DTNH22-95-H-07002

UMTRI FIFTH-WHEEL LOAD TRANSDUCER
—USERS' GUIDE—

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INTRODUCTION AND BACKGROUND

The UMTRI fifth-wheel load transducer was created for the NHTSA under Cooperative Agreement number DTNH22-95-H-07002 and is the property of NHTSA. It is intended to measure all four primary loads which a semitrailer applies to a tractor (or dolly) through the fifth wheel. These loads, diagrammed in figure 1, are:

F_x longitudinal (fore/aft) force,
F_y lateral (sideways) force,
F_z vertical force,
M_x overturning (roll) moment.

The UMTRI fifth-wheel load transducer system measures these loads by replacing the standard fifth-wheel chairs with specially-made chairs, each of which are a four-component load transducer. The four signals from an individual chair are combined appropriately by a data reduction matrix calculation to yield the three forces (longitudinal, lateral, and vertical) and one moment (overturning) acting on that chair. In turn these values for both the left and right chairs are combined by a matrix calculation to determine the total loads on the fifth wheel.

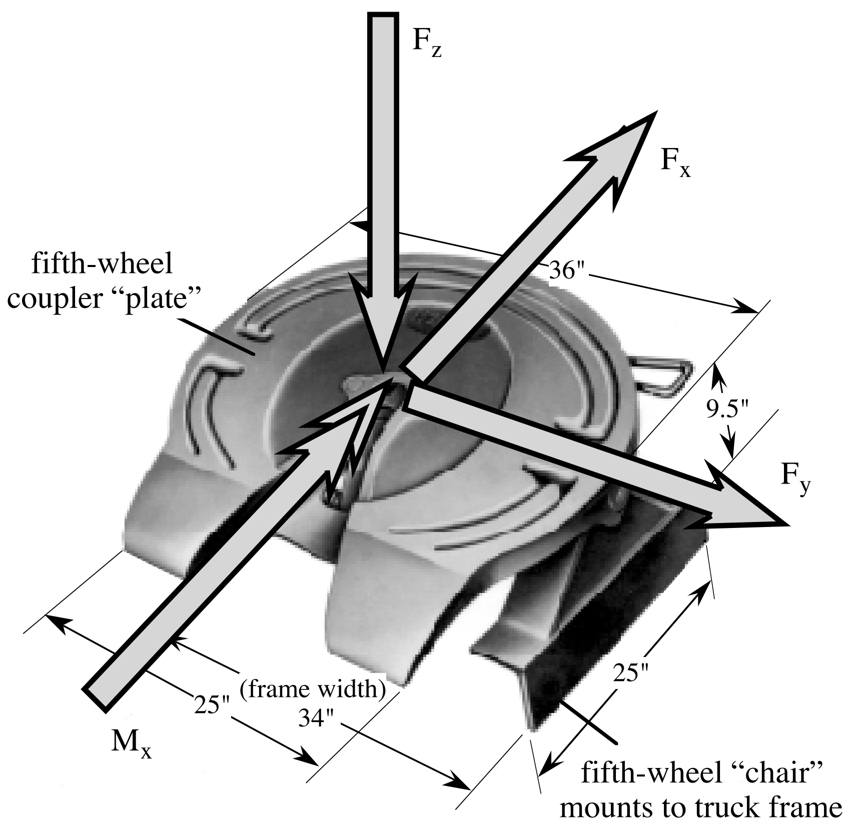


Figure 1. A standard fifth-wheel with loads and nomenclature

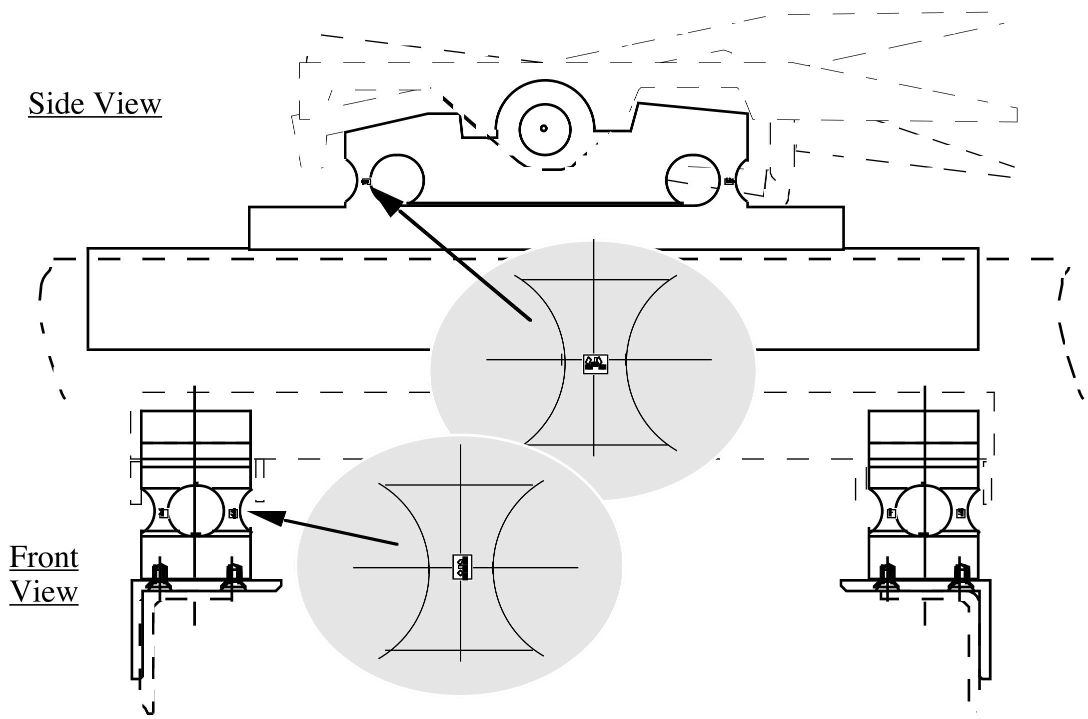
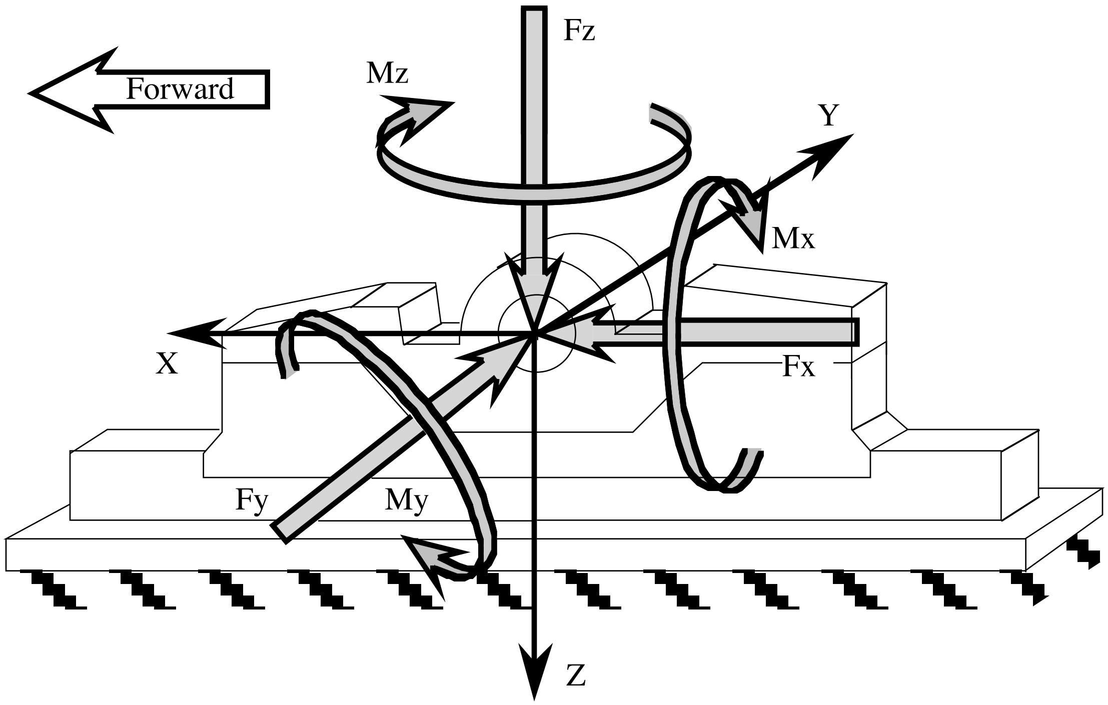


