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TRACK GEOMETRY DEVELOPMENT UMTA URBAN RAIL SUPPORTING TECHNOLOGY PROGRAM

F.J. Rutyna, Editor

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16. Abstract

The DOT Transportation Systems Center (TSC) has been designated by the Urban Mass Transp. Admin. as Systems Manager for its Urban Rail Supporting Technology Program. As part of this effort, TSC has been developing a track geometry system for use on rail transit properties.

Measurement of transit system track geometry parameters, under normal operating conditions, is essential for planning and conducting an effective maintenance program. The pertinent parameters are profile, gage, alignment, and cross level.

Present methods of determining track conditions are inefficient and highly subjective. To overcome these deficiencies, TSC has investigated and evaluated several track geometry measurement methods. These methods are all designed for use under revenue service conditions. The goal is to make available to the operating properties a system which is simple, reliable, mobile, inexpensive, and which yields a real-time output in a form directly useable for track diagnostics and maintenance planning.

The general results of the investigations and tests are presented here, together with a discussion of the system selected for prototype test and evaluation.

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PREFACE

The track geometry test program has been under the direction of George Neat, Manager of the Test and Evaluation Task for the Urban Mass Transportation Administration Urban Rail Supporting Technology Program.

The instrumentation development is under the direction of John Nickels and Paul Poirier heads the task group responsible for data processing.

The written material was submitted by Gunars Spons. Mr. Spons is also technically responsible for the development of the prototype "Mark II Systems" currently being fabricated under contract to MB Associates.

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1. INTRODUCTION

The Urban Mass Transportation Administration (UMTA), in an effort to improve efficiency and to increase the attractiveness of urban rail systems, is conducting programs of research, development, test, and evaluation directed toward the goal of improving urban rail technology. The principal objectives to be derived from the technological improvements are:

a. Improved system capacity and service.

b. Improved system safety and reliability.

c. Reduced adverse environmental effects.

d. Reduced costs of operation and maintenance.

The major portion of the cost of improving and upgrading the existing systems and the construction of new systems will be borne by the Federal Government through the UMTA Capital Assistance Program. To assist in meeting these objectives, the UMTA Rail Programs Office within the Office of Research and Development, designated the Transportation Systems Center (TSC) in Cambridge, Massachusetts as the Systems Manager for the UMTA Urban Rail Supporting Technology Program.

1.1 BACKGROUND

The Urban Rail Supporting Technology Program is an integrated, goal-oriented program of research, development, test and evaluation directed toward the systematic improvement and evolutionary development of urban rail technology. As System Manager, TSC has accepted the responsibility of implementing the program and of providing all requirements, specifications and plans as required to UMTA for evaluation and program development. TSC, working with UMTA and the transit industry, is responsible for identification of primary system and technology objectives; the establishment of priorities; the examination and evaluation of new and existing technologies and methods for applicability; and the recommendation of technologies and methods to be demonstrated for proof of concept.

The Track Geometry Project (Track Maintenance Diagnostic Project), falls under this broad scope of activity. The project seeks to systematize the inspection of urban rail track and track structures by the use of track geometry measuring equipment, and is the subject of this status report.

1.2 TRACK MAINTENANCE DIAGNOSTICS

Track maintenance practices are well established within transit operations, and, for the most part, are satisfactory in restoring track to its nominal service requirements. The situation with respect to track inspection itself, however, is far from satisfactory at the present time.

Track inspection today is implemented largely by trackwalkers who perform visual inspection and who often evaluate track conditions by subjective methods which vary from individual to individual. Manual track inspection procedures also suffer from the difficulty of making comparative measurements of the same track conditions. Time histories of track degradation are useful in preventing serious problems from occurring, and in developing an understanding of the causes of track degradation and the preventive measures that are effective in arresting these changes. Another serious drawback of manual inspection is that measurements generally must be made on unloaded track, a condition which masks certain track deficiencies, particularly localized ballast settlement. Finally, some established manual measurements methods can be misleading, particularly stringline chord data which has been shown to depend upon the selection of the end points of the chord.

The solution to most of these track inspection problems is the automated inspection of track by diagnostic vehicles. This solution has been recognized for many years. Early attempts to provide improved track inspection include the development of flaw detection cars which reveal, through ultrasonic detection, the existence of gross structural flaws in the rails. A number of these cars have been in operation of many years.

The next step in automated track inspection involves the measurement of track geometry, which consists of the following four basic parameters:

a. Gage - the distance measured between the inside heads of the rails at right angles to the rails in a plane 5/8 inch below the top of the rail head. Standard gage in the United States is 56.5 inches.

b. Profile - the vertical deviation of the rail top surface from the theoretical reference line, and therefore, a measure of the rail vertical curvature.

c. Alignment - the horizontal deviation of the rail side from a reference line, and therefore, a measure of the horizontal rail curvature. Alignment is the horizontal measurement that corresponds to profile as the vertical measurement.

d. Cross level - the difference in height betwee the rails with respect to a horizontal plane. The rate of change of cross level is referred to as warp or twist.

The instrumentation required to make these measurements is quite complex, and the volume of data generated by continuous track measurements necessitates a highly developed data handling system.

1.2.1 Diagnostic Vehicles

At present there are diagnostic or inspection cars in operation on main-line railroads, and to a limited extent, on transit systems. The principal vehicles in use in the U.S. and Canada which measure track geometry are:

Owner	Name
DOT/FRA	T-2
Southern Railroad	R-1
Canadian National	TR-Car
Boston & Maine	Track Fax
NYCTA	X-116

The Appendix details the principal features of these cars. All of the cars measure gage, profile and cross level. All but one also measure alignment. Three of the cars measure warp. Of the five cars mentioned, only the measurement of gage is comparable. All other measurements are quantitatively effected by either wheel loading, wheel spacing, averaging methods and mid-chord length, or combinations thereof.

In addition to the track inspection cars mentioned above, the Sperry Company has been offering a service for the detection of rail flaws since 1928. More recently the Association of American Railroads (AAR) test cars also have been making these measurements.

One of the principal benefits of these diagnostic cars has been making available test data (primarily to the railroads) from which quantitative standards of track geometry can be established by the individual property and for application to programs designed to maintain track to those standards. Despite limited use of diagnostic cars, the bulk of track inspection conducted primarily by visual means, i.e., by trackwalkers.

It should be noted that none of the test vehicles mentioned provide measurements for alignment, profile or cross-level which can be used for testing compliance with the track safety standards recently established by the Federal Railroad Administration (FRA), since none of the vehicles produces a maximum track loading condition.

