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EVALUATION OF ALTERNATIVE AXLE SENSOR TECHNOLOGIES

by

Saïd O. Majdi

and

Wiley D. Cunagin

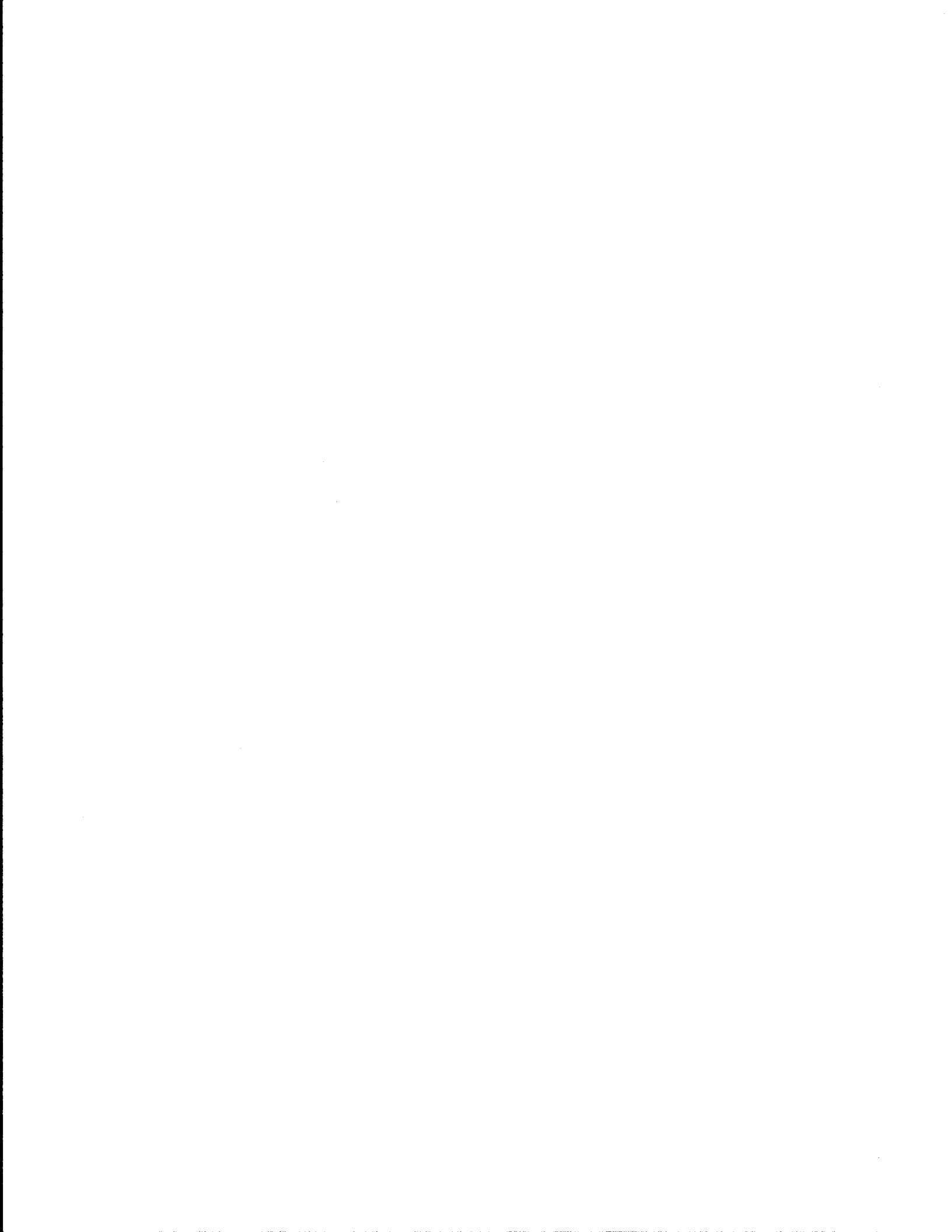
Research Report 2038-1F  
Research Study 2-10-88-2038  
"Evaluation of Alternative Axle Sensor Technologies"

Sponsored by

Texas State Department of Highways and Public Transportation

TEXAS TRANSPORTATION INSTITUTE  
The Texas A&M University System  
College Station, Texas 77843-3135

November 1988



# METRIC (SI\*) CONVERSION FACTORS

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol        | When You Know | Multiply By | To Find     | Symbol |
|---------------|---------------|-------------|-------------|--------|
| <b>LENGTH</b> |               |             |             |        |
| in            | inches        | 2.54        | millimetres | mm     |
| ft            | feet          | 0.3048      | metres      | m      |
| yd            | yards         | 0.914       | metres      | m      |
| mi            | miles         | 1.61        | kilometres  | km     |

| <b>AREA</b>     |               |        |                     |                 |
|-----------------|---------------|--------|---------------------|-----------------|
| in <sup>2</sup> | square inches | 645.2  | millimetres squared | mm <sup>2</sup> |
| ft <sup>2</sup> | square feet   | 0.0929 | metres squared      | m <sup>2</sup>  |
| yd <sup>2</sup> | square yards  | 0.836  | metres squared      | m <sup>2</sup>  |
| mi <sup>2</sup> | square miles  | 2.59   | kilometres squared  | km <sup>2</sup> |
| ac              | acres         | 0.395  | hectares            | ha              |

| <b>MASS (weight)</b> |                      |       |           |    |
|----------------------|----------------------|-------|-----------|----|
| oz                   | ounces               | 28.35 | grams     | g  |
| lb                   | pounds               | 0.454 | kilograms | kg |
| T                    | short tons (2000 lb) | 0.907 | megagrams | Mg |

| <b>VOLUME</b>   |              |        |              |                |
|-----------------|--------------|--------|--------------|----------------|
| fl oz           | fluid ounces | 29.57  | millilitres  | mL             |
| gal             | gallons      | 3.785  | litres       | L              |
| ft <sup>3</sup> | cubic feet   | 0.0328 | metres cubed | m <sup>3</sup> |
| yd <sup>3</sup> | cubic yards  | 0.0765 | metres cubed | m <sup>3</sup> |

NOTE: Volumes greater than 1000 L shall be shown in m<sup>3</sup>.

| <b>TEMPERATURE (exact)</b> |                        |                            |                     |    |
|----------------------------|------------------------|----------------------------|---------------------|----|
| °F                         | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

## APPROXIMATE CONVERSIONS TO SI UNITS

| Symbol        | When You Know | Multiply By | To Find | Symbol |
|---------------|---------------|-------------|---------|--------|
| <b>LENGTH</b> |               |             |         |        |
| mm            | millimetres   | 0.039       | inches  | in     |
| m             | metres        | 3.28        | feet    | ft     |
| m             | metres        | 1.09        | yards   | yd     |
| km            | kilometres    | 0.621       | miles   | mi     |

| <b>AREA</b>     |                                   |        |               |                 |
|-----------------|-----------------------------------|--------|---------------|-----------------|
| mm <sup>2</sup> | millimetres squared               | 0.0016 | square inches | in <sup>2</sup> |
| m <sup>2</sup>  | metres squared                    | 10.764 | square feet   | ft <sup>2</sup> |
| km <sup>2</sup> | kilometres squared                | 0.39   | square miles  | mi <sup>2</sup> |
| ha              | hectares (10 000 m <sup>2</sup> ) | 2.53   | acres         | ac              |

| <b>MASS (weight)</b> |                      |        |            |    |
|----------------------|----------------------|--------|------------|----|
| g                    | grams                | 0.0353 | ounces     | oz |
| kg                   | kilograms            | 2.205  | pounds     | lb |
| Mg                   | megagrams (1 000 kg) | 1.103  | short tons | T  |

| <b>VOLUME</b>  |              |        |              |                 |
|----------------|--------------|--------|--------------|-----------------|
| mL             | millilitres  | 0.034  | fluid ounces | fl oz           |
| L              | litres       | 0.264  | gallons      | gal             |
| m <sup>3</sup> | metres cubed | 35.315 | cubic feet   | ft <sup>3</sup> |
| m <sup>3</sup> | metres cubed | 1.308  | cubic yards  | yd <sup>3</sup> |

| <b>TEMPERATURE (exact)</b> |                     |                   |                        |    |
|----------------------------|---------------------|-------------------|------------------------|----|
| °C                         | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |

These factors conform to the requirement of FHWA Order 5190.1A.

\* SI is the symbol for the International System of Measurements



## ACKNOWLEDGMENT

This research was sponsored by the Texas State Department of Highways and Public Transportation and the Federal Highway Administration. Saïd O. Majdi was the Study Supervisor and Jon Underwood was the SDHPT Study Contact Representative. Dr. Wiley Cunagin provided direction and valuable technical insight.

## ABSTRACT

The provisions contained in the Federal Highways Administration's recently issued Traffic Monitoring Guide as well as the traffic data collection portion of the Long Term Pavement Performance monitoring effort within the Strategic Highway Research Program (SHRP) require the use of automated vehicle classification for their implementation. The vehicle types specified in that document can only be identified from data acquired from axle detectors. Current traffic data collection practice includes only one proven axle detector technology--pneumatic tubes. Unfortunately, these devices are inappropriate in many situations.

This report presents the results of an evaluation of alternative axle sensor technologies. Namely, piezoelectric ceramic cable (PZCC), piezoelectric plastic cable (PZPC), piezoelectric film (PZF), and tapeswitch (TSW). These sensors were tested under different environmental and load conditions. Experimental results include a characterization of the linearity and the uniformity of the response of each sensor, and a comparison of the four sensors tested.

## **IMPLEMENTATION**

The main objective of this study was to evaluate by laboratory testing four types of axle sensors for the purpose of permanent installation. Two of the sensors tested are commercially available, whereas the other two are prototypes designed and constructed for this study. These sensors were then tested under different environmental and load conditions to characterize their behavior. This has been accomplished.

## **DISCLAIMER**

The contents of this report reflect the views of the authors who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration or the State Department of Highways and Public Transportation. This report does not constitute a standard, specification, or regulation.



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## INTRODUCTION

The objective of this study was to evaluate four different types of axle sensors which could be installed in the pavement for an extended period of time and operated under different environmental and loading conditions. Three of the sensors tested use piezoelectric technology; the fourth sensor acts as a mechanical switch. One of the piezoelectric sensors is commercially available through Streeter Richardson and uses a piezoelectric ceramic cable. Two prototype axle sensors were constructed for the purpose of this study: one uses piezoelectric plastic cable, the other uses piezoelectric film. The fourth is a tapeswitch available through Tapeswitch Corporation of America. The piezoelectric ceramic cable, piezoelectric plastic cable, piezoelectric film, and tapeswitch will hereafter be referred to as PZCC, PZPC, PZF, and TSW, respectively.



## AXLE SENSOR TECHNOLOGIES

The following is a discussion of technologies that are used for vehicle axle detection.

### PNEUMATIC TUBES

Pneumatic tubes are usually connected to an on/off pressure transducer that responds to the compression of air trapped inside a section of the tube. These sensors are widely used, inexpensive, reusable, and easy to install. However, pneumatic tubes cannot be used for extended periods of time, are not suitable for high traffic situations, and are only used in temporary installations.

