FHWA/RD-80/134

Wheel Force Transducer

CALIBRATION REPORT

MD-R-1166-03

May 1979

Contract DOT-FH-11-9437

Prepared for:

DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION
Washington, D.C. 20590

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Wheel Force Transducer

CALIBRATION REPORT

1.0 INTRODUCTION

The Wheel Force Transducer was developed for the Federal Highway Administration under Contract DOT-FH-11-9437 for dynamic measurement of vertical, longitudinal and transverse truck wheel loads. Modification No. Two (2) to the development contract required that a limited static calibration and a functional dynamic test of the transducer be completed prior to delivery. The tests involved three setups:

1) The transducer was statically loaded to 3000 lb for transverse calibration in a shop setup.

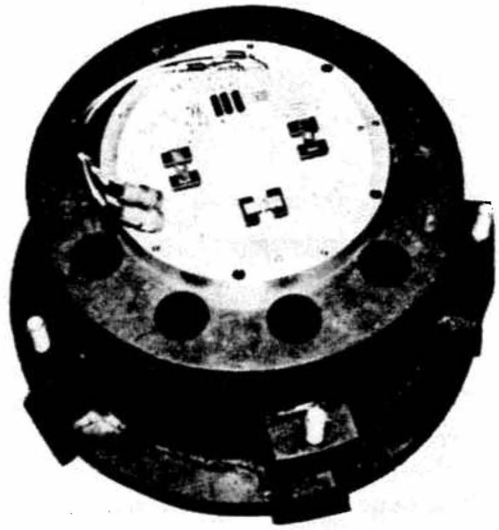
2) The shear gages were calibrated under static loads up to 8000 lb with the transducer mounted on a loaded truck.

3) For the functional dynamic test, the transducer outputs were monitored on a strip chart recorder with the truck in motion over short distances.

Figure 1 includes a photo of the transducer mounted on the test truck.

It should be recognized that these calibration tests were limited in several respects:

- The available static loads did not approach the full-scale sensor capacity.
- The method of loading and force measurement allowed only limited evaluation of crosstalk effects.
- The functional dynamic test involved only low speed operation over a smooth surface.



(a) Unmounted - Tires/rims and cover assembly removed

(b) Installed on truck for functional dynamic test

Figure 1. Wheel Force Transducer Photos

2.0 TEST PROCEDURE

Two tires, rims and a spacer were assembled on the Wheel Force Transducer. The dual wheel assembly was electrically connected to the power supplies and read-out devices via the vertical and horizontal Analog Resolver as shown in Figure 2. A Western Scale Company 10,000 lb portable axle scale was used to measure the applied force. The scale description is shown in Figure 3. A copy of the scale calibration run by the manufacturer immediately before this test is shown included as Figure 4; the calibration points are all well within the ±50 lb quoted accuracy.

Transverse Load Calibration

The wheel sensor and tire assembly was placed in an upright position on the tires and power applied to the system. After a one-hour warm-up period, the T amplifier output was adjusted to zero volts using potentiometer R-6. (See Operation Manual, Figure 5). The dual wheel assembly was rotated until the reference line on the cover assembly was vertical and the A amplifier output adjusted to zero volts using R-2. The wheel assembly was then rolled until the reference line was horizontal and the B amplifier output adjusted to zero volts using R-4.

The test setup for the transverse wheel load calibration is shown in Figure 5. This setup allowed the application of up to 3000 lb as an inboard loading on the tires. The scale was leveled and the weight of the assembly fixture alone was noted. This weight plus 18.7 lb (which represents the weight of the inner cylinder not measured by the transverse gages) became the tare weight and was subtracted from all scale readings to establish the net load. The Wheel Force Transducer, the load fixture, and the hydraulic jack were placed on top of the assembly fixture. The load fixture has three legs which fit on the rims and provide for clearance between the jack and the transducer cover assembly. The whole assembly was centered under a post

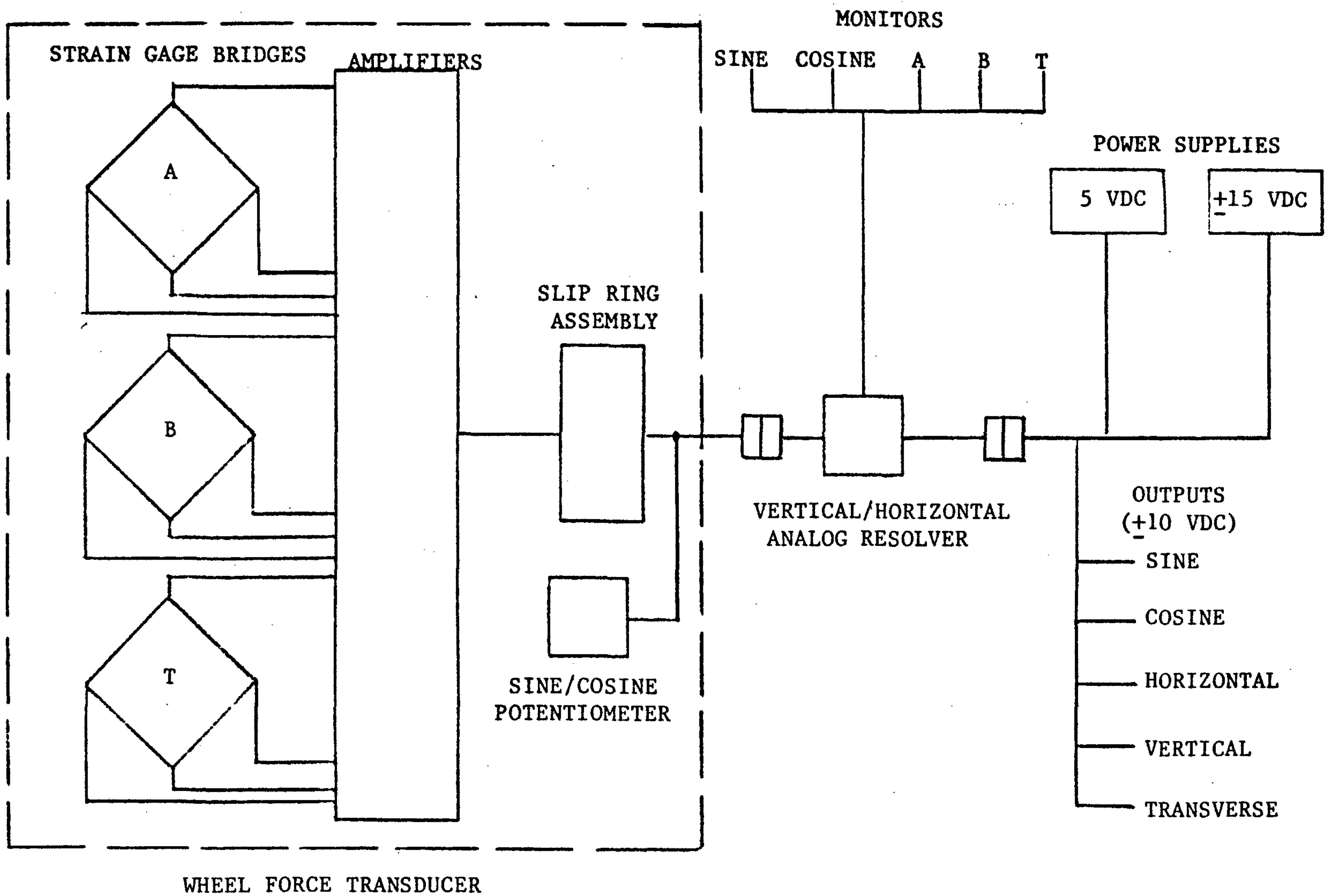


Figure 2. System Block Diagram

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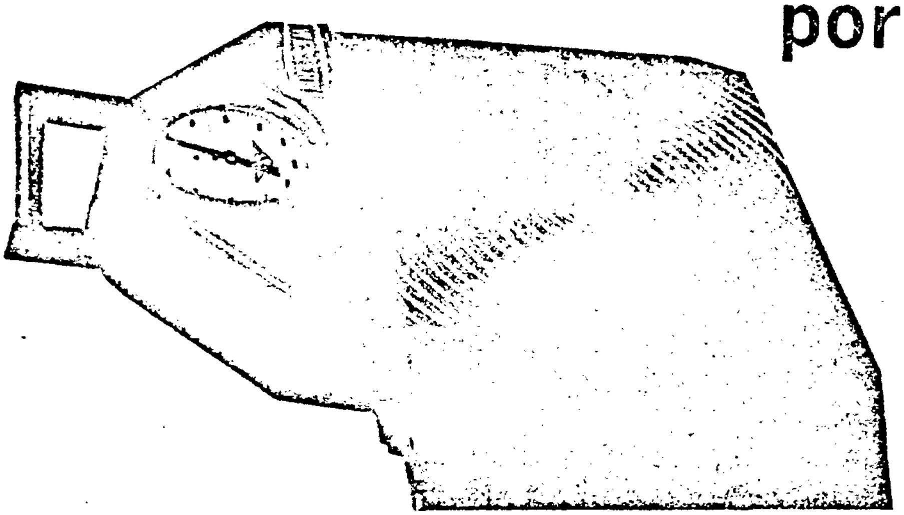
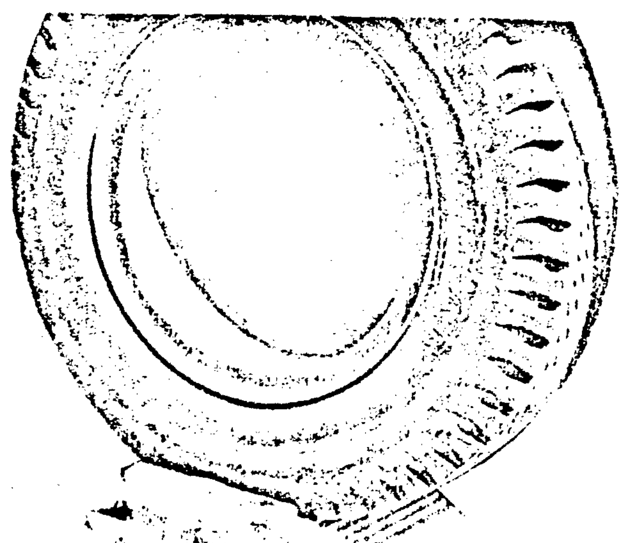
WESTERN WEIGHING EQUIPMENT



