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LOCOMOTIVE TRACK HAZARD DETECTOR PROGRAM (LTHD) INTERIM REPORT

AUGUST 1981

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7. Author(s): J. Corbin, J. Lazzaro, C. Peterson

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1820 Dolley Madison Boulevard
McLean, VA 22102

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16. Abstract

This interim report summarizes work performed by The MITRE Corporation for the Federal Railroad Administration Office of Rail Safety Research to develop a Locomotive Track Hazard Detector (LTHD). The objective of the LTHD program is to develop a simple and inexpensive unmanned track geometry measurement capability that can be used by the railroads to detect unsafe track conditions during routine revenue operations. The results of LTHD computer analysis and field testing phases as well as the goals of the remaining LTHD systems engineering and pilot test program phases are described. The results show that the simple LTHD concept can measure profile, variational cross-level and long wavelength alignment as well as the considerable more complex track geometry measurement systems mounted on full-size rail vehicles. It is concluded that LTHD is capable of providing a simple and effective method of acquiring data for track hazard detection and track geometry measurement purposes. Further development is recommended.

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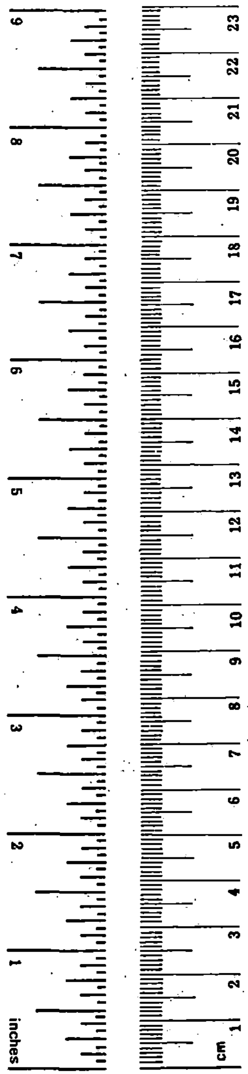
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

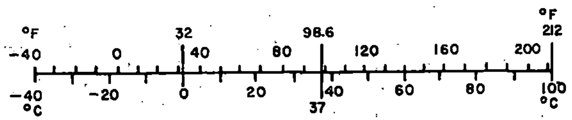
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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1. INTRODUCTION AND PROGRAM OVERVIEW

The objective of the Locomotive Track Hazard Detector (LTHD) program was to develop a simple and inexpensive measurement system mounted on a locomotive that can be used to detect potentially unsafe track conditions. MITRE's work on this program, sponsored by the Federal Railroad Administration's Office of Rail Safety Research, began early in 1978 with the formulation of the following requirements:

a. Automatic operation.

b. Ability to detect potentially unsafe conditions at normal train speeds.

c. Provision of a real-time warning to the locomotive locomotive engineer.

d. Recording track conditions on a routine basis.

e Simple design and installation.

f. Rugged, reliable, and easy to maintain and calibrate.

g Inexpensive.

Several measurement techniques were assessed for use in the LTHD system.* Systems that were evaluated for their potential applicability included track geometry, derailment detection and ride quality. The evaluation resulted in the selection of a simplified track geometry measurement concept that could be used to detect potentially unsafe wheel/rail acceleration levels. The only sensors necessary for such a measurement concept consisted of two vertical accelerometers mounted on each end of a locomotive truck axle, and one lateral accelerometer mounted at either end of the same axle.

*Romanzi, R.A., "A Feasibility Study for a Locomotive Borne Track Measurement System (LTMS)," WP-12945, The MITRE Corporation, McLean, Virginia, March 1978.

Although the proposed LTHD approach involved a substantial reduction in the number of sensors when compared to large scale track geometry measurement systems, it was intended to be capable of detecting data that could be used to warn the locomotive engineer of unsafe conditions. An important by-product was that the LTHD data could also be used to generate profile, cross-level variations and centerline alignment data.*

There are two primary reasons why the large reduction in the number of sensors used in the LTHD resulted in a relatively small reduction in measurement capability. First, LTHD measurements would be made from the axle of a locomotive thereby eliminating the need for off-axle displacement measurements. Second, the LTHD system was designed to measure track conditions from a moving train, making non-variational (static) measurement unncessary.

The elimination of the rate gyro data, velocity data, displacement data and gage data normally used in track measurement did however result in some reservations about the accuracy and potential applicability of LTHD data. The major points of concern were that:

a. acceleration data had not previously been shown (by itself) to be a usable measure of track geometry,

b. the accuracy of accelerometer-based track geometry measurements could possibly be unacceptably degraded (without non-accelerometer compensation for angular and gravitational effects),

c. the placing of accelerometers on the axles of locomotives could result in unacceptably high sensor failure rates, and

d. speed-sensitive accelerometer outputs might not result in repeatable hazard detection and/or track geometry outputs over the same section of track.

*Centerline alignment is defined as long wavelength, left and right rail alignment during wheel flange contact in curves.

To offset these concerns, it was decided that raw acceleration data would not be used directly since data processing techniques could convert acceleration data to displacement data. The data processing technique would correct for angular and gravitational effects. Experience with T-6 truck mounted instrumentation indicates that accelerometers can survive the railroad environment if they are properly protected. To assure data repeatability, it was decided that accelerometer speed sensitivity would be corrected during data processing.

A final answer to these concerns, was the result of analysis which predicted that the output of a three accelerometer LTHD could also be used to generate accurate profile and variational crosslevel and with somewhat lower accuracy centerline alignment measurements.

Based on these preliminary conclusions a four phase development program was initiated to test the LTHD concept.* The objective of Phase 1 - LTHD Computer Simulation (described in Section 2 of this report) was to model the capability of generating track geometry measurements using LTHD three accelerometer data. The successful completion of this phase led to in the initiation of Phase 2.

Phase 2 - LTHD Development and Testing (described in Section 3 of this report) consisted of three subtasks. The first subtask designed, fabricated and laboratory tested an experimental version of the LTHD sensor package. The second subtask installed and field tested the experimental LTHD on a locomotive at the Transportation Test Center (TTC). The third subtask compared in detail LTHD track geometry data with a reference track of known geometry. The results of Phase 2 demonstrated the feasibilty and potential of the LTHD concept as a relatively inexpensive means of implementing a locomotive hazard/ derailment warning capability as well as an inexpensive means of augmenting existing track geometry measurement and data acquisition capabilities.

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*Romanzi, R.A., "Work Statement - Development of the Locomotive Borne Track Measurement System (LTMS) Concept," WP-13045, The MITRE Corporation, McLean, Virginia, May 1978.

Phase 3 is currently planned to include: implementating and comparing of track hazard detection algorithms as specified by the FRA; selecting of LTHD data recording options; and development of a prototype LTHD system specification. Design trade-offs to be investigated are planned to include: on-board real time processing capabilities; data recording requirements versus system reliability and cost; a comparison of alternative methods for referencing potential track hazard locations; and the cost impact of various LTHD fabrication, operation and maintenance alternatives.

Phase 4 is planned to consist of a pilot railroad test program, where a prototype LTHD system would be tested over a period of several months on a locomotive of a cooperating Railroad. The test would involve the collection of data to evaluate LTHD applicability, reliability and maintainability. Operational performance monitoring of the LTHD system would also be accomplished to compare the effectiveness of the LTHD system with more complex and expensive track geometry measurement systems.

2. LTHD COMPUTER SIMULATION

The purpose of the LTHD Computer simulation was to demonstrate that the output of three axle mounted accelerometers (Figure 2-1) could be used to generate accurate data for use in track hazard detection algorithms.

Since FRA's T-6 track measurement railcar included three accelerometers that were configured in a way that closely resemble the LTHD concept, it was proposed that the LTHD be simulated using T-6 accelerometer data. An important advantage of the T-6 data was that sufficient sensor redundancy existed to verify the accuracy of the T-6 output data prior to its comparison with simulated LTHD outputs.

2.1 Approach

Figure 2-2 shows the T-6 sensor configuration. Although the LP and RP (left profile and right profile) and the AL (alignment) accelerometers were not mounted on the same axle on the T-6 railcar, they were located sufficiently close together to permit LTHD simulation.* The method used to generate LTHD variational track geometry outputs from accelerometer and time between sample (TBS) data is shown in Figure 2-3 and 2-4. Figure 2-3 shows how LP, RP and AL accelerometer data were filtered and digitized at one foot intervals. The TBS input was generated by a time interval counter controlled by the one foot sample pulse These outputs are shown as inputs in Figure 2-4.

The purpose of the first set of T-6/LTHD data processing operations (Figure 2-4a) was to convert the LP, RP and AL analog filtered acceleration data into short mid-chord offset (MCO) displacement data. This was accomplished using a modified second finite difference (SFD) operation. Figure 2-5 shows how a basic SFD ($x_i - 2x_{i-1} + x_{i-2}$) is equal to minus two times a short mid-chord offset (MCO) measurement. The same figure shows how the SFD data was converted back to its original form through a double integration process (used in steps 2.4c and f).

*Since FRA track hazard algorithm development efforts have not yet reached a definitive stage, LTHD accuracy was tested by comparing T-6 and LTHD track geometry data. This is considered to be a valid approach since to this date definitions of hazards have in some way involved track geometry.