### TAPESWITCHES

These sensors are mainly used in temporary applications. They are formed of two long metallic strips separated by insulation along the edges (Figure 1). A vinyl sheath protects the metallic strips from the environment. When installed, a tapeswitch acts like a mechanical switch as the metallic contacts touch and cause a switch closure. This operation makes it more reliable than the pneumatic tube.

### PIEZOELECTRIC CABLE

The active element in a piezoelectric cable axle sensor is a coaxial cable with a copper core and sheath, separated by a compressed piezoelectric ceramic powder (Figure 2).

The operation of piezoelectric cables is based on the principle that when the cable is subjected to a mechanical stress or strain, an electrical signal appears between the core and the sheath. The signal generated is proportional to the magnitude of the excitation. This characteristic allows the piezoelectric cable to have two modes of operation:

- ON/OFF mode: The presence or absence of a signal at the passage of an axle is sufficient for detection. This mode is used for sensing and counting of vehicle axles, and accurately measuring speed and axle spacing (with two sensors separated by a known distance.)

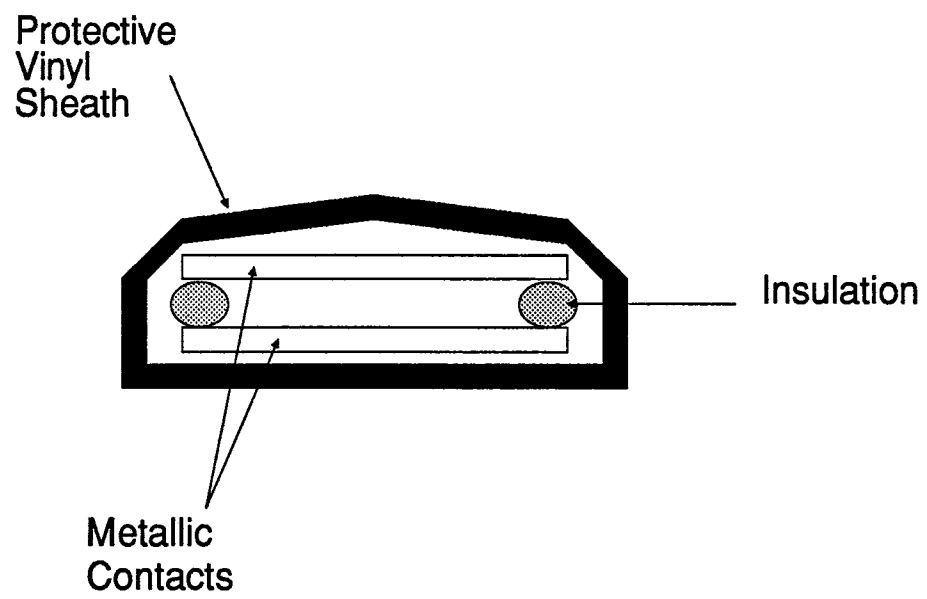


Figure 1. Cross Section of a Tapeswitch.

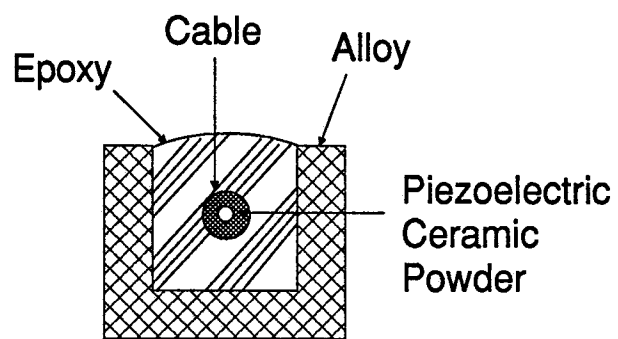


Figure 2. Cross Section of a Piezoelectric Ceramic Cable Axle Sensor.

- Analog mode: The weight or weight class of an axle can be evaluated, depending on the accuracy requirements, by measuring the magnitude of the signal generated in response to the stress or strain exerted. Also, depending on accuracy requirements, more complex signal processing techniques could be used in this mode to determine the loads transmitted to the pavement by axles and vehicles.

### **CAPACITIVE STRIP**

The capacitive strip is an axle sensor based on the bending of conducting plates caused by the passage of an axle. The plates are separated by a rubber dielectric. The decrease in the distance between the plates results in an increase of the capacitance of the sensor. This change in the capacitance is measured to determine the presence or passage of an axle.

The method of measuring the capacitance change is also used to determine axle weight.



## PROPERTIES OF PIEZOELECTRICITY

Piezoelectricity (piezo, greek for pressure) is the characteristic that a certain class of crystals have to transform mechanical stress or strain to an electrical voltage. This phenomenon is reversible; i.e., when an electrical voltage is applied to a piezoelectric material, a mechanical strain is induced.

Among several types of piezoelectric materials, polyvinylidene fluoride (PVDF) film exhibits the largest piezoelectric coefficients. When used as the basic element in an axle sensor, the PVDF film could generate voltages greater than 100 volts, which yields a high signal to noise ratio. The PVDF film is also anisotropic, and therefore selective; i.e., only one direction generates a relatively large response. The PVDF film can be made as thin as 9 microns, but its resistance to impact and mechanical strength remain high. Figure 3 is a cross section of a piezoelectric film-based axle sensor (PZF).

The piezoelectric ceramic cable is a coax with compressed ceramic powder between a copper core and sheath. When a force is applied to the cable, the ceramic powder is compressed and a voltage appears between the core and the sheath.

The piezoelectric plastic cable (Figure 4) is similar to the ceramic cable. The only difference is that the latter uses a ceramic powder, whereas the first uses piezo plastic. Because of their cylindrical symmetry, both sensors are isotropic and, therefore, are not selective. Also, signals generated by these two cables are about 10 times less than those generated by the PVDF film.

The electrical voltage generated by the piezoelectric cables, for instance, is given by the following formula:

$$V = K \cdot D P \cdot \frac{1}{L} \cdot \frac{C}{C + C_m} \cdot e^{-t/T}$$

where:

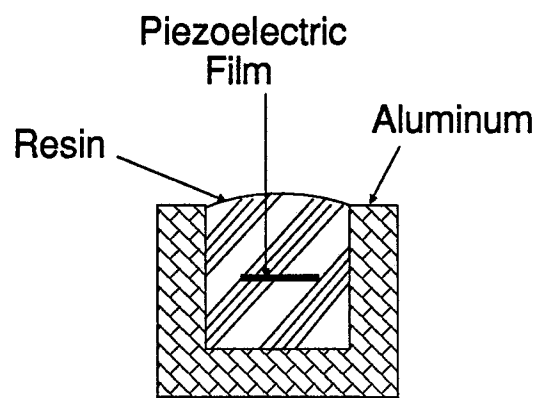


Figure 3. Cross Section of a Piezoelectric Film Axle Sensor.

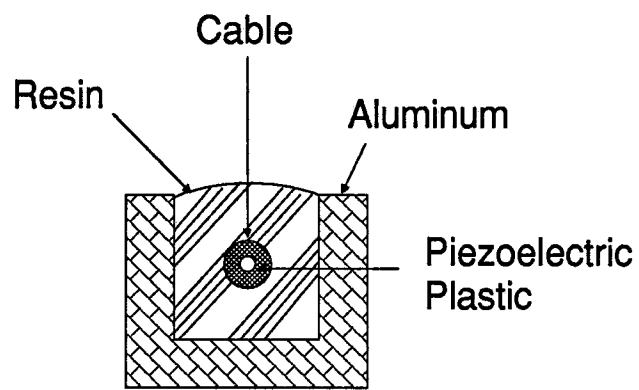


Figure 4. Cross Section of a Piezoelectric Plastic Cable Axle Sensor.

D P is the variation of the applied pressure,  
l is the length of the cable subjected to the excitation,  
L is the total length of the cable,  
C is the capacitance of the cable,  
 $C_m$  is the input capacitance of the measurement instrument,  
T is the time constant of the combined cable and circuitry, and  
K is a constant that characterizes the sensitivity (depends on the cable used.)

It must be noted that the magnitude and the shape of the signal generated by the piezoelectric sensors is greatly dependent on the input impedance of the interfacing electronics.

## LABORATORY TESTING

The laboratory testing was designed to provide data in order to evaluate the response of the axle sensors. The test setup was devised to acquire waveforms generated in response to variable loads applied to different sections of the sensors (Figure 5).

### APPARATUS

The experimental apparatus used for the testing consisted of an MTS Loading Machine, a Hewlett Packard 7090A Measuring Plotter, a Compaq Portable 286 equipped with a Math Coprocessor and a GPIB (General Purpose Interface Bus) card. The laboratory testing setup is depicted in Figure 6.

#### MTS Loading Machine

The MTS Loading Machine is capable of applying loads up to 50,000 pounds in half-sine, square and ramp shapes. The half-sine shape was used as it simulates best the variation in time of the load applied by a moving wheel.

In order to give full support to the sensors while they are being tested, a support structure was used in which each sensor was mounted.

#### Measuring Plotter

The HP 7090A is a digitizing plotter that has three input channels, each with one kilobyte buffer and 33 khz throughput. This plotter was used extensively to acquire and plot the waveforms generated by the sensors.

#### Portable Microcomputer

A Compaq Portable 286 microcomputer equipped with an 80287 Math Coprocessor, was used to retrieve the waveforms from the HP 7090A plotter through a GPIB card installed in the microcomputer. A data acquisition program was developed in MS-BASIC to control and set the plotter's parameters, and to retrieve the waveforms from the plotter's memory using HPGL (Hewlett Packard Graphics Language) and HPIB (Hewlett Packard Interface Bus) command libraries. A listing of this data acquisition program is provided in the appendix.

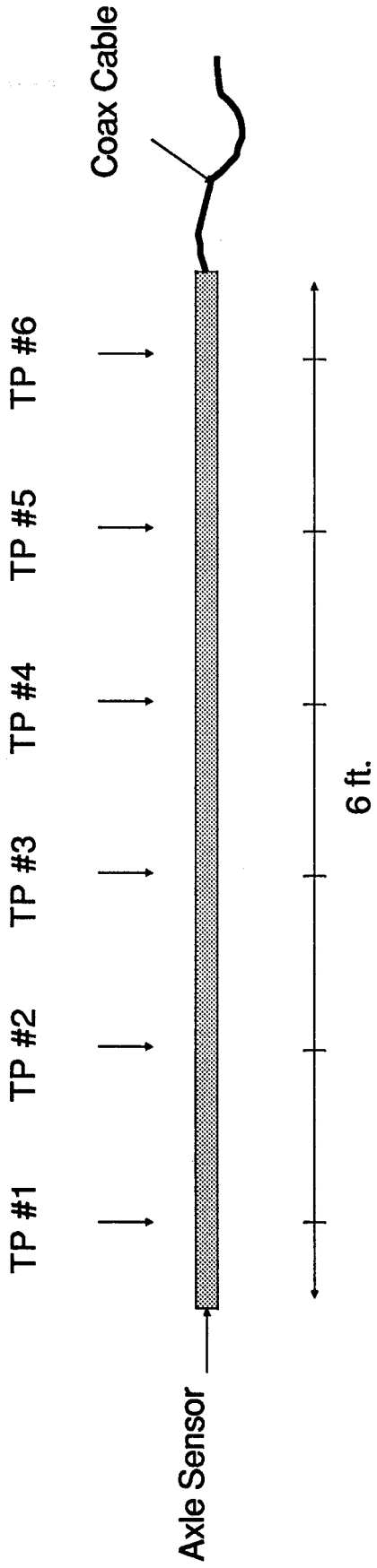


Figure 5. Testing Points.

