T-2000:
A Railroad Track Geometry
Inspection Vehicle
For the 21st Century

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ABSTRACT

In February of 2001, the Federal Railroad Administration (FRA) introduced a new Track Geometry Vehicle, the T-2000, that offers the state-of-the-art in track inspection and measurement technology. The car features the latest in vehicle systems computer controls, monitoring and on-board diagnostics. The car is capable of measuring track parameters at speeds up to 110 mph in a towed configuration or at speeds up to 90 mph under self-propulsion. Two diesel engines with a combined horsepower of 1300 allow the vehicle to reach 90 mph in 4 minutes while disc brakes equipped with anti-lock braking slow the car to a stop from 90 mph in 40 seconds. The car utilizes a satellite differential geo-positioning system to tag all measurements accurately to their location to allow track repair crews to quickly locate sites needing repair. Vehicle position is also continuously tracked by the home base over a satellite link. The car measures track gage, crosslevel, alignment and profile and vehicle ride quality utilizing non-contact sensors. This data is compared to FRA track standards in real time and an exception report is printed for use by the track inspector. The vehicle also includes a ride quality measurement system to assess the relative passenger ride of tracks surveyed.

The vehicle is described in detail in this paper, which includes several figures depicting the vehicle and its systems.
INTRODUCTION

In February of 2001, the Federal Railroad Administration (FRA) introduced a new Track Geometry Vehicle, the T-2000, which is operated under the Office of Safety’s Automated Track Inspection Program (ATIP). FRA recently decided to keep the T-2000’s predecessor (the T-10) in limited service performing high priority surveys whenever the T-2000 is not available. Both cars are designed to determine compliance with the Federal Track Safety Standards (FTSS), 49 CFR Part 213, for track classes 1 through 9. Railroads have found that the data is useful for both short and long range maintenance planning. The cars provide early indications of potential trouble areas. The T-2000 incorporates new technologies such as ride quality and global positioning (GPS) which enhance the overall capabilities of the car.

ENSCO, Inc. was responsible for delivering the T-2000 under contract to FRA. Plasser American built the vehicle system itself under contract to ENSCO. The specifications for vehicle and measurement systems were developed by the Office of Safety, Track Division, in consultation with the Volpe National Transportation Systems Center, which provided valuable technical advice. FRA used a combination of performance-based specifications and specific design requirements. The Office of Safety, with the help of FRA’s Office of Research and Development, examined many potential technologies and incorporated state-of-the-art measurement systems such as ride quality and global positioning (GPS) capabilities in the new geometry car. FRA would like to thank the railroad professionals who gave FRA advice during the planning stages. A review of the published work of AREMA Committee 2 was especially useful in FRA’s deliberations.
The T-2000 is capable of measuring track parameters at speeds up to 110 mph in a towed configuration or at speeds up to 90 mph under self-propulsion. Two diesel engines with a combined horsepower of 1300 allow the vehicle to reach 90 mph in 4 minutes, while disc brakes equipped with anti-lock braking slow the car to a stop from 90 mph in 40 seconds. The car utilizes a satellite differential geo-positioning system to tag all measurements accurately to their location to allow track repair crews to quickly locate sites needing repair. Vehicle position is also continuously tracked by the home base over a satellite link. The car measures track gage, crosslevel, curvature, alignment, profile and warp utilizing non-contact sensors. This data is compared to FRA track standards in real time and an exception report is printed for use by the track inspector. The T-2000 also has a ride quality system that is integrated with the GPS and track geometry systems. Although not a regulatory requirement, if the railroad representative requests the information, FRA will provide a listing of locations where the T-2000 experienced a poor ride. Railroads have found that this information gives an excellent indication of relative track quality and facilitates future planning.

BACKGROUND AND MISSION

For over three decades, the FRA has operated track geometry measurement cars to inspect the Nation’s railroads for compliance with the FTSS. The previous vehicle, T-10, was a modified Budd SPV 2000, self-propelled diesel passenger car that operated from 1979 till January 2001. Due to its age and resulting difficulty in maintaining the vehicle, the FRA decided to upgrade to a new state-of-the-art vehicle.
The vehicle itself uses a design similar to the Union Pacific EC-4 geometry car. The T-2000 uses the same advanced computerized control system and has the same general shape and dimensions as the EC-4, but T-2000 differs in the following ways:

Structurally, the T-2000 has reinforced collision posts and corner posts, which meet FRA’s new Passenger Equipment Standards. T-2000 uses a unique truck design, which is capable of speeds over 110 mph. The layout of the car features an approach where the FRA inspectors and railroad engineering personnel face to the rear of the car for track observation during track surveys.

