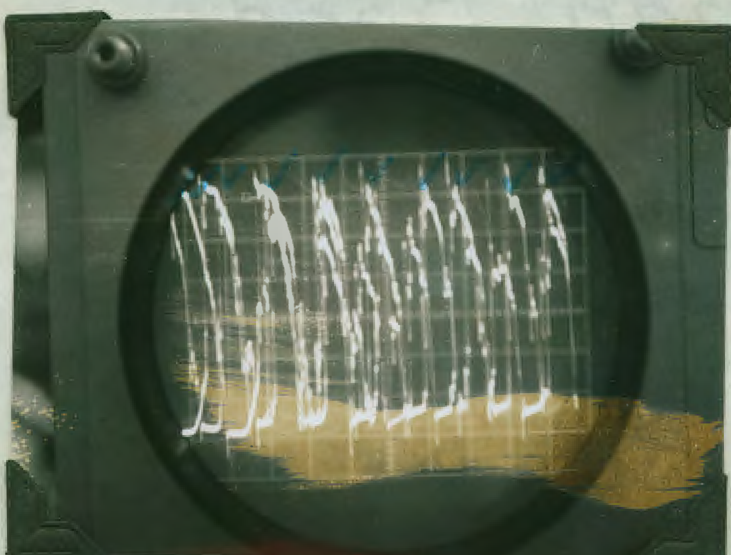
One social problem today is that of unemployment. The writer feels this theory has application for those handicapped due to being blind or crippled. This method of testing requires a minimum of physical ability by the individual doing the testing. By training blind or crippled individuals to operate this technical equipment and send the data to a computer by telephone, they will play a significant and worthwhile role in our society.

APPENDIX A

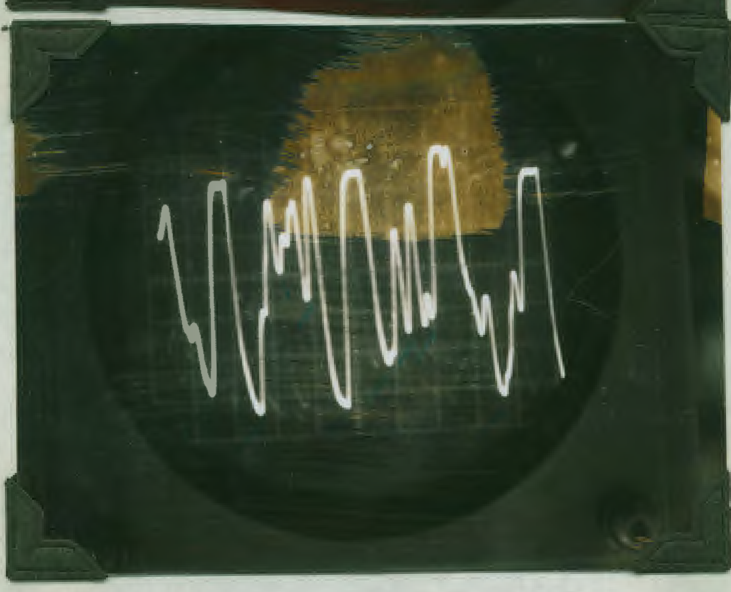
13.



14.

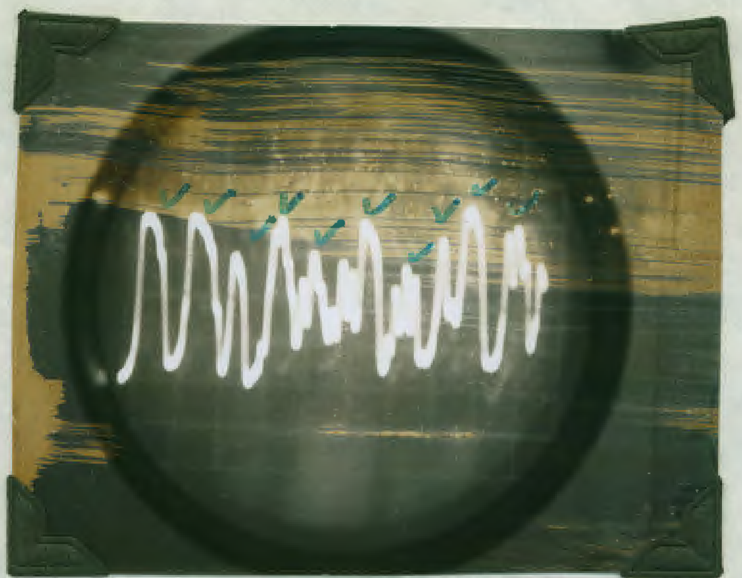


15.