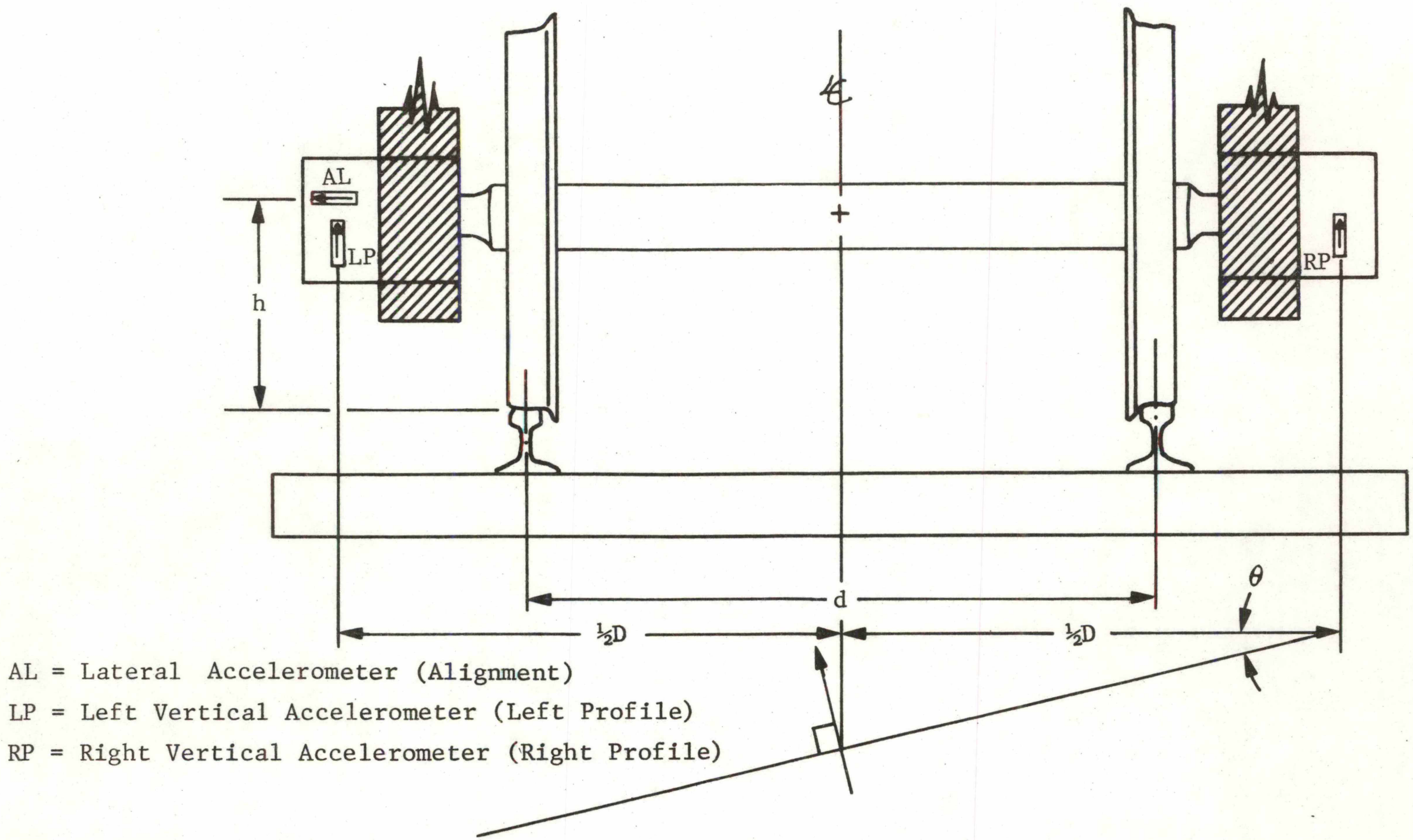


FIGURE 2-1. LTHD SENSOR CONFIGURATION

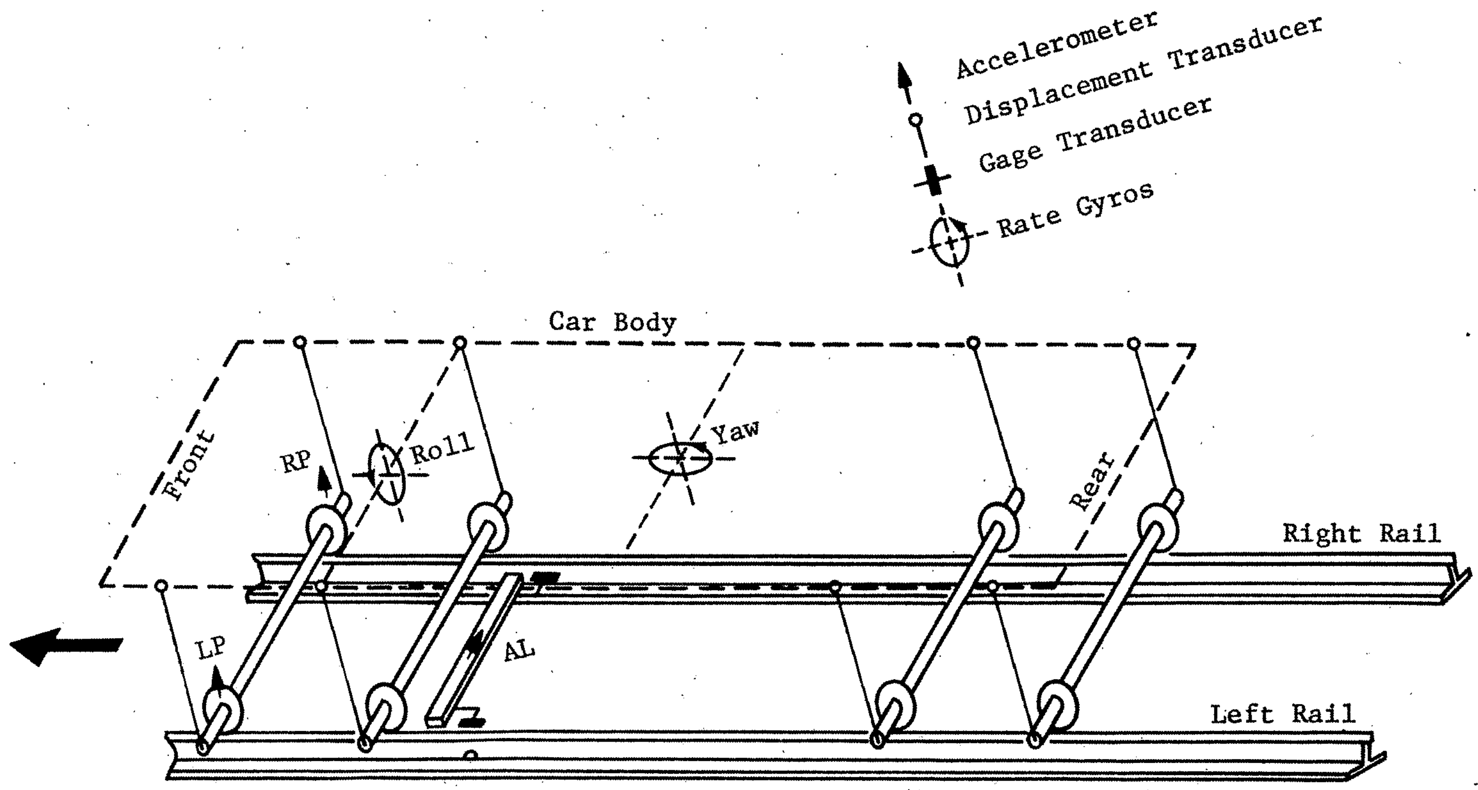


FIGURE 2-2. T-6 SENSOR CONFIGURATION

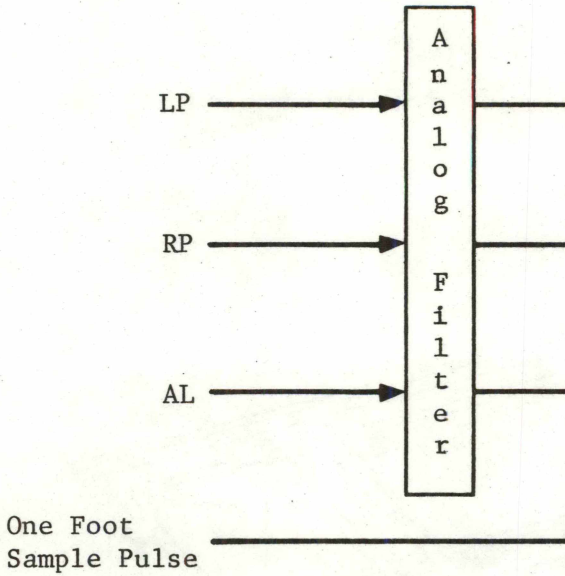
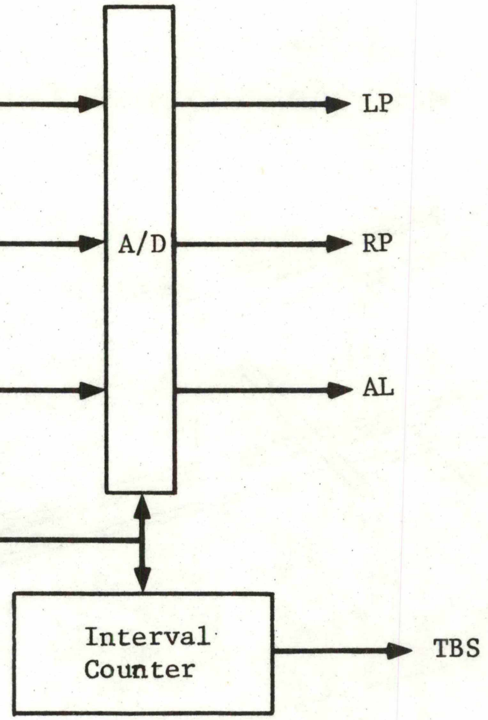
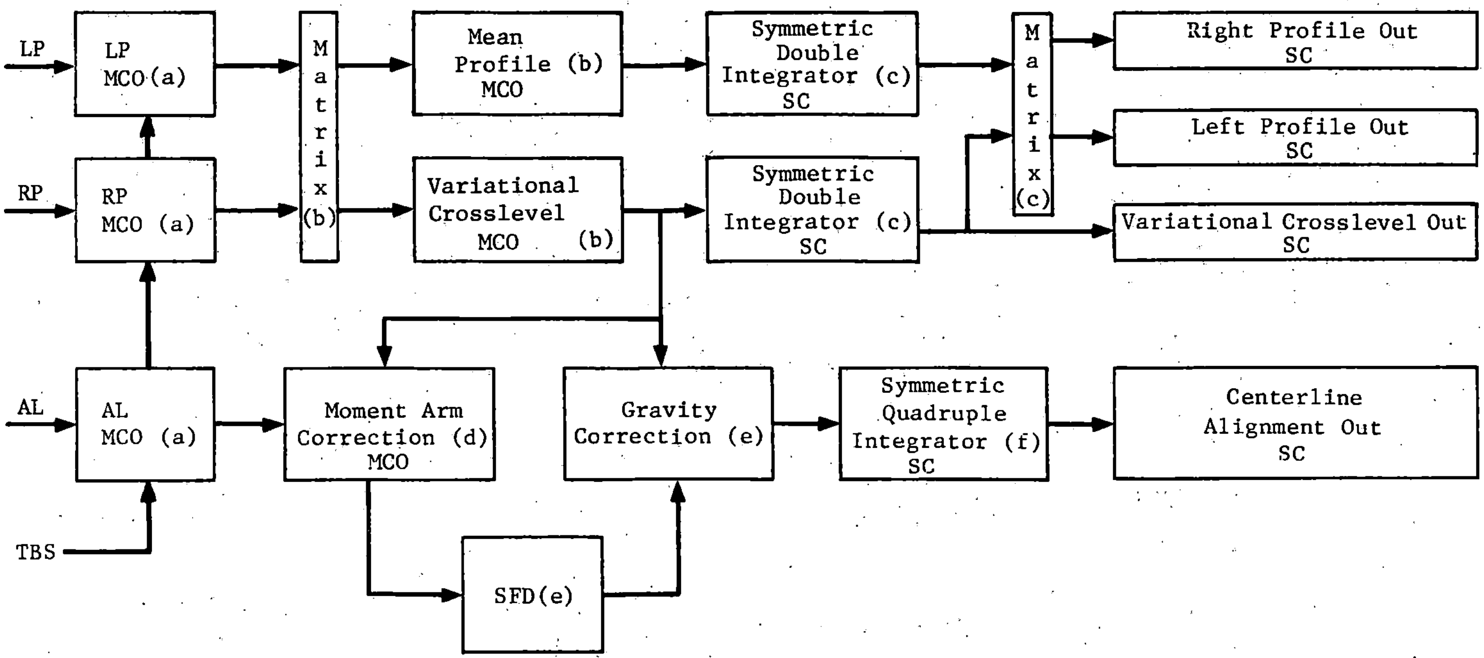


FIGURE 2-3.

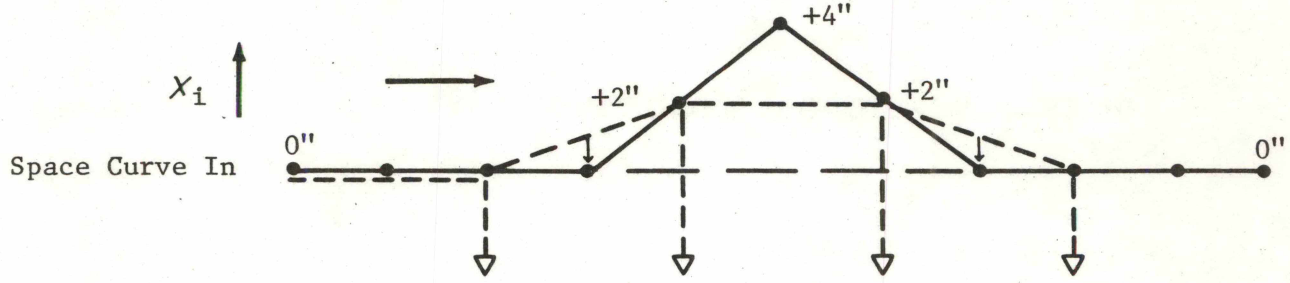


T-6/LTHD PRE-PROCESSING



MCO – Mid Chord Offset
SC – Space Curve

FIGURE 2-4. T-6/LTHD VARIATIONAL TRACK GEOMETRY PROCESSING



Short MCO	0	0	0	0	−1	0	+2	0	−1	0	0
$(X_i - 2X_{i-1} + X_{i-2})$	0	0	0	0	+2	0	−4	0	+2	0	0
Double Integration	0	0	0	0	+2	+2	−2	−2	0	0	0
	0	0	0	0	+2	+4	+2	0	0	0	0

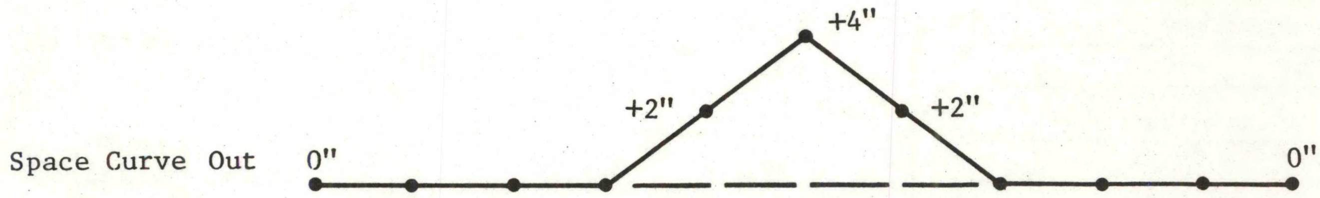


FIGURE 2-5. SECOND FINITE DIFFERENCE/MID CHORD OFFSET/ DOUBLE-INTEGRATION TRANSFORMATION

The reason that a modified SFD was utilized was to correct for errors that were introduced by the use of analog (integration) filters. Such errors include signal phase distortion as well as the potential for noise and drift problems. Of these potential problems, phase distortion is known to result in undesirable speed and direction dependent LTHD measurements.

The solution to these phase distortion, noise and drift problems was to generate a hybrid analog/digital SFD (filter) that produced an isoceles triangle shaped impulse response. This was performed as follows:

$$\text{Mod, SFD} = x_i\ (1 - k_1\ \text{TBS} + k_2\ \text{TBS}^2)$$
$$-2x_{i-1}\ (1 - k_2\ \text{TBS}^2)$$
$$+x_{i-2}\ (1 + k_1\ \text{TBS} - k_2\ \text{TBS}^2)$$

where $k_1 + k_2$ are fixed analog filter constants and TBS is the time between samples x_i and x_{i-1}.