Figure 2. General design of the UMTRI fifth-wheel load transducer

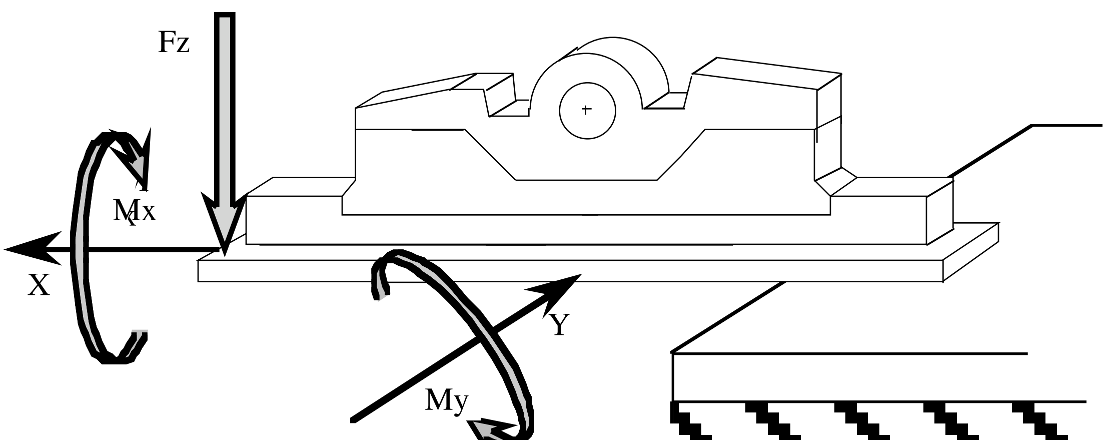
Figure 2 is a sketch which shows the general design of the transducer system. The transducer has approximately the same overall dimensions as the standard chair shown in figure 1. However, this chair is cut from a solid block of high-strength steel in a manner such that all loads applied to it by the fifth-wheel plate flow down into the truck frame through four precisely-machined posts, each of which have twelve strain gauges applied.

The calibration process (of May, 1998) showed the nominal accuracy of these cells to be in the range of one to two percent. Additional test have shown the cells to be rather insensitive to twisting and bending loads applied through their base. (This is an especially important issue for a fifth-wheel load cell since it is normal for the typical commercial truck frame to flex substantially during use). Calibration loading is depicted in figure 3 and results are reviewed in tables 1 and 2. The loads for the base-distortion sensitivity tests are depicted in figure 4 with results presented in table 3.



Fx, Fy, Fz, Mx, My, and Mz loads are applied through the load cell to ground.
Load cell transduces only Fx, Fy, Fz, and Mx.

Figure 3. Load-cell calibration tests



Loads are applied through base to ground.
NO loads are applied through the load cell.

Figure 4. Base distortion tests

Table 1. Calibration results—UMTRI 5th-Wheel Load Cell #1

Calibration of May, 1998

Load Cell Evaluation

Correlation coefficients (r^2)				
Test	Fx	Fy	Fz	Mx
All**	0.999998	0.999996	0.999786	0.999880