**VEHICLE DESCRIPTION**

The FRA T-2000, shown in figure 1, is a 90-ft. long single unit railbound vehicle. The total vehicle gross weight is about 100 tons. The truck centers are located 65 ft. - 11 in. apart with truck wheelbase of 8.2 ft. The vehicle is powered by two 650 HP Cummins diesel engines driving all four axles through Voith Automatic transmissions and Voith Gearboxes. The vehicle is braked by Knorr disk brakes with an anti skid system. Table 1 provides the basic specifications for the vehicle.
Figure 1, Exterior Photos of the FRA T-2000 Vehicle
TABLE 1, Vehicle Specifications for FRA T-2000

Propulsion: Two 650-Hp Turbocharged Diesel Engines (Cummins QSK19-R650)

Transmissions: Voith Type T311r Four-Speed (Two Forward and Two Reverse) Automatic with Torque Converter

Trucks: Plasser High Speed Truck; All Axles Driven; 90 mph Gearing (110 mph towed); Air-Coil Spring Suspension; Outboard Roller Journal Bearings

Dimensions and Weights:
Weight, w/o Fuel – 200,000 pounds (100.0 tons)
Length Over Pulling Force of Couplers (PFC) – 91.8 feet
Truck Center Distance – 65.9 feet
Truck Wheelbase – 8.2 feet
Maximum Width Carbody – 10.0 feet
Maximum Height - Rail to Top Roof - 12.9 feet
Maximum Height - Rail to Top of Engine Cooler, 15.4 feet
Height, Rail to Top of Finished Floor - 53-3/8 inches
Wheel Diameter (New) – 36 inches
Loading Each Axle – 25 tons
Maximum Curvature – 13.5 degrees

Fuel Capacity: 1050 U.S. gallons diesel

Auxiliary Power:
Engine: Two 74 Hp Turbocharged Diesel (Cummins 4BT3.9-G3)
Generator: Stamford 58 kW, 480 VAC, 3 PH, 60 Hz
Instrumentation Power: 7.5 KVA Uninterruptible Power Supply (UPS)
Wayside: 480VAC, 3 PH, 60 Hz

Cooling System Capacities:
Propulsion Engines (Each) – 10.5 gallons
APU Engine [Each] – 1.9 gallons

Brakes:
Knorr Disk Brakes
Anti-skid, ABS with Sanders
Parking Brake with Manual Override.

Environmental Control:
Twelve 1.2-Ton Air Conditioners; Electrical Resistance Heat Supplemented by Electric Floor Heat; Integrated Temperature Control System; 5,400 cfm Ventilation
The vehicle drive engines are placed below the floor level to maximize interior space within the car. The vehicle has two onboard diesel generators that provide 58 kW of 480 volt, 3 phase, AC power each. For normal operations, only one generator is required; during hot summer operations, both generators can be run and phase locked to provide sufficient power to run the 12 AC units. The diesel generators are stacked one on top the other inside a sound proof room with a large swing up exterior door for servicing. The compartment also has a roof hatch too allow the units to be removed. The two generators are shown in figure 2.

Figure 2, Two 58 kW Diesel Generators Installed in Vehicle
The roof of the vehicle is used to hold the 12 AC/heater units and the two engine coolant radiator units as shown in figure 3. Also on the roof are antennas for the communications systems as well as horns and spotlights.