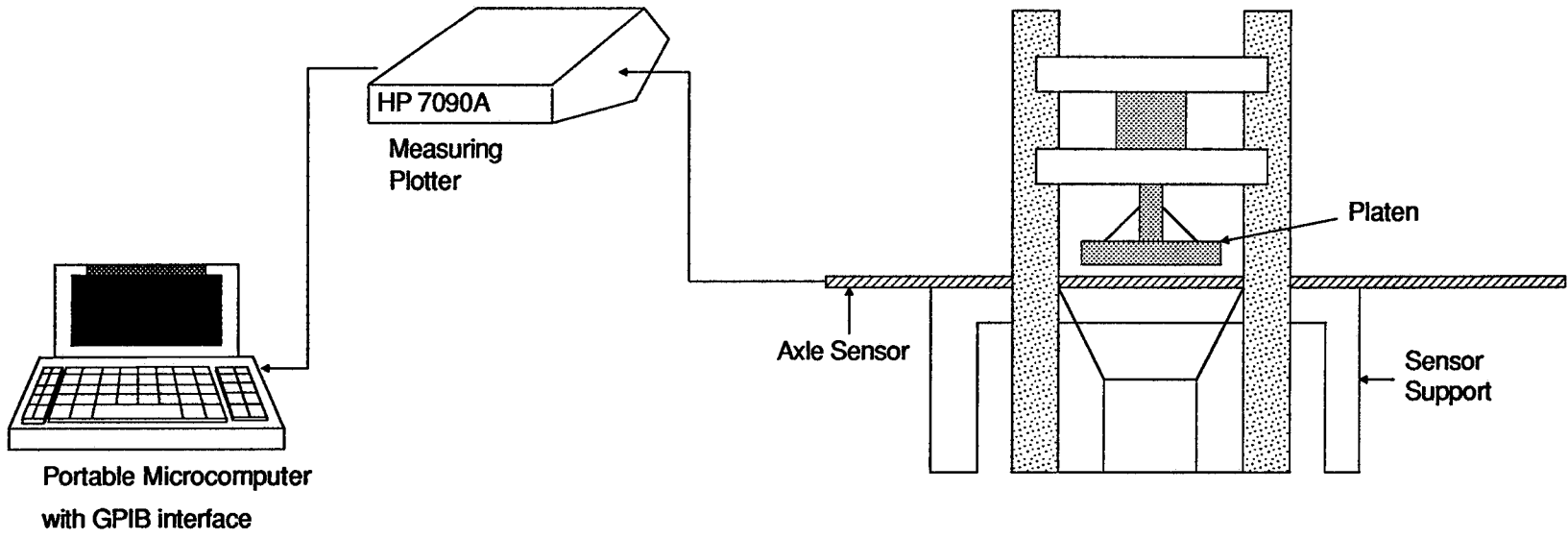


Figure 6. Laboratory Testing Setup.

## PROCEDURE

The experimental procedure used to evaluate the performance of each of the axle sensors tested consisted of: (1) applying loads varying from 1 kip to 10 kips (at 1 kip interval) at six evenly spaced testing points (TP #1 to #6) on each sensor, and (2) acquiring the waveform generated by the sensors and measuring the peak voltage value. Item (2) does not apply in the case of the tapeswitch which does not generate a voltage as a response to a load application.

The loads were applied through a steel platen with a rubber pad to emulate a tire.

The environmental tests were carried out by placing the sensors in an environmental chamber. The TTI Materials Laboratory has 12 walk-in chambers with available temperature and humidity ranges of  $-20^{\circ}\text{F}$  to  $140^{\circ}\text{F}$  and 25% to 95%, respectively. Temperature is controlled to within  $\pm 2$  F and humidity to within  $\pm 4\%$ . All the chambers are approximately 11' x 16' in area. Each room's temperature and humidity can be controlled individually with controls at the room or from a central control panel (Figure 7).

## RESULTS OF EXPERIMENTS

The waveforms collected from the sensors were stored on the hard disc in ASCII format. Each waveform was stored in a separate file of 1000 data points. The data were used in a spreadsheet to regenerate the waveforms and to further analyze the response of the sensors.

Figures 8, 9 and 10 show a typical response of each sensor. Because the TSW sensor does not generate a voltage, it was monitored only as a switch; therefore, no corresponding waveform was stored. The TSW was connected to a pull-up resistor circuit to yield a low when a load is applied and a high when no load is applied. The other three sensors did not necessitate additional circuitry and were directly connected to the measuring plotter.

Figures 11, 12 and 13 are 3-dimensional bar plots representing the linearity of the response at each testing point (TP) as the load increases, and also the uniformity of the response to the same load along the sensor.

Figures 14, 15 and 16 show line plots that characterize the linearity and the uniformity of the response of each sensor in a 2-dimensional manner.



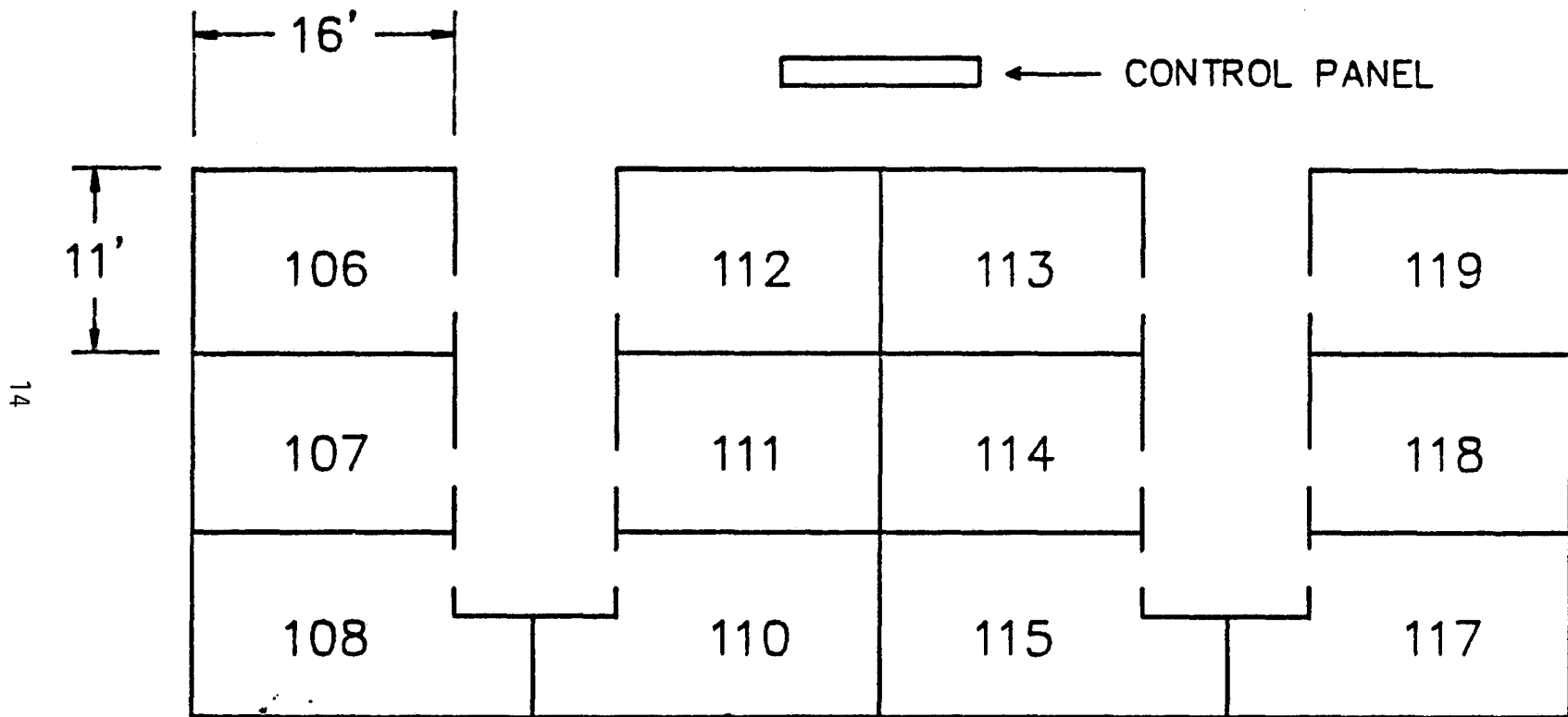


Figure 7. Environmental Chambers.