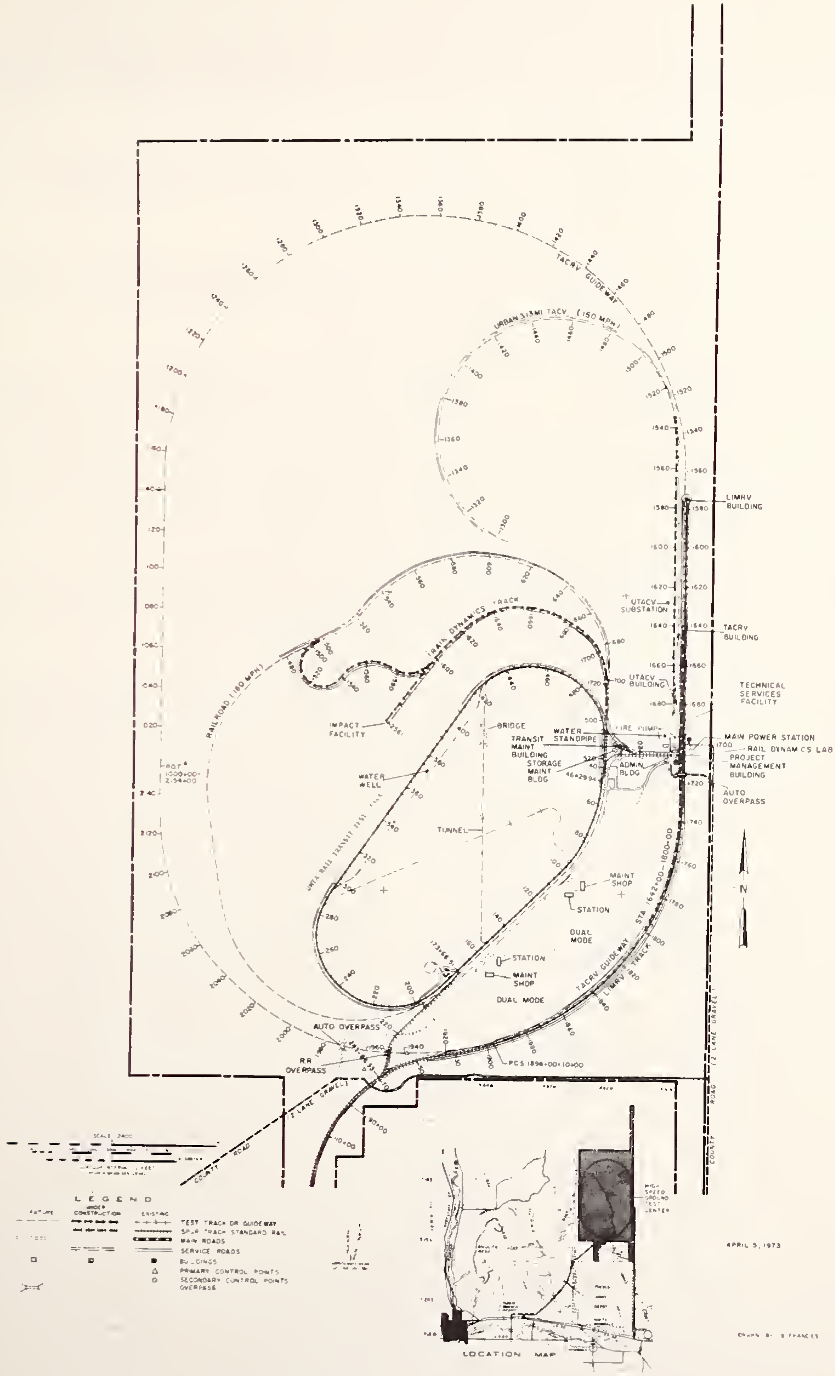

Figure 1. The High Speed Ground Test Center

1.2.2 Objectives for a Track Geometry Measurement Capability

The Track Geometry Project, seeks to systematize the inspection of urban rail track and to derive the benefits which can result from comprehensive, orderly and complete track inspection data. These benefits include:

a. Reduced maintenance costs through more efficient utilization of maintenance resources.

b. More effective maintenance programs through a priority rating of maintenance activities.

c. Minimizing costly or disastrous accidents and track system failures through a preventive maintenance program.

d. Improved ride quality, noise characteristics and safety by virtue of improved track quality.

e. Quantification of overall track condition to aid in transit operations resource allocation.

In order to achieve the above benefits, the project has focused on the development of track geometry measurement instrumentation and on a series of planned tests both on service track and on the Rail Transit Test Track at the High Speed Ground Test Center (HSGTC) near Pueblo, Colorado. The Rail Transit Test Track is shown in Figure 1. The purpose of these tests is to demonstrate the system capability, to prove the feasibility of making track geometry measurements using a revenue vehicle rather than a specialized car, and to gather baseline experimental data. Once baseline data are established, it will be used as the basis of comparison for the general evaluation of any track installation.

A major portion of the project is directed at providing an automatic track diagnostic capability to the transit operation at a reasonable cost. The adoption and enforcement of Federal track standards will make the widespread use of automatic track diagnostic equipment mandatory if the standards are to be enforced on all transit track.

The track maintenance instrumentation and test procedures developed also should yield an understanding of the quality of installed transit track relative to a realistic "standard track". When this comparison can be made easily, the process of correcting substandard track can be improved, simplified and reduced in cost.

2. TRACK GEOMETRY MEASUREMENT SYSTEM

The development of instrumentation and test procedures for making track geometry measurements is intended to satisfy a transit industry need for a more efficient and quantitative track inspection program. In order to accomplish the objectives of the program, a track geometry measurement capability is being developed which can be used by the properties as a supplementary tool for track maintenance inspection programs. Based on the test data obtained from a breadboard system referred to as "Mark I", a prototype "Mark II" Track Geometry Sensor System is now being developed. The track geometry measurement system will consist of a sensor system, a data acquisition system and a power conditioning system. Feasibility, and capability to function as a tool for track maintenance inspection programs will be tested and evaluated on the operating properties after initial tests have been completed at the High Speed Ground Test Center.

2.1 INSTRUMENTATION DEVELOPMENT

To date, TSC has conducted tests on the New York City Transit Authority (NYCTA) system, on the Rail Transit Test Track, and on the Massachusetts Bay Transportation Authority (MBTA) system for the purposes of developing a test program and of providing base-line information for the development of instrumentation and data systems. Each series provided data on vehicle dynamics and sensor performance which has led to the specification of a track geometry measurement system now being fabricated.

Various techniques for making the geometry measurements have been investigated. The two most common approaches are measurement of the dynamic inputs from the rails to the wheels of the truck, and the use of sensors to measure rail position and to detect changes in that position.

Dynamic measurement techniques, which have been tested by other agencies, include the use of two rate gyros for measuring the roll and yaw rates of one axle, from which profile and cross level are derived, and the use of vertical accelerometers shock-mounted on the journal boxes of one axle for obtaining the vertical inputs and thus the track profiles.

The Canadian National Railways TR car uses a vertical accelerometer mounted on the truck side frame along with a velocity probe connected between the side frame and the journal box.

Sensor systems measure the distances from the rails to sensor reference points. These varying distances are then processed, and combined with the information relating the sensor reference points to produce the final track geometry data.

Several types of sensors have been investigated. The Mark I breadboard system used capacitance probes. Work on improving these sensors is continuing at TSC. However, capacitance sensors have inherent limitations such as:

a. Long, tedious calibration process

b. Frequent recalibration requirements because humidity changes will affect the dielectric constant of the air gap and hence the probe calibration.

c. Changes in capacitance value due to mounting beam vibration.

Accordingly, other techniques are being investigated, such as the use of mechanical, inductive, and electro-optical probes.

Various measuring techniques have also been investigated. The Mark I breadboard measured profile by the midordinate-to-chord method, using the same 14.5 foot chord length used by the Federal Railroad Administration. Use of the same chord length simplifies the comparison of data obtained from the two different systems measuring the same section of track.

A disadvantage of the midchord measurement technique is that the midordinate-to-chord distance does not provide the ture profile of the rail, but only a number that is related to true profile. To obtain the actual profile from the data, additional processing is necessary.

The measurement of the other track parameters using sensors is straightforward and is not influenced by arbitrary external factors such as beam length.

TSC has adopted the features of several approaches in an effort to measure a complete set of parameters. The configuration presently being tested consists of two shock-mounted vertical servo accelerometers placed on the journal boxes of the same axle. The data, once processed, yields the loaded profile of each rail. By a simple arithmetic process, the track cross level is also obtained from the profile data. The alignment and gage measurements utilize capacitance probes and a lateral accelerometer mounted in line with the gage probes.

Based on the result of the TSC-conducted tests and the data obtained from various techniques, the measurement of the dynamic inputs from the rails to the wheel/axle assembly demonstrated the greatest potential for the measurement of rail profile and therefore was incorporated in the prototype system.

2.1.1 NYCTA Test Program

The first series of TSC tests in the development of track geometry measurement instrumentation were conducted on the NYCTA property in May, 1971. Two R-42 class cars provided the test bed for the breadboard instrumentation as well as the preliminary data on the dynamics of rail transit vehicles. The instrumentation mounted on the cars was designed to measure ride quality, noise and journal box acceleration with the test objectives as follows:

a. Obtain a set of baseline data on the vibration environment in which on-board track geometry and other instrumentation will be required to function.

b. Obtain typical sound and vibration data in the passenger compartment under typical operating conditions.

c. Gain operational experience with the vibration and sound measurement instrumentation to be used in future experiments.

The objectives were met during the test phase, specifically the determination of the environmental conditions at the journal box in which the track geometry sensors must operate.

2.1.2 HSGTC Test Program

A further series of tests using two NYCTA R-42 class vehicles was conducted on the Rail Transit Test Track at Pueblo, Colorado.

During the November 1971 and 1972 test series, two approaches were investigated; a capacitance midchord scheme and a direct measurement approach using accelerometers mounted on the journal boxes. The results of the tests provided further baseline information which has been incorporated into the specification for the Mark II track geometry sensor system.

For the midchord measurement technique, which was used in obtaining track profile, non-contacting capacitance probes were mounted on 14.5 foot beams. The beams were initially attached to the suspended truck frame and later mounted on the equalizer bars. Mounting of the beams on the equalizer bars kept them relatively parallel to the rail during the test runs instead of allowing them to pitch as a function of acceleration-and-deceleration torques applied to the axles. The data obtained from the capacitance midchord scheme yielded measurements which compared favorably with the measurements made by the FRA Test Train (T-2) over the same track.