Both the modified SFD and the double integration operations were utilized in the LTHD computer simulation effort due to their relatively simple implementation and their suitability as continuous data stream operators.

The next T-6/LTHD data processing operation (Figure 2-4b) combined the LP and RP mid-chord offset values to generate mean profile* (MP) and overhang corrected variational crosslevel (CL)*.

The crosslevel scaling computation corrected the left and right profile variational displacement MCOs for overhang of the LP and RP accelerometers beyond the rail heads. This produced a peak to peak variational crosslevel displacement measurement (based on a 56.5 inch nominal gage) for each centerline profile measurement.

*Mean profile is defined as the profile of an imaginary rail located midway between the left and right rails.

The next operation (Figure 2-4c) was to convert overlapping blocks of profile and crosslevel short chord data to a space curve form* (4,5). Centerline profile space curve data was then combined with variational crosslevel space curve data (CL) to generate left and right profile outputs as follows:

$$LP = MP + \tfrac{1}{2}CL$$

$$RP = MP - \tfrac{1}{2}CL$$

Since the T-6 alignometer accelerometer (AL) was located above the plane of the rail heads a moment arm computation (Figure 2-4d) was required to correct for lateral accelerations caused by variational crosslevel. In addition, a gravity computation (Figure 2-4e) preceded by an additional SFD operation was performed to correct for gravity field effects when the horizontally oriented accelerometer (AL) was tilted by crosslevel variations.** Since space curve center-line alignment data was desired, two sets of symmetric double integrations (Figure 2-4f) i.e. a quadruple integration was performed to complement preceding double SFD operations (AL, $MCO_{(a)}$ and $SFD_{(e)}$).

The result of this processing was to generate data one would expect to see at the output of a LTHD designed to measure space curve track geometry data.*** Such processing is probably more than will be required to warn a locomotive engineer of potential danger; however, it was used here to permit a more stringent validation of three-accelerometer LTHD data by comparing it with T-6 track geometry data. Such processing will be available for off-line operations although the production model LTHDs may eventually be designed to perform space curve measurements onboard a locomotive if they can be implemented with low cost microprocessors.

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* A measurement of absolute rail position relative to a long baseline.

** The additional SFD operation provided a convenient means of making the gravity correction.

***T-6 data was also presented in a space curve form to permit direct T-6/LTHD comparison.

To add confidence to the data comparison process, the T-6 data was incrementally converted to the more austere LTHD data. For example, alignment was compared with and without gage correction and profile with and without axle accelerometer displacement corrections.

2.2 Data Processing and Analysis

2.2.1 TTC Perturbed Track Data Used For Analysis

The data selected for the LTHD comparisons was taken from a series of T-6 track geometry measurement runs performed in 1978 over a tangent portion of the TTC perturbed track and an arbitrarily selected curved section of revenue track. Figure 2-6 shows T-6 space curve data for the 2500' section of perturbed test track. The left hand portion of track shown (a) was designed so that the left rail and right rail profiles were out of phase an equal amount resulting in a double amplitude crosslevel output.* The middle portion (b) of track was designed with alignment perturbations only. The right hand portion of track (c) was designed with out-of-phase profile and alignment perturbations together. T-6 data was recorded while traversing the test track both in forward and reverse directions.

2.2.2 Comparison of T-6 and LTHD Processing Results

LTHD-simulated data were compared with T-6 track geometry data as shown in Figures 2-7 to 2-9. Four basic comparisons were made:

- Profile, left and right
- Crosslevel
- Alignment - long wavelength
- Alignment - short wavelength

Figure 2-7 shows that a close agreement exists between T-6 and LTHD left and right profile data. Figure 2-8 shows that T-6 and LTHD crosslevel data are also well matched throughout the test zone. Any profile and crosslevel variations observed appear to be within the bounds of T-6 data repeatability as seen between Runs 3-W (Figure 2-6) and 1-W (Figures 2-7,2-8).

*The data indicates alignment variations also existed in this section.

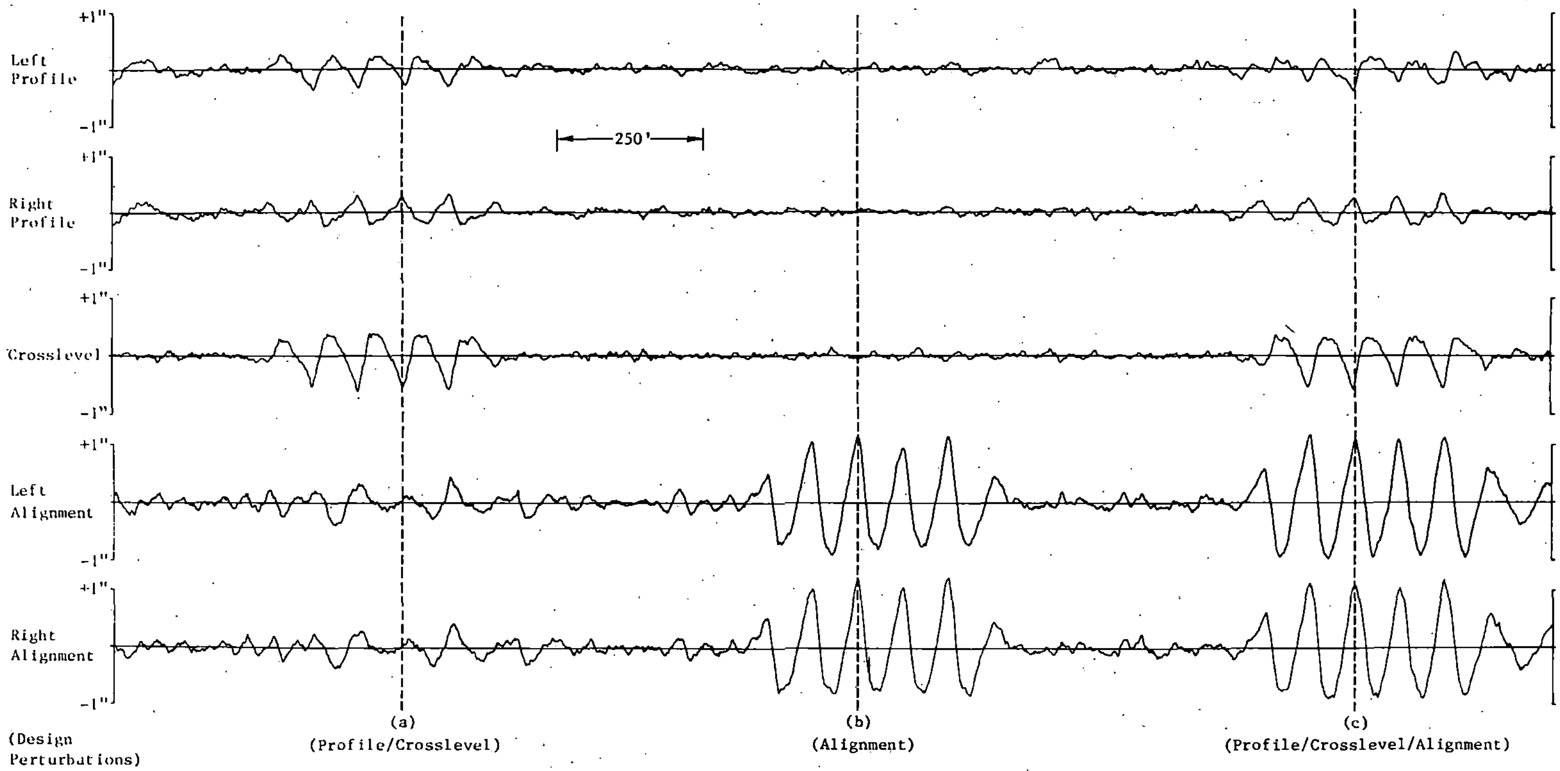

FIGURE 2-6. T-6/TCC PERTURBED TEST TRACK SPACE CURVE DATA (RUN 3-W)

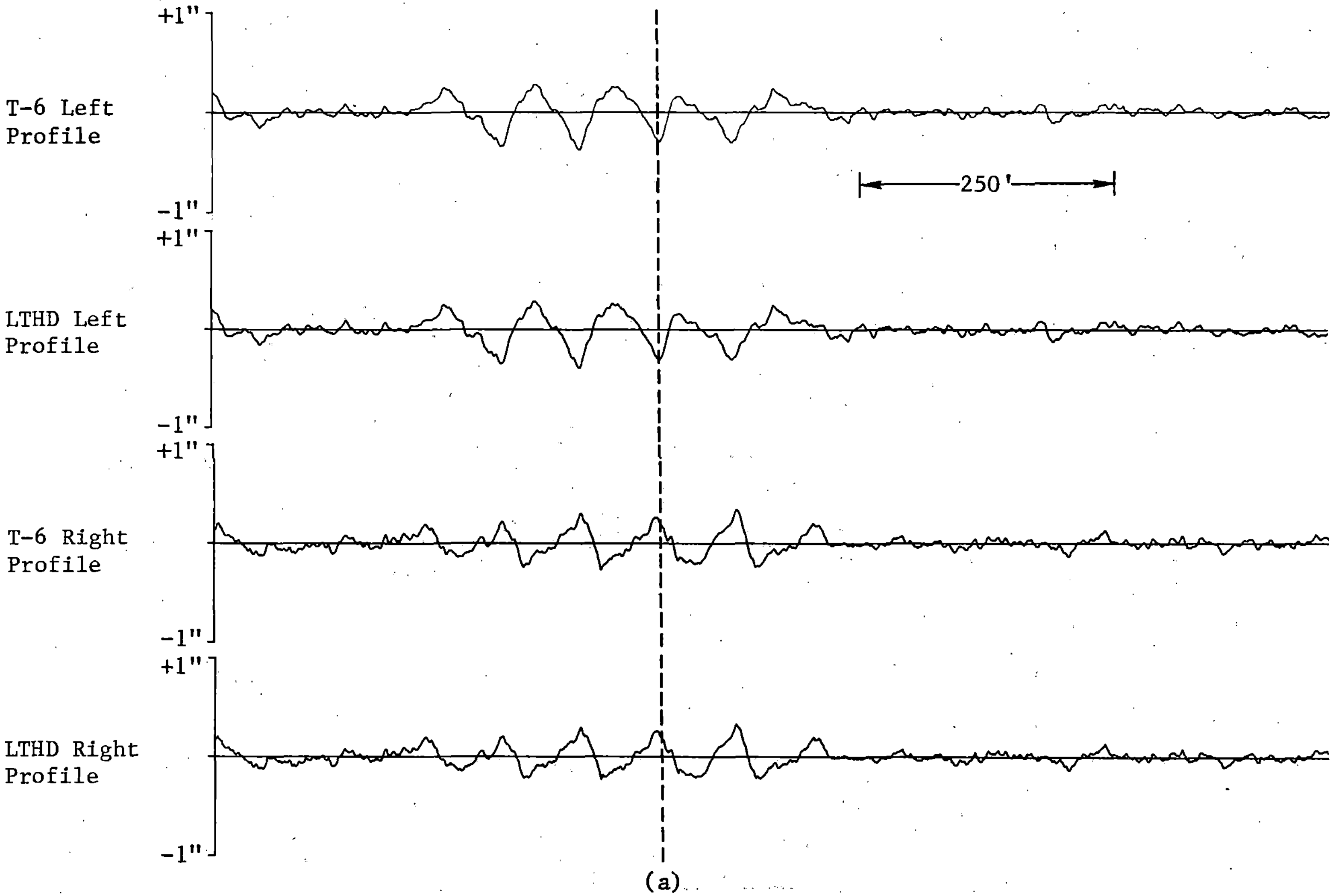

FIGURE 2-7. T-6/LTHD PROFILE DATA COMPARISON (RUN 1-W)