# TTI DATA ACQUISITION

## PZCC AXLE SENSOR

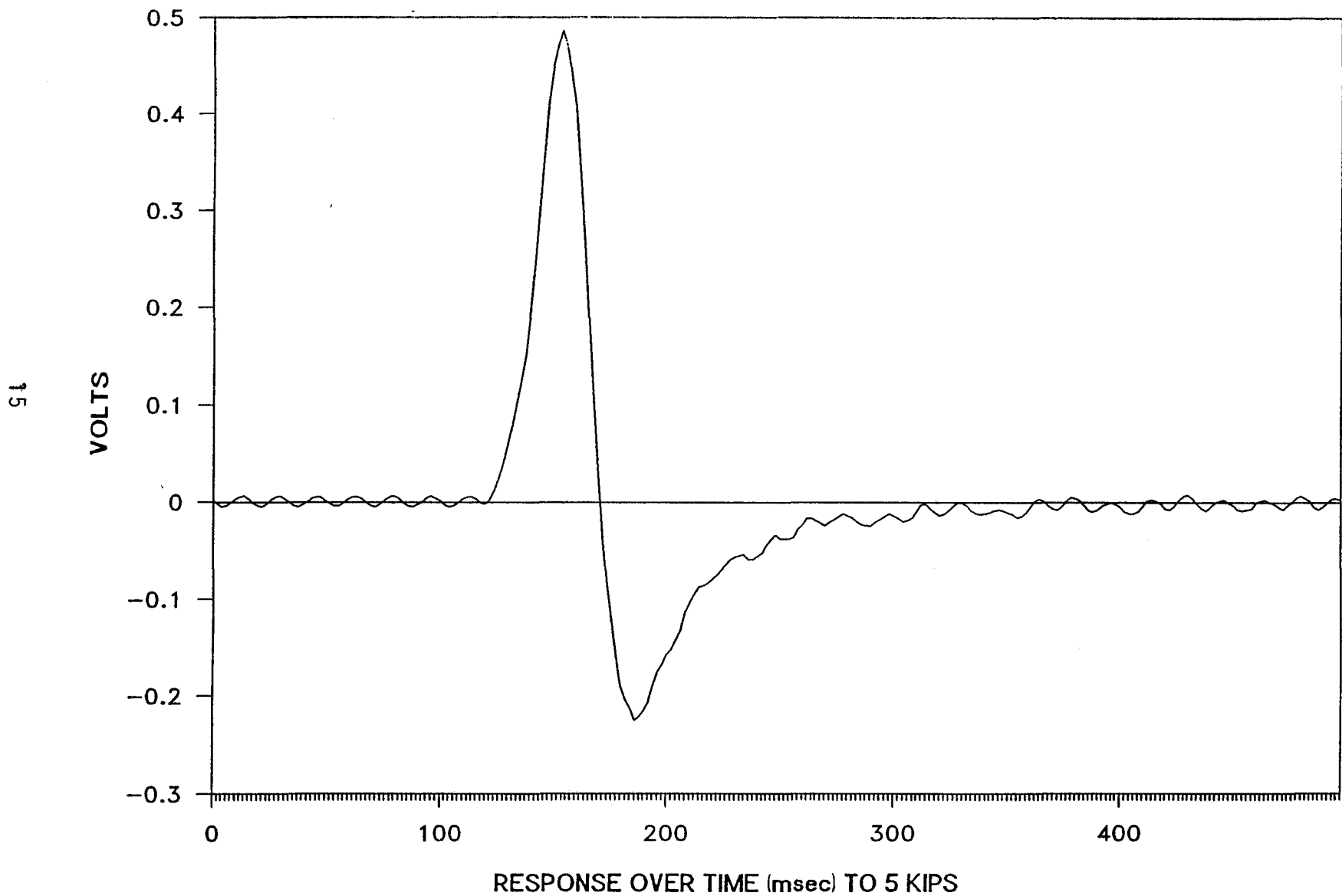


Figure 8. Typical Time Response of the PZCC Axle Sensor.

# TTI DATA ACQUISITION

## PZPC AXLE SENSOR

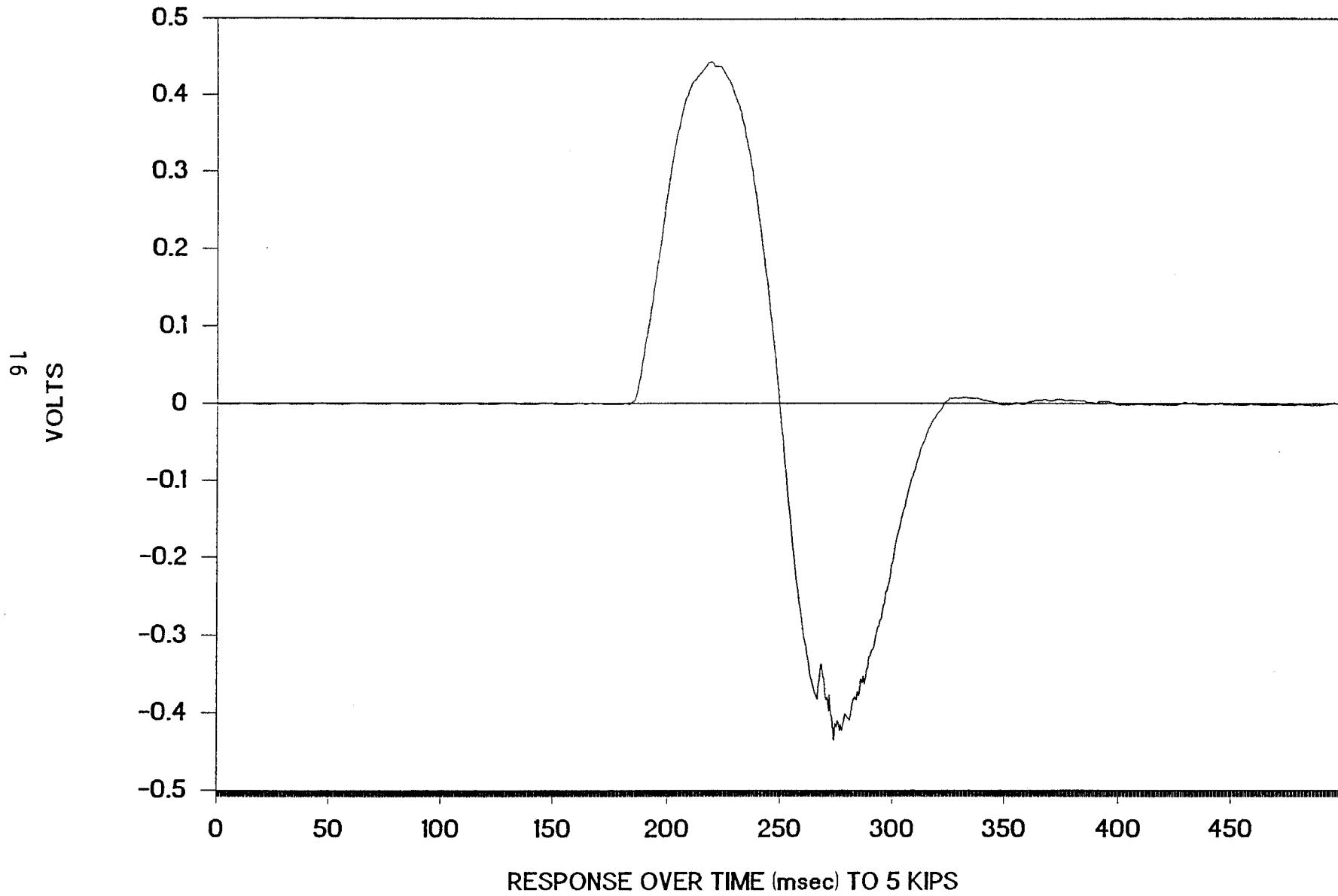


Figure 9. Typical Time Response of the PZPC Axle Sensor.

# TTI DATA ACQUISITION

## PZF AXLE SENSOR

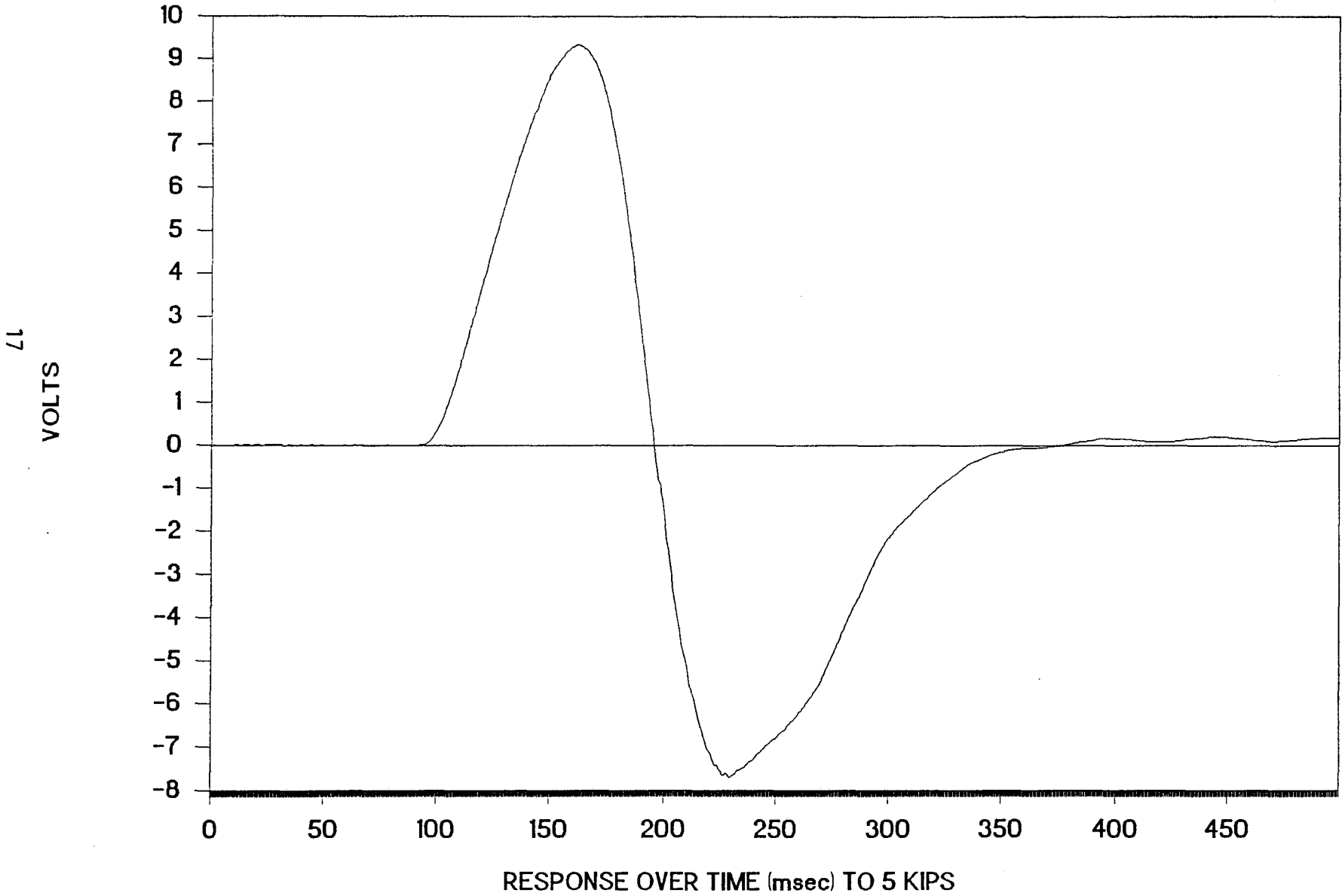


Figure 10. Typical Time Response of the PZF Axle Sensor.