The initial attempts at obtaining profile using the direct measurement approach (accelerometers mounted on the journal box) resulted in saturated signals due to high-frequency vibrations. Vibration-isolation accelerometer mounts were developed and used to filter out mechanically the unwanted vibration in the accelerometer profile as well as in the alignment measurement. TSC is continuing work on this technique, and on system design improvement and data analysis.

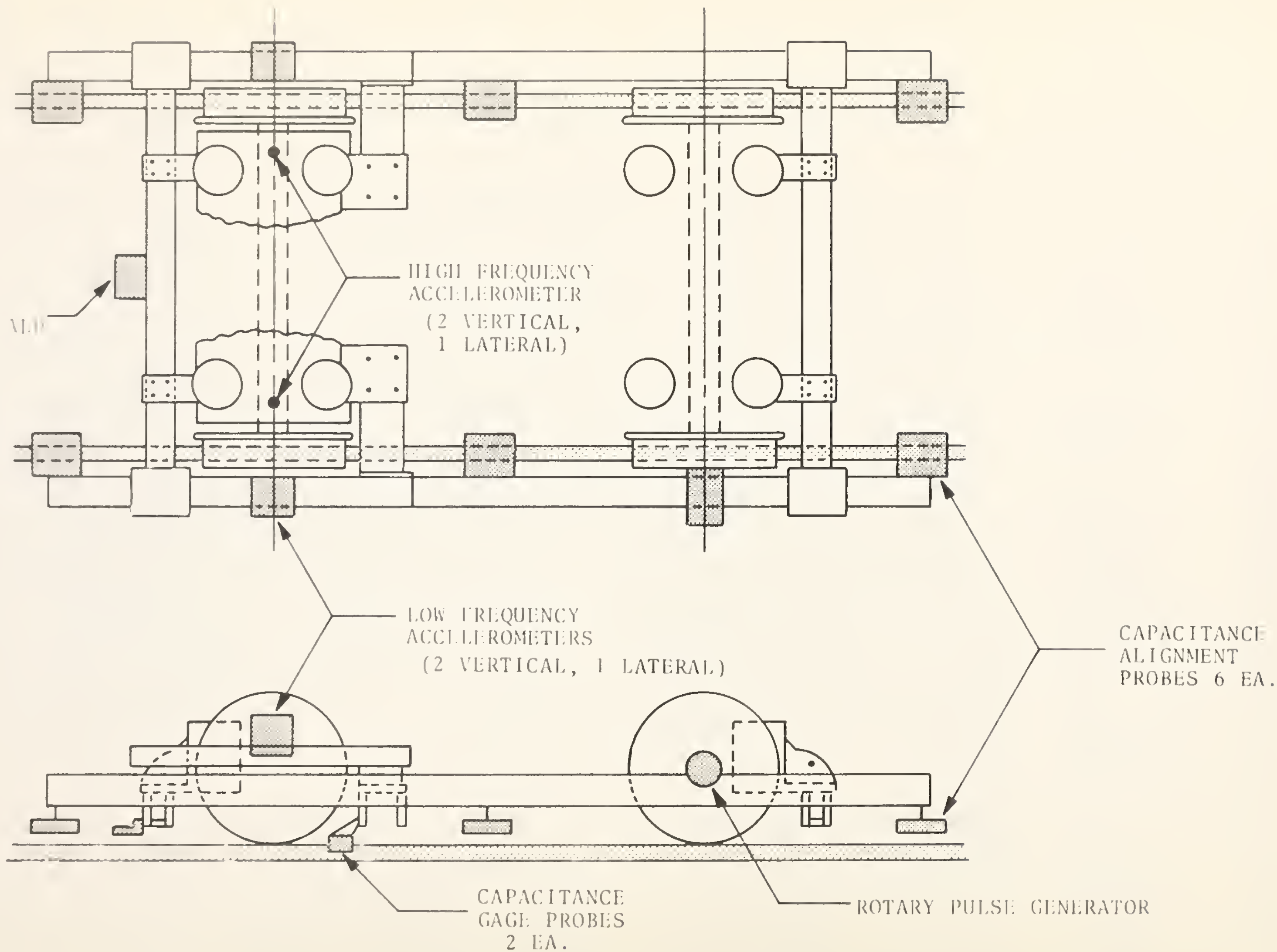

Figure 2. Sensor Frame Configuration, MBTA Green Line PCC Truck

2.1.3 MBTA Green Line Test Program

Based on the experience gained at the HSGTC and on the improved breadboard track geometry instrumentation, TSC conducted a test program on the MBTA Green Line during December, 1972.* The primary objective of this test was to determine track geometry prior to a planned major refurbishment of the track, and again after the refurbishment program is completed. Comparison of these data will provide a quantitative measure of the benefits derived from an improved track in terms of rider comfort, and eventually in reduced maintenance costs. The immediate results of the tests provided the required input for the development of the software interface for the track geometry measurement system as well as more refinement to the final system specification. The results of the tests also provided the first input to an operating property for the determination of track maintenance priorities in the refurbishing program.

The tests were implemented using a PCC streetcar operating at revenue speeds during daylight hours. A special frame mounted on the rear truck of the vehicle contained the sensors for measuring the track geometry (Figure 2).

The straight beams suspended along the sides of the instrumented truck provided the measurement base for rail midchord profile. Three capacitance probes mounted on each beam were used as sensors for the profile measurement. One capacitive probe on each side of the beam next to the rail provided the gage measurement. Track roughness in both the vertical and lateral direction was measured (at the low frequencies) by the servo accelerometers mounted on the beam. The higher frequencies were measured by peizoelectric accelerometers mounted on the journal box.

A location reference signal was automatically provided by a capacitive probe mounted on a transverse beam at the rear of the truck, midway between the two rails. This signal was recorded on the magnetic tape recorder each time the probe passed over a signal

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*Neat, G.W., Ed., MBTA Green Line Tests-Riverside Line, Volume I, Test Description, Final Report, DOT-TSC-UMTA-73-9, I, September 1973.

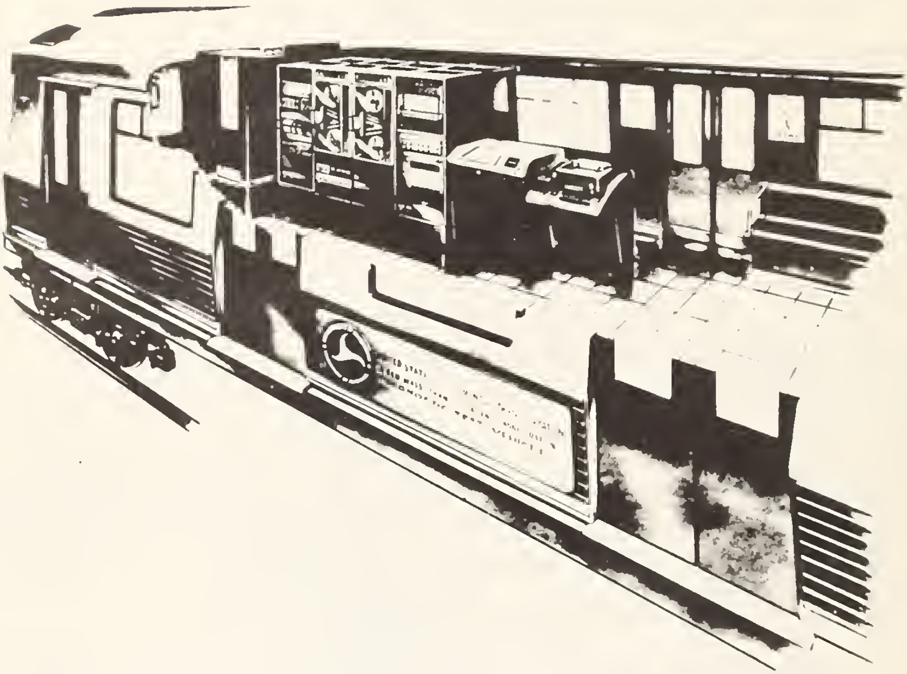


Figure 3. Instrumented Rail Car

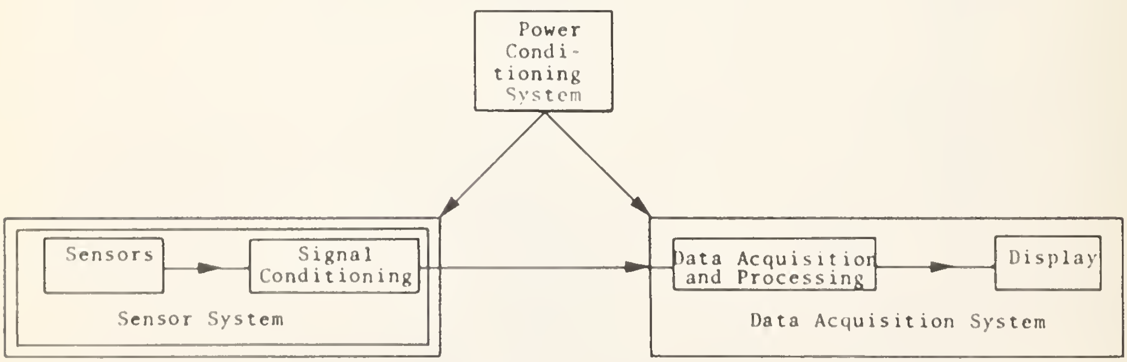


Figure 4. Track Geometry Measurement System

switch, turnout, crosswalk etc. Speed and distance reference data were obtained from a rotary pulse generator driven by the front axle of the instrumented truck.