Errors in measured loads								
Test	Fx [lb]		Fy [lb]		Fz [lb]		Mx [in-lb]	
	Peak to peak	RMS	Peak to peak	RMS	Peak to peak	RMS	Peak to peak	RMS
All**	69	12	132	15	545	80	599	118
***	0.5%	0.1%	0.6%	0.1%	2.3%	0.3%	2.1%	1.3%
1	68	14	22	12	120	43	37	7
2	91	43	25	15	122	54	49	18
3	75	29	28	10	126	45	82	19
4	96	13	29	10	141	45	95	26
5	59	14	31	12	131	51	53	10
6	55	30	28	10	111	42	213	103
7	50	14	31	15	103	35	194	85
8	45	12	8	1	155	63	166	69
9	51	13	7	2	155	69	172	72
10	67	13	18	7	149	72	57	24
11	59	14	20	7	142	54	55	13
12	78	13	16	5	142	57	56	21
13	95	36	25	12	152	71	43	11
14	58	16	22	12	147	68	45	10
15	12	5	68	16	316	130	163	89
16	9	3	59	16	320	139	218	61
17	12	2	66	19	261	88	541	212
18	15	4	64	16	269	109	469	251
19	15	5	59	19	266	120	571	250
20	12	5	104	13	273	113	614	288
21	14	5	105	12	277	100	672	313
22	10	4	67	12	171	67	235	76
23	9	3	74	16	171	72	286	91
24	11	5	54	12	562	235	620	252
25	10	2	61	12	513	228	632	217
26	7	1	161	48	298	126	313	144
27	6	1	54	9	280	133	237	130
28	16	5	94	11	295	128	370	142
29	17	8	43	13	287	139	281	141
30	9	2	46	12	282	141	391	184
31	11	5	66	12	280	141	386	178
32	6	1	49	14	188	82	236	65
33	8	1	57	11	175	77	226	59
34	9	3	50	17	525	259	891	303
35	11	5	49	18	529	258	833	255
36	16	7	46	13	217	114	380	167
37	8	4	57	22	257	146	323	118
38	14	6	17	6	286	133	401	146
39	14	5	18	4	266	121	376	120
40	10	2	55	18	211	100	408	97
41	9	3	51	17	198	100	387	102
42	20	10	69	25	262	138	407	137
43	21	7	71	26	260	133	450	144
44	14	6	11	3	47	22	113	28
45	13	5	10	2	42	17	111	32
46	9	3	19	5	63	33	148	41
47	20	9	94	41	86	42	245	95
48	16	7	95	47	90	43	281	136

Test Conditions*

Peak values of applied loads

	Fx	Fy	Fz	Mx	My	Mz
Test	[kilo lb]			[kilo in-lb]		
1	20.3					
2	21.1					
3	20.2					40.3
4	21.2					42.5
5	20.5					-41.1
6	-20.4					40.9
7	-20.9					41.8
8	-20.8					-41.5
9	-20.4					-40.8
10	-22.6					
11	-22.6					
12	-22.6					
13	22.9					
14	23.4					
15		22.3				
16		22.5				
17		20.0				-40.0
18		19.9				-39.8
19		20.0				-40.0
20		19.0				38.0
21		19.0				38.0
22		20.0		-40.0		
23		20.0		-40.0		
24		21.2		42.4		
25		20.7		41.4		
26		-21.2				
27		-20.6				
28		-21.0				42.0
29		-20.5				41.1
30		-20.8				-41.7
31		-20.9				-41.8
32		-21.0		-42.0		
33		-21.0		-41.9		
34		-21.0		42.1		
35		-21.1		42.2		
36			20.8			
37			22.4			
38			22.9	45.7		
39			22.8	45.7		
40			17.1	-34.1		
41			16.7	-33.3		
42			23.7			
43			24.0			
44			10.3		-20.5	
45			10.5		-21.0	
46			10.5		21.0	
47			-20.8			
48			-20.8			

*Loads smoothly applied from zero to maximum to zero over approximately 30 seconds.
**Results for all tests combined are after digital filtering at 5 hz. (Results for Individual testsfrom unfiltered data.)
*** Percent of maximum applied.