# PZCC AXLE SENSOR

## MTS Load Test

18

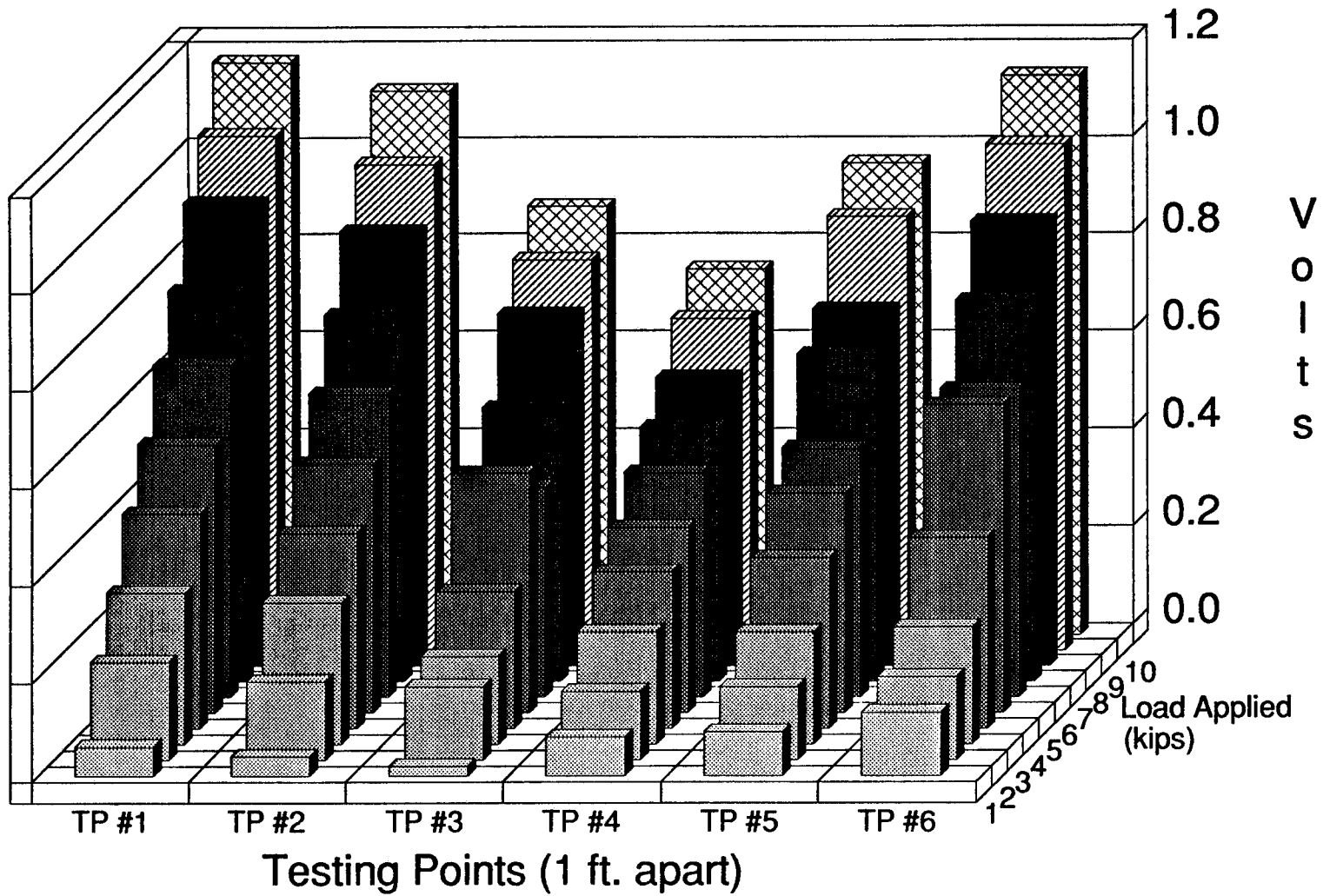


Figure 11. 3-D Plot of the PZCC Response.

# PZPC AXLE SENSOR

## MTS Load Test

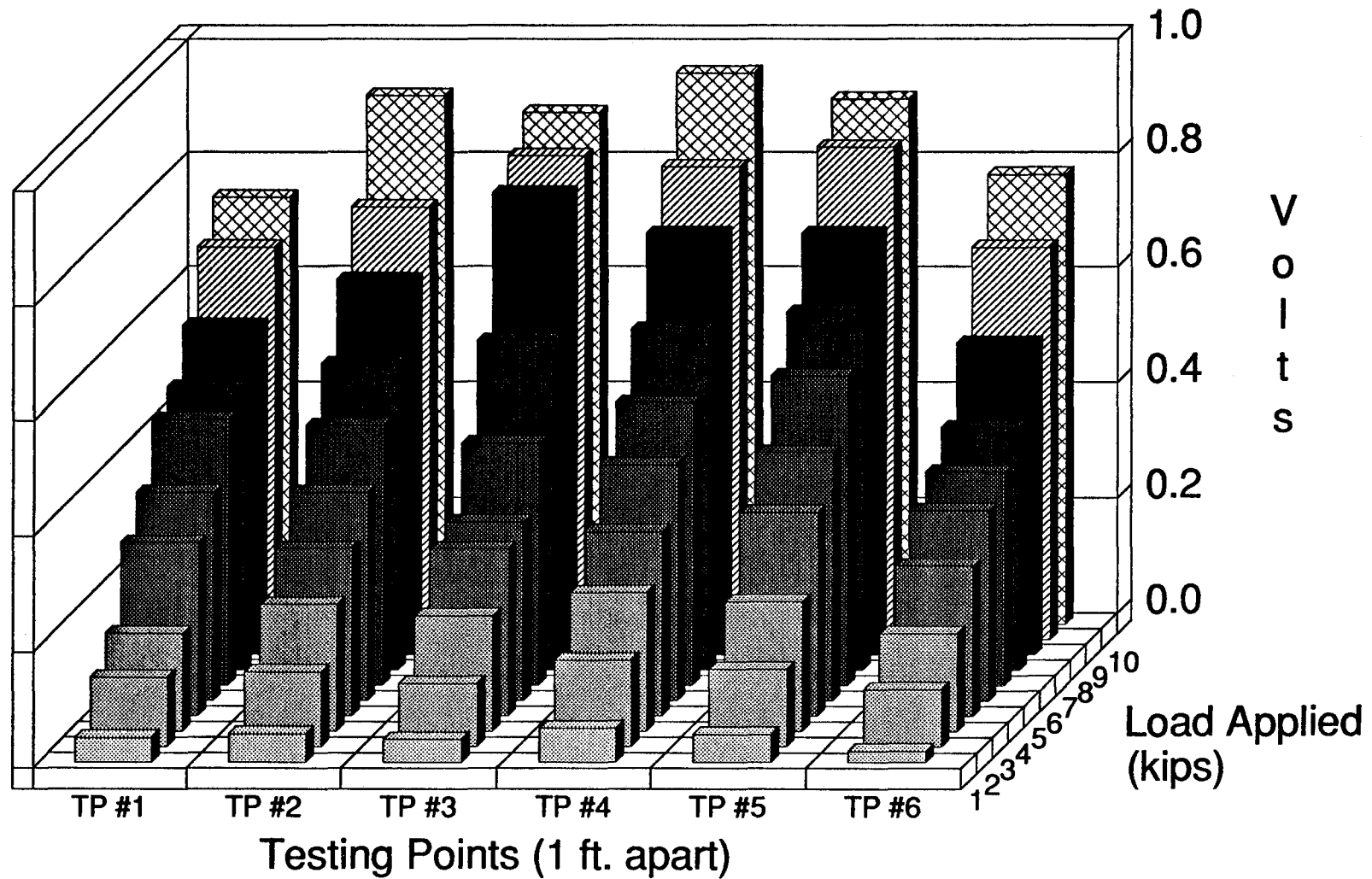


Figure 12. 3-D Plot of the PZPC Response.

# PZF AXLE SENSOR

## MTS Load Test

20

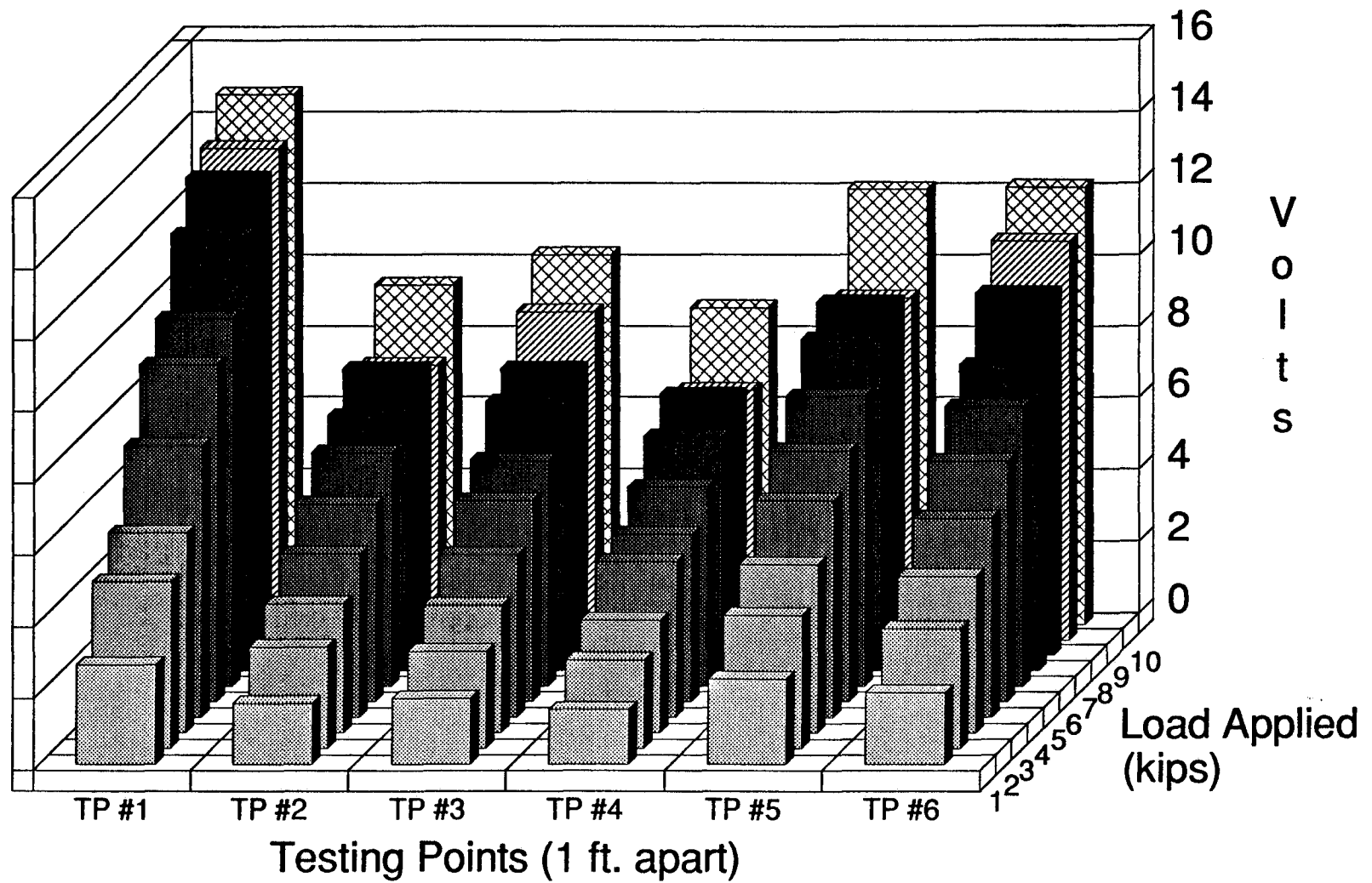


Figure 13. 3-D Plot of the PZF Response.