All of the electronic equipment for the sensors was contained in one shock mounted instrumentation rack. The primary components mounted in the rack consisted of a time code generator, FM multiplex equipment, seven-channel monitorscope, signal conditioners, calibration panel, VCO assembly, processor and filters, RPG pulse processor and capacitance probe electronics. Not included in the rack itself but part of the system was a fourteen-track magnetic tape recorder and an eight-channel chart recorder. Power for the instrumentation and data acquisition equipment was provided by a battery bank backed up by a 1.75 KW gasoline engine generator.

The results of the tests, the instrumentation capabilities, and the analog and reduced data are presented in detail in the final report of the Green Line Test.

2.2 TSC SYSTEM CONCEPT

The initial TSC plan for a diagnostic capability that would link the UMTA research and development efforts with the real-world problems of the operating transit systems called for the manufacture of a specially-configured diagnostic vehicle. The instrumentation on the vehicle would have had the capability of acquiring data on track geometry, ride quality, noise, and vibration at operating speeds without interruption to normal revenue operations. After considerable research this concept was modified to the "Black Box" concept - a track geometry instrumentation package compatible with transit cars now in operation, (shown in Figure 3). This approach is more consistent with the needs of the majority of the operating properties. In addition, from a technical and economical viewpoint, this approach is more likely to achieve the objectives as set forth in the test and evaluation program.

The sensor system, real time data acquisition system and the power conditioning system are the primary components that make up the total track geometry measurement system, shown in Figure 4.

2.2.1 Mark II Track Geometry Sensor System

A specification for the development of two prototype track geometry sensor systems (Mark II), based upon the direct measurement approach, was formulated using information gathered from transit properties and the baseline data obtained from the TSC conducted tests.

The track geometry sensor system will provide raw data to an on-board data acquisition system which will calculate the geometric parameters of the track, i.e., rail gage, profile, cross level, and alignment. In addition to the sensors for measuring the geometric parameters, sensors for measuring reference data such as vehicle speed, distance traveled and vehicle location are included in the system, shown in Figure 5. The techniques incorporated into the Mark II system for obtaining the four basic geometric parameters of the track are as follows:

a. Rail gage - defined as the distance between the inside heads of the rails at right angles to the rails in a plane 5/8 inch below the top of the rail head, will be measured by an electro-optical sensor system. The electro-optical sensor system will be mounted on a rigidly supported gage sensor beam attached to the unsprung portion of the vehicle truck.

b. Alignment - defined as the horizontal deviation of the rail side from a reference line will be determined by measuring the lateral acceleration of the gage beam (on which the accelerometer is mounted, double integrating the output with regard to time, and adding that displacement value to the distance to each rail gage point as measured by the gage sensor. This calculation yields the lateral displacement with regard to some moving reference.

c. Profile - defined as the vertical deviation of the rail top surface from the theoretical reference line will be determined by measuring the vertical accelerations of the two journal boxes of one axle over a limited frequency

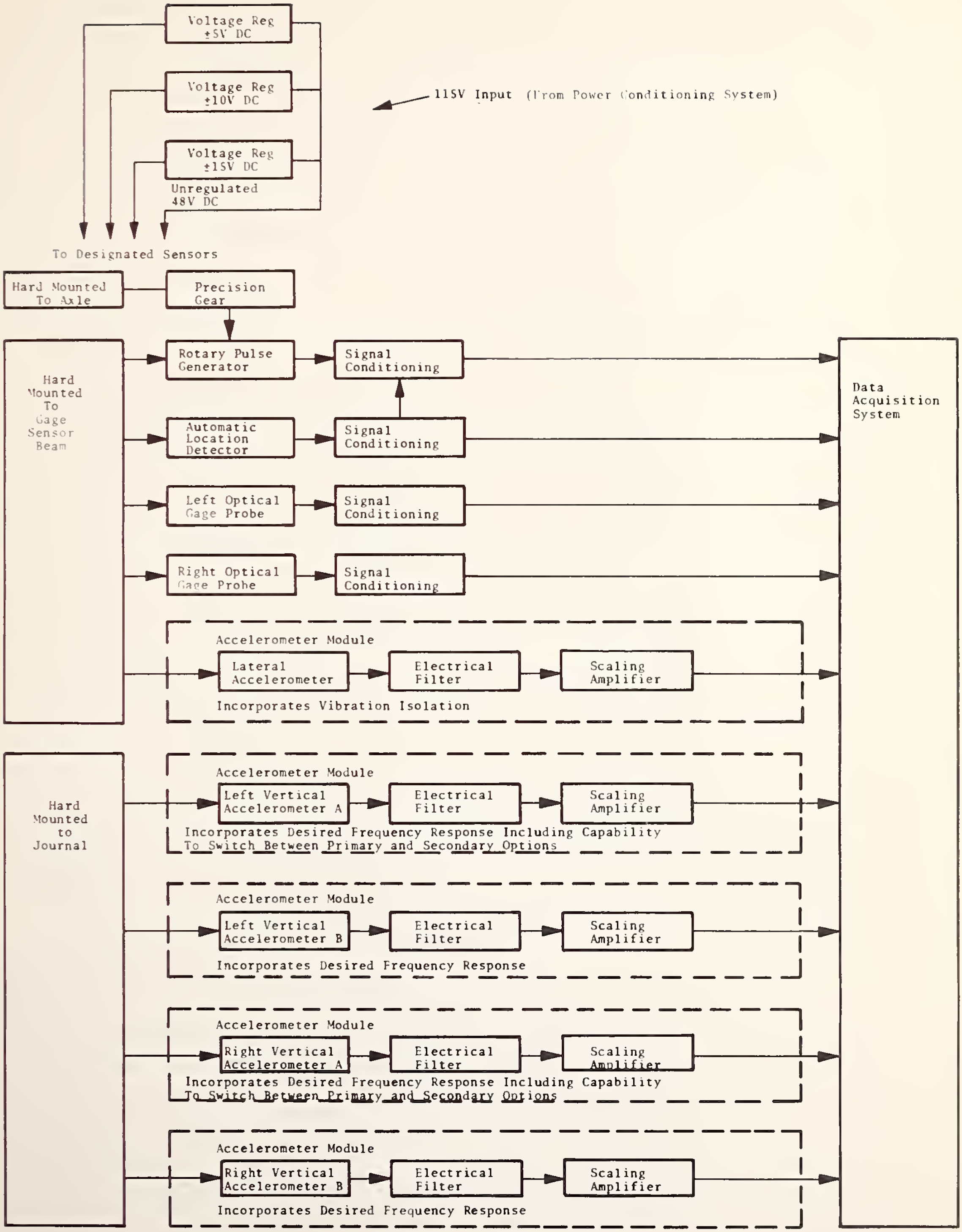


Figure 5. Mark II Track Geometry Sensor System

range and then double integrating these acceleration signals with respect to time to obtain the rail displacement with regard to some moving reference.

d. Cross level - defined as the difference in height between the rails with respect to the horizontal plane will be computed by taking the arithmetic difference between the left and right profile measurement.

All sensors mounted on the journal boxes or other unsprung portions of the truck will be designed to operate in the presence of a vibration environment as represented by the power density spectrum in Figure 6. This will include discrete frequency vibrations of 10g peak at any frequency up to 500 Hz in and direction, and half sinsuoid shock pulses of 1 millisecond duration having a peak amplitude of 120g in the vertical direction. Components mounted on the truck frame will be designed to operate in the presence of vibrations of 4g peak at any frequency up to 500 Hz in any direction, and shock loads of 50g for 1 millisecond in the vertical direction. This design shock-and-vibration environment, as specified for the track geometry sensor system, is based on data obtained from the TSC test programs.