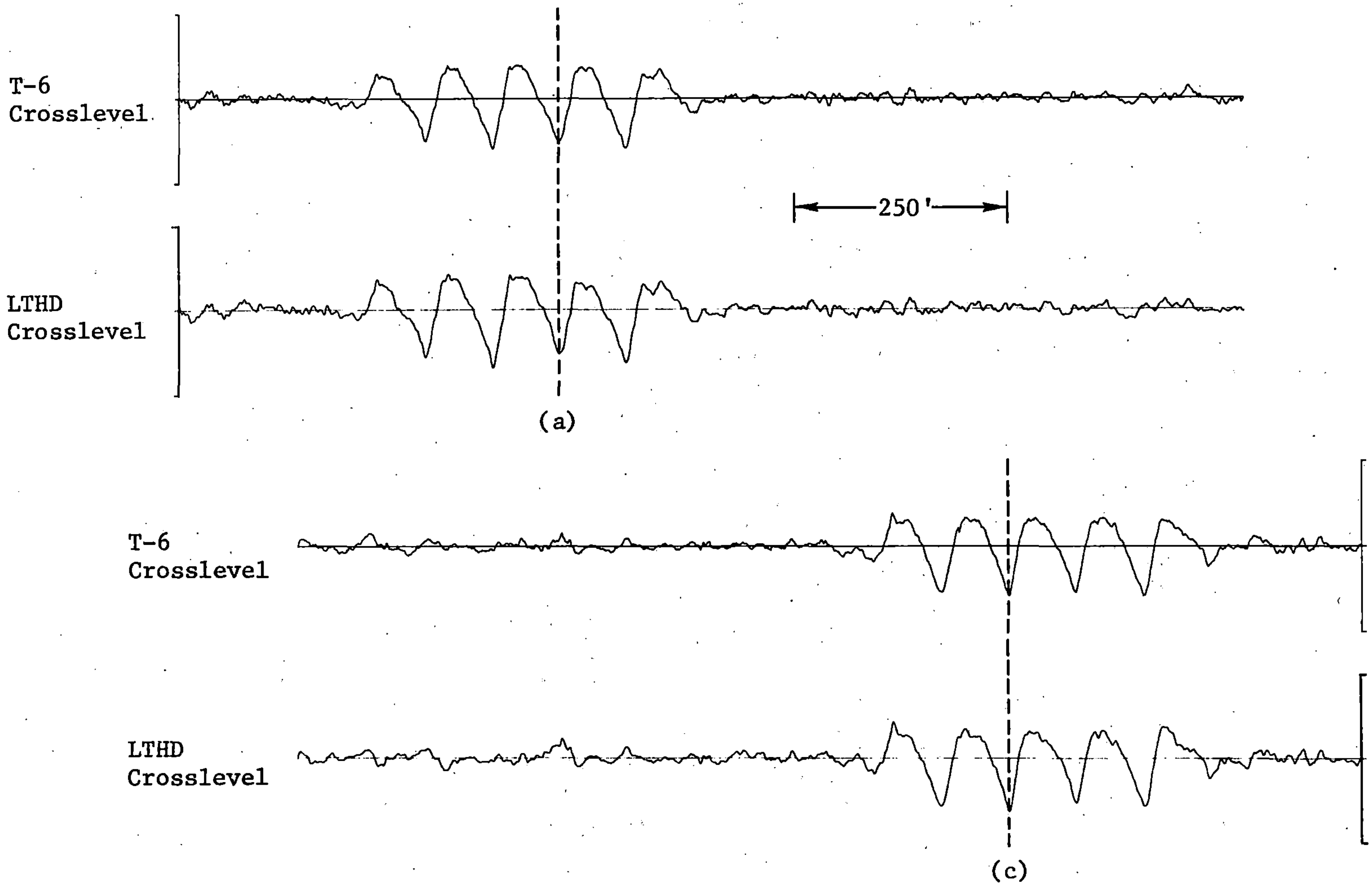

FIGURE 2-8. T-6/LTHD CROSSLEVEL DATA COMPARISON (RUN 1-W)

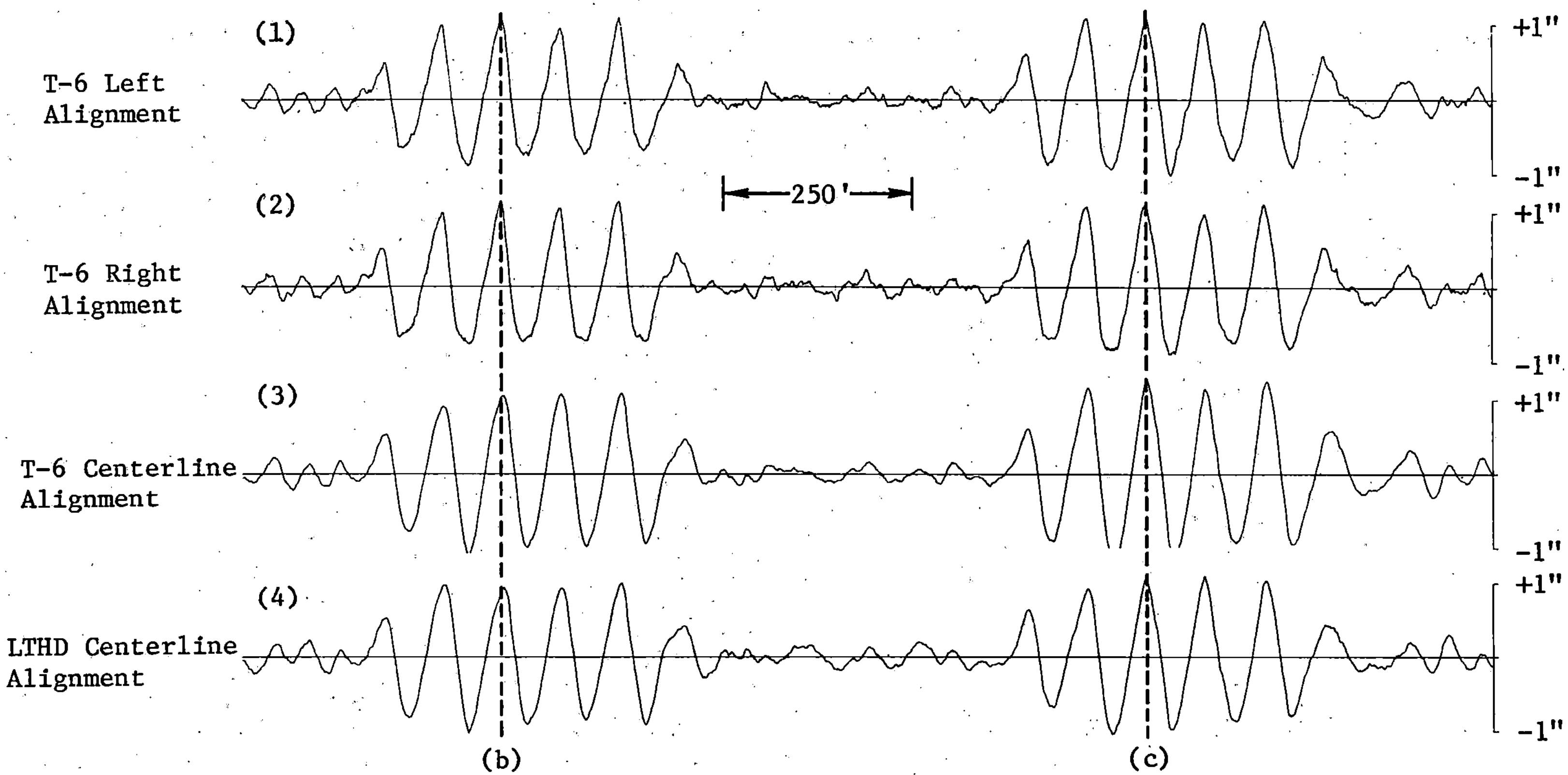

FIGURE 2-9. T-6/LTHD ALIGNMENT DATA COMPARISON (RUN 1-W)

Figure 2-9 shows the similarity of long wavelength tangent track data between T-6 left and right alignment data (trace 1,2) with T-6 centerline alignment data (3) with LTHD centerline alignment data (4); this figure shows that long wavelength alignment data (< 60 feet) exists in a nearly identical manner in the left rail the right rail and (as measured by the LTHD) along the centerline of the two rails.

One final analysis was made to determine if centerline alignment could be related to "high-rail" alignment in curves when the wheel flanges of the measurement vehicle were in contact with the railhead. If so, LTHD instrumentation could be used to measure both short and long wavelength alignment of the load-bearing-rail in curves when wheel flange contact occurred. Figure 2-10 shows the results of this analysis.

The top pair of traces in Figure 2-10 show a space-curve representation of crosslevel. The smooth trace is a filtered version of the higher frequency crosslevel signal. The left hand portion of the two traces shows a positive 3.2 inches of crosslevel in the curve; followed by a constantly reduced cross-level in the spiral; and ending on the right with zero crosslevel in the tangent track.

The middle trace shows T-6 left alignment data (purposely offset) and T-6 centerline alignment data on the bottom. Since forward motion of the measurement vehicle was from left to right and crosslevel was positive (meaning the left rail was elevated to compensate for a curve to the right), wheel flanges on the left side of the vehicle would have been in contact with the left rail. This means that centerline alignment data should closely match left rail alignment data, which it did throughout the entire curve plus part of the spiral (Figure 2-10 Section X).

Examination of the bottom pair of traces of Figure 2-10 (right aligment data and T-6 centerline alignment data) shows only the long wavelength alignment relationship of the type described previously. This means that the centerline alignment signal is directly related to the left rail alignment signal as hypothesised*. Data to the right (Figure 2-10 section Y) shows

*The T-6 left alignment signal consists of the AL accelerometer output and the left gage displacement output; therefore, when the rims of the wheels are in contact with the rail, the left gage displacement output is a constant.

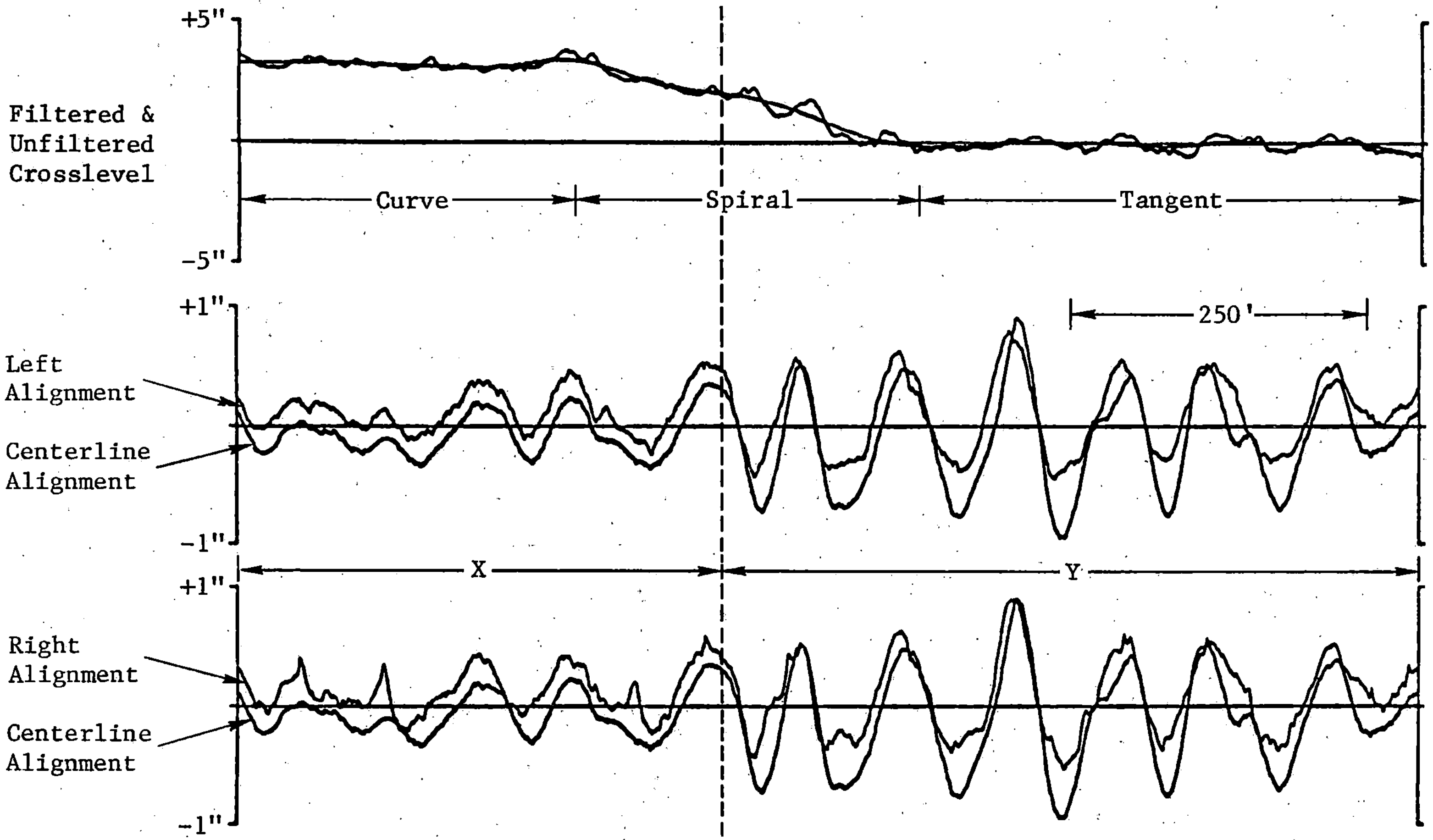

FIGURE 2-10. T-6 ALIGNMENT COMPARISONS IN CURVES

that a number of 80'-90' long wavelength alignment variations exist throughout the spiral and tangent track area. This is a common railroad maintenance-of-way problem found at the exit and entrance of curves. The problem is caused by the resistance inertia of locomotives and trains to sudden changes in direction. Dissipation of the inertia takes the form of a hunting resonance that damps itself out after a number of cycles. This data also shows that centerline and right and left alignment traces can deviate from each other in tangent track during periods of hunting and/or when the wheel sets impact the railheads. However, since centerline alignment data is actually a measure of lateral displacement of the railcar, such a measurement may be of greater importance to train safety than knowledge of the physical alignment of the track.