Table 2. Calibration results—UMTRI 5th-Wheel Load Cell #2

Calibration of May, 1998

Test Conditions*

Peak values of applied loads

Test	Fx [kilo lb]	Fy [kilo lb]	Fz [kilo lb]	Mx [kilo in-lb]	My [kilo in-lb]	Mz [kilo in-lb]
1			-20.9			
2			-20.8			
3			-20.8	-41.6		
4			-20.7	-41.3		
5			-20.5	-41.0		
6			-20.4	-40.9		
7			-20.4			
8			-20.5			
9			-20.2	40.5		
10			-20.3	40.7		
11			20.5	-41.0		
12			20.4	-40.8		
13			20.4	40.9		
14			20.5	41.0		
15			20.5			
16			22.4			
17			13.6		27.2	
18			19.3		38.7	
20			20.4		-40.7	
21		21.2				
22		21.3				
23		21.0		-42.0		
24		20.7		-41.4		
25		20.8		41.7		
26		20.9		41.8		
27		20.7				41.5
28		21.3				42.5
29		20.6				-41.2
30		20.5				-41.1
31		-20.5				
32		-20.7				
33		-20.6		-41.2		
34		-20.8		-41.5		
35		-20.4		40.8		
36		-20.6		41.2		
37		-20.6				41.2
38		-20.5				41.0
39		-20.5				-41.0
40		-20.5				-41.1
41	-20.6					
42	-20.7					
43	-20.6					41.2
44	-20.6					41.3
45	-20.6					-41.2
46	-20.5					-41.1
47	20.7					41.5
48	20.7					41.3
49	20.6					
50	20.7					
51	20.5					-41.1
52	20.5					-41.1

Load Cell Evaluation**

Correlation coefficients (r^2)								
Test	Fx		Fy		Fz		Mx	
All	0.999994		0.999989		0.999874		0.999895	
Errors in measured loads								
Test	Fx [lb]		Fy [lb]		Fz [lb]		Mx [in-lb]	
	Peak to peak	RMS	Peak to peak	RMS	Peak to peak	RMS	Peak to peak	RMS
All	101	14	139	25	522	86	729	150
	0.5%	0.1%	0.7%	0.1%	2.3%	0.4%	1.7%	0.4%
1	12	86	86	195	67	36	195	115
2	12	83	83	184	70	41	184	87
3	14	19	19	462	108	7	462	237
4	13	18	18	482	117	8	482	260
5	13	19	19	391	166	8	391	204
6	11	19	19	367	142	9	367	179
7	10	76	76	423	97	32	423	201
8	10	78	78	411	95	34	411	246
9	13	139	139	611	115	62	611	270
10	14	138	138	633	104	65	633	195
11	18	108	108	512	152	20	512	102
12	17	79	79	481	167	16	481	100
13	16	124	124	662	155	59	662	184
14	15	127	127	683	163	61	683	204
15	12	81	81	295	105	38	295	123
16	13	91	91	360	138	49	360	171
17	5	37	37	73	64	16	73	20
18	11	68	68	165	95	30	165	45
20	27	86	86	620	112	43	620	328
21	6	50	50	179	295	19	179	50
22	6	54	54	184	286	14	184	63
23	5	61	61	430	166	14	430	254
24	4	55	55	418	159	12	418	192
25	6	52	52	646	500	12	646	247
26	8	60	60	729	503	16	729	296
27	11	55	55	206	284	13	206	85
28	13	51	51	181	296	13	181	71
29	15	51	51	143	305	13	143	58
30	13	43	43	182	305	10	182	54
31	4	65	65	147	287	40	147	50
32	5	47	47	214	291	11	214	67
33	5	52	52	288	196	21	288	107
34	5	33	33	253	200	9	253	119
35	6	58	58	473	490	17	473	178
36	6	43	43	540	522	8	540	216
37	8	41	41	343	290	13	343	166
38	8	50	50	355	292	14	355	205
39	9	43	43	522	270	9	522	258
40	9	39	39	504	274	9	504	259
41	90	20	20	93	130	12	93	50
42	82	15	15	101	126	7	101	52
43	75	10	10	43	134	5	43	25
44	101	6	6	35	145	2	35	18
45	71	7	7	144	129	3	144	67
46	68	7	7	148	124	2	148	76
47	84	2	2	100	111	0	100	54
48	64	6	6	96	106	3	96	48
49	59	11	11	94	113	5	94	45
50	61	11	11	97	112	5	97	43
51	54	13	13	269	180	8	269	144
52	55	15	15	258	167	9	258	132

*Loads smoothly applied from zero to maximum to zero over approximately 30 seconds.
**Evaluations performed following digital filtering at 5 hz.
*** Percent of maximum applied.