2.2.1.1 Optical Rail Gage Measurement Subsystem. Track gage will be measured by an electro-optical system. The technique represented in Figure 7 works on the principle of illuminating the base of the rail and detecting the position of the shadow cast by the gage side of the rail head onto a photo detector array.

The optical components of each gage sensor will be mounted on a rigid gage sensor beam, with one sensor located over each of the rails. It will detect the position of a line tangent to the rail head and perpendicular to the ton surface of the tie at the gage side of the rail head. The position of this tangent point at either rail, with respect to its particular optical sensor, will be determined such that the maximum error is no greater than 0.02 inches.

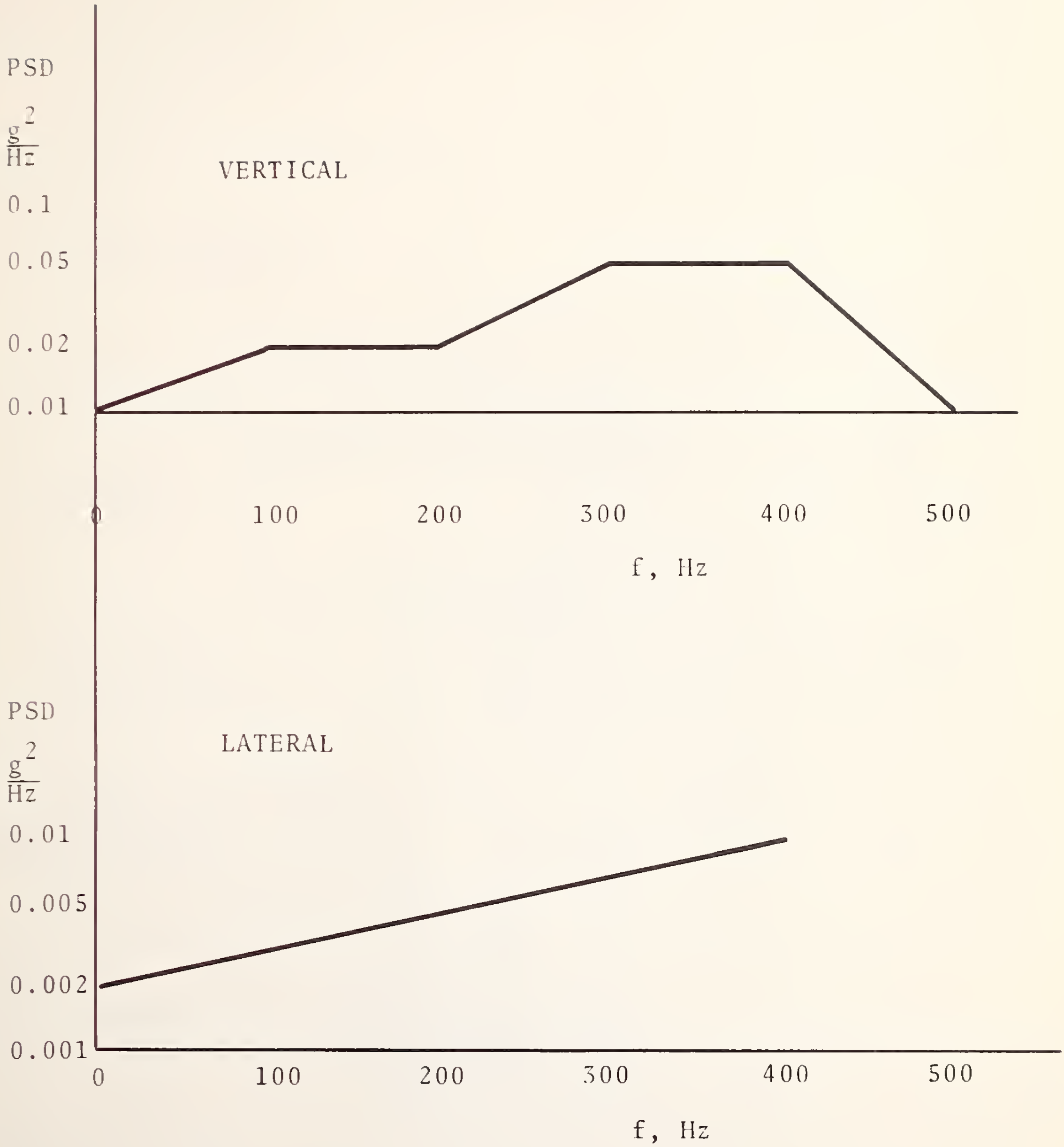


Figure 6. Journal Box Vibration Acceleration Power Spectrum Density

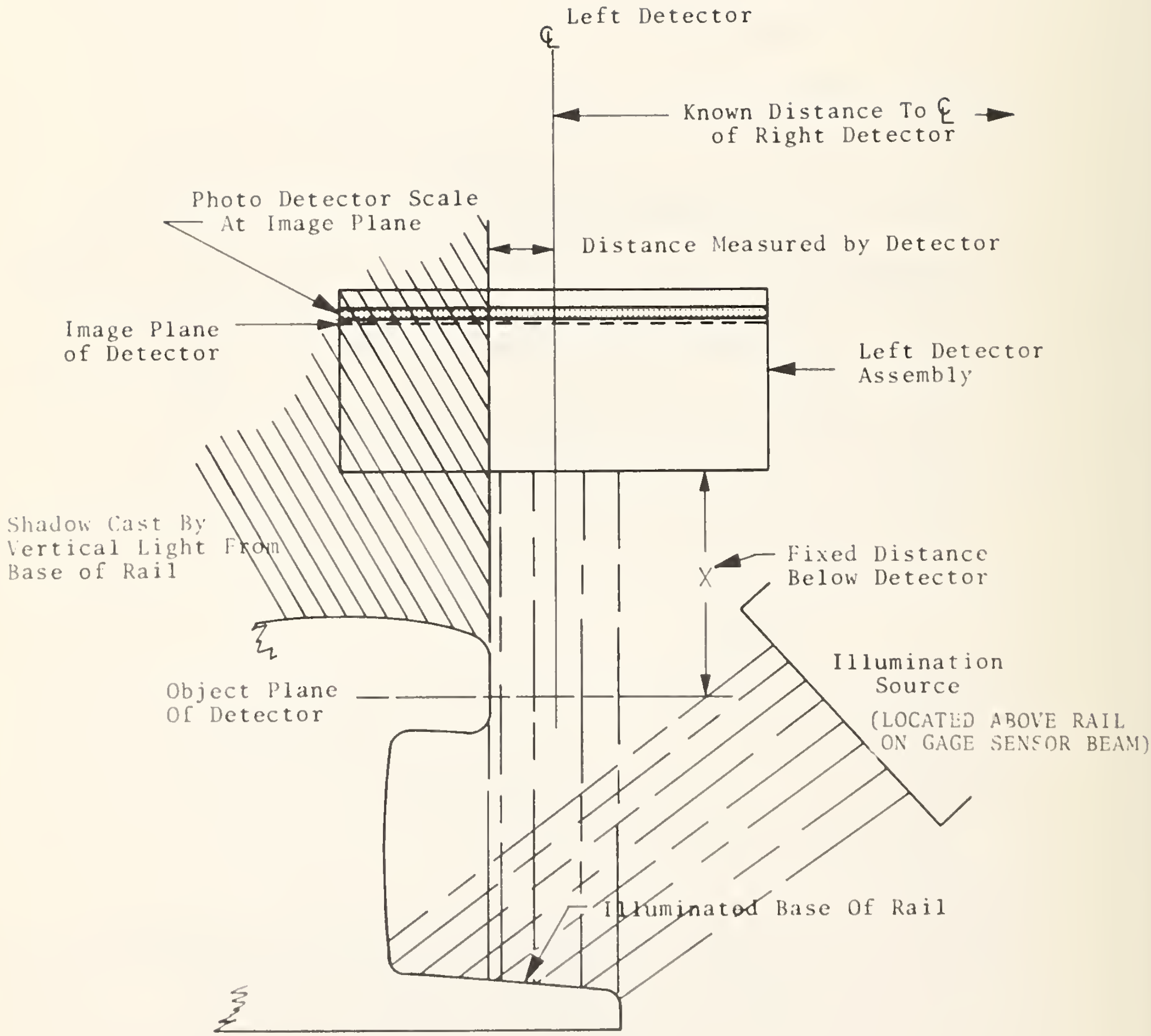


Figure 7. Schematic of Mark II Gage Measurement Technique

The system will measure gage for all vehicle speeds between zero and eighty miles per hour with the capability of making a gage measurement every six inches of travel at the maximum vehicle speed. The sampling of gage measurements will be accomplished on a time or a distance basis.