2.2.3 Simulation Summary and Conclusion

In summary, LTHD computer simulation efforts showed that:

a. left and right rail profile could be measured at all significant wavelengths of interest;

b. crosslevel can be measured at wavelengths of approximately 200 feet and less (variational crosslevel);

c. centerline alignment, can be measured at wavelengths between 60 and 200 feet on both curved and tangent track, and;

d. high rail alignment can be measured in curves at wavelengths less than 60 feet whenever wheel flange contact occurs.

As a result, it was concluded that LTHD data can closely match profile, crosslevel and some alignment track data obtained by large scale track geometry measurement systems at a fraction of the complexity of such systems. This encouraging result permitted the initiation of the LTHD development and testing phase.

3. LTHD DEVELOPMENT AND TESTING

Three separate subtasks comprised the LTHD development and testing effort. The first involved the design, fabrication and laboratory testing of an experimental LTHD sensor package. The second the installation and operation of the LTHD sensor package on a locomotive at the Transportation Test Center (TTC), and the third the generation and evaluation of variational track geometry measurements from LTHD sensor data.

3.1 LTHD Sensor Design, Fabrication and Laboratory Testing

When LTHD computer simulation results indicated that the output from the three LTHD accelerometer configurations could be used to generate accurate track hazard detection data, an engineering study was performed to identify desired LTHD accelerometer sensor characteristics. The first concern was to quantify the acceleration environment of a locomotive axle. The literature generally identifies unsprung truck acceleration levels in the track geometry measurement range-of-interest as 10 to 30 g's vertical and 10 g's lateral over a frequency range of 0 to 20 Hz. The 20 Hz frequency corresponds to wavelengths of: six feet at 80 mph; three feet at 40 mph; etc.

Acceleration levels that exist at frequencies higher than 20 Hz would require accelerometers having a much higher measurement range resulting in a loss in resolution at the lower frequencies. Elimination of the higher frequencies was planned through the use of foam isolation materials similar to those used to protect the alignometer mounted on the truck of FRA's track geometry measurement vehicle T-6.

3.1.1 Accelerometer Selection

The next task was to determine the type accelerometer that would be best suited for LTHD operation. Commercially available accelerometers fall into one of three categories: force-balance servo, piezoelectric or piezoresistive. A comparison of the characteristics offered by each of these technologies is shown in Table 3.1.

TABLE 3.1 - TYPICAL CHARACTERISTICS OF COMMERICALLY AVAILABLE ACCELEROMETERS

Parameter	ACCELEROMETER TYPE Force-Balance Servo	Piezoelectric	Piezoresistive
Range (g's)	±0.001 - ±200	±50 - ±10,000	±20 - ±50,000
Frequency Response	DC - 250 Hz	2 - 100,000 Hz	DC - 5,000 Hz
Cross Axis Sensitivity	1% full scale	5% full scale	1% full scale
Linearity Error	.2% full scale	1% full scale	1% full scale
Internal Amplifier	Yes	Yes	No
Shock (Maximum)	3,000 g's	10,000 g's	5,000 g's
Vibration (Maximum)	50 g's	1,000 g's	1,000 g's
Cost	$500 - $1,500	$350 - $600	$150 - $375

The characteristics of each of the three accelerometer types were compared with LTHD requirements. Piezoelectric accelerometers were eliminated since they lack the D.C. response required by the LTHD approach (to avoid signal phase-shift problems.) A direct comparison of the characteristics offered by force-balance servo and piezoresistive sensors was then made. On the basis of superior transverse sensitivity and linearity, force-balance servo accelerometers were selected for use in the experimental LTHD sensor package. Specifications for the accelerometers selected for LTHD are given in Table 3.2.

3.1.2 Accelerometer Mounting

In order to prevent signal saturation and/or damage to the accelerometers over the frequency range of interest as well as isolate the accelerometers from high frequency vibrations, it was necessary to enclose the accelerometers inside a foam chamber. The configuration of the LTHD sensor package is shown in Figure 3-1. One of the sensor packages contained both a vertical and lateral accelerometer while the other contained only a vertical accelerometer.

Polyethylene foam was selected for use as the isolation material. The physical properties of foam offered a significant advantage over other materials commonly used in shock/vibration isolator design. Ease of fabrication was a major asset. In addition, polyethylene foam provided a barrier to the penetration of dust and moisture due to its closed cell construction. This was considered to be an important long term advantage since the accelerometer packages were to be mounted external to the locomotive cab and would be continuously exposed to the elements.

Material density, controlled by the degree of expansion during manufacture, is one of the primary design factors used to generate specific isolation properties of polyethylene foam. Other design factors included the thickness and configuration of the foam and the contact area and weight of the accelerometer enclosure. As a result, a laboratory-based approach to the design of the experimental LTHD sensor package was used. Foams which were tested in the LTHD sensor package included Ethafoam 400, which is manufactured in densities of 4 pound per cubic foot (4PCF) and 2 PCF. Initial tests with the 4 PCF foam indicated that the material was too rigid to obtain the desired high frequency roll-off of 20 Hz.

TABLE 3.2 - SPECIFICATIONS FOR LTHD FORCE-BALANCE SERVO ACCELEROMETERS

	Parameter	Lateral	Vertical*
1.	Sensitivity	1000 mv/g ±5%	100 mv/g ±5%
2.	Range	±10g	±30g
3.	Frequency Response	0-50 Hz ±2dB	0-50 Hz ±2dB
4.	Dynamic Range	100 dB	100 dB
5.	Transverse Sensivitity	0.0005 g/g	0.0005 g/g
6.	Temperature Range	-40°F to 200°F	-40°F to 200°F
7.	Resonant Frequency	200 Hz	200 Hz
8.	Output Impedance	10 OHM	10 OHM
9.	Full Scale Output	±10 VDC	±3 VDC
10.	Amplitude Linearity	.05% full scale	.05% full scale
11.	Humidity	Hermetically Sealed	Hermetically Sealed
12.	Input Voltage	±9 to 18 VDC	±9 to 18 VDC
13.	Input Current	±8 ma	±8 ma
14.	Shock	500g, 5ms; 3000g, 1ms	500g, 5ms; 3000g, 1ms
15.	Grounding	Isolated From Case	Isolated From Case
16.	Size	3" x 2" x 1.6"	3" x 2" x 1.6"
17.	Weight	7 oz.	7 oz.

* The 30g accelerometers were manufactured in such a way that they could be changed, if desired, to a 10g configuration during field tests.

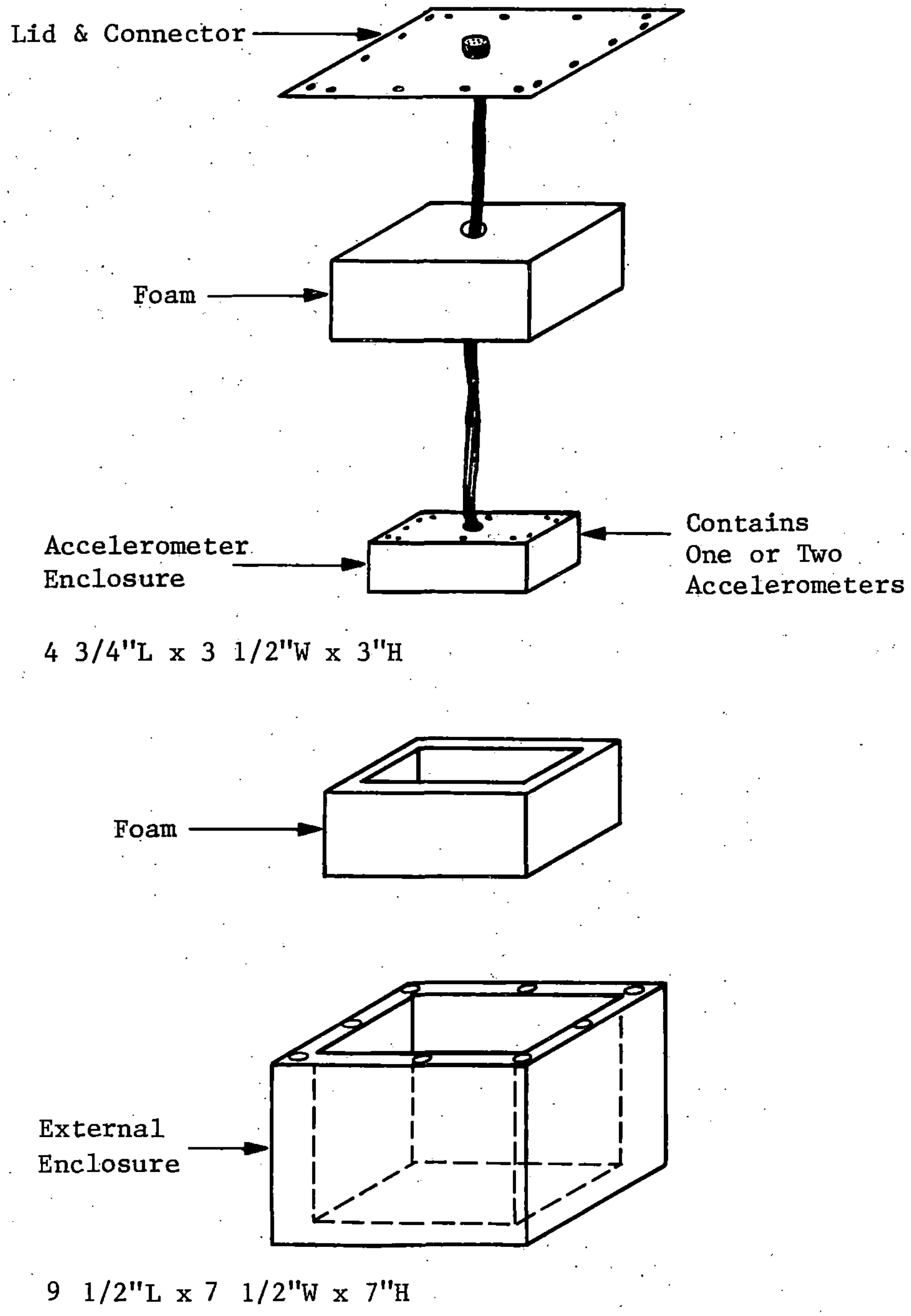

FIGURE 3-1. LTHD SENSOR PACKAGE

Tests with the 2 PCF foam indicated an initial natural frequency in the 30 to 50 Hz range. Additional weight (lead) was added to the smaller accelerometer enclosure to obtain the desired natural frequency of approximately 20 Hz. Laboratory tests were then performed to verify the electrical characteristics of the LTHD sensor packages prior to field testing.

3.2 LTHD Field Tests

The purpose of the LTHD field test was to validate the LTHD concept utilizing an instrumented locomotive and track with known geometry perturbations. The specific objectives of the test were:

a. to prove that adequate data to accomplish the LTHD processing could be obtained from axle-mounted accelerometers,

b. to validate the proposed foam-isolated accelerometer package design concept for locomotive applications, and

c. to obtain field data to permit the comparison of variational LTHD track geometry processed data with a reference track of known geometry.

The field tests were conducted on the perturbed section of TTC track (Figure 3-2) in Pueblo, Colorado during September 23-24, 1980.* This track contained profile, cross-level and alignment perturbations of the type suspected to known to contribute to the cause of derailments (Figure 3-3.)

The LTHD sensor packages were mounted on the journal boxes of the lead axle of the rear truck of a General Electric U30C locomotive (DOT-001) as shown in Figure 3-4. This locomotive uses a tapered roller bearing journal configuration which directly transmitted lateral and vertical motions of the axle to the LTHD package. Data conditioning, digitizing and recording support was provided by FRA's T-5 Data Acquisition Car shown in the same figure.

*The track utilized for the LTHD test was curved as the tangent perturbed track was no longer in place.