Table 3. Base-deformation tests of the UMTRI fifth-wheel load cells —May, 1998—

Load Cell #1

Test	Loads applied to base			False Load Cell Signals			
				F_x, lb	F_y, lb	F_z, lb	M_x, in-lb
49	F_z, lb	609	Max	32	7	21	293
	M_x, in-lb	50,522	Min	-6	-18	-125	-56
	M_y, in-lb	8,522	Range	37	25	146	349
50	F_z, lb	612	Max	31	8	21	253
	M_x, in-lb	50,834	Min	-9	-17	-126	-62
	M_y, in-lb	8,574	Range	40	25	147	315
51	F_z, lb	593	Max	5	6	12	155
	M_x, in-lb	1,779	Min	-39	-56	-109	-31
	M_y, in-lb	55,155	Range	44	62	120	185
52,53	F_z, lb	618	Max	14	14	33	188
	M_x, in-lb	1,853	Min	-42	-67	-127	-56
	M_y, in-lb	57,457	Range	56	82	160	244

Load Cell #2

Test	Loads applied to base			False Load Cell Signals			
				F_x, lb	F_y, lb	F_z, lb	M_x, in-lb
53	F_z, lb	588	Max	-24	-29	11	526
	M_x, in-lb	48,816	Min	-141	-52	-112	47
	M_y, in-lb	8,234	Range	99	40	123	479
54	F_z, lb	663	Max	-22	-28	5	568
	M_x, in-lb	55,047	Min	-142	-51	-114	52
	M_y, in-lb	9,285	Range	85	42	119	516
55	F_z, lb	616	Max	-12	-29	-66	147
	M_x, in-lb	1,849	Min	-38	-53	-353	-836
	M_y, in-lb	57,305	Range	26	45	288	983
56	F_z, lb	666	Max	-13	-36	-33	144
	M_x, in-lb	1,999	Min	-38	-59	-366	-772
	M_y, in-lb	61,970	Range	26	49	333	916

CONNECTORS, CIRCUITS, AND PIN-OUT

Each of the two transducers is wired for four individual channels: X, Y, ZR, and ZL. Two of these channels are each composed of four, 4-arm strain gauge bridges in parallel. The other two channels each have two bridges.

The associated circuits are shown in figure 5. Each circuit has six external connections: +signal, -signal, +sense, -sense, +excitation, -excitation. These connections are accomplished via a single, 24-pin connector (Amphenol PT02E-16-26P). Pin-outs for this connector are also indicated in the figure.