The optical gage system will be capable of measuring gage variations over the range of from 0.5 inch tight to 1.5 inches open with a repeatability of 0.01 inches.

2.2.1.2 Profile and Cross Level Measurement Subsystem. Profile is a direct physical input into the rail vehicle operating on the track. The technique incorporated into the track geometry measurement system for measuring the loaded profile of each rail will consist of using two pairs of accelerometers mounted on the same wheel/axle assembly so as to sense the vertical acceleration of each wheel of the instrumented truck (Figure 8). Both accelerometers (A and B) will be hard mounted on the unsprung portion of the journal and located as close to the axle as is possible so the measurement is made of the deflected track. Accelerometer A will contain a dynamic range circuit (DRC) which will allow the accelerometer to switch between two modes. In the primary mode, accelerometer A will measure the linear acceleration in the range $\pm$ 0.002g to $\pm$ 2.0g in the frequency range of 0.2 Hz $\leq$ f $\leq$ 20 Hz. The secondary mode will allow for measurements in the range $\pm$ 0.001g to $\pm$ 1.0g for a frequency range of 0.2 Hz $\leq$ f $\leq$ 10 Hz. Accelerometer B will not incorporate a DRC capability, so that in effect there will be no mechanical filter between the accelerometer and the wheel/axle assembly. The linear accelerometer B will measure in the range from 0.1g to 10g in the frequency range of 5 $\leq$ f $\leq$ 100 Hz. Accelerometer B is used only in the secondary mode. Each accelerometer output signal will be amplified and filtered electrically, and converted for processing in the on board aquisition system (DAS). The DAS will then perform a double integration with respect to time of the output of each accelerometer to compute the deviation in the vertical position of each

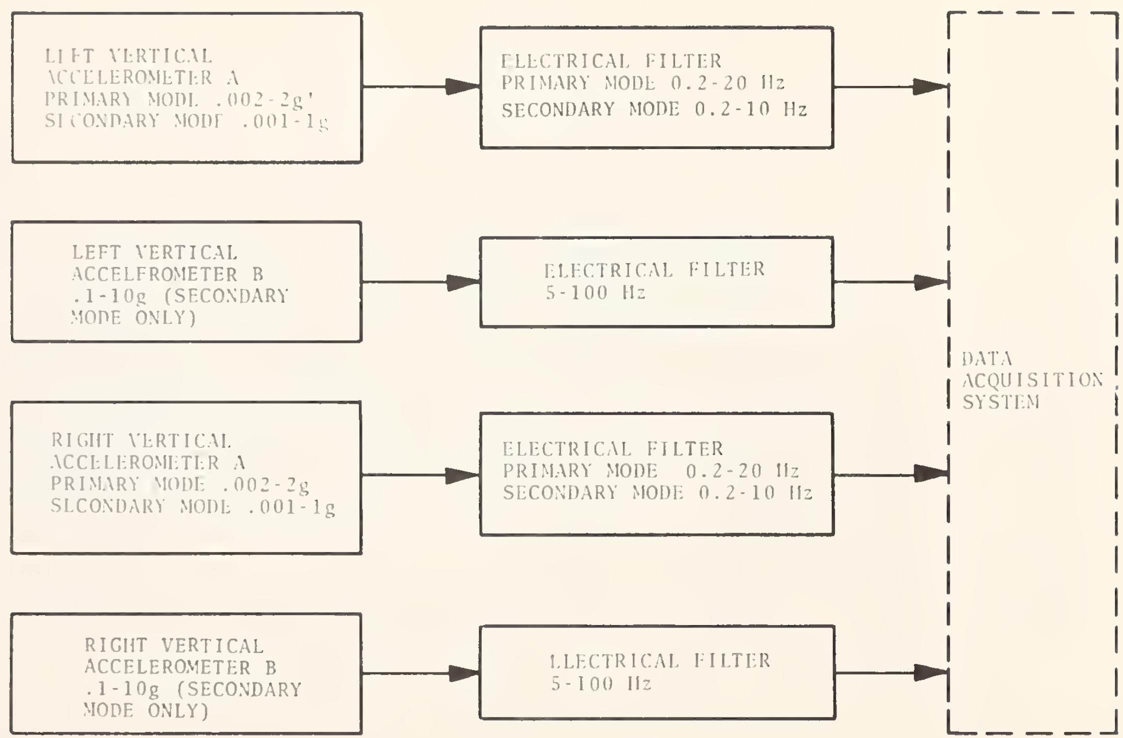


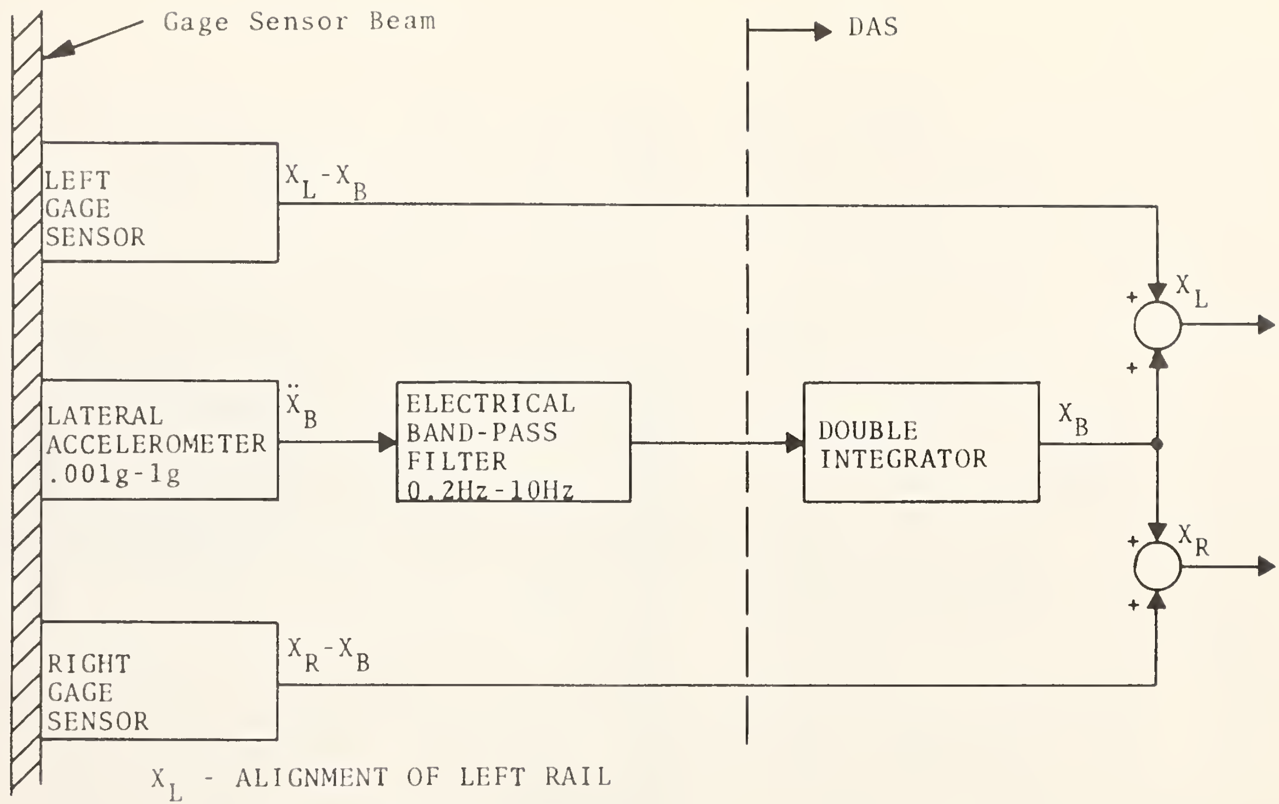
Figure 8. Profile Measurement Technique

rail with respect to the moving reference. Since each pair of accelerometers will be selected to sense acceleration in a specific frequency range, the computer deviation from each accelerometer will reflect the profile deviation in the selected frequency range.

Since the two pairs of accelerometers will be mounted on the same wheel/axle assembly, the profile data for each rail will be correlated to the same points along the track. This will permit the generation of cross level data in the DAS by simply taking the arithmetic difference between the left and right profile data. Cross level is defined as the algebraic difference between the left and right profile measurements. With the described technique, profile and cross level measurements at vehicle speeds between twenty to eighty miles per hour will have a system accuracy better than 0.1 percent.