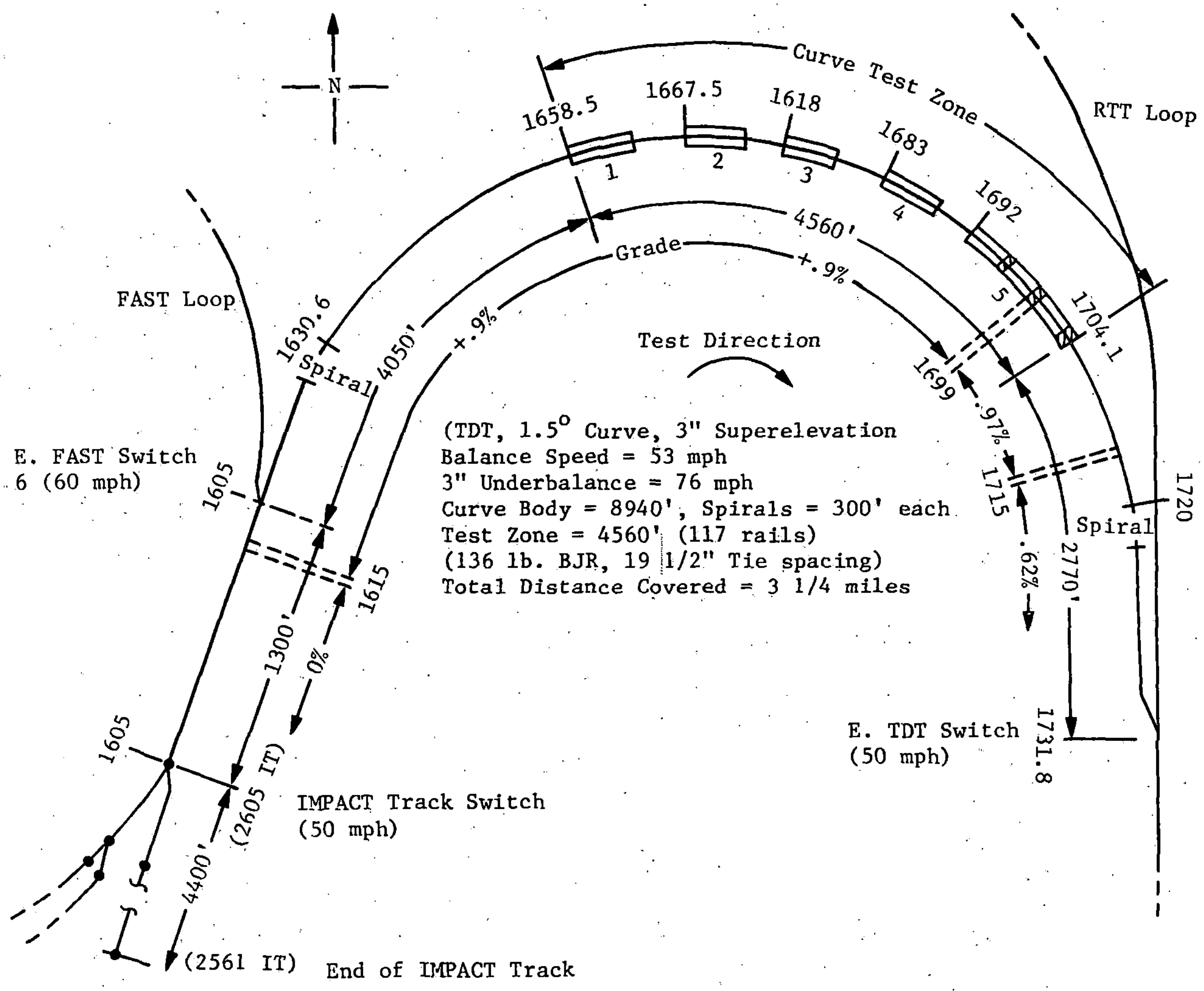

FIGURE 3-2. PERTURBED TEST TRACK — CURVED ZONE

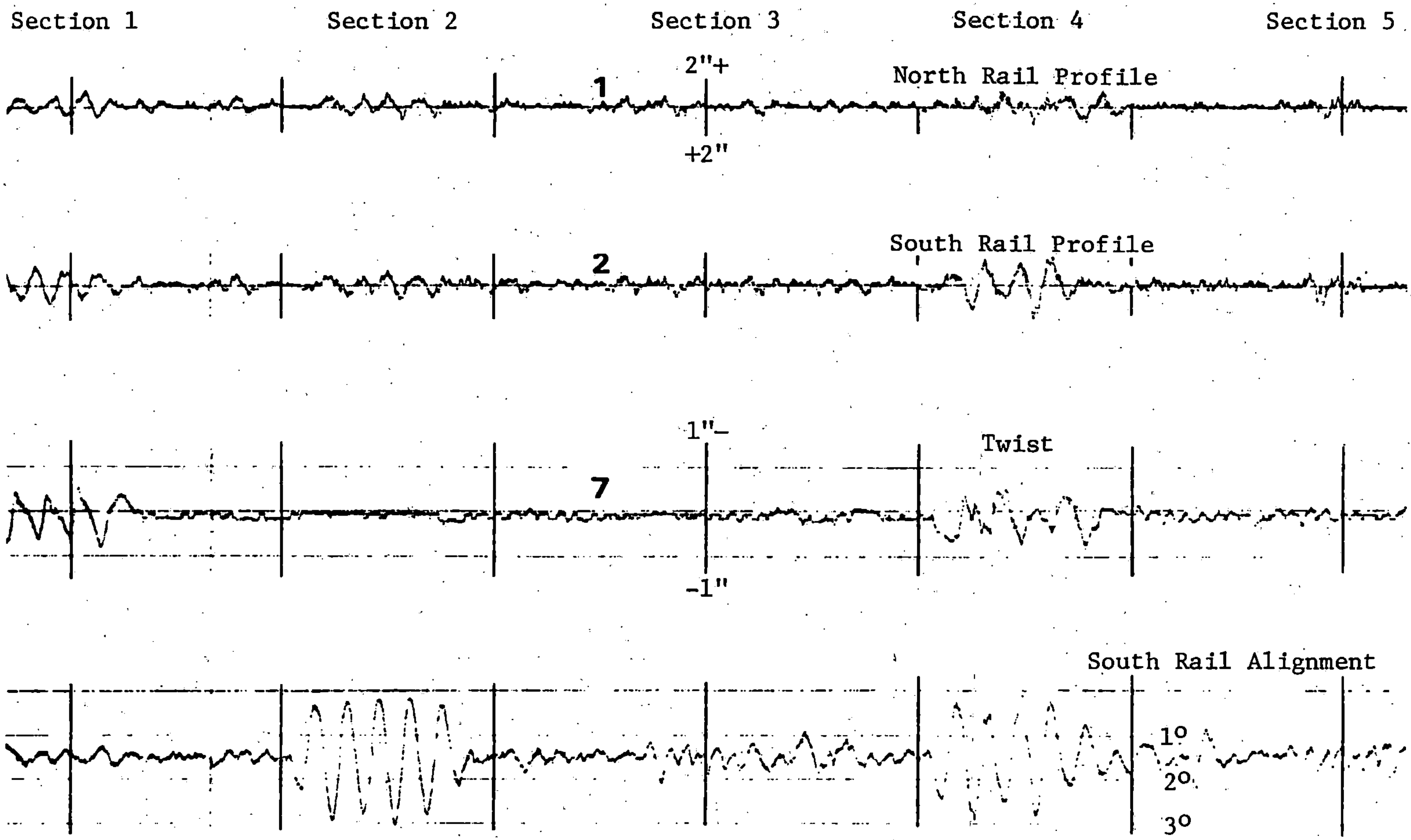

FIGURE 3-3. TRACK GEOMETRY OF PERTURBED TRACK MADE BY PLASSER EM-80 (62′ CHORD)

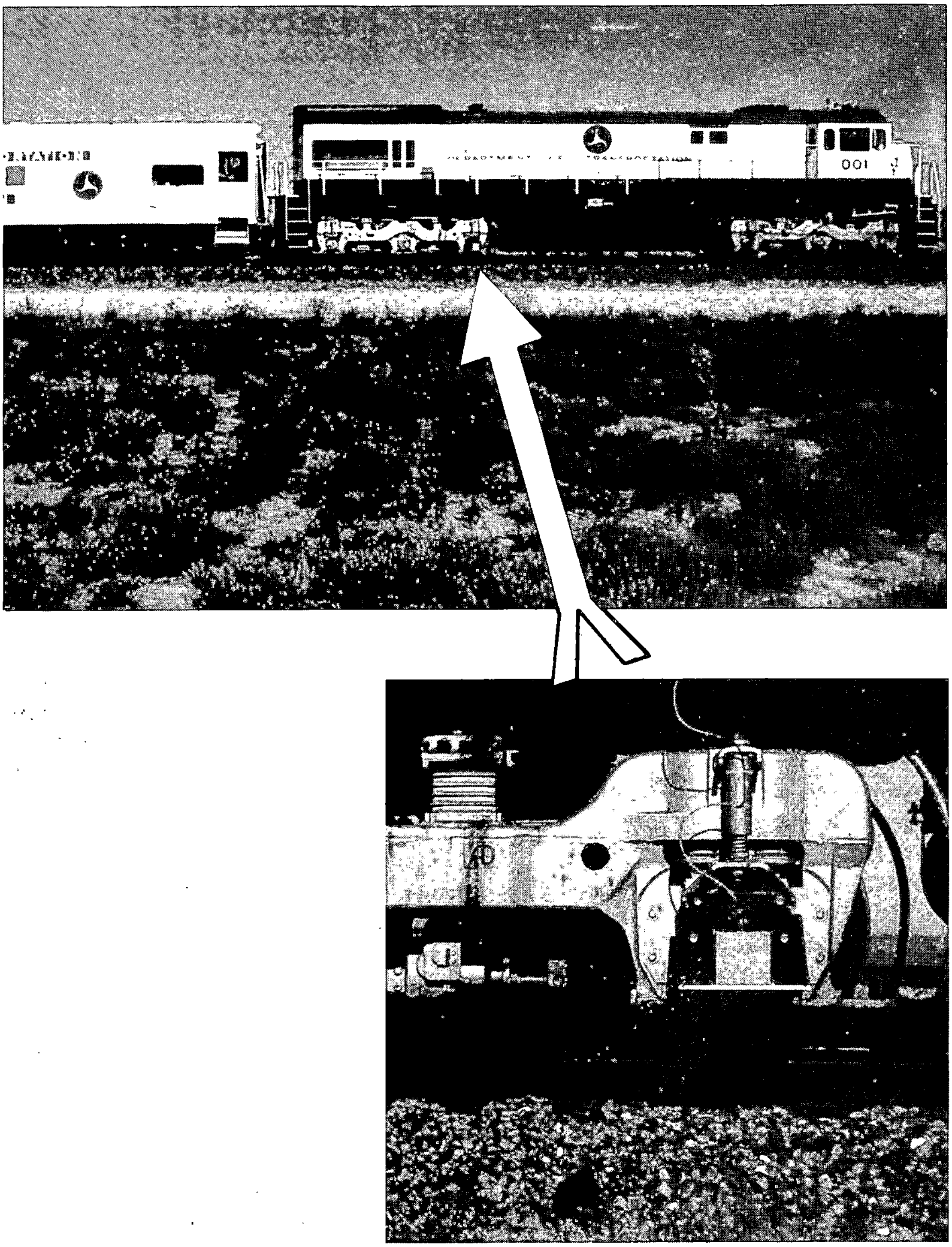

FIGURE 3-4. LTHD SENSOR AXLE MOUNTING

A total of fourteen test runs were performed. Table 3.3 lists the test runs in chronological order. Practice runs were conducted prior to the test runs to allow for the calibration and adjustment of the accelerometers and the setting of the gains of the T-5 data acquisition amplifiers. The LTHD test data was sampled at one foot intervals and recorded digitally on magnetic tape. In addition, the collected data was monitored on a strip chart recorder.

A block diagram of the instrumentation used during the LTHD field tests is shown in Figure 3-5. Operation of the LTHD/T5 data acquisition system was as follows: acceleration levels at the journal bearings of the locomotive were converted to electrical signals by the accelerometers; each accelerometer signal was input to a four-pole Bessel filter which was detuned to provide a second order low pass filter; data acquisition system amplifiers provided variable gain amplification for each of the accelerometer signals; the A/D converter digitized acceleration data for formatting and recording on the magnetic tape drive; and a D/A converter transformed the digital data back to an analog form for output to the distance-driven strip chart recorder. Additional hardware utilized included an automatic location detector (ALD), a triangle wave generator and a speed and distance unit.

The ALD was used to detect turnouts, road crossings, guard rails and other track characteristics that could be used as a reference for LTHD track geometry measurements. The speed and distance unit provided a distance-based signal and instantaneous digital readouts of train speed and distance traveled. The distance -based signal was input both to the strip chart recorder to permit data to be recorded as a function of distance and to the computer where it was used to generate one foot data sampling controls for the digitizer. The triangle wave generator provide an alternate means for determining time between samples during off-line data processing operations.

The track geometry of the test zone was measured prior to and following the test runs by TTC's Plasser EM-80 track geometry measurement vehicle. These measurements plus track design records provided the baseline for LTHD data comparisons. In-field results of the test indicated that non-saturated LTHD acceleration data could be recorded from the axle of a locomotive and that LTHD accelerometer outputs exhibited expected amplitude/ speed characteristics.