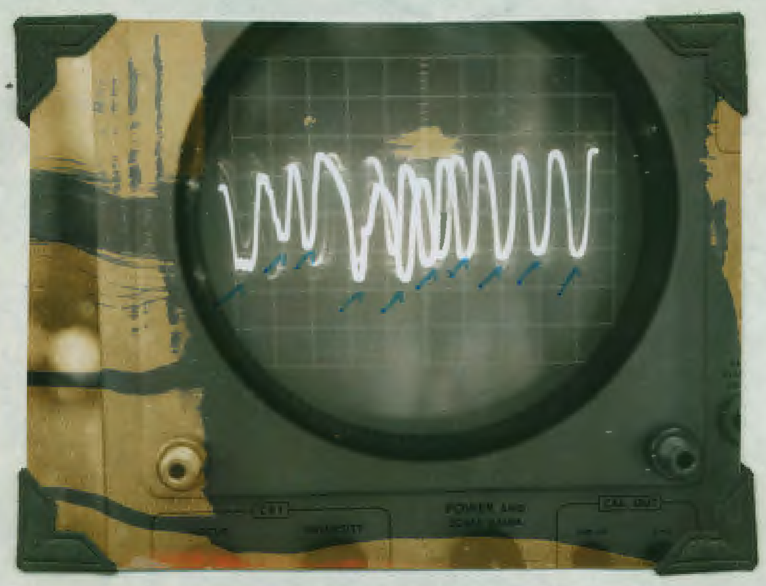


APPENDIX A, Cont'd

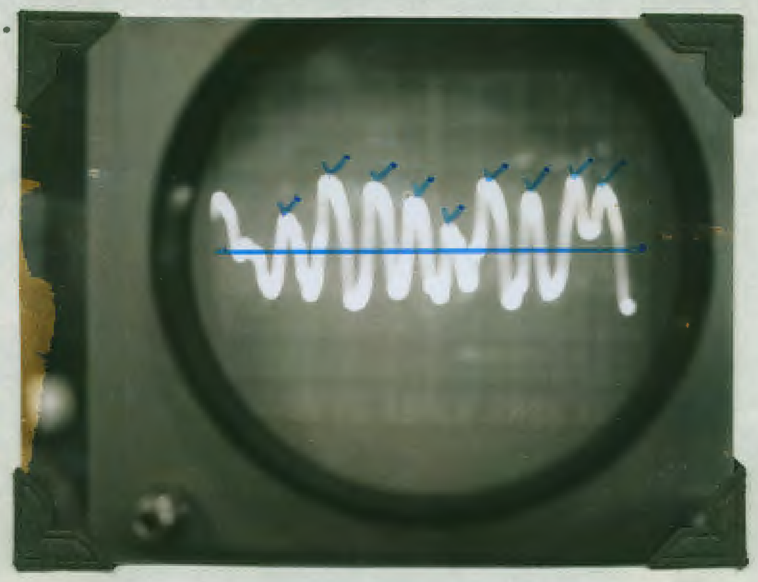
16.



17.



18.

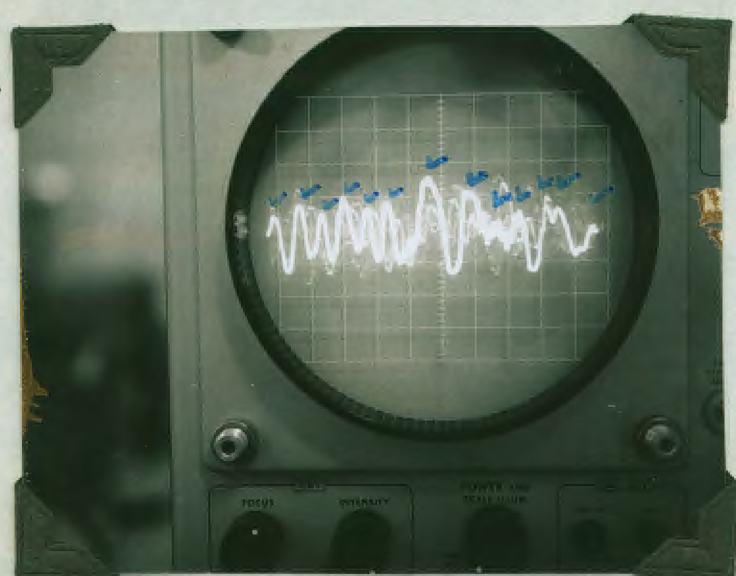


APPENDIX A, Cont'd

19.