2.2.1.3 Alignment Measurement Subsystem. The alignment to be measured by this subsystem is the lateral (horizontal) deviation of each rail with respect to some moving reference. The method by which the alignment of a rail will be measured (Figure 9) is as follows: an accelerometer for sensing the lateral accelerations will be hard mounted on the gage sensor beam. The beam, a rigid structure, will be supported from an unsprung portion of the rail car truck assembly and located as close to the axle as feasible, to assure that the measurements are made on the deflected track. The output signal from the accelerometer will be amplified and filtered electrically, and then converted for processing in the DAS. The DAS will perform a double integration with respect to time of the accelerometer signal to compute the lateral position of the gage sensor beam with respect to some moving reference. This lateral position of the gage sensor is then added to the distance from each rail to the reference point of its optical probe, to yield the distance from each rail head to the moving reference.

The alignment data will be measured over a range of $\pm$ 5 inches in the frequency range of $0.2 < f < 10$ Hz, for vehicle speeds



X_L - ALIGNMENT OF LEFT RAIL

X_R - ALIGNMENT OF RIGHT RAIL

X_B - BEAM LATERAL DISPLACEMENT

Figure 9. Alignment Measurement Method

between twenty and eighty miles per hour. The lateral accelerometer will measure the linear acceleration in the range from 0.001g to 1g in the frequency range of $0.2 < f < 10$ Hz. The low frequency cutoff at 0.2 Hz eliminates the effect of accelerometer bias errors while still permitting long wavelength measurements of rail alignment (0.2 Hz is equivalent to 147 feet at 20 miles per hour and 587 feet at 80 miles per hour). The 10 Hz cutoff permits a shorter wavelength measurement of rail alignment of 2.9 to 11.7 feet for the respective vehicle speeds.

To provide the greatest resistance to the higher vibration inputs a dynamic range change (DRC) accelerometer with a critical frequency of 10 Hz will be used. This accelerometer will provide a -3 db ratio of output/input at 10 Hz with more than 14 db attenuation at 60 Hz and a roll-off slope greater than 20 db/decade. The DRC feature will allow application of peak inputs as high as 5g at 50 Hz without servo saturation, while still retaining the accuracy, linearity and stability of a $\pm$ 1g or $\pm$ 2g accelerometer.

This system accuracy will be better than 0.1 percent with the statistical summation of all the errors from all sources in the accelerometer channel not exceeding the equivalent of 0.002g, 2 sigma in the operating frequency range of $0.2 < f < 10$ Hz, and the specified operating shock and vibration environment of the total system.

2.2.1.4 Automatic Location Detector. The automatic location detector (ALD) (either an inductive or optical sensor) is responsive to the physical features found between the rails such as switches, guard rails or metal plates which provide a unique signature of the track structure. The signal from the sensor also provides a positive identification of the vehicle location as a function of time and the detected track feature.

The ALD sensor, located beneath the car and above a plane tangent to the top surface of the rail heads at a position midway between the two rails, will be designed to detect track features at vehicle speeds from zero to eighty miles per hour. In this speed range the maximum location measurement uncertainty with respect to the target surface detected will be less than 1.0 inch.

2.2.1.5 Speed and Distance Detector. Speed and distance are two basic reference parameters which will be measured by use of a rotary pulse generator coupled to the vehicle axle. The generator, an optical incremental encoder, will produce 1000 pulses per revolution of the axle with a measurement accuracy of 10 minutes of arc with respect to the leading edge of the pulse. The distance parameter is important in track geometry measurement since it provides an accurate means of locating a particular track condition while the instantaneous vehicle speed, provided by the rotary pulse generator, is used in the processing of the data.

2.2.2 Data Acquisition and Processing

For handling the track geometry measurements quickly and economically, a Data Acquisition System (DAS) is being developed in conjunction with the track geometry sensor system. The function of the DAS will be real-time data acquisition display and storage with a secondary function of off-line signal processing and display.

The basic configuration of the DAS will consist of a Sperry UNIVAC 1616 CPU, 16k of 16 bit/word memory, 2 high speed A/D converters with 32 multiplexed analog inputs, 10 D/A converters, one discrete input controller, one nine-track magnetic tape, one high speed printer and one TTY with paper tape reader and punch (Figure 10). This small-scale computer, together with the multiplexed analog-to-digital converter with sample hold capability, and a bulk storage device, comprise the nucleus of the system.

The primary task of the central processor will be the real-time collecting of data from the analog-to-digital converter at a minimum data rate of 60 kilobytes per second, the limited processing of the data, and the storing of all the data on a bulk storage device. The central processor will also have the capability to perform off-line data processing such as spectral analysis, auto

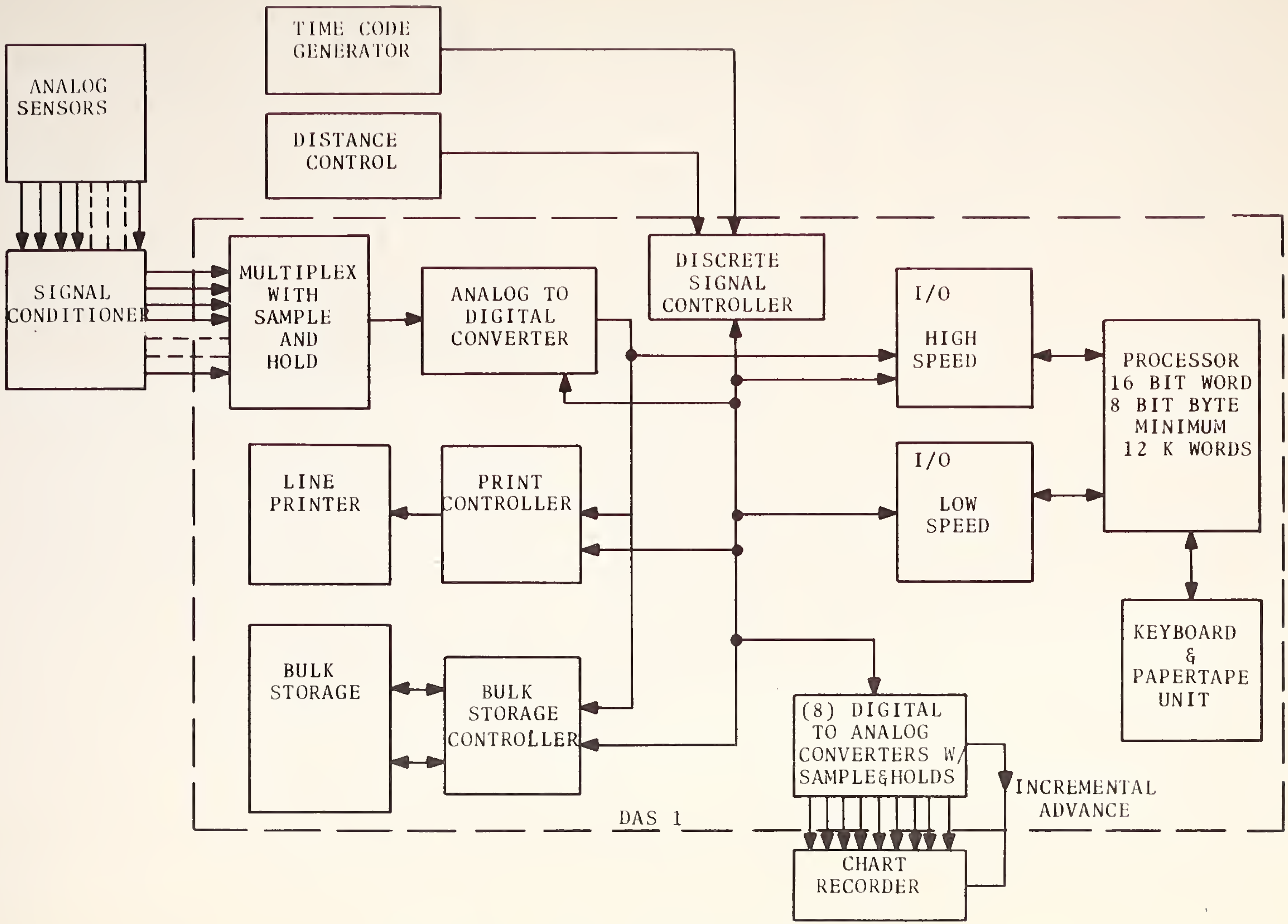


Figure 10. Data Acquisition System

and cross correlations, generation of histograms, and statistical processing. Output of the off-line processed data will be in a format compatible with an eight-channel chart recorder or line printer.

2.3 INFORMATION OUTPUT

Raw track geometry measurements are made by the track geometry sensor system, and the raw data thus obtained is processed by the data acquisition system to yield the desired output information. The output information is presented in two formats, analog strip-charts and digital computer printouts.*

The analog stripcharts present the measured parameters, plus reference information, as a function of distance. The digital printouts quantize the parameters into zones or classes, and present the location at which the parameter changes from one zone to another. Both formats permit the user to specify the acceptable tolerance, or error, of a parameter, and then quickly determine the locations where the track measurements fall outside of the specified tolerance.