TABLE 3.3 - TEST RUNS IN CHRONOLOGICAL ORDER

Run Number	Test Characteristics
9/23-1*	Forward 30 mph
9/23-2*	Forward 30 mph
9/23-3	Forward 15 mph
9/23-4	Forward 45 mph
9/23-5	Reverse 30 mph
9/24-1	Forward 50 mph
9/24-2	Reverse 30 mph
9/24-3	Forward 56 mph
9/24-4	Reverse 30 mph
9/24-5	Forward 60 mph
9/24-6	Reverse 30 mph
9/24-7	Forward 30 mph
9/24-8	Reverse 30 mph
9/24-9	Forward Variable Speed

*Run Numbers 9/23 1-2 were the only tests utilizing the 30g vertical accelerometer configuration. All other runs were performed using 10g vertical and 10g lateral accelerometers.

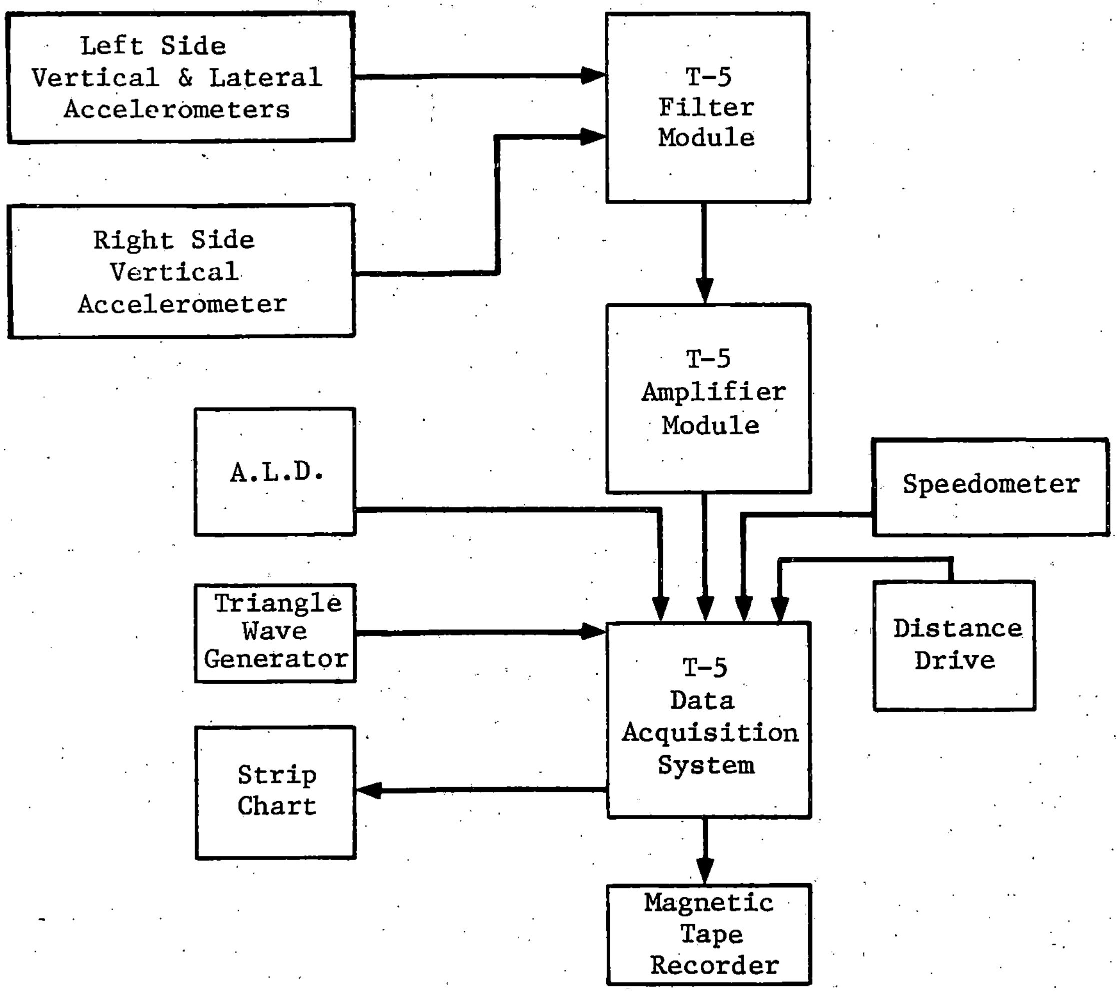

FIGURE 3-5. LTHD FIELD TEST INSTRUMENTATION

3.3 LTHD Field Test Data Processing

The purpose of the LTHD field test data processing effort was to show that three accelerometers mounted on the axle of a locomotive could be used to generate accurate data for use in track hazard detection algorithms. This was done in a manner similar to the computer simulation study described in Section 2, that is by the comparison of track geometry vehicle data with LTHD track geometry data.

Two sets of data comparisons were made. The first was to show the similarity that existed between EM-80 track geometry data and LTHD track geometry data (62 foot chord.) The second was to show the wide speed range over which LTHD (space curve) track geometry data remains valid.

Figure 3-6 shows the comparison of EM-80 and LTHD 62 foot chord data. All traces including left and right profile, variational crosslevel and centerline alignment (compared to the EM-80 left rail alignment trace) closely agreed.* Figures 3-7 to 3-9 show that LTHD locomotive runs at different speeds and directions of measurement ranging from 15 mph to 60 mph resulted in nearly identical left profiles, right profile and variational crosslevel outputs.

Figure 3.10 shows that centerline alignment traces differ only slightly from each other at speeds of 30 mph and above. The 15 mph centerline alignment trace was notably different due to intermittent wheel flange contact.

*The slight horizontal scale difference is caused by Xerox reduction error.

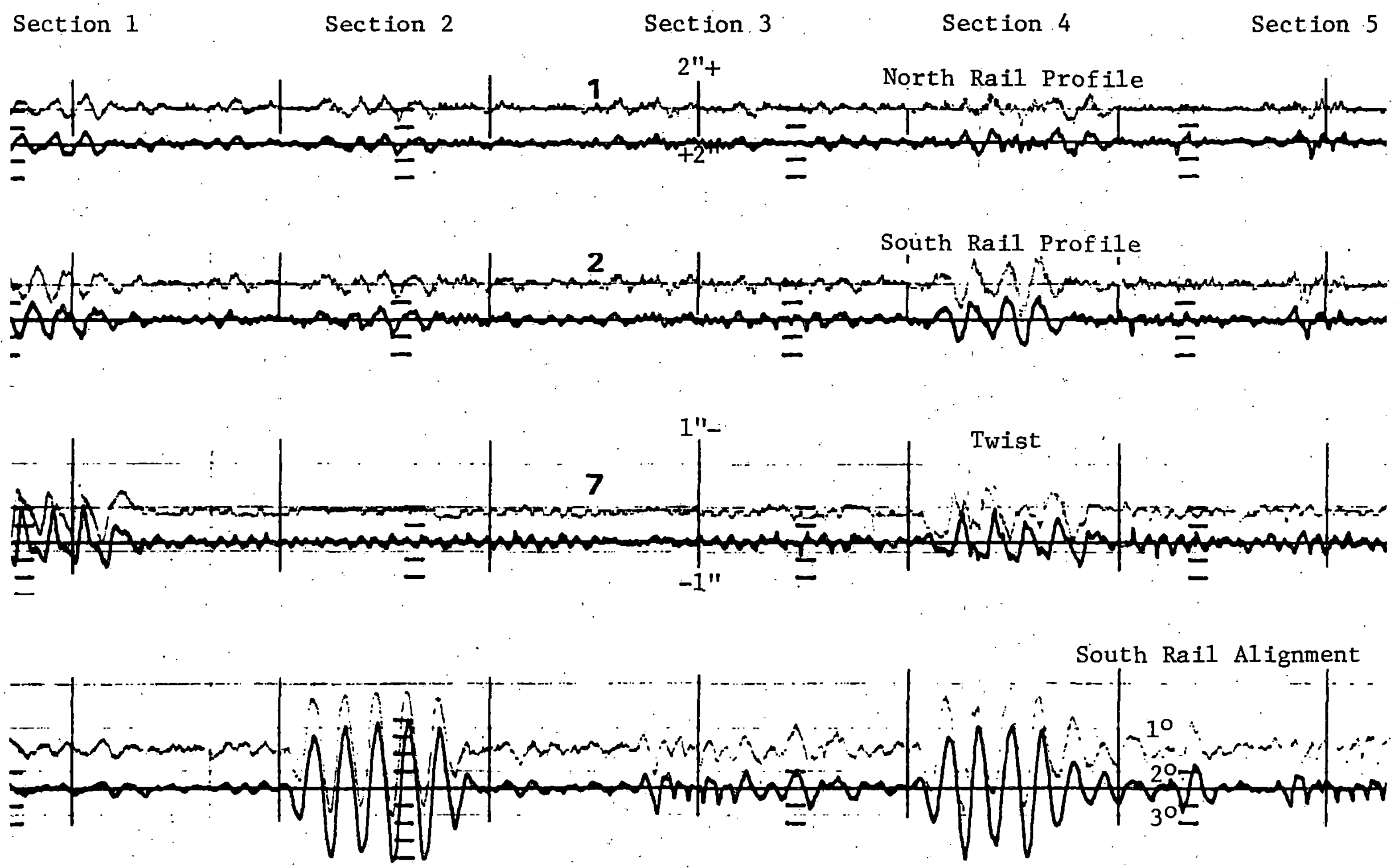

FIGURE 3-6. EM-80 TRACK GEOMETRY DATA (TOP TRACES) COMPARED WITH LTHD TRACK GEOMETRY DATA (45 MPH FORWARD)

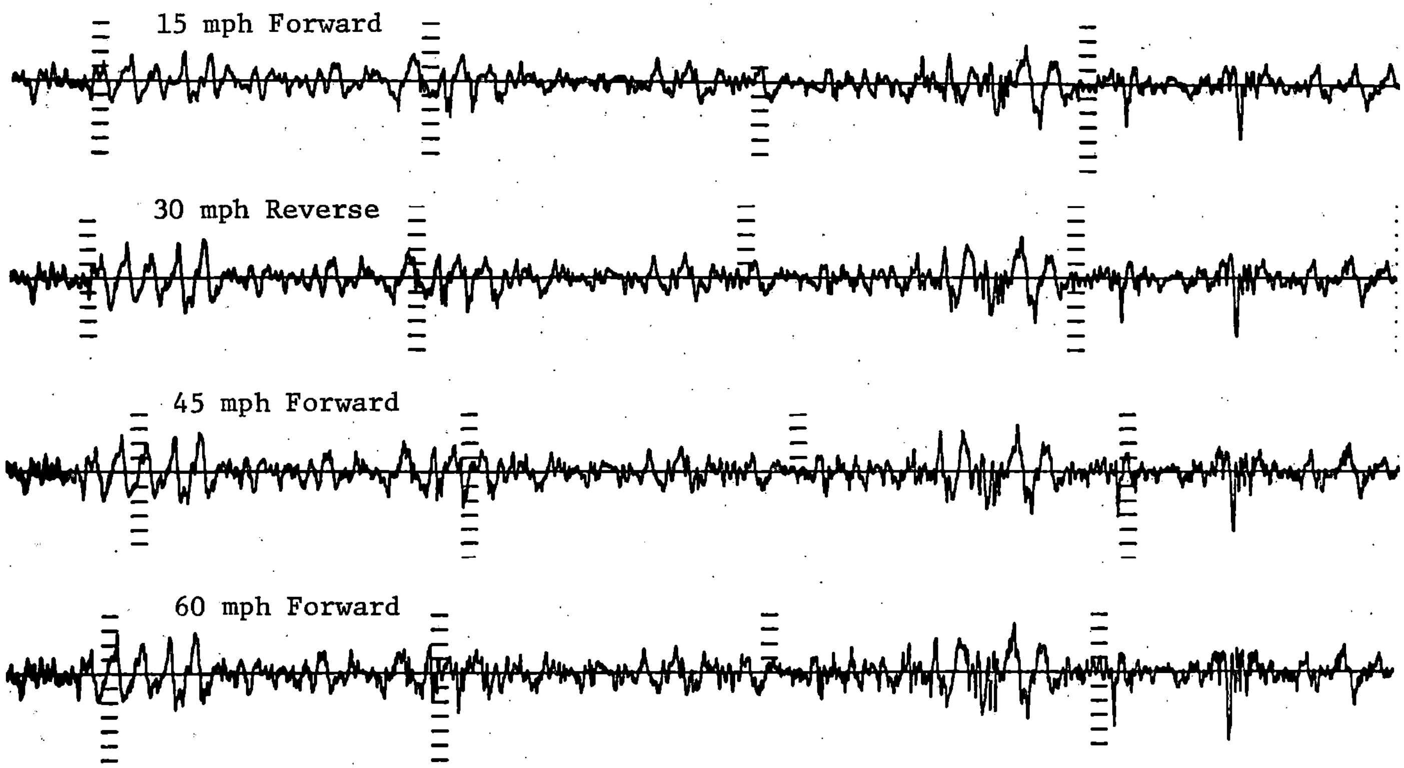

FIGURE 3-7. LTHD RIGHT PROFILE DATA (SPACE CURVE)