![Figure 3, Roof Mounted Engine Coolers and AC Units](image)

The vehicle can be driven from either end from duplicate driving desks. To switch from one driving desk to the other requires only turning off a switch on one desk and turning on the same switch on the other.
CRASHWORTHINESS

The FRA T-2000 was designed to conform to the latest FRA crashworthiness standards for passenger cars. To accomplish this, highly braced corner posts and a center collision post were built into the vehicle structure on both ends. The corner posts consist of 4” x 6” x 3/8” wall rectangular mechanical tubing with a diagonal brace and plate webbing. The center collision post consists of 6” x 6” x 3/8” wall rectangular mechanical tubing with a diagonal brace and plate webbing. The corner posts and collision post are connected by horizontal 6” x 6” x 3/8” wall crossmembers above and below the windshields. In addition, stub posts connect between the frame and the lower windshield horizontal crossmembers. Figure 4 shows the collision structure during construction from the inside.

Figure 4, Interior Unfinished View of Collision Structure
The vehicle frame consists of 4 longitudinal 8” square rectangular tubing frame members. The two inner frame members connect to the coupler draft gear and are diagonally braced to the outer frame members to spread coupler loads to all frame members.

**INTERIOR FEATURES**

The interior was designed to accommodate up to 16 people. Normally there are seven people onboard including a crew of four, Railroad pilot, FRA inspector and Railroad track supervisor. During normal operations the crew travels around the country and stays in motels at night. The car, therefore, has a large kitchen, an eating area and a lavatory, but no sleeping quarters. The car was designed to be self-sufficient since it rarely returns to its home base. The car is designed to allow field repairs and maintenance. It has a large workshop that includes ample tool and spare parts storage. Throughout the car, built- in cabinets and drawers allow for the storage of supplies, paper, manuals and safety equipment. Figure 5 shows the interior layout of the car.
Figure 5, Interior Layout of T-2000
MEASUREMENT SYSTEMS

Through the use of advanced electronic sensing and data processing, the T-2000 vehicle is able to collect track geometry data while traveling at speeds up to 90 mph in the self-propelled mode and 110 mph towed. The Track Geometry Measurement System (TGMS) is capable of determining compliance with Track Class 1 to Track Class 9. Table 2 summarizes the TGMS measured parameters.

**TABLE 2, TGMS Measurement Capabilities**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Measurement Range</th>
<th>Speed Range</th>
<th>Accuracy</th>
<th>Resolution</th>
<th>Repeatability (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>Gage</td>
<td>53-3/4 to 58-1/4 inches</td>
<td>0-150+mph</td>
<td>± 1/16 Inch</td>
<td>1/32 Inch</td>
<td>1/32 Inch</td>
</tr>
<tr>
<td>Crosslevel</td>
<td>± 7-1/2 Inches</td>
<td>0-150+mph</td>
<td>± 1/16 Inch</td>
<td>1/32 Inch</td>
<td>1/32 Inch</td>
</tr>
<tr>
<td>Curvature</td>
<td>± 20 deg.</td>
<td>5-150+mph</td>
<td>± 0.2 deg.</td>
<td>0.1 deg.</td>
<td>.01 deg.</td>
</tr>
<tr>
<td>Profile</td>
<td>± 5 Inches</td>
<td>5-150+mph</td>
<td>± 1/16 Inch</td>
<td>1/32 Inch</td>
<td>1/32 Inch</td>
</tr>
<tr>
<td>Alignment</td>
<td>± 6 Inches</td>
<td>5-150+mph</td>
<td>± 1/8 Inch</td>
<td>1/32 Inch</td>
<td>1/32 Inch</td>
</tr>
<tr>
<td>Distance</td>
<td>N/A</td>
<td>0-150+mph</td>
<td>5 ft/mile</td>
<td>0.1 ft.</td>
<td>N/A</td>
</tr>
<tr>
<td>Speed</td>
<td>0 – 150 mph</td>
<td>0-150+mph</td>
<td>2% but not less than 2 mph</td>
<td>.5 mph</td>
<td></td>
</tr>
</tbody>
</table>

T-2000 is equipped with an inertial based track geometry system that includes a servo laser system and a vision based gage system. Depending on the track, the system
operator can choose either of the gage systems for display and processing. The gage and inertial systems are described below.