portable axle scale

A 10,000 lb hand-portable axle scale for field weighing of loaded vehicles.

Scale Range	50 lbs to 10,000 lbs
Accuracy	±50 lbs @ full scale
Weight	35 lbs
Platform Height	2 inches
Platform Size	11 x 12
Overall Size	18 x 19



A unique hydraulic totalizing scale system offering unequalled portability, reliability and ruggedness. Developed specifically for field verification that vehicle loads are within legal and safety limits.

Figure 3

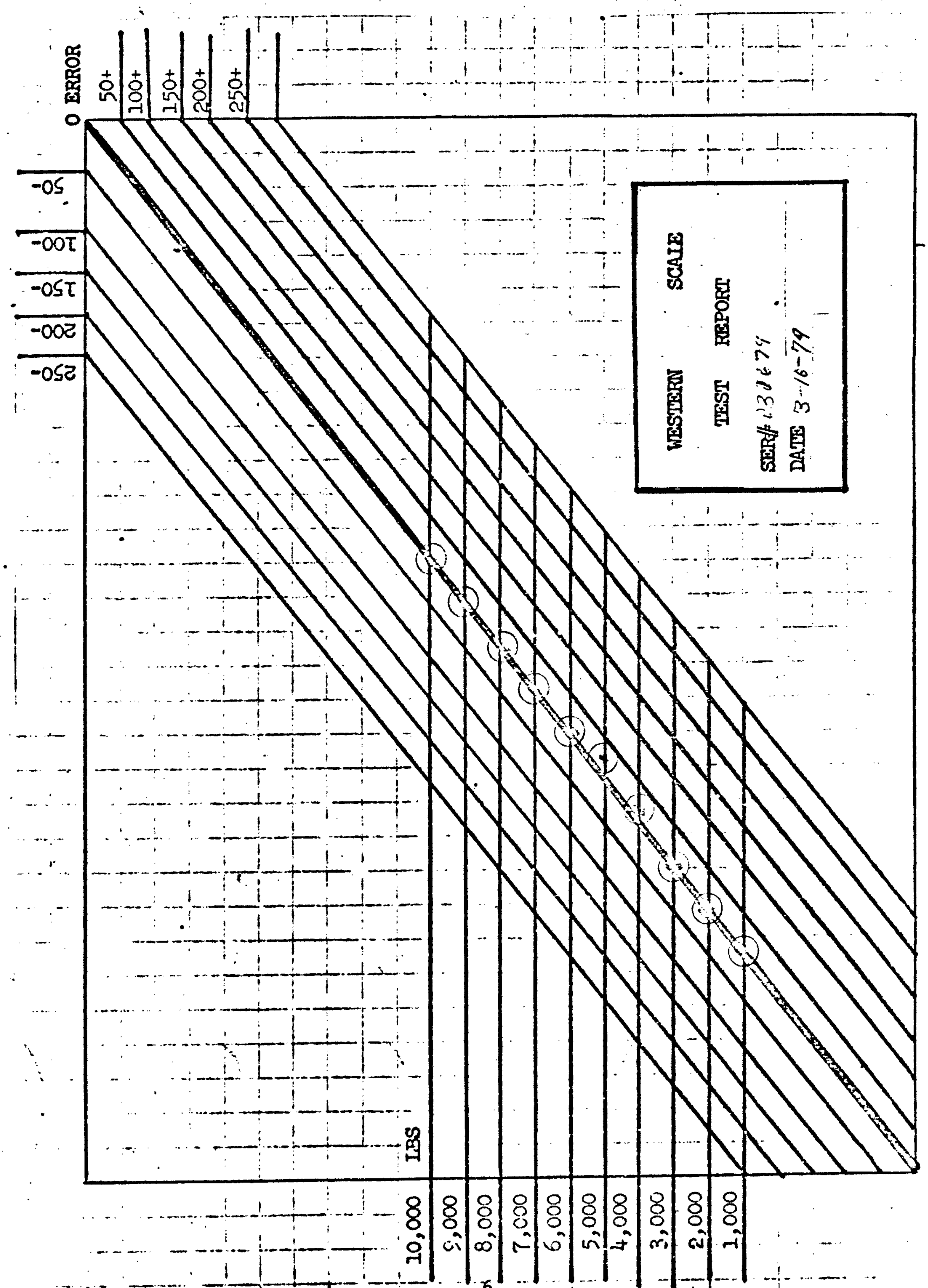

0 ERROR
50+
100+
150+
200+
250+
50-
100-
150-
200-
250-
LBS
10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
WESTERN SCALE
TEST REPORT
SER#
DATE 3-16-79

Figure 4

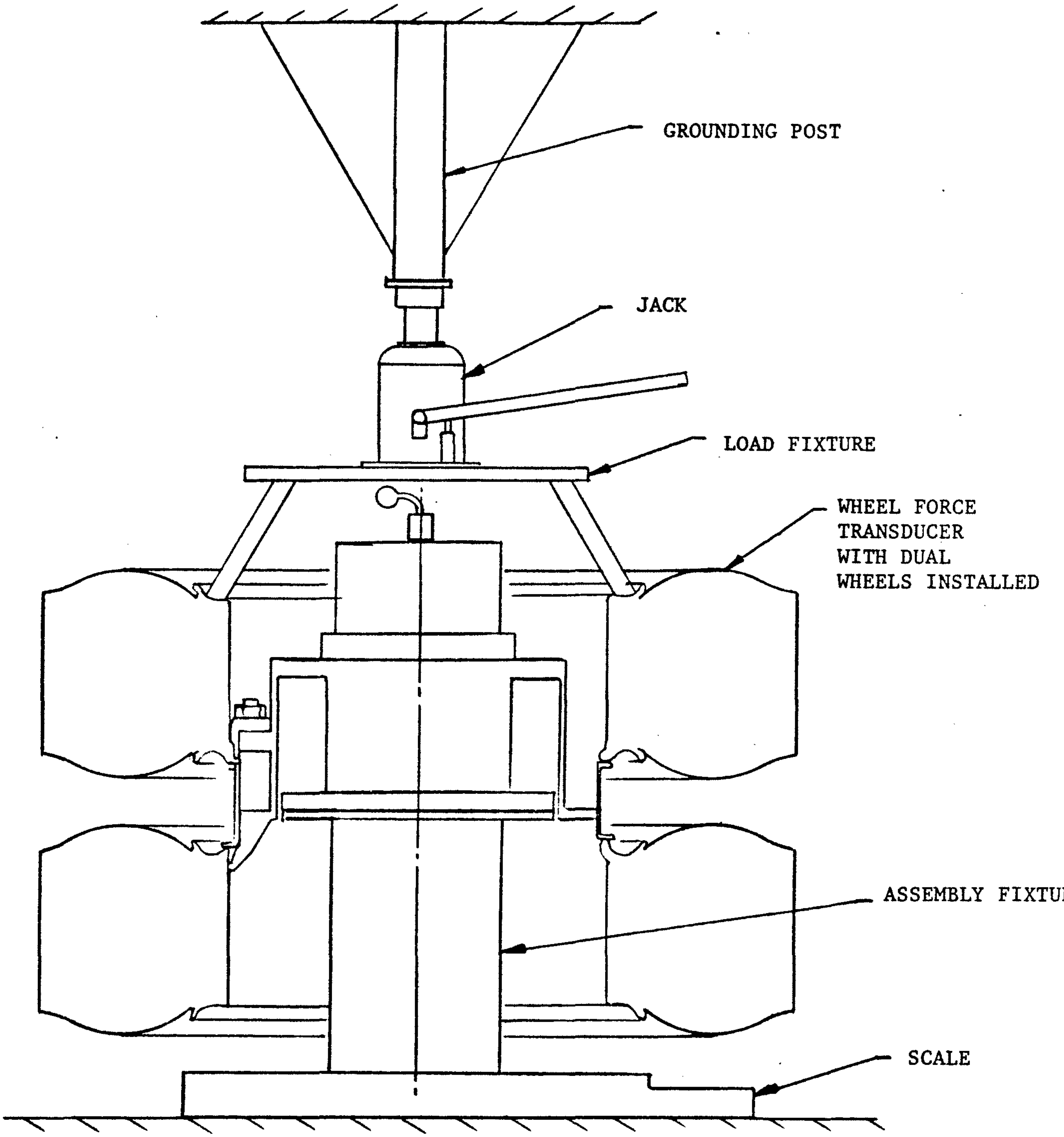


Figure 5. Transverse Load Test Setup

mounted from a ceiling beam. A net load of 3000 lb was applied and potentiometer R-5 adjusted until the output was +1.905 volts. This gain setting nominally corresponds to 15,000 lb at 10 volts full-scale. Two test series were run with the applied force being increased, decreased and increased to evaluate linearity, hysteresis, and repeatability. The data sheets and a plot of the data are included in the Section 3.0.

Shear Load Calibration

The shear load calibration used a single-axle dump truck loaded with four yards of sand as the source of applied load. The Wheel Force Transducer with dual wheels installed was mounted on the rear axle of the test vehicle. The 10,000 lb axle scale was placed under the Wheel Force Transducer on level ground with the off-side wheels blocked up so that the rear axle was level. A hydraulic jack under the axle close to the test wheel assembly was used to control the amount of applied load. A load distribution plate was placed between the wheel assembly and the scale such that the load could be applied through either tire or both tires as desired. Load applied to both tires simulated the normal dual wheel installation whereas load applied to the inboard tire only simulated a front wheel installation. Load applied to the outboard tire provided a third set of data used to determine the shear gage sensitivity to bending moment. The Wheel Force Transducer and dual tire assembly weight is 500 lb; this tare reading was used when calculating the net applied vertical load. The A and B amplifiers were zeroed as described in the Operation Manual. The gains were nominally set for 10 volts full scale output at 25,000 lb shear load.

Static vertical loads in an increasing and decreasing direction were applied to the maximum available net load of 8000 lb. These loads were applied at wheel rotations of 0°, 90°, 180° and 270° with the inboard and outboard tires loaded independently. The dual wheel load test was performed at the above angles plus 215°. For each of the load points and rotation angles, the voltage outputs of the A, B, and T amplifiers; the sine and cosine outputs; and the vertical and horizontal load outputs were recorded. Data sheets and plots of the data are included in Section 3.0.

Dynamic Functional Test

A dynamic functional test was performed by driving the loaded truck back and forth over a short distance (limited by cable length). The sine, cosine, vertical, horizontal and transverse voltage outputs were recorded on a stationary strip chart recorder. These outputs were monitored while moving the truck smoothly and also while performing a series of abrupt starts and stops. Copies of representative strip chart data from these tests are included in Section 3.0.

3.0 CALIBRATION DATA

Table I presents the recorded data from the transverse load calibration. The transverse output and the A and B amplifier outputs all were monitored; however, it is probable that some extraneous side loading was present which would cause shear gage output; thus only the transverse output data is considered meaningful. Figure 6 shows a plot of the data with the calculated best straight line fit and a $\pm 1\%$ FS error band. The calculated slope of the best straight line is +.0006908 volts per lb of transverse load applied inboard on the tires. The calibration resistor which is placed into the circuit with S-1 in Position 1 caused an output voltage change of +4.886 volts at this gain setting.

Table II lists the measured data for the dual wheel shear load calibration. In these tests the A, B, T, sine, cosine, vertical and horizontal outputs all were monitored. The transverse bridge output is not considered meaningful since there was no measurement of extraneous transverse forces which may have been present as the tires were loaded and unloaded. Figure 7 is a plot of the vertical output data taken at all rotation angles compared

TABLE I - Test #1

WHEEL SENSOR

DATA SHEET

TRANSVERSE LOAD CALIBRATION

TARE LOAD 86 lb (ASSY FIXTURE + 18.7 lb)

	Voltage Output		
Net Load	Trans	A	B
3000 lb	1.935 v	-.016 v	-.117 v
2250	1.380	-.013	-.076
1500	.840	-.023	-.037
750	.346	-.013	-.020
500	.237	-.015	-.016
500	.228	-.016	-.016
750	.340	-.014	-.024
1500	.844	-.016	-.048
2250	1.385	-.009	-.082
3000	1.955	-.009	-.126
2250	1.410	-.009	-.085
1500	.854	-.013	-.050
750	.370	-.014	-.027
500	.231	-.016	-.015
Cal. SW 0			

TABLE I - Test #2

WHEEL SENSOR

DATA SHEET

TRANSVERSE LOAD CALIBRATION

TARE LOAD 86 lb (ASSY FIXTURE + 18.7 lb)

Net Load	Voltage Output Trans	A	B
3000 lb	1.970 v	-.018 v	-.130 v
2250	1.400	-.015	-.083
1500	.845	-.021	-.040
750	.343	-.018	-.017
500	.226	-.020	-.014
750	.360	-.018	-.020
1500	.835	-.022	-.036
2250	1.410	-.014	-.084
3000	1.975	-.021	-.133
2250	1.405	-.015	-.083
1500	.830	-.023	-.036
750	.330	-.018	-.016
500	.220	-.021	-.013
0	-.073	-.035	+.005
Cal. SW 0 Position 1	4.813	-.037	+.006

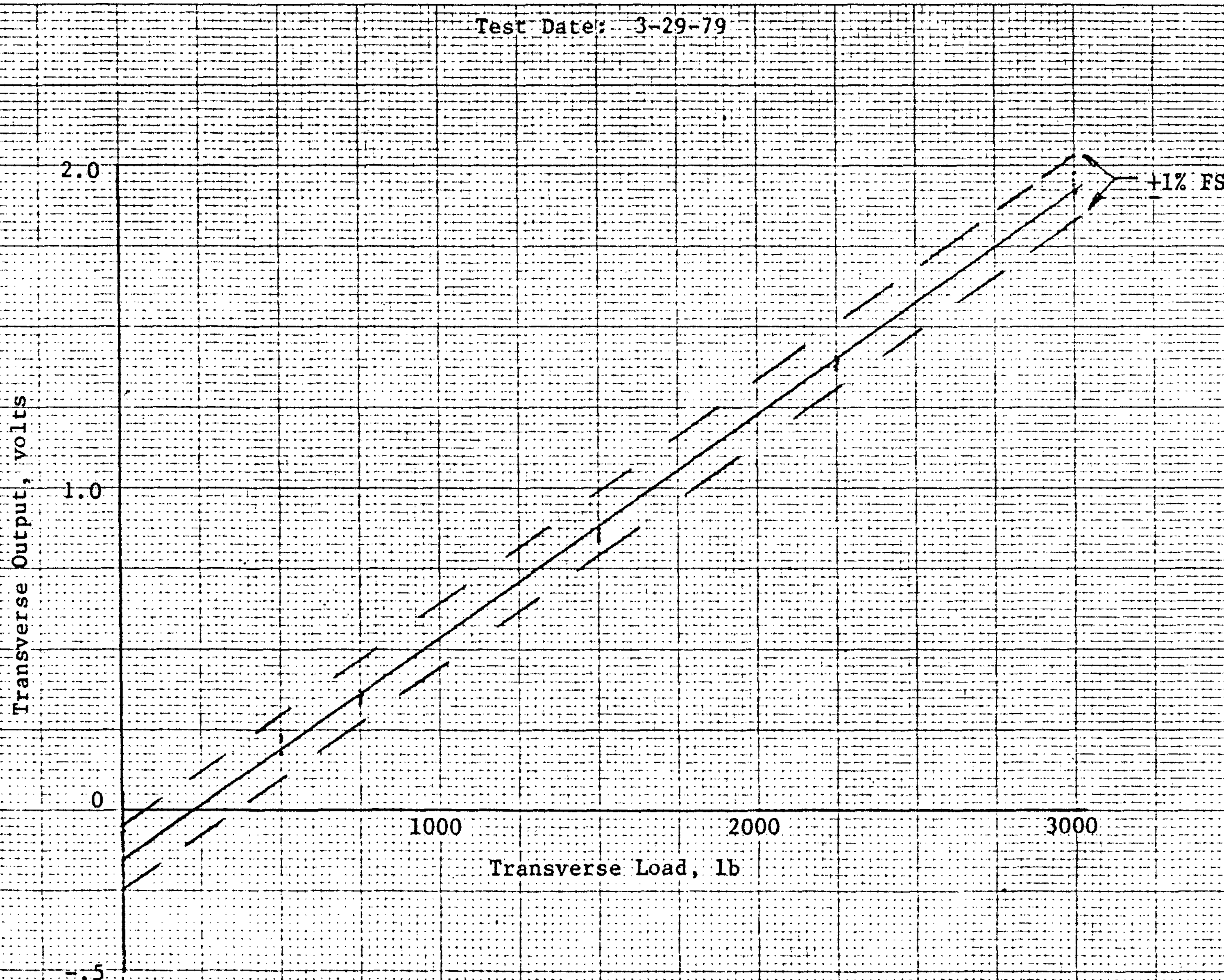


Figure 6. Transverse Load Test,
Loading Direction - Inboard on Tire

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WHEEL SENSOR

DATA SHEET

VERTICAL LOAD CALIBRATION

Dual Tires Loaded

	Net Load	α	A	B	T	Sin	Cos	Vert.	Horz.
					Voltage Output				
0%		45°							
25%		↓							
50%									
75%									
100%									
75%									
50%									
25%									
0%									
0%	0	90°	+.020	+.009	+.000	-9.959	-.018	-.024	+.004
25%	2000	↓	+.883	-.031	+.082	-9.959	-.017	-.855	-.039
50%	4000		+1.786	-.068	+.124	↓	↓	-1.750	-.078
75%	6000		+2.685	-.109	+.126			-2.625	-.116
100%	8000		+3.596	-.153	+.134			-3.551	-.169
75%	6000		+2.681	-.114	+.106			-2.668	-.120
50%	4000		+1.787	-.073	+.078			-1.787	-.081
25%	2000		+.849	-.027	+.052			-.856	-.038
0%	0		+.008	+.007	-.019	-9.958	-.013	-.029	+.001
Cal. SW Position 3	0		1.704						
0%	0	180°	+.006	-.012	-.016	-.319	+9.964	-.020	-.007
25%	2000	↓	-.035	-.887	+.011	-.321	+9.963	-.873	-.076
50%	4000		-.071	-1.786	-.013	↓	↓	-1.766	-.130
75%	6000		-.107	-2.711	-.029			-2.683	-.194
100%	8000		-.140	-3.603	-.054			-3.580	-.246
75%	6000		-.112	-2.679	-.024			-2.678	-.189
50%	4000		-.076	-1.786	+.015			-1.790	-.137
25%	2000		-.047	-.883	+.082			-.900	-.083
0%	0		-.019	+.013	+.078	-.281	+9.963	-.009	-.031

TABLE II

WHEEL SENSOR

DATA SHEET

VERTICAL LOAD CALIBRATION - Cont'd.

Dual Tires Loaded

Voltage Output

	Net Load	α	A	B	T	Sin	Cos	Vert.	Horz.
0%	0	215°	-.024	-.021	+.118	+6.987	+6.931	-.039	-.013
25%	2000		-.675	-.601	+.122	+6.987	+6.931	-.885	-.059
50%	4000		-1.363	-1.211	+.063			-1.778	-.102
75%	6000		-2.046	-1.817	+.013			-2.662	-.140
100%	8000		-2.711	-2.414	-.017			-3.560	-.193
75%	6000		-2.027	-1.809	+.011			-2.683	-.139
50%	4000		-1.339	-.1196	+.044			-1.778	-.098
25%	2000		-.661	-.592	+.119			-.892	-.057
0%	0		-.019	-.020	+.144	+7.008	+6.906	-.058	-.018
0%	0	270°	-.057	-.018	+.169	+9.976	+.082	-.075	+.005
25%	2000		-.932	+.013	+.240	+9.976	+.094	-.918	-.031
50%	4000		-1.824	+.045	+.212			-1.806	-.068
75%	6000		-2.722	+.075	+.191			-2.682	-.106
100%	8000		-3.607	+.112	+.180			-3.584	-.146
75%	6000		-2.696	+.081	+.189			-2.693	-.108
50%	4000		-1.815	+.048	+.207			-1.833	-.071
25%	2000		-.912	+.020	+.253			-.944	-.037
0%	0		-.030	-.005	+.227	+9.976	+.081	-.061	-.005
0%	0	0°	-.047	+.014	+.227	+.087	-9.956	-.030	+.045
25%	2000		-.033	+.884	+.319	+.087	-9.957	-.885	+.024
50%	4000		-.021	+1.781	+.332			-1.770	+.003
75%	6000		-.013	+2.698	+.331			-2.675	-.011
100%	8000		+.003	+3.620	+.351			-3.607	-.021
75%	6000		-.018	+2.698	+.321			-2.696	-.001
50%	4000		-.031	+1.791	+.283			-1.802	+.018
25%	2000		-.042	+.868	+.240			-.886	+.035
0%	0		-.058	+.019	+.156	+.063	-9.956	-.042	+.053
Cal. SW Position 2	0			1.710					

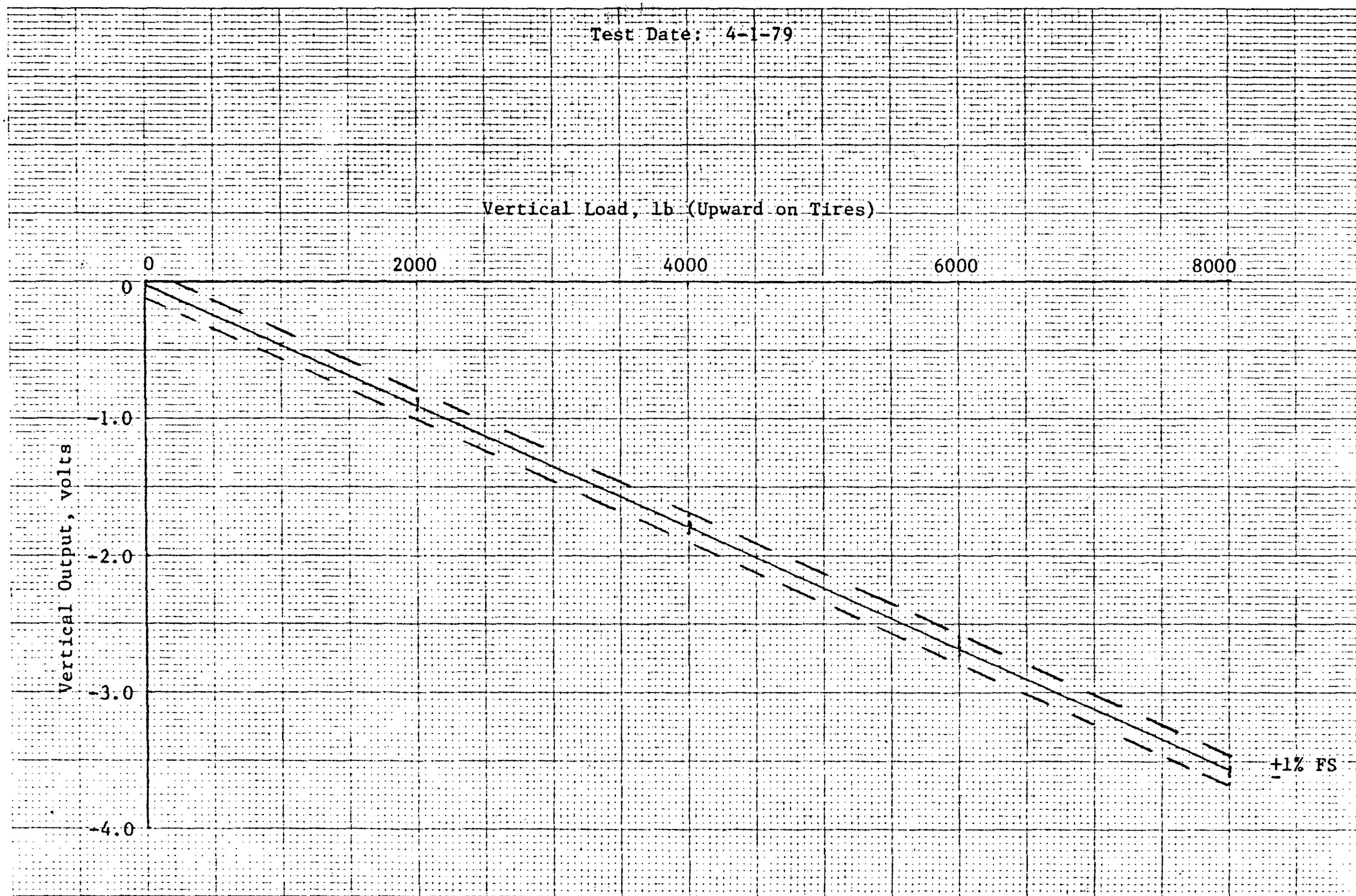

Figure 7. Shear Load Test,
Both Dual Wheels Loaded

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with the calculated best straight line and a ±1% FS error band. The calculated slope of the best straight line fit for the dual wheel test data is -.0004428 volts per lb applied load. The A bridge calibration resistor placed into the circuit by S-1 Position 3 caused an output voltage change of +1.696 volts. The B bridge calibration resistor placed into the circuit by S-1 Position 2 caused an output voltage change of +1.691 volts. These voltage changes can be used to readjust the amplifier gains to the as-calibrated gain. Figure 8 presents plots of the A and B amplifier output voltages at 90° and 270° rotation where the A bridge "sees" the full vertical load and the B bridge is on an insensitive axis. The vertical load is plotted positive on both sides of the y-axis in order to better illustrate the ± voltage linearity of the bridges. Figure 9 plots the A and B amplifier output voltages at 0° and 180° rotation where the B bridge sees the full vertical load and the A bridge is on an insensitive axis. Figures 8 and 9 indicate a low level of cross axis sensitivity between the active and inactive gages.

Table III lists the recorded data for the shear calibration with the inner wheel only loaded. This condition is equivalent to a front wheel installation of the sensor. Again, all outputs were monitored and recorded. Figure 10 is a plot of the vertical output data at all rotation angles compared with the calculated best straight line fit and a ±1% FS error band. The calculated slope of the best straight line fit for inner wheel loading is -.0005147 volts per lb of applied load. Figure 11 plots the A and B amplifier output voltages at the 90° and 270° rotation and Figure 12 plots the A and B amplifier output voltages at the 0° and 180° rotation.

A third set of shear load tests were conducted with only the outer wheel loaded. These tests established a best-fit slope of -.0003783 volts per lb of applied load. Figure 13 is a plot of these three scale factors versus the moment arm of the applied load measured from the plane of the

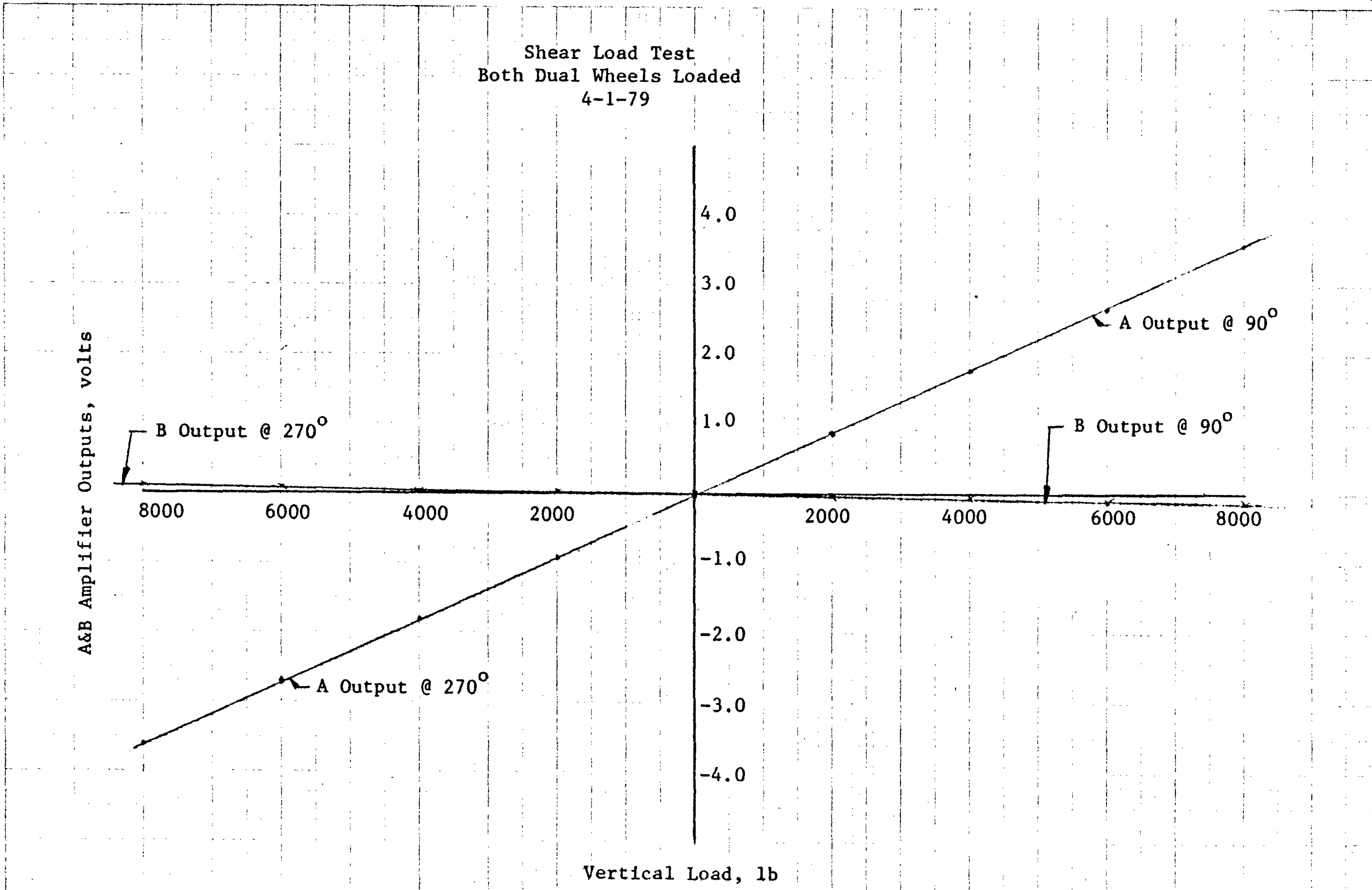

Figure 8. A&B Outputs at 90 & 270° Rotation; Dual Wheel Load

Shear Load Test
Both Dual Wheels Loaded
4-1-79

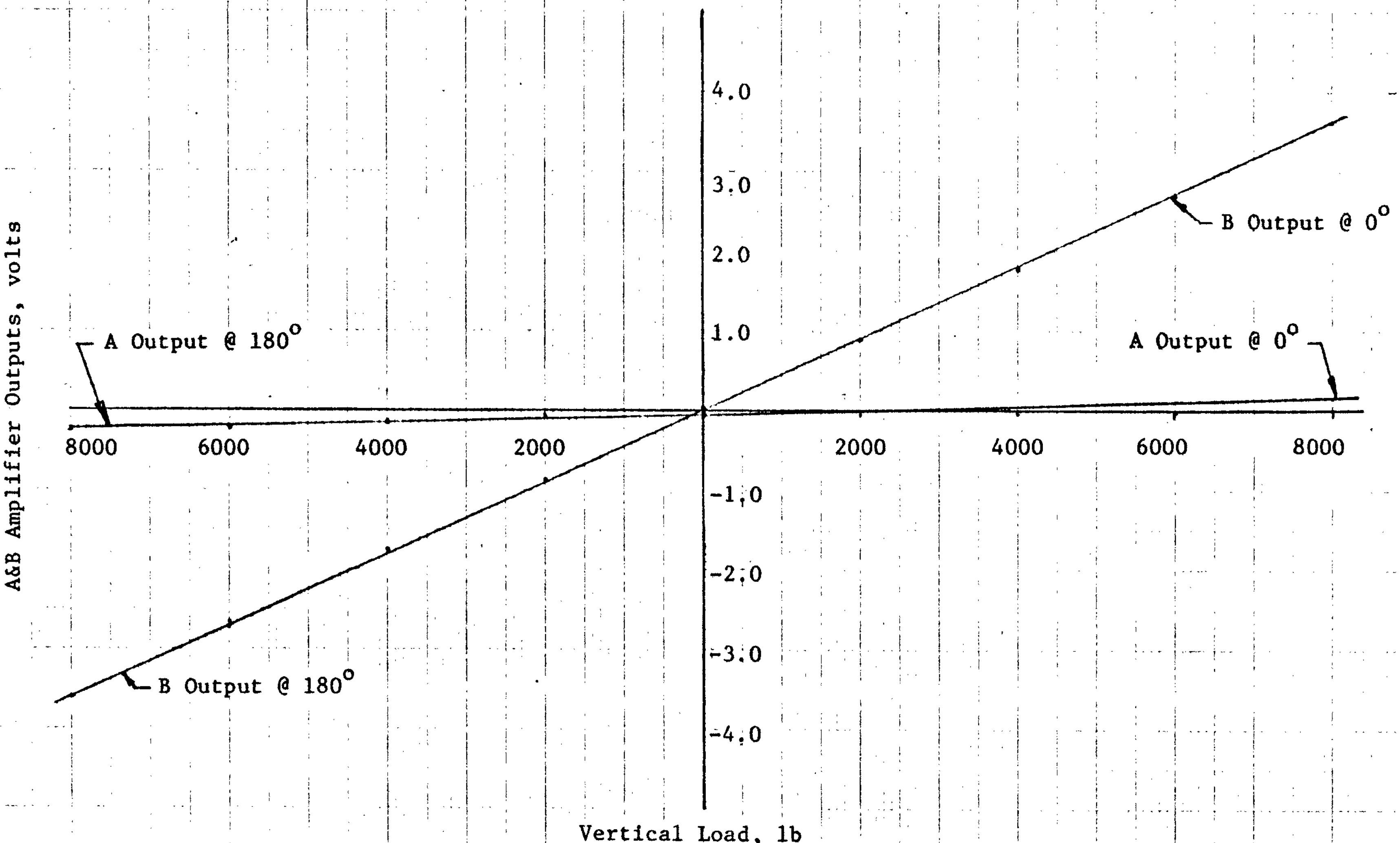

Figure 9. A&B Outputs at 0 & 180° Rotation; Dual Wheel Load

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TABLE III

WHEEL SENSOR
DATA SHEET

VERTICAL LOAD CALIBRATION

Inboard Tire Loaded

		Voltage Output						
Net Load	α	A	B	T	Sin	Cos	Vert.	Horz.
	45^{o}							
0	90^{o}	+.003	+.007	+.087	-9.960	-.176	-.011	+.006
2000		+1.027	-.023	+.101	-9.960	-.139	-1.005	-.042
4000		+2.075	-.086	+.177			-2.046	-.120
			Tire clearance limit					
5525		+2.925	-.130	+.174			-2.885	-.169
4000		+1.951	-.055	+.116			-1.953	-.083
2000		+1.050	-.024	+.073			-1.055	-.044
0		+.030	+.003	+.047	-9.960	-.180	-.041	-.001
0	180^{o}	+.014	-.035	+.011	-.226	+9.966	-.046	-.004
2000		-.055	-1.049	-.009	-.200	+9.966	-1.042	-.086
4000		-.119	-2.091	-.012			-2.070	-.163
5500		-.169	-2.968	+.009			-2.950	-.217
4000		-.117	-2.006	+.020			-2.007	-.160
2000		-.058	-1.071	+.079			-1.077	-.086
0		-.016	-.047	+.122	-.196	+9.965	-.065	-.026

TABLE III

WHEEL SENSOR

DATA SHEET

VERTICAL LOAD CALIBRATION - Cont'd.

Inboard Tire Loaded

Voltage Output

Net Load	α	A	B	T	Sin	Cos	Vert.	Horz.
	215°							
0	270°	-.060	-.035	+.159	+9.978	+.038	-.077	+.026
2000		-1.041	+.007	+.174	+9.978	+.032	-1.034	-.017
4000		-2.158	+.069	+.280			-2.130	-.077
5100		-2.710	+.091	+.320			-2.696	-.098
		Outer tire about to contact scale face						
4000		-2.023	+.040	+.282			-2.037	-.047
2000		-1.092	+.001	+.273	↓	↓	-1.113	-.009
0		-.067	-.025	+.267	+9.978	+.030	-.094	+.021
0	0°	-.054	+.040	+.160	+.040	-9.958	-.047	+.044
2000		+.010	+1.057	+.309	+.025	-9.959	-1.046	-.017
4000		+.047	+2.180	+.539			-2.193	-.058
5525		+.112	+3.004	+.634			-2.992	-.104
		Outer tire about to contact scale face						
4000		+.021	+2.017	+.489			-2.024	-.021
2000		-.022	+1.072	+.315	↓	↓	-1.080	+.022
0		-.059	-.001	+.179	+.012	-9.959	-.021	+.054

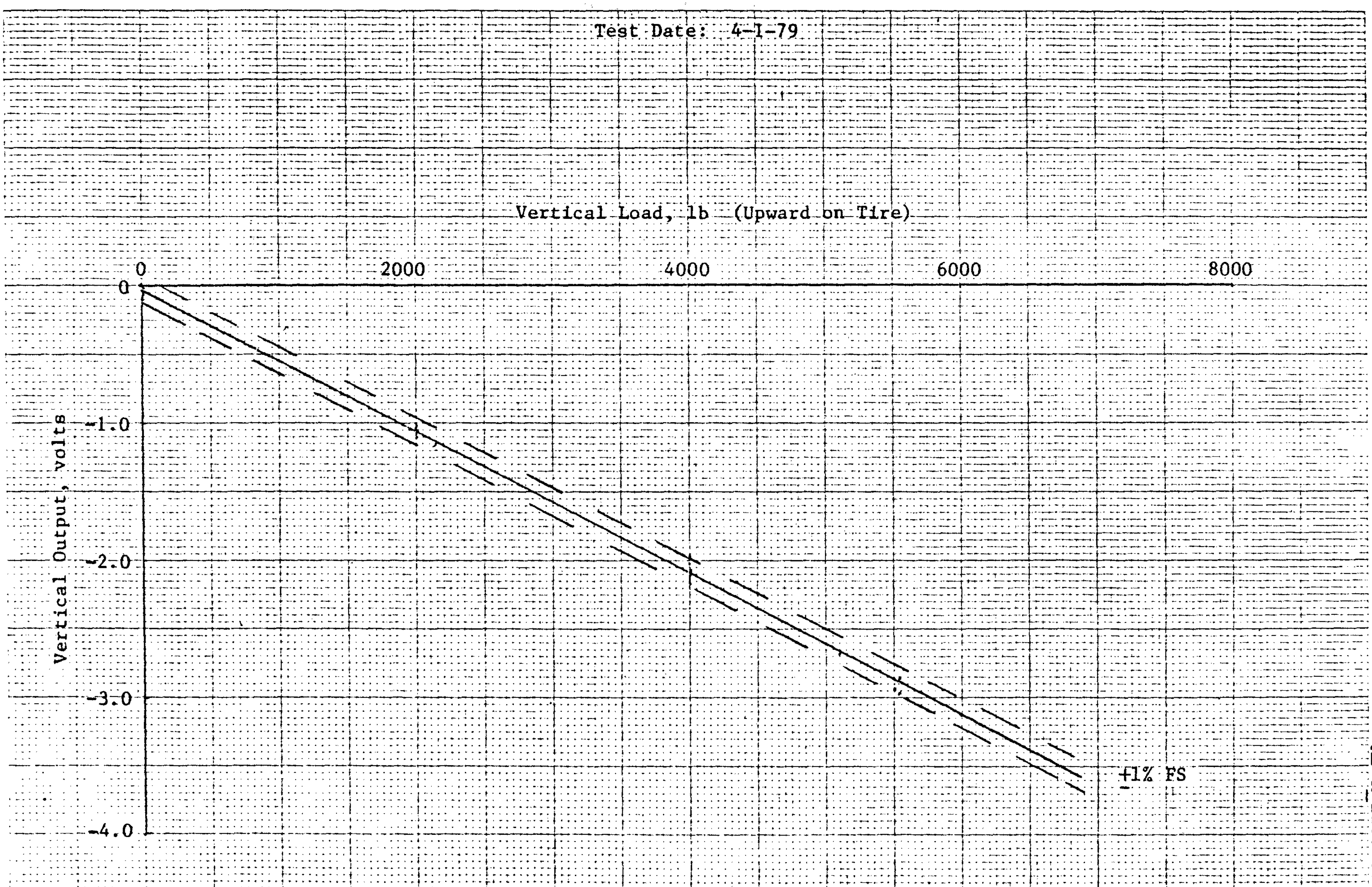

Figure 10. Shear Load Test,
Inboard Wheel Loaded

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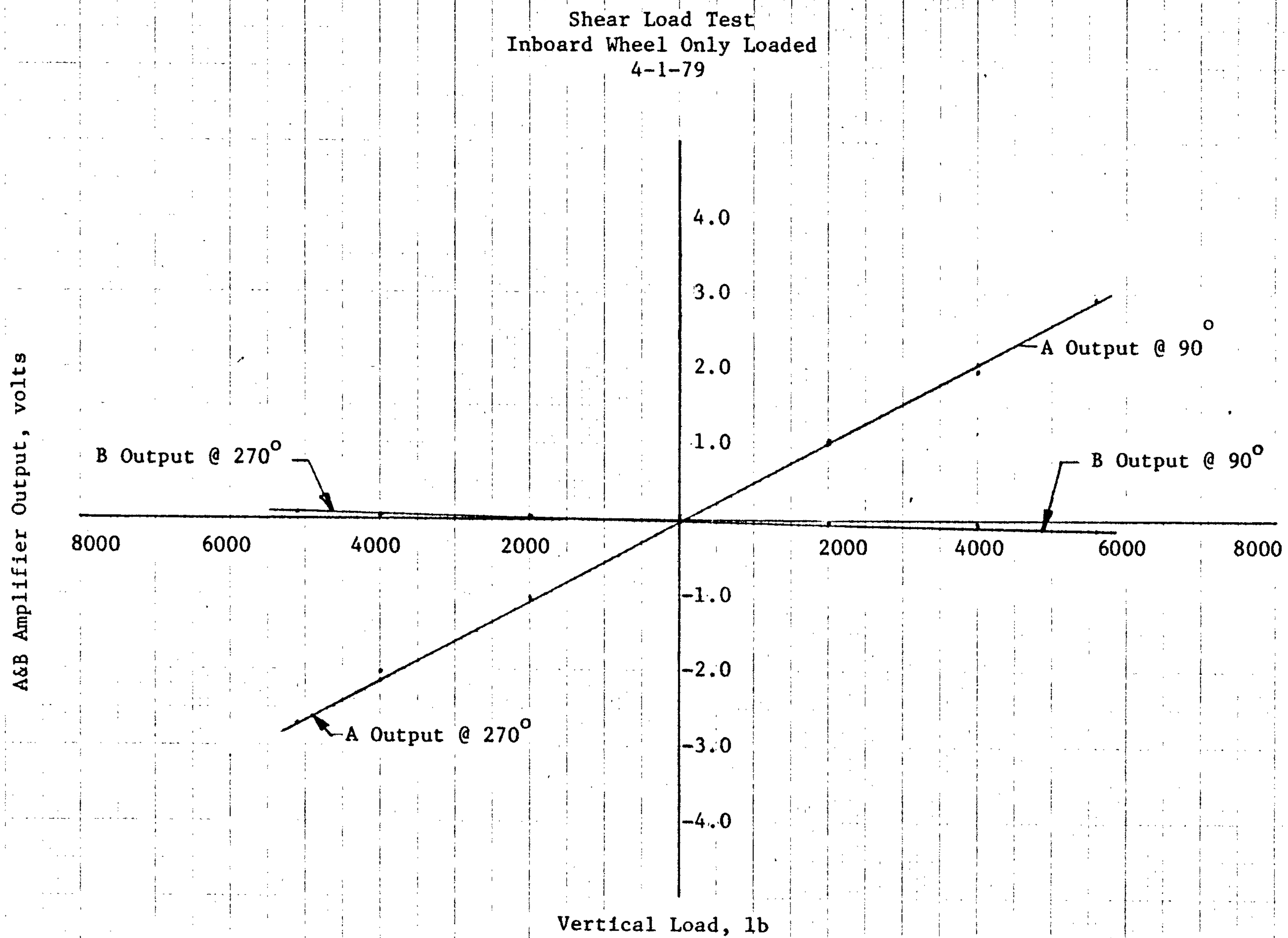

Figure 11. A&B Outputs at 90 & 270°, Inboard Wheel Load

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Shear Load Test
Inboard Wheel Only Loaded
4-1-79

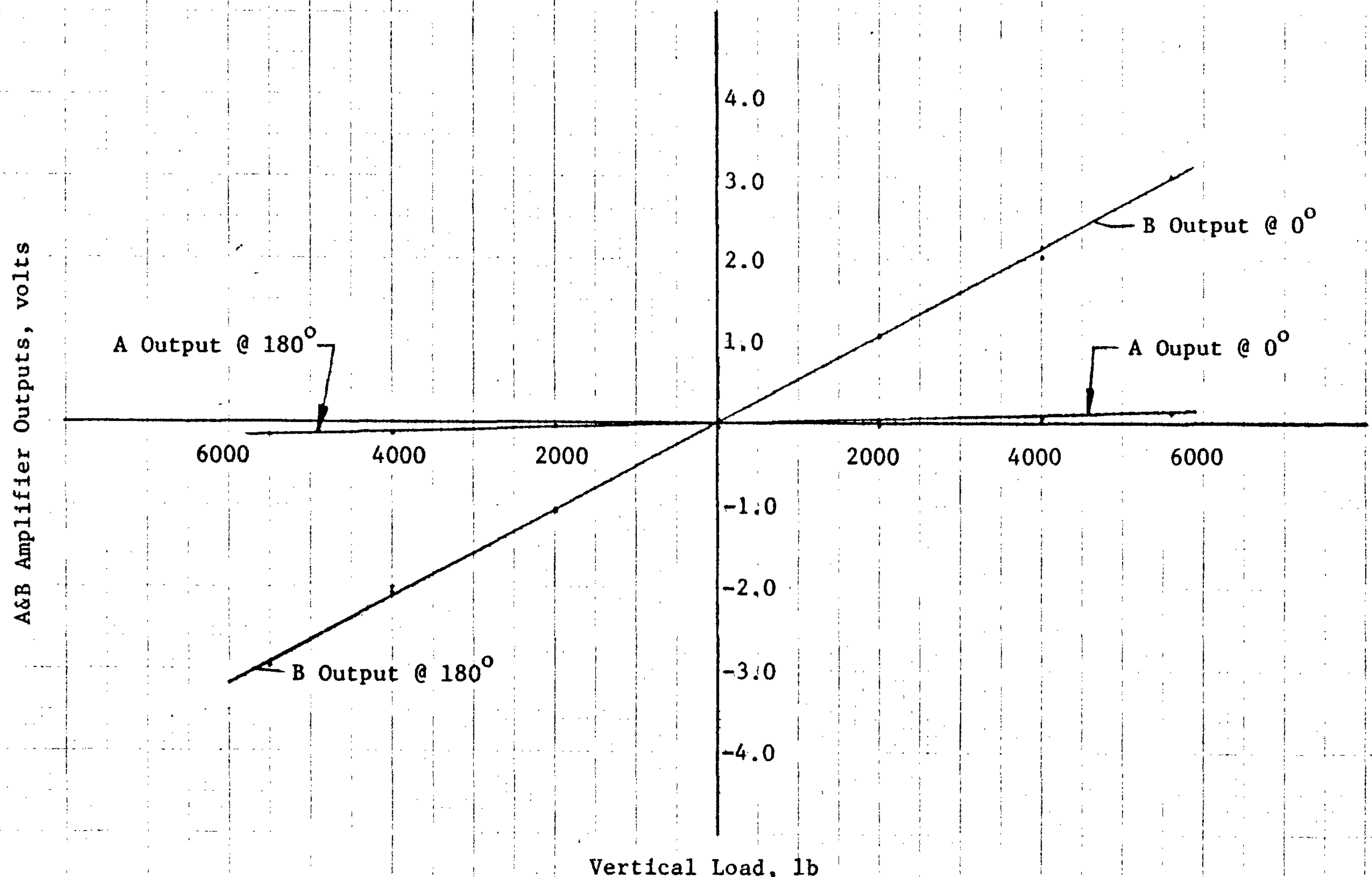

Figure 12. A&B Outputs at 0 & 180°,
Inboard Wheel Load

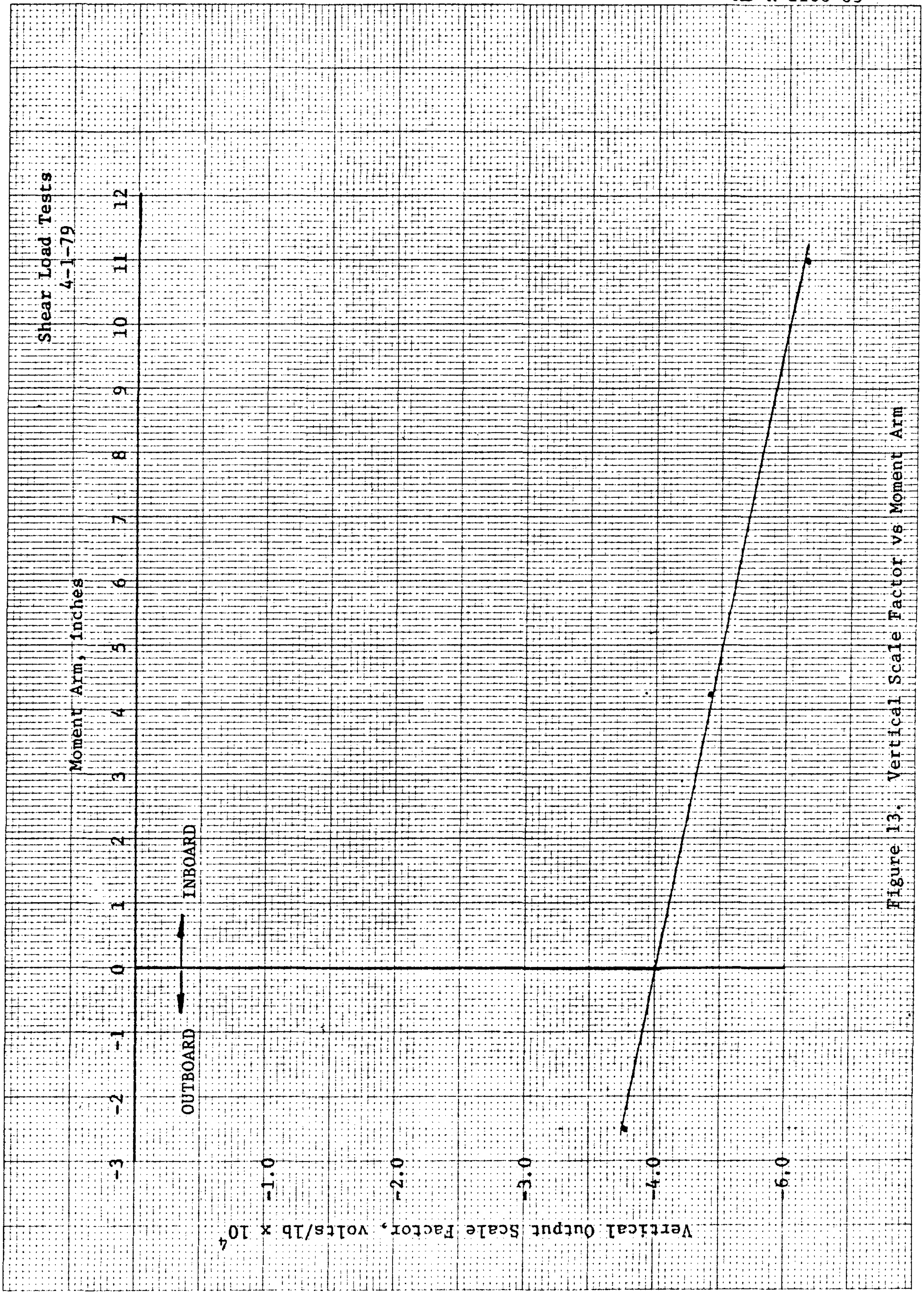

Figure 13. Vertical Scale Factor vs Moment Arm

gages. The best-fit straight line using the three scale-factor points indicates a shear gage moment sensitivity of $+1.0104 \times 10^{-5}$ volts per in-lb of moment where the + sign is applicable for moments which tend to roll the bottom of the tire inboard. When significant transverse forces are present a vertical force correction can be calculated based on the measured transverse force; corrections should be added to or subtracted from the measured vertical force as appropriate. The dual wheel and single wheel calibration curves (Figures 7 and 10)incorporate the moment effect of the vertical loading plane. A sample application of the suggested bending moment correction is included in the Operation Manual. A discussion of the probable source of this sensitivity is also included, with recommendations for possible reduction or elimination of the effect.