# PZCC AXLE SENSOR

## MTS Load Test

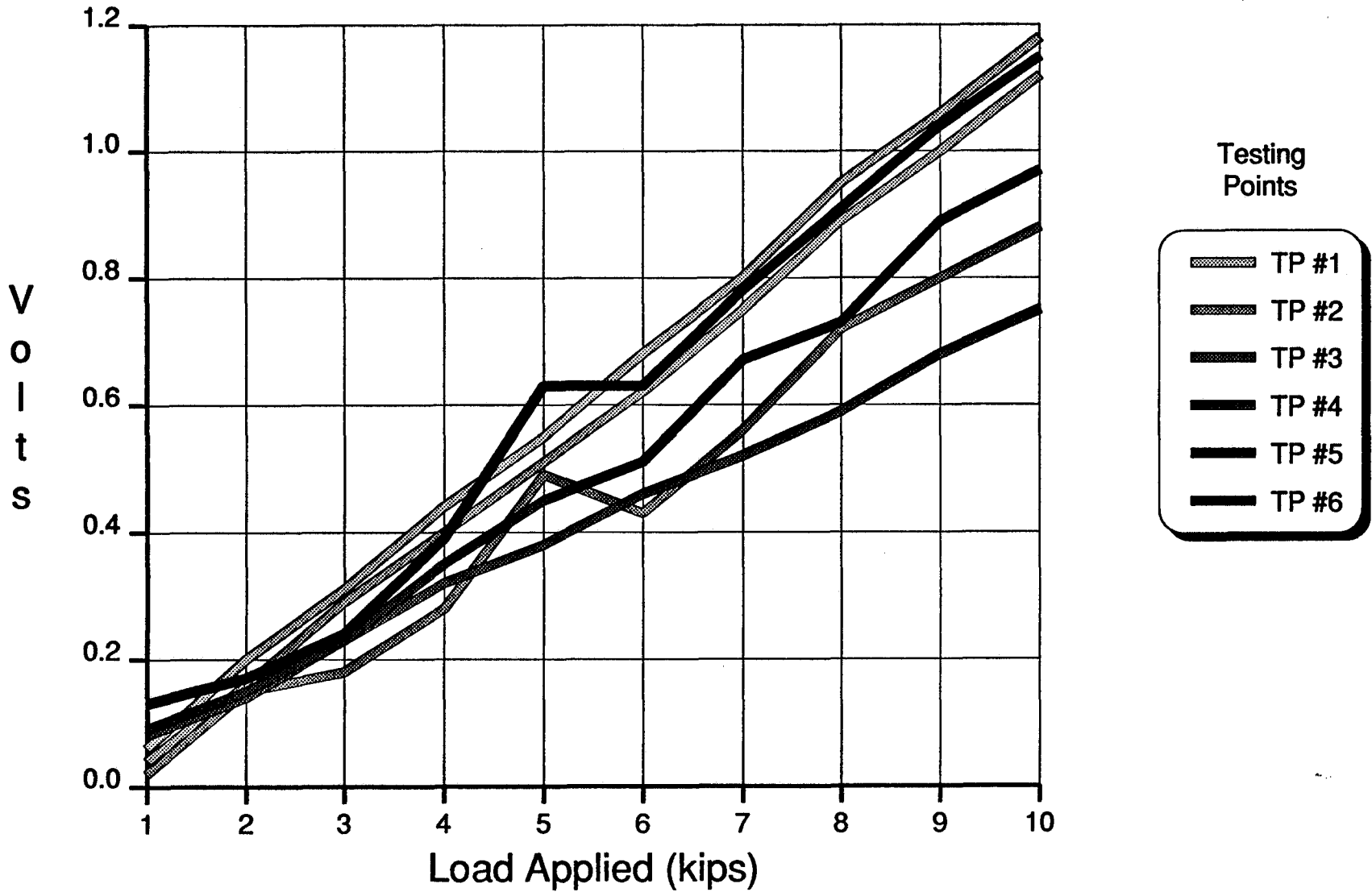


Figure 14. 2-D Plot of the PZCC Response.



# PZPC AXLE SENSOR

## MTS Load Test

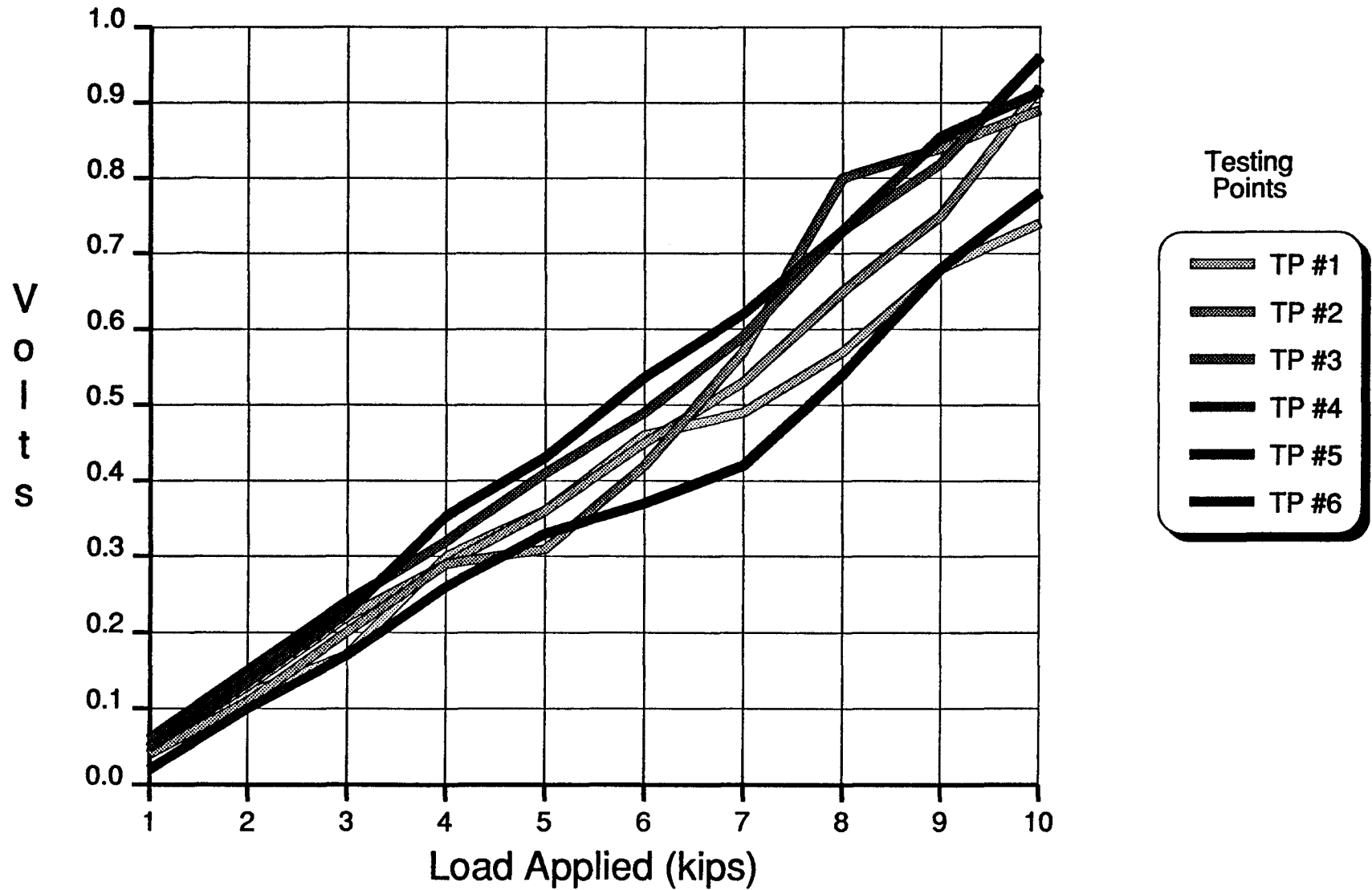


Figure 15. 2-D Plot of the PZPC Response.

# PZF AXLE SENSOR

## MTS Load Test

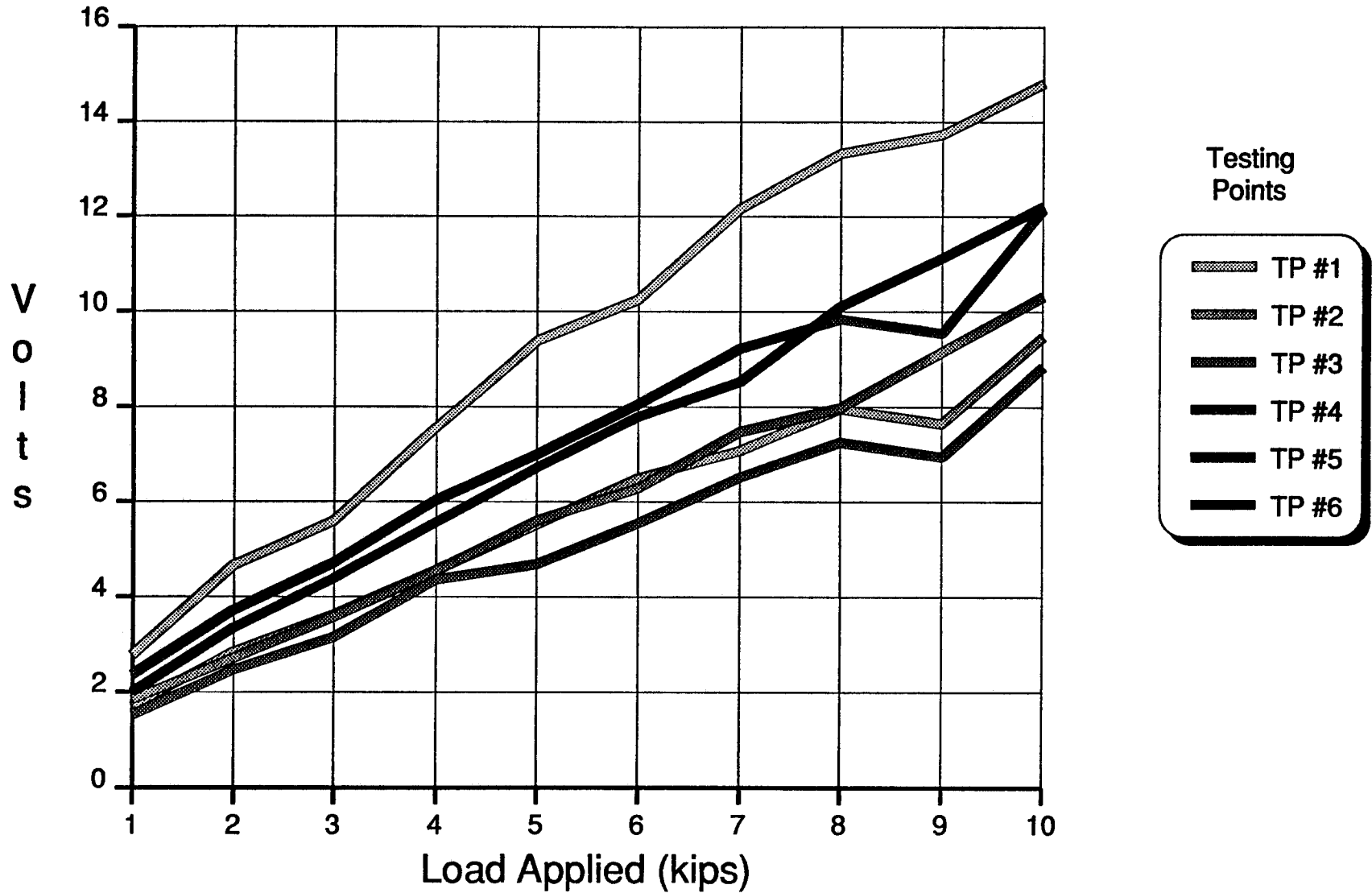


Figure 16. 2-D Plot of the PZF Response.