**Servo Laser System**

The ENSCO servo laser gage system is housed in a crossbeam that is mounted to the unsprung part of the truck (see figure 6). The crossbeam, therefore, moves laterally with the wheel axle while maintaining a fixed height from the rail top. Two non-contact, laser sensors are mounted on the beam to measure the lateral distance from the beam to each rail. These laser sensors make non-contact distance measurements from a height of about three inches (75 mm) above the rail. As the vehicle travels along the track, the measurement beam moves laterally with the bogie. In order to keep the sensors within their range of linearity and high accuracy, each laser sensor assembly is mounted on an electro-mechanical servomechanism to keep the sensor at a fixed distance from the rail. The position of each servomechanism is measured separately. The measured servo positions and the outputs of the two laser sensors are added to form the gage measurement. The lateral position of the left (or right) rail relative to the bogie is also used as a component in forming the versine (alignment) measurement of the left (or right) rail.

**Vision Based Gage System**

A KLD Laboratory’s High-Speed Gage Measurement System (HSGMS) vision-based system (see figure 7) provides a second gage measurement. The HSGMS system processes the image and provides the Track Geometry Measurement System (TGMS) a
Figure 6, Servo Laser Gage System

Figure 7, Video Laser Gage System
signal for left (LG) and right gage (RG). These signals are combined in the TGMS with the appropriate offset and scale factor to calculate gage. This system also provides a profile of the gage face of the rails and can measure gage on head free and severely worn rail.

**Alignment**

Alignment of each rail is measured by the combination of an inertial sensing system and either of the two selectable gage systems. An inertial accelerometer is mounted laterally inside the measurement beam. The signal from the accelerometer is processed to yield the lateral path in space taken by the truck. Compensations for effects due to speed, truck roll and curving are made in software. The path of the truck is combined with the left and right gage measurements to form the alignment of each individual rail. The outputs are provided in the form of a space curve and mid-chord offsets with multiple chord lengths.

**Surface Profile**

Surface profile of each rail is measured by the combination of two inertial accelerometers mounted vertically on the carbody and two vertical displacement measurements from the carbody to the axle. Displacement transducers provide the vertical displacement measurements. The signal from the accelerometers is processed to yield the up-and-down paths in space taken by the car floor. These paths are combined with the displacement measurements to form the vertical
paths in space taken by the left and right wheels. Compensations for effects due to speed are made in software. The outputs can be represented in the form of a space curve or mid-chord offsets with respect to a selectable chord length.

**Crosslevel (or Superelevation)**

The system determines track Crosslevel on tangent track and Superelevation on curved track by measuring the inclination angle of a loaded axle. The system first establishes the inclination of the carbody with a compensated accelerometer system (CAS). A CAS sensor package, consisting of an inclinometer, a fiber optic gyro (FOG) yaw and roll rate gyro, is mounted under the floor of T-2000. Algorithms implemented in a combination of analog and digital schemes are used to process the CAS signals and yield the inclination of the carbody. Compensations are made to correct for the effects due to car speed, and centrifugal acceleration. Axle inclination is then computed by measuring the relative roll angle between the axle and the carbody.

**Curvature (or Curve Radius) of Track**

The curvature measurement system determines track curvature by measuring the spatial rate of turn in the track. The system employs a rate-of-turn gyro to measure the temporal yaw rate. The temporal track yaw rate (in degrees per second) is converted to spatial track curving rate (in degrees per foot) by dividing train speed (in feet or meters per second) into it. Speed of the vehicle is provided by the speed and distance measurement system. The output of the curvature
system, \( d \) = degree of curve, is scaled to a unit of degrees per 100 feet (30.48 meters) of track.

**Differential GPS Measurement System (DGMS)**

The T-2000 is equipped with a DGMS to accurately identify the location of track defects and track structures using map coordinates, latitude and longitude. The system has the capability to identify milepost location automatically based on GPS coordinates and enter these locations into the data stream.

**Automatic Track Data Alignment System (ATDAS)**

To allow comparisons of track condition over time, the T-2000 incorporates software called an ATDAS that overlays the current track geometry data with historical data. The software automatically aligns the data on a foot-by-foot basis and compensates for distance axis variations that normally occur when data is overlaid.

**Ride Quality Measurement System (RQMS)**

The RQMS on T-2000 measures the vertical and lateral acceleration of the car body and the trucks. The FTSS prescribes limits for carbody and truck accelerations that cannot be exceeded in Track Class 7 through Track Class 9. High lateral and/or vertical accelerations can be indicative of track geometry anomalies. This data is provided to the railroad for their use but is not used for enforcement purposes.
The track geometry data is simultaneously recorded on hard disk, and CD-ROM, displayed on an oscillograph for immediate viewing, and processed in real-time to produce the Track Geometry Exception Report.

