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Progress Report

Development of Maintenance Procedures for Tren Urbano Vehicles

by

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Table of Contents

Abstract

Tren Urbano is a heavy rail system being constructed in San Juan, PR and its planned to start operations in year 2002. To ensure a quality service throughout the service life of the system, a well designed maintenance program is necessary. In the development of the research, we first address maintenance as a whole, and then limited our scope to maintenance strategies for the truck (bogies) of the train's vehicles. The alignment of the rails for Tren Urbano presents sharp turns and other conditions that increment the stress to the trucks. In the project we present preventive devices for the bearings and other truck components. Currently there is a number of sensors that could be implemented into the rail system to get important data and predict possible failures. Preventing failures reduces the costs produced by extensive corrective repairs. To improve the maintenance program as a whole we are using Total Productive Maintenance (TPM) philosophy, whose main concepts are also included in this report. The next steps in our investigation will be to make suggestions on which specific sensor systems to use and also learn how other rail transportation agencies deal with predictive maintenance.

Problem description

Transit operators expend approximately one-fifth of their operating budget on vehicle maintenance. Even more, over the life of the railroad fleet, the maintenance cost could exceed the original purchase price. Being maintenance costs a significant part of the operating budget; any effort to make maintenance systems more efficient is valuable. Currently there is a tendency to overlook the need of maintenance for infrastructure. Several reasons have been identified:

1) Under-investment in public programs
2) Lack of efficient management systems
3) Failure to address the lifecycle of systems and the importance on economy
4) Failure to replace infrastructure as it wears

It is expected that Tren Urbano rail system start its operations on year 2002. Once the system is running, most of the vehicles will operate for long periods under stressing conditions. The alignment of the rails for Tren Urbano presents sharp turns and other conditions that increment the stress to the vehicles and their components. In order to keep the system in good conditions, the maintenance program should be carefully designed. From all vehicle systems, trucks may be one of the more important in terms of functionality and maintenance. Trucks, or bogies, are defined as all components from the rail to and including the first components rigidly fastened to the car body; this includes wheels, bearings axles. The user may have a higher perception of security if these components give the impression of being well maintained.

Siemens Transit Team plans to use a Maintenance Management System that will support all aspects of vehicle and facility maintenance, including:

- Scheduling and tracking maintenance activities
- Tracking components
- Tracking vehicle history
- Issuing work orders
- Calculation costs
- Tracking statistics on the performance of repairs and other maintenance actions

The maintenance philosophy of the Tren Urbano Project will be to optimize the mix of in-house and contract maintenance activities so that the system is safely and efficiently maintained in the most cost-effective manner. Maintenance personnel will carry out a controlled maintenance program that will encompass both preventive and corrective maintenance activities. **Preventive maintenance** includes tasks scheduled on a routine periodic basis, and is designed to prolong equipment life and minimize overall system maintenance costs, reduce failures, and assure safety and dependability. **Corrective maintenance** consists of troubleshooting repairing