20.

21.

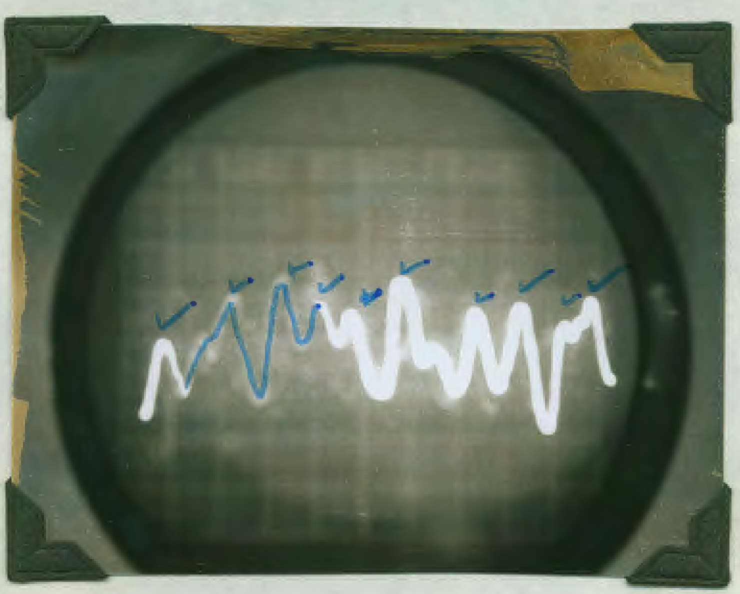


APPENDIX A, Cont'd

22.

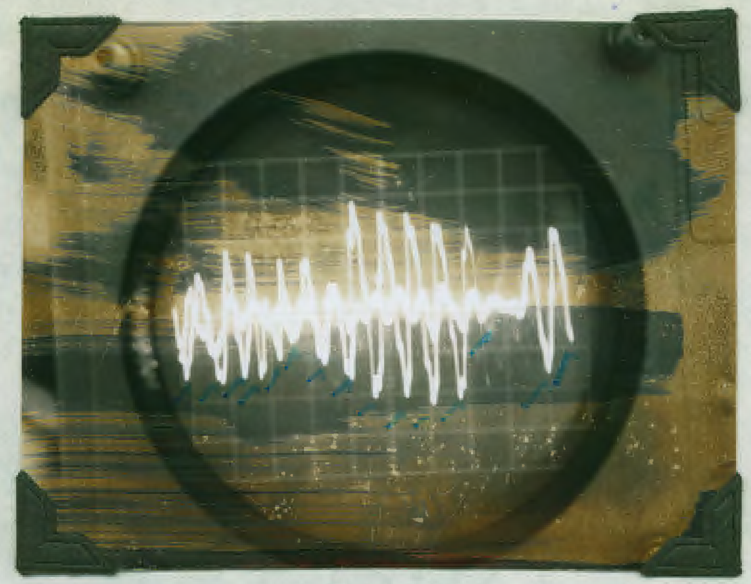
23.

24.



APPENDIX A, Cont'd

25.



35MM Film Chart

This chart gives data on the 35mm picture failures.

No.	F Stop	Speed	Printed
1	1.8	1000	#2
2	"	"	#3
3	"	"	#4
4	2	"	#5
5	"	"	no
6	"	"	no
7	"	"	no
8	"	"	no
9	"	"	no
10	"	"	#6
11	"	"	no
12	"	"	#7
13	"	"	#8
14	"	"	no
15	"	"	#9
16	"	"	#10
17	"	"	no
18	"	500	#11
19	"	250	# 1
20	1.8	"	#12

APPENDIX B

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