## DISCUSSION OF RESULTS

All load tests were performed at 32°F, 70°F, and 140°F degrees. For all four sensors temperature did not seem to have any significant effect on the response. At 32°F and 142°F, a humidity level of 92% was applied. No humidity effects were apparent within the range of the testing.

As it was expected, the PZF sensor generated voltages larger in magnitude than the PZCC and the PZPC. The two latter sensors had a similar response in linearity, but as far as uniformity is concerned, the PZPC appears to be more sensitive in the middle whereas the PZCC is more sensitive at the extreme ends of the sensor. The PZF shows some uniformity except at one end (TP #1).



## CONCLUSION

Three types of piezoelectric sensors and a tapeswitch sensor were evaluated under different environmental and load conditions. The results of the testing allowed a full characterization of the sensors as it is illustrated in the 3-dimensional bar graphs.

The tapeswitch, being based on a mechanical switch closure principle, does not generate a voltage but yields an on/off condition to indicate the passage of an axle. The response of the piezoelectric sensors to the passage of an axle is different as they generate a voltage proportional to the load applied by the axle. This property of the piezoelectric axle sensors is interesting for it allows the detection of axles for counting and classification purposes as well as the determination of the weight or weight class of axles.

It must be made clear that the PZPC and PZF prototypes used in this study were designed for axle detection. An improvement of the design and the manufacturing process would yield better response characteristics (i.e., linearity and uniformity), making these two sensors even more attractive for use in axle weight applications.



**APPENDIX**





```

1  /*****
2  /*          TEXAS TRANSPORTATION INSTITUTE          *
3  /*          TRAFFIC MONITORING                      *
4  /*          *                                       *
5  /*          DATA ACQUISITION PROGRAM              *
6  /*****
10 /*****
20 /* Lines 60 through 1140 are provided in the Hewlett Packard HPIB *
30 /* set up program for MS-DOS HP-IB I/O Library for use independent *
40 /* of the PC instrument bus system.                    *
50 /*****
60 DEF SEG
70 CLEAR ,&HFE00
80 I=&HFE00
90 /
100 / PCIB.DIR$ represents the directory where the library files
110 /     are located
120 / PCIB is an environment variable which should be set from MS-DOS
130 /     i.e. A:> SET PCIB=A:\LIB
140 /
150 /     If there is insufficient environment space a direct assignment
160 /     can be made here, i.e
170 /         PCIB.DIR$ = "A:\LIB"
180 /     Using the environment variable is the preferred method
190 /
200 PCIB.DIR$ = ENVIRON$("PCIB")
210 I$ = PCIB.DIR$ + "\PCIBILC.BLD"
220 BLOAD I$,&HFE00
230 CALL I(PCIB.DIR$, I%, J%)
240 PCIB.SEG = I%
250 IF J%=0 THEN GOTO 320
260 PRINT "Unable to load.";
270 PRINT " (Error #";J%;")"
280 STOP
290 /
300 / Define entry points for setup routines
310 /
320 DEF SEG = PCIB.SEG
330 O.S     = 5
340 C.S     = 10
350 I.V     = 15
360 I.C     = 20
370 L.P     = 25
380 LD.FILE = 30
390 GET.MEM = 35
400 L.S     = 40
410 PANELS  = 45
420 /
430 / Establish error variables and ON ERROR branching
440 /
450 DEF.ERR = 50
460 PCIB.ERR$ = STRING$(64,32)
470 PCIB.NAME$ = STRING$(16,32)
480 CALL DEF.ERR(PCIB.ERR,PCIB.ERR$,PCIB.NAME$,PCIB.GLBERR)
490 PCIB.BASERR = 255

```

```

500 ON ERROR GOTO 820
510 '
520 J=-1
530 I$=PCIB.DIR$+"\HPIB.SYN"
540 CALL O.S(I$)
550 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
560 '
570 ' Determine entry points for HP-IB Library routines
580 '
590 I=0
600 CALL I.V(I,IOABORT,IOCLEAR,IOCONTROL,IOENTER)
610 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
620 CALL I.V(I,IOENTERA,IOENTERS,IOEOI,IOEOL)
630 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
640 CALL I.V(I,IOGETTERM,IOLLOCKOUT,IOLOCAL,IOMATCH)
650 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
660 CALL I.V(I,IOOUTPUT,IOOUTPUTA,IOOUTPUTS,IOPPOLL)
670 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
680 CALL I.V(I,IOPPOLL, IOPPOLLU,IOREMOTE,IORESET)
690 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
700 CALL I.V(I,IOSEND,IOSPOLL,IOSTATUS,IOTIMEOUT)
710 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
720 CALL I.V(I,IOTRIGGER,IODMA,J,J)
730 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
740 CALL C.S
750 I$=PCIB.DIR$+"\HPIB.PLD"
760 CALL L.P(I$)
770 IF PCIB.ERR<>0 THEN ERROR PCIB.BASERR
780 GOTO 950
790 '
800 ' Error handling routine
810 '
820 IF ERR=PCIB.BASERR THEN GOTO 850
830 PRINT "BASIC error #";ERR;" occurred in line ";ERL
840 STOP
850 TMPERR = PCIB.ERR
860 IF TMPERR = 0 THEN TMPERR = PCIB.GLBERR
870 PRINT "PC Instrument error #";TMPERR;" detected at line ";ERL
880 PRINT "Error: ";PCIB.ERR$
890 STOP
900 '
910 ' COMMON declarations are needed if your program is going to chain
920 ' to other programs. When chaining, be sure to call DEF.ERR as
930 ' well upon entering the chained-to program
940 '
950 COMMON PCIB.DIR$,PCIB.SEG
960 COMMON LD.FILE,GET.MEM,PANELS,DEF.ERR
970 COMMON PCIB.BASERR,PCIB.ERR,PCIB.ERR$,PCIB.NAME$,PCIB.GLBERR
980 COMMON IOABORT,IOCLEAR,IOCONTROL,IOENTER,IOENTERA,IOENTERS,IOEOI,IOEOL,
IOGETTERM,IOLLOCKOUT,IOLOCAL,IOMATCH,IOOUTPUT,IOOUTPUTA,IOOUTPUTS,
IOPPOLL,IOPPOLL, IOPPOLLU,IOREMOTE,IORESET,IOSEND,IOSPOLL,IOSTATUS,IOTIMEOUT,
IOTRIGGER,IODMA
990 '
1000 FALSE = 0
1010 TRUE = NOT FALSE

```

```

1020 NOERR      = 0
1030 EUNKNOWN  = 100001!
1040 ESEL      = 100002!
1050 ERANGE    = 100003!
1060 ETIME     = 100004!
1070 ECTRL     = 100005!
1080 EPASS     = 100006!
1090 ENUM      = 100007!
1100 EADDR     = 100008!
1110 COMMON FALSE, TRUE, NOERR, EUNKNOWN, ESEL, ERANGE, ETIME, ECTRL, EPASS,
ENUM, EADDR
1120 '
1130 ' End Program Set-up
1140 ' User program can begin anywhere past this point
1145 '*****
1146 '* Here begins the instruction routine for the 7090A plotter control *
1147 '* system. It was written to utilize the HPIB interface bus. This *
1148 '* program was written by T.T.I. *
1149 '*****
1150 CLS
1160 '*****
1161 '* Lines 1170-1300 initialize the HPIB interface for the HP 7090A plotter
1162 '*****
1170 ISC = 7
1180 ENABLE = 1
1190 PLT = 705
1200 DIM READS(2000)
1210 DIM VOLTAGE(1000)
1220 DIM READING(1000)
1240 CALL IORESET(ISC)
1260 CALL IOEOI(ISC,ENABLE)
1280 CALL IOREMOTE(ISC)
1300 CALL IOCLEAR(ISC)
1310 '*****
1311 '* THIS SECTION INQUIRES ABOUT SKIPPING THE SETUP OR NOT *
1312 '*****
1320 F$=""
1330 RESP$ = ""
1350 CLS:INPUT "DO YOU WISH TO SKIP THE SETUP ";RESP$
1360 IF RESP$="Y" OR RESP$="y" THEN 7710
1370 '*****
1371 '* THIS SECTION INQUIRES THE NUMBER OF CHANNELS BEING USED FOR DATA *
1372 '*ACQUISITION. IT THEN SENDS THAT INFORMATION TO THE PLOTTER. THE VALUE*
1373 '*IS ALSO USED IN THE LAST MODULE. *
1374 '*****
1375 NUMCHAN$=""
1380 CLS:INPUT "HOW MANY CHANNELS DO YOU NEED TO USE:";NUMCHAN$
1390 IF VAL(NUMCHAN$)<1 OR VAL(NUMCHAN$)>3 THEN PRINT "PLEASE TRY AGAIN"
:FOR I = 1 TO 2000:NEXT I:GOTO 1380
1391 IF VAL(NUMCHAN$)=1 THEN CODE$="re 9;" ELSE IF VAL(NUMCHAN$)=2
THEN CODE$="re 13;" ELSE CODE$="re 15;"
1392 IF VAL(NUMCHAN$)=1 THEN GOTO 1394; ELSE IF VAL(NUMCHAN$)=2
THEN GOTO 1410;ELSE GOTO 1430
1394 CODE$="re 9;"
1395 LENGTH=LEN(CODE$)