This exception report documents the magnitude of any exceptions from the established Federal Track Safety Standards (FTSS) for profile, crosslevel (superelevation), warp, curvature, gage, and alignment. The detailed exception listings in this exception report provide FTSS information keyed to geographic location (i.e., distance from a milepost, or GPS latitude and longitude location). The exception report and the oscillograph charts are used as tools by the Federal Track Safety Inspector to monitor compliance with Federal Track Safety Standards.

Railroad maintenance planners also use the exception report and the oscillograph charts to pinpoint sections of track that will require maintenance, both short-range (days) and long-range (months). The report can also be used to identify the types of maintenance actions required at specific locations, to prepare work-crew schedules, to estimate future track maintenance workloads and to insure compliance with Federal Track Safety Standards. Since T-2000 started in service, the ride quality listing has also been shown to be a valuable tool for maintenance planning.

Utilizing the data stored on the hard disk and CD-ROM, additional analysis can be performed. This analysis provides more detailed information such as track geometry
space curves, track quality indices, and other track geometry descriptors. This data is used to support FRA's effort to develop performance-based track geometry standards.

EXPERIENCE TO DATE
Currently the geometry car is deployed to expand inspector capabilities and productivity, provide regional analysis and statistical characterizations of safety trends, support efficient and effective track system maintenance and planning, and most importantly, determine compliance with the track geometry requirements of the Federal Track Safety Standards. During the first five months of operation, the T-2000 surveyed over 12,000 miles since its inauguration run on February 3, 2001. With the exception of a small electrical fire in the control cab caused by an overloaded circuit, the performance of the car has met expectations. FRA operates the T-2000 as a train and requires that absolute block protect be afforded whenever possible. In the last few months, FRA has become aware of a few instances where some confusion existed about the FRA rules, and we are taking steps to improve communication with the railroad dispatchers and operating personnel. Overall, FRA has received some very favorable comments about the car.

FRA field staff and railroad personnel have provided valuable recommendations concerning improvements to the car, and FRA is in the process of implementing several of those recommendations. For example, visibility in bright sunlight will be addressed with better retroreflective striping. We are also installing additional large monitors for better visibility of real-time data.
THE FUTURE OF THE ATIP PROGRAM

FRA is constantly looking into new technologies to improve the measurement of track parameters and to improve the processing of this valuable information. Some of these new systems are being evaluated on FRA R&D’s new T-16 car. The T-16 is a modified Amtrak Amfleet car, which is equipped with several new systems, including neural network and wireless remote monitoring technology. As new technologies are proven to be practical and feasible, FRA plans to migrate the technology to the T-2000.

The T-2000, as mentioned before, has differential GPS capability, which records the latitude and longitude for each exception found during the survey. This system is accurate within 5 or 10 feet. After several months of testing, FRA recently purchased Palm Pilots with GPS capability so that Federal and State inspectors can more easily and accurately locate exceptions during follow-up inspections. While the hand-held devices do not currently have differential GPS capability, we are finding that we are locating defects within 30 feet. FRA plans to continue showing the milepost and feet on the exception reports and will continue to use the T-2000’s paint spraying system to mark defect locations on the track structure.

GeoEdit is a software program, which has been available to our inspectors for several years. The program runs on an inspector’s laptop computer and displays the exceptions and visual geometry traces. FRA is presently working to improve the program to be easier to use and better integrate it with the GPS and ride quality systems.
FRA is presently implementing a Geography Information System (GIS). The system will help inspectors and railroad personnel onboard, and FRA personnel in remote locations, follow the progress of the car on a computer screen, even thousands of miles away. The GIS will graphically show T-2000's position and detected exceptions on the map relative to mapping features, (i.e., mileposts, bridges, highway-rail crossings, cities), and other objects of interest. In its default mode, the map will move with the car. Highway-rail grade crossings, significant bridge structures, and other fixed reference locations, which are available in map databases, will also be displayed. By “clicking” on an exception icon on the map, the screen will present more detailed information about the exception (i.e., mileposts, footage, types of exception and value).
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