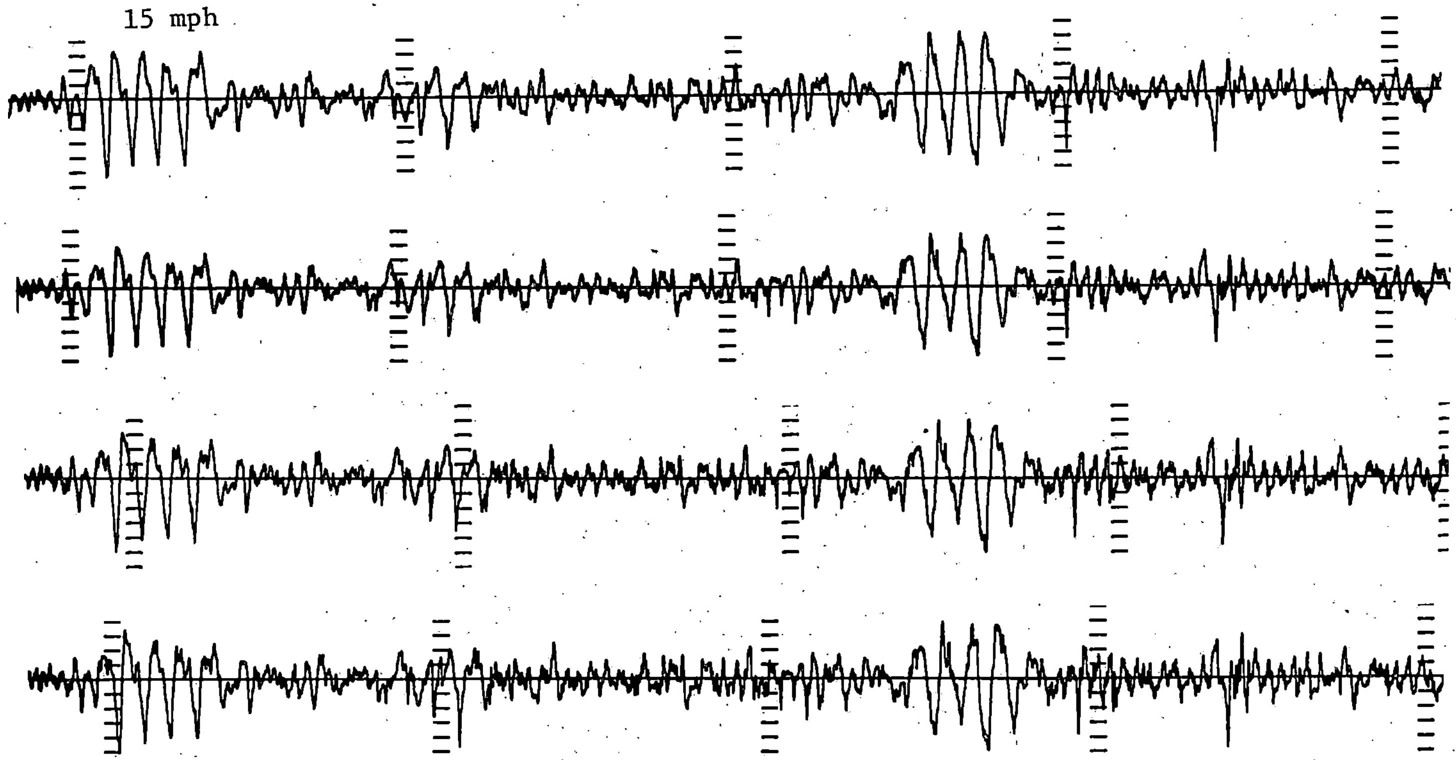

FIGURE 3-8. LTHD LEFT PROFILE DATA (SPACE CURVE)

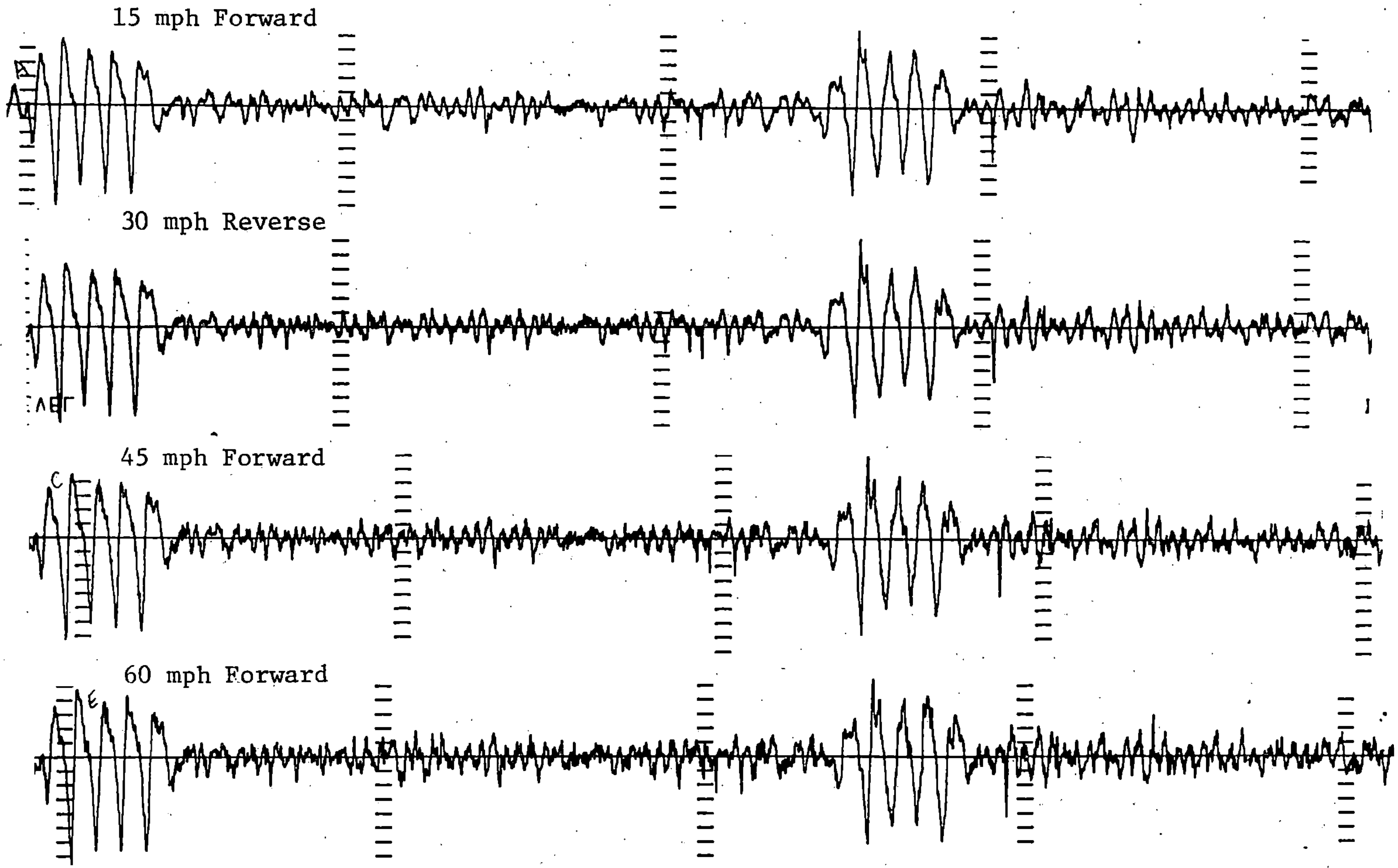

FIGURE 3-9. LTHD VARIATIONAL CROSSLEVEL DATA (SPACE CURVE)

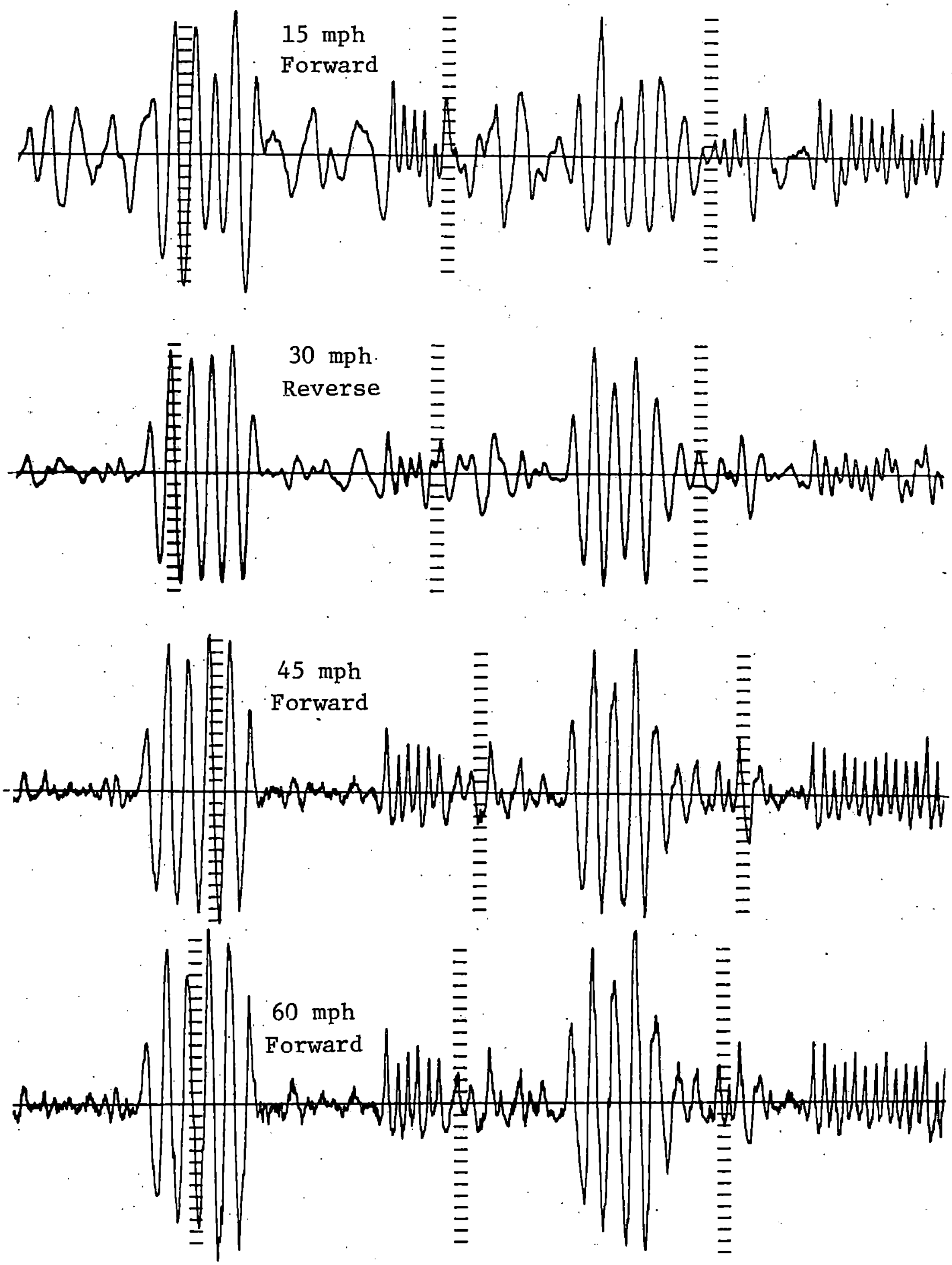

FIGURE 3-10. LTHD CENTERLINE ALIGNMENT DATA (SPACE CURVE)

4. CONCLUSIONS AND RECOMMENDATIONS

It has been shown both by computer simulation using real data and field tests using an experimental LTHD sensor that the LTHD concept can produce to almost the same accuracy as the T6 and EM-80 track geometry systems the following track geometry parameters:

a. left and right profile at all significant wavelengths of interest;

b. crosslevel at wavelengths of approximately 200 feet and less (variational crosslevel);

c. centerline alignment at wavelengths between 60 and 200 feet on both curved and tangent track, and

d. high rail alignment in curves at wavelengths less than 60 feet whenever wheel flange contact occurs.

It is concluded therefore that the LTHD is capable of providing a simple and effective method for acquiring data both for track hazard detection warning and track geomtery measurement purposes.

It is recommended that LTHD be further developed. Proposed LTHD efforts include the design and implementation of a prototype LTHD that can be used to permit field evaluation of potential track hazard warning algorithms and to demonstrate the capability of generating low cost railroad-oriented track geometry plots.