The track inspector and maintenance planner thus readily can determine how much track footage is out of tolerance and where that track is located. The measurements can be made at revenue speeds and the information output is available in real-time. Thus the maintenance supervisor readily can obtain an up-to-date status report whenever needed, and easily can observe the change of track condition by comparing successive reports.

*Ibid.

3. APPLICATIONS FOR URBAN RAIL TRANSIT

Track inspection is an essential part of any transit system maintenance program. Through inspection, properties can determine which track sections require maintenance work, how best to program maintenance work and future inspections, and whether maintenance work was completed satisfactorily. The demand for improved track quality (through an inspection program) has been increasing steadily as new car configurations with increased vehicle speeds are becoming operational.

The primary objectives in the application of a track geometry measurement system to urban rail transit can be summarized as follows:

a. Maximizing effectiveness of maintenance resources

b. Avoiding costly or disastrous accidents

c. Establishing priority maintenance schedules

d. Improving ride quality, noise characteristics and safety

Each of these objectives has its own requirements, which determine the frequency and the method of inspection that is required.

The frequency of track geometry measurements also depends primarily on the manner in which the results are to be used. For the establishment of priority work in an annual maintenance program, measurements of track conditions two to four times per year may be considered sufficient. However, if quick detection and early corrective action is desired, then weekly or even bi-weekly measurements may be considered.

Track geometry measurements provide data which can be used in determining not only the condition of the track prior to rework and again after the maintenance work has been completed, but also for providing a quantitative justification for maintenance budget requests as well.

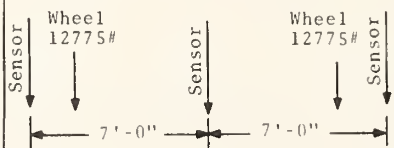
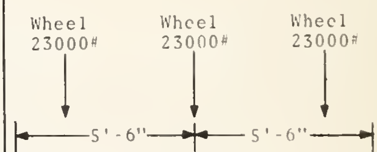
The benefits from a well defined maintenance program, which is facilitated by a track geometry measurement capability, can be related in terms of more efficient utilization of maintenance crews and resources, and improved safety, noise levels, ride quality, and vehicle and track wear. Although a dollar figure is difficult to estimate without first conducting an indepth study, indications from operating transit properties and from the results of survey studies conducted by TSC do verify that substantial benefits can be gained. One area which requires further study before a quantitative conclusion can be established is whether the potential benefits would exceed the cost of the capital investment for the instrumentation and the trailing of the personnel to use it.

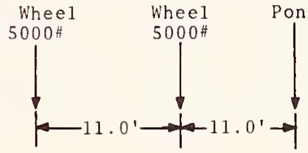
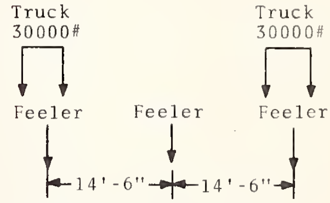
Proper maintenance of the track, in terms of track geometry alone, can result in an estimated noise level decrease of 5 dBA which is a significant amount in itself without even considering the cost savings due to the reduction of wear and fatique damage to the vehicles and track,

The need for establishing measurable geometric standards for track is becoming more evident as old systems are being refurbished and new systems are being put into operation. The DOT Track Safety Standards for Railroads has already been established. The Institute for Rapid Transit is taking similar steps by preparing the Safety Guide Lines for Urban Rapid Transit Systems, which is an indication that track safety standards may be established by the Federal Government in the near future. To conform to such standards or test for conformance, geometry measurement techniques as well as computer processing of the data will become essential.

APPENDIX

DIAGNOSTIC CARS

NAME	T - 2	R-1
OWNER	DOT	Southern Rwy
MANUFACTURER	Budd Co.	
Geometry Measured		
a Gage	Sensors measure actual gage by capacitance	Contact feelers against gage side of each rail
b Vertical Alignment (each rail)	Beam attached to wheel truck. Three sensors measure mid-ordinate of 14' chord by capacitance.	Vertical displacement of middle axle of 3-axle truck with respect to straight line chord connecting end axles
		
c Horizontal Alignment (each rail)	Same as vertical alignment. Mid-ordinate of 14' chord.	Curvature measured over 59.5' chord from position of truck center pins Local alignment variation measured by sensor 5.5' apart
d Cross Level	Measures vertical distance one rail out of level with respect to other rail by means of gyro.	Super elevation measured by gyro-stablized pendulum mounted in center of car body
e Warp Twist	Computes twist from cross level in terms of specified rates of change.	Twist is the differential in cross level over 11' chord

TR-Car	TRACKFAX	X-116
Canadian National	Boston & Maine	N.Y.C.T.A.
Converted Pass. Car	Matisa	
Magnetic probes located fixed distance apart & above inside edge of rail	Double feeler from center of car to each rail measures gage	Spring actuated feeler measures actual gage
Instrument box mounted on side of truck frame. Acceleration and velocity probe connected between side frame and journal box establishes vertical moves of wheel as car moves. (Wheel load 19,000# $\pm$)	Beam attached to pony truck and car wheel measures deflection of 22' chord  (May be ballasted to 6,000#)	Contact feelers measure mid-ordinate deflection of 29' chord  (7,500# wheel load) (Can ballast to 12,500# wheel load)
Not measured	Contract feelers measure mid-ordinate of 32.8' chord	Same as vertical alignment Mid-ordinate of 29' chord
Vertical rail measurements are differenced to give cross level error	Oil dampened pendulum measures angle from horizontal	Gyro senses angular deviation in relation to horizontal axis
Not measured	Twist is recorded from vertical movement of axles 9.1' apart	Not measured

Diagnostic Car	T-2	R-1
DATA OUTPUT	Graph of gage, vertical and horizontal alignment for each rail, and cross level with respect to distance along track. Also furnishes magnetic tape of track measurements for processing on off-board computer	Graph of gage, vertical and horizontal alignment for each rail, super elevation, and twist with respect to distance along track. Mechanical to electrical interface support on-board computer which provides priority defect output and track index
DATA USE	Programs have been prepared to show deviations from specified standards by location. Car being used for experimental and development purposes	Priority defect record supplied local maintenance officers for correction Quarterly tests provide statistical check for trends in maintenance defect Test records used to evaluate results of maintenance work
PHYSICAL CHARACTERISTICS		
a. Length	85' 0"	85' +
b. C to C of trucks	59' 6"	59' 6"
c. No. of axles	4	6
d. C to C of truck axles	8' 6"	5' 6"
e. Height	12' 62"	
f. Weight	102200#	275000#
g. Max. recording speed	150 mph	80 mph
h. Self-Propelled	Yes	Yes

COMMENTS	T-2	RI
	Vertical alignment measurement is not deflection from unloaded position of rail, which is criteria of new DOT track standards. Horizontal alignment measurement not compatible with DOT track standards either	The Southern has probably used the Track Inspection Car results for maintenance programming purposes to a greater extent than any other Railroad. The Southern has also developed the most definitive standards and priorities for use with the inspection car data

TR	TRACKFAX	X-116
Teletype printout of surface roughness and cross level indices 4 times per mile Dynamic rail profile graph Mini-chart of surface roughness and cross level index numbers. Surface roughness is sum of vertical defect slopes.	Graph of gage, vertical and horizontal alignment of each rail, cross level, and twist with respect to distance along track On-board computer recently developed to print out deviations from specified standards	Graph of gage vertical and horizontal alignment of each rail, and cross level with respect to distance along track
Identifies and locates track conditions requiring immediate corrective action Assists maintenance officers in planning short range preventative & corrective work programs Determines quality of work performed	To identify & locate conditions of gage, line or surface requiring immediate action To formulate maintenance programs To evaluate quality of work performed	Identifies & locates rail conditions requiring immediate attention
4 150000# ± 100 MHP No	20' 4" 2 9' 10" 20000# 19 mph Yes	40' ± 29'0" 4 60000# 35 mph No
The CNR is still testing and developing standards for track to use with inspection car results. One unique development of the CNR test vehicle is measurement of roughness by summation of the slopes between vertical defects rather than by the deflection itself. This method may give the best single indication of vertical alignment	The comparative light weight of car must be taken into consideration in evaluation of vertical alignment data. Low operating speed limits its productivity and may effect vertical alignment magnitudes. Has had the longest period of use of any car listed	Relatively inexpensive test car. Has no computer program to assist in use of data produced