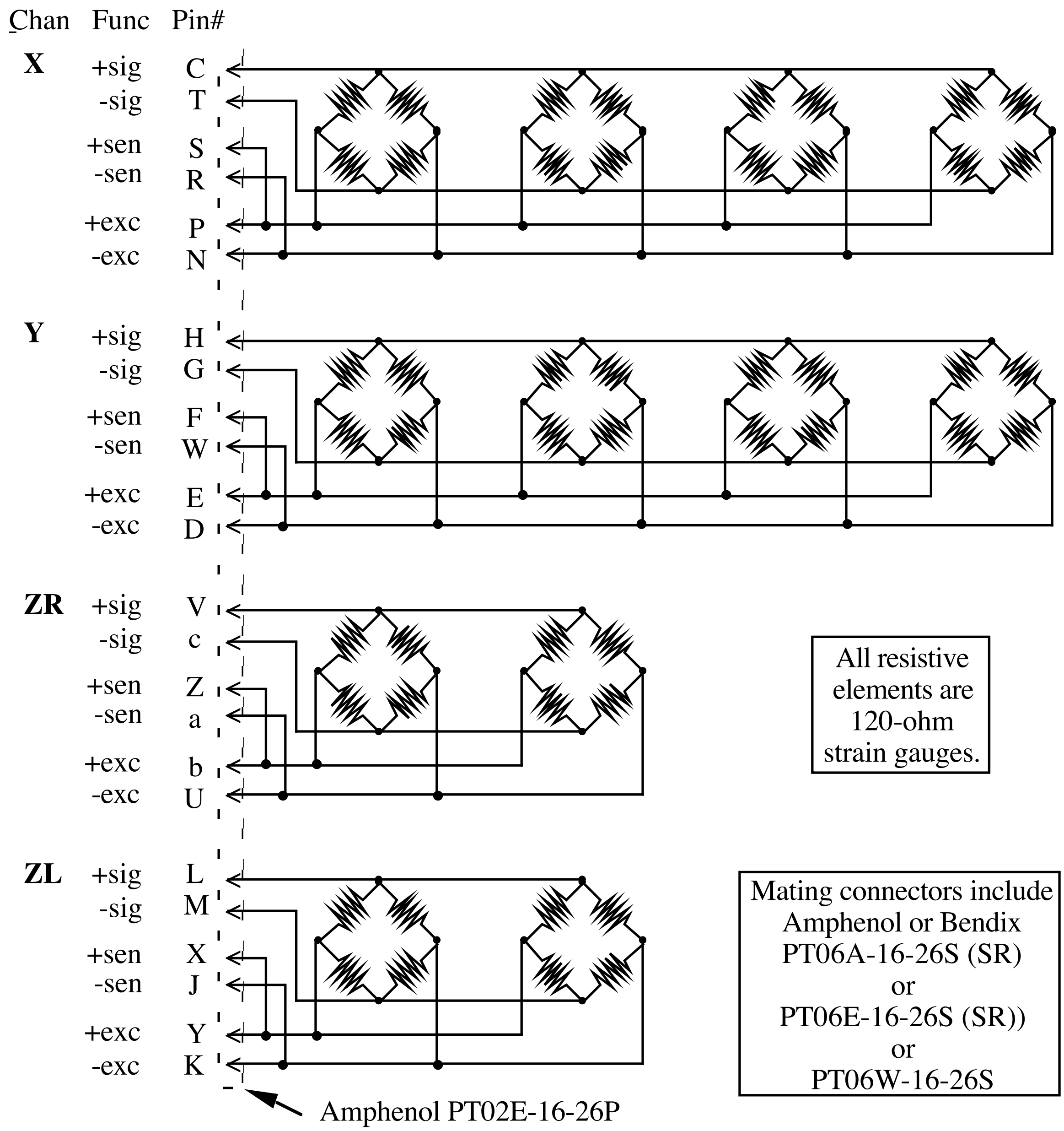


Figure 5. Circuits and pin-outs

EXCITATION

Recommended excitation is a precision regulated 2.5 volts. At this voltage, channels X and Y require 0.083 amperes and channels ZR and ZL require 0.042 amperes.

Higher excitation voltages (not exceeding 10 volts) may be used to increase signal strength, but the cells sensitivity to temperature may also increase as a result.

Calibrations Factors and Data Reduction

The following information is based on calibrations conducted in May, 1998. Calibration factors are in reference to the use of precision resistors of the indicated values applied as shunt-calibration resistors across the +sig, +sen terminals of the indicated strain-gauge bridge channels. (See figure 5.)

Note that the reference center of each individual transducer, which identifies the height of the longitudinal axis about which overturning moments (M_X) are defined, is located on the centerline of the bushing for the fifth-wheel-plate retaining pin. (See figure 3.)

In all of the following, polarities are such that the resulting values represent forces applied by the trailer to the fifth wheel according to the polarities of the SAE vehicle-dynamics axis systems (SAE J670,e). (Also see figures 1 and 3.)

Channel calibrations for right-side transducer

Channel	*Shunt cal resistance, ohms*	*Equivalent pounds*
XR	10,000	9,216
YR	10,000	9,125
ZLR	16,000	19,271
ZRR	16,000	19,331

Channel calibrations for left-side transducer

Channel	*Shunt cal resistance, ohms*	*Equivalent ponds*
XL	10,000	9,200
YL	10,000	8,999
ZLL	16,000	19,363
ZRL	16,000	19,388

The load-cell signals, in engineering units (pounds), are used in the following matrix calculations to determine the loads on the individual transducers.

Reduction matrix calculation for right-side transducer

$$\begin{bmatrix} F_{XR} \\ F_{YR} \\ F_{ZR} \\ M_{XR} \end{bmatrix} = \begin{bmatrix} 1 & -.0002 & -.0042 & -.0012 \\ -.0005 & 1 & .0083 & -.0167 \\ -.0044 & .0185 & 1 & 1 \\ .0071 & -2.0490 & -1.5237 & 1.5479 \end{bmatrix} \begin{bmatrix} XR \\ YR \\ ZLR \\ ZRR \end{bmatrix}$$

where XR, YR, ZLR, ZRR, F_{XR}, F_{YR}, and F_{ZR} are in pounds and M_{XR} is in inch-pounds.