```

```

1396 CALL IOOUTPUTS(PLT, CODE$, LENGTH)
1397 CODE$="IR10.0,10.0,10.0;"
1398 PRINT "SELECT VOLTAGE RANGE FOR CHANNEL 1"
1400 PRINT "RANGE: .005 TO 10.0 Volts"
1402 PRINT "input EXACTLY four characters including the decimal point"
1404 INPUT "CHANNEL 1: ";RESP$
1406 MID$(CODE$,3)=RESP$
1407 LENGTH=LEN(CODE$)
1408 CALL IOOUTPUTS(PLT, CODE$, LENGTH)
1409 GOTO 1460
1410 CODE$="re 13;"
1411 LENGTH=LEN(CODE$)
1412 CALL IOOUTPUTS(PLT, CODE$, LENGTH)
1413 CODE$="IR10.0,10.0,10.0;"
1414 PRINT "SELECT VOLTAGE RANGE FOR CHANNELS 1 AND 2"
1416 PRINT "RANGE: .005 TO 10.0 Volts"
1418 PRINT "input EXACTLY four characters including the decimal point"
1420 INPUT "CHANNEL 1: ";RESP$
1422 MID$(CODE$,3)=RESP$
1424 INPUT "CHANNEL 2: ";RESP$
1426 MID$(CODE$,8)=RESP$
1427 LENGTH=LEN(CODE$)
1428 CALL IOOUTPUTS(PLT, CODE$, LENGTH)
1429 GOTO 1460
1430 CODE$="re 15;"
1431 LENGTH=LEN(CODE$)
1432 CALL IOOUTPUTS(PLT, CODE$, LENGTH)
1433 CODE$="IR10.0,10.0,10.0;"
1434 PRINT "SELECT VOLTAGE RANGE FOR CHANNELS 1, 2, and 3"
1436 PRINT "RANGE: .005 TO 10.0 Volts"
1438 PRINT "input EXACTLY four characters including the decimal point"
1440 INPUT "CHANNEL 1: ";RESP$
1442 MID$(CODE$,3)=RESP$
1444 INPUT "CHANNEL 2: ";RESP$
1446 MID$(CODE$,8)=RESP$
1448 INPUT "CHANNEL 3: ";RESP$
1450 MID$(CODE$,13)=RESP$
1451 LENGTH=LEN(CODE$)
1452 CALL IOOUTPUTS(PLT, CODE$, LENGTH)
2370 '*****
2371 '* THIS SECTION SELECTS THE OFFSET VOLTAGES FOR YOUR CHANNELS. *
2372 '* IT THEN SENDS THAT INFORMATION TO THE PLOTTER. *
2373 '*****
2375 NUMCHAN$=""
2380 CLS:INPUT "HOW MANY CHANNELS DO YOU NEED TO DEFINE THE OFFSET: ";NUMCHAN$
2390 IF VAL(NUMCHAN$)<1 OR VAL(NUMCHAN$)>3 THEN PRINT "PLEASE TRY AGAIN"
:FOR I = 1 TO 2000:NEXT I:GOTO 2380
2392 IF VAL(NUMCHAN$)=1 THEN GOTO 2394; ELSE IF VAL(NUMCHAN$)=2
THEN GOTO 2410;ELSE GOTO 2430
2394 '
2397 CODE$="SV0.00,0.00,0.00;"
2398 PRINT "SELECT VOLTAGE OFFSET FOR CHANNEL 1"
2400 PRINT "RANGE: -100 to +100 Volts"
2402 PRINT "input EXACTLY four characters including the sign"
2404 INPUT "CHANNEL 1: ";RESP$

```

```

2406 MID$(CODE$,3)=RESP$
2407 LENGTH=LEN(CODE$)
2408 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
2409 GOTO 2460
2410 '
2411 '
2412 '
2413 CODE$="SVO.00,0.00,0.00;"
2414 PRINT "SELECT VOLTAGE OFFSET FOR CHANNELS 1 AND 2"
2416 PRINT "RANGE: -100 to +100 Volts"
2418 PRINT "input EXACTLY four characters including the sign"
2420 INPUT "CHANNEL 1:";RESP$
2422 MID$(CODE$,3)=RESP$
2424 INPUT "CHANNEL 2:";RESP$
2426 MID$(CODE$,8)=RESP$
2427 LENGTH=LEN(CODE$)
2428 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
2429 GOTO 2460
2430 '
2431 '
2432 '
2433 CODE$="SVO.00,0.00,0.00;"
2434 PRINT "SELECT VOLTAGE RANGE FOR CHANNELS 1, 2, and 3"
2436 PRINT "RANGE: -100 to +100 Volts"
2438 PRINT "input EXACTLY four characters including the sign"
2440 INPUT "CHANNEL 1:";RESP$
2442 MID$(CODE$,3)=RESP$
2444 INPUT "CHANNEL 2:";RESP$
2446 MID$(CODE$,8)=RESP$
2448 INPUT "CHANNEL 3:";RESP$
2450 MID$(CODE$,13)=RESP$
2451 LENGTH=LEN(CODE$)
2452 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
2460 GOTO 3462
3461 '*****
3462 '*THIS SECTION QUERIES FOR THE TIME INTERVAL OF THE DESIRED SAMPLE. *
3464 '*IT THEN SENDS THAT INFORMATION TO THE PLOTTER. THIS IS THE DURATION*
3466 '*THAT THE PLOTTER WILL SAMPLE. *
3467 '*****
3468 CLS:PRINT "SELECTION OF THE TOTAL TIME FOR THE TEST"
3470 PRINT "Input 0 for SECONDS, 1 for MINUTES, 2 for HOURS"
3472 INPUT RESP$
3474 IF VAL(RESP$)<0 OR VAL(RESP$)>2 THEN GOTO 3472
3476 CODE$="tb5.000,0;"
3478 LENGTH=LEN(CODE$)
3480 MID$(CODE$,9)=RESP$
3482 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
3484 IF VAL(RESP$)=0 THEN GOTO 3490
3486 IF VAL(RESP$)=1 THEN GOTO 3502
3488 IF VAL(RESP$)=2 THEN GOTO 3514
3490 PRINT "You have selected SECONDS for the test total time"
3492 PRINT "Choose now the range"
3494 PRINT "RANGE: 0.030 to 100.0"
3496 PRINT "Input EXACTLY five characters including the decimal point"
3498 INPUT "SECONDS:";RESP$

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```

3500 GOTO 3522
3502 PRINT "You have selected MINUTES for the test total time"
3504 PRINT "Choose now the range"
3506 PRINT "RANGE: 1.000 to 100.0"
3508 PRINT "Input EXACTLY five characters including the decimal point"
3510 INPUT "MINUTES: ";RESP$
3512 GOTO 3522
3514 PRINT "You have selected HOURS for the test total time"
3516 PRINT "Choose now the range"
3518 PRINT "RANGE: 1.000 to 24.00"
3520 PRINT "Input EXACTLY five characters including the decimal point"
3521 INPUT "HOURS: ";RESP$
3522 LENGTH=LEN(CODE$)
3524 MID$(CODE$,3)=RESP$
3526 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
3536 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
3537 GOTO 4462
4460 /*****
4462 /* THIS SECTION QUERIES FOR THE PRE AND POST TRIGGER OPTION *
4464 /*****
4466 /
4468 CLS:PRINT "SELECTION OF THE PRE AND/OR POST TRIGGER VALUES"
4470 PRINT "Input 0 for SECONDS, 1 for MINUTES, 2 for HOURS"
4472 INPUT RESP$
4474 IF VAL(RESP$)<0 OR VAL(RESP$)>2 THEN GOTO 4472
4476 CODE$="tg0.000,0;"
4478 LENGTH=LEN(CODE$)
4480 MID$(CODE$,9)=RESP$
4482 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
4484 IF VAL(RESP$)=0 THEN GOTO 4490
4486 IF VAL(RESP$)=1 THEN GOTO 4502
4488 IF VAL(RESP$)=2 THEN GOTO 4514
4490 PRINT "You have selected SECONDS for the pre or post trigger values"
4492 PRINT "Choose now the range"
4493 PRINT "Choose a positive sign for post-trigger range"
4494 PRINT "Choose a negative sign for pre-trigger range"
4495 PRINT "RANGE: +0.00 to +100.0 for post-trigger"
4496 PRINT "RANGE: -0.00 to -100.0 for pre-trigger"
4497 PRINT "Input EXACTLY five characters including the decimal point and sign"
4498 INPUT "SECONDS: ";RESP$
4500 GOTO 4522
4502 PRINT "You have selected MINUTES for the pre or post-trigger value"
4504 PRINT "Choose now the range"
4506 PRINT "RANGE: 1.000 to 100.0"
4507 PRINT "RANGE: +1.00 to +100.0 for post-trigger"
4508 PRINT "RANGE: -1.00 to -100.0 for pre-trigger"
4509 PRINT "Input EXACTLY five characters including the decimal point and sign"
4510 INPUT "MINUTES: ";RESP$
4512 GOTO 4522
4514 PRINT "You have selected HOURS for the pre or post-trigger value"
4516 PRINT "Choose now the range"
4518 PRINT "RANGE: +1.00 to +24.0 for post-trigger"
4519 PRINT "RANGE: -1.00 to -24.0 for pre-trigger"
4520 PRINT "Input EXACTLY five characters including the decimal point and sign"
4521 INPUT "HOURS: ";RESP$

```

```

4522 LENGTH=LEN(CODE$)
4524 MID$(CODE$,3)=RESP$
4526 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
4537 GOTO 5538
5538 /*****
5540 /*THIS SECTION ASKS THE USER FOR THE TRIGGER MODE AND THE OPTION FOR *
5542 /*THAT MODE. REFER TO PAGE 3-14 IN THE HP7090A INTERFACING MANUAL. *
5543 /*****
5544 CLS:PRINT "WHAT IS THE TRIGGER MODE YOU WISH ?"
5546 PRINT "          0=MANUAL"
5548 PRINT "          1=EXTERNAL"
5550 PRINT "          2=INTERNAL"
5560 INPUT "WHAT IS THE TRIGGER MODE ";RESP$
5570 IF VAL(RESP$)<0 OR VAL(RESP$)>2 THEN 5560
5580 CODE$="TM2,0;"
5590 MID$(CODE$,3)=RESP$
5600 CLS:PRINT "PLEASE SELECT THE TRIGGER MODE OPTIONS"
5610 PRINT "          0=ABOVE LEVEL"
5620 PRINT "          1=BELOW LEVEL"
5630 PRINT "          2=INSIDE WINDOW"
5640 PRINT "          3=OUTSIDE WINDOW"
5650 INPUT "WHAT OPTION DO YOU SELECT ";RESP$
5660 IF VAL(RESP$)<0 OR VAL(RESP$)>3 THEN GOTO 5600
5670 MID$(CODE$,5)=RESP$
5680 LENGTH = LEN(CODE$)
5690 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
7700 /*****
7702 /* THIS SECTION ACQUIRES DATA USING THE DIRECT MODE *
7704 /* AT A RATE OF 100 SAMPLES PER SECOND. *
7706 /*****
7710 CLS: PRINT "TURN SOURCE ON, THEN PRESS RETURN"
7720 INPUT RESP$
7730 CODE$ = "MS0;"
7740 LENGTH = LEN(CODE$)
7750 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
7760 CODE$ = "SD.010;"
7770 LENGTH = LEN(CODE$)
7780 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
7850 CODE$ = "D01,100,0,0;"
7860 LENGTH = LEN(CODE$)
7870 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
7900 CODE$ = "QD;"
7910 LENGTH = LEN(CODE$)
7920 CALL IOOUTPUTS(PLT,CODE$,LENGTH)
7930 MAXSAMPL = 100
7940 ACTSAMPL = 0
7950 CALL IOENTERA(PLT,VOLTAGE(1),MAXSAMPL,ACTSAMPL)
7955 FOR N=1 TO 20
7960 PRINT N,VOLTAGE(N)
7965 NEXT N
7975 CLS:INPUT "Do you wish to continue data acquisition ";RESP$
7980 IF RESP$="Y" OR RESP$="y" THEN 1320
7985 REM ****
7990 SYSTEM
7995 END

```