Figures 14 and 15 are copies of representative strip recorder data from the functional dynamic load test. Figure 14 shows the outputs for sine, cosine, vertical, horizontal and transverse load while smoothly moving the truck. Figure 15 shows the same outputs while moving the truck in a series of sharp starts and stops. This very limited test demonstrates the functional dynamic capability of the sensor as well as a number of interesting features of truck dynamic wheel loads, including a clear vertical plane motion resonance.

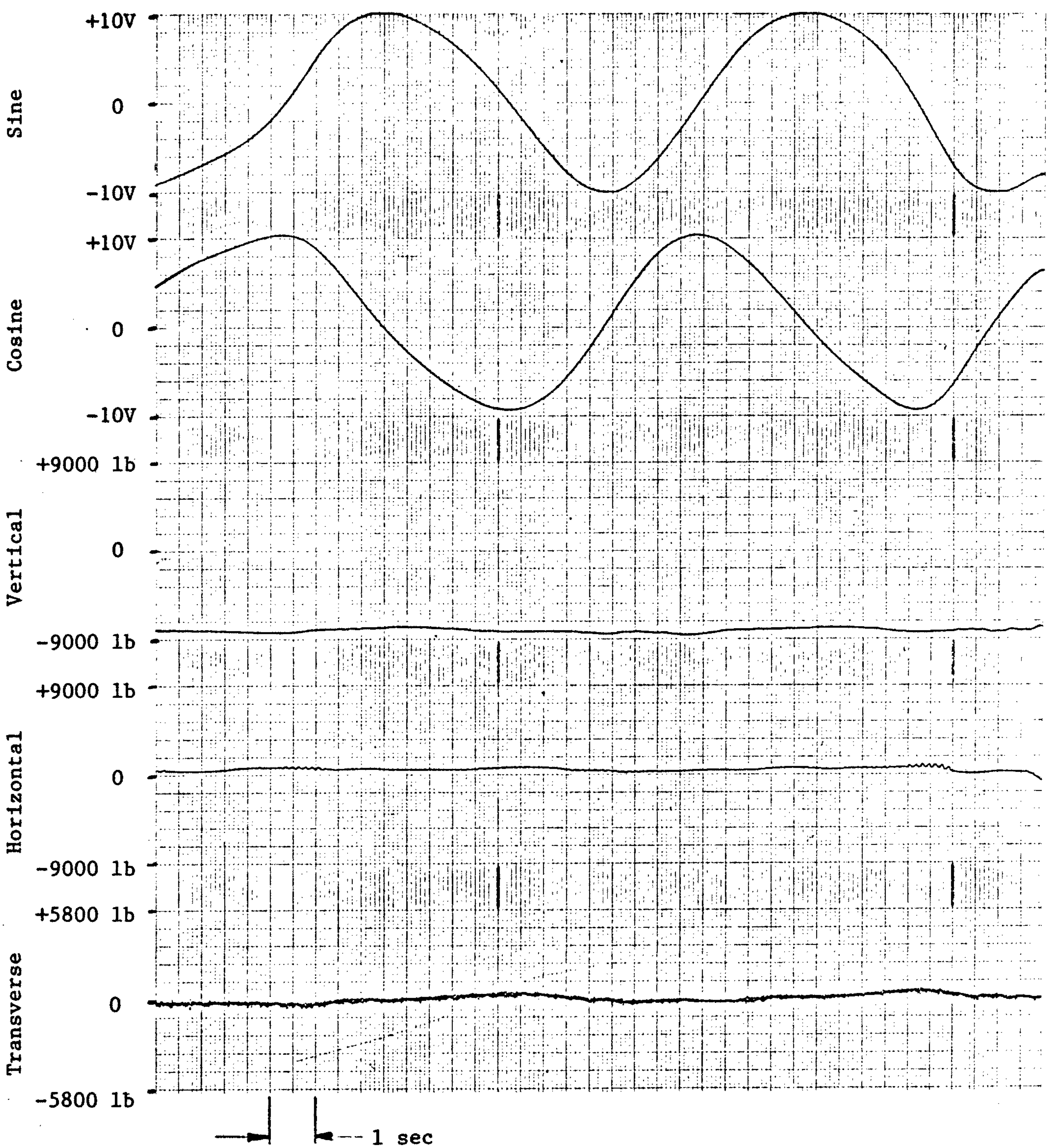

Figure 14. Dynamic Test Record, Smooth Motion

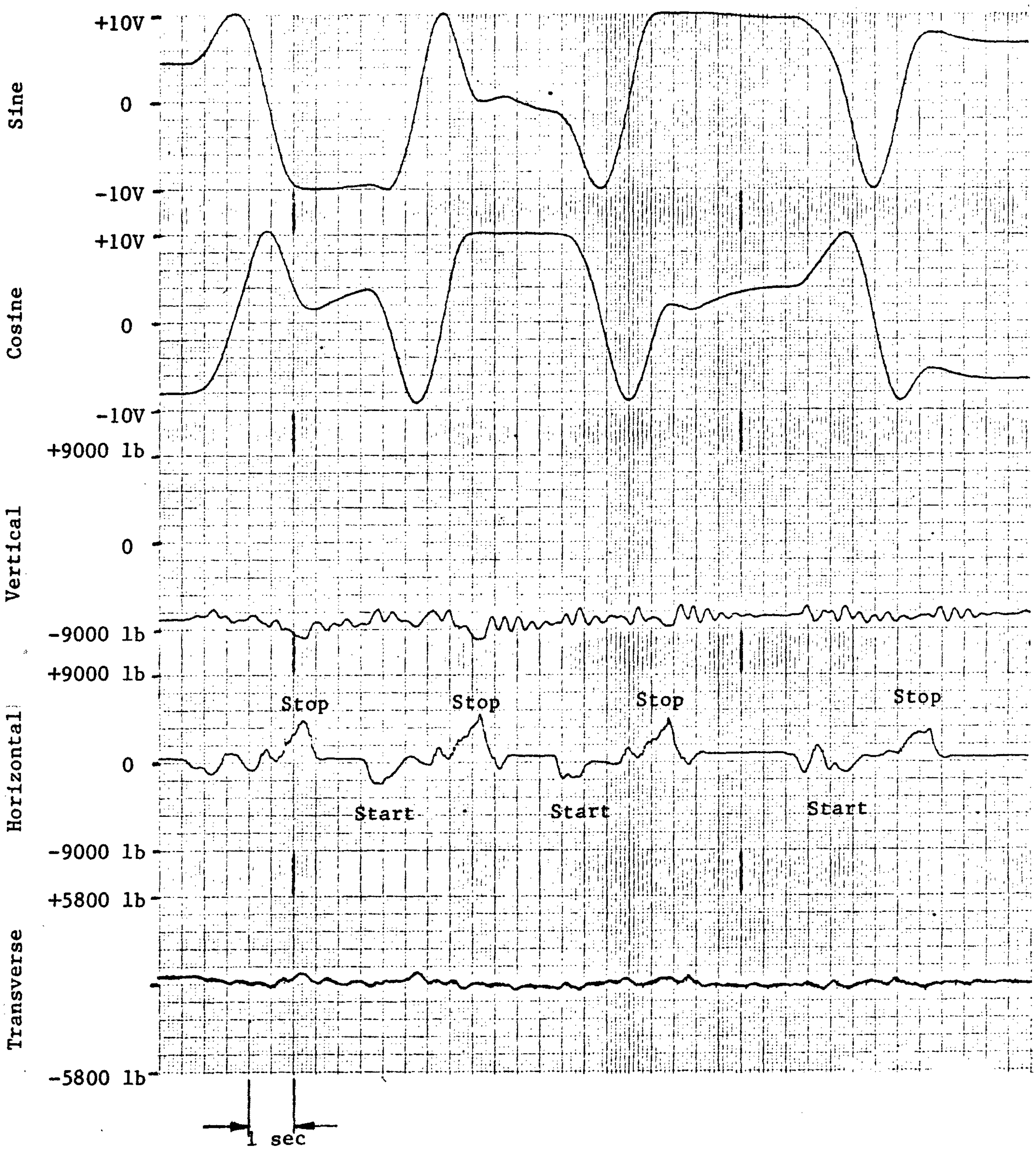

Figure 15. Dynamic Test Record, Starts and Stops