Reduction matrix calculation for left-side transducer

$$\begin{bmatrix} F_{XL} \\ F_{YL} \\ F_{ZL} \\ M_{XL} \end{bmatrix} = \begin{bmatrix} 1 & -.0008 & .0005 & -.0008 \\ -.0018 & 1 & .0111 & -.0137 \\ .0176 & .0159 & 1 & 1 \\ .0239 & -2.0313 & -1.4709 & 1.5980 \end{bmatrix} \begin{bmatrix} XL \\ YL \\ ZLL \\ ZRL \end{bmatrix}$$

where XL, YL, ZLL, ZRL, F_{XL}, F_{YL}, and F_{ZL} are in pounds and M_{XL} is in inch-pounds.

Finally, the loads determined for the two individual cells are used in the following calculations to determine fifth-wheel loads.

$$F_X = F_{XR} + F_{XL}$$

$$F_Y = F_{YR} + F_{YL}$$

$$F_Z = F_{ZR} + F_{ZL}$$

$$M_X = S/2\,(F_{ZR} - F_{ZL}) + M_{XR} + M_{XL}$$

where F_X, F_Y, and F_Z are in pounds, M_X is in inch-pounds, and S is the lateral spacing of the two transducers, centerline-to-centerline, in inches. S is nominally 29.5 inches, but should be determined for each installation. See the following section on physical installation.

INSTALLATION

In order to insure fairly balanced sharing of lateral loading, the UMTRI fifth-wheel chair transducers are design to fit more closely in the bushing pockets of the fifth-wheel plate than are typical chairs. To insure that the chairs can be properly mounted on most truck frames, the transducers are mounted on their angle-iron bases such that the inner vertical surfaces of those angle irons will have lateral spacing slightly in excess of the typical 34-inch width of truck frame rails. Thus, it is expected that some shimming between the frame rail and the angle iron base of at least one chair will be required.

Accordingly, to install the fifth-wheel load transducer assembly, the entire assembly, including fifth-wheel plate should first be placed on the truck frame at the desired fore/aft position, and one side only should be firmly bolted to its frame rail. Then, with a feeler gauge, the width of the lateral gap between the other chair base and its frame rail should be determined. Shims of the appropriate size to fill this gap should be prepared and installed. (Shims may be installed on only one side, or they may be split and installed on both sides to put the fifth-wheel accurately on the centerline of the frame.) The entire assembly should then be bolted in place in accordance with normal practice for mounting fifth wheels.

DESIGN LOADS

Since little is known about the dynamic loads which can be expected at the fifth wheel coupling (either in conventional use or under conditions of proving grounds testing) it is difficult to clearly specify the maximum allowable trailer weights and/or static fifth-wheel loads which can be used with the UMTRI fifth-wheel load transducer. The following are provided as guidelines.

For on-highway use or for handling and braking tests on nominally smooth surfaces at proving-grounds, the UMTRI fifth-wheel load transducer should be limited to use with trailers whose static vertical fifth-wheel load does not exceed 30,000 pounds. By way of example, with such a nominal load, maximum stresses in the most heavily stressed sections can reach or exceed 50% of yield under either of the following load conditions: (1) simultaneous loads equivalent to 3 g vertical (90,000 lb) and 1 g longitudinal and lateral (30,000 pounds each); (2) a vertical load only of 8 g (240,000 pounds).

For use on uneven surfaces, trailer load should be significantly less than 30,000 pounds. Users should proceed cautiously, examining data closely during testing.

For operational safety, two 1-1/4 inch grade-8 bolts back up the heavily stressed, sensitive sections of each transducer chair. In normal use, these bolts carry no load. But in the case of failure of the highly stressed, sensitive sections of the transducer, these bolts would come into play to secure the upper and lower sections of the transducers to one another. (Note these bolts are not overload protectors which would prevent damage to the transducer; they are fail-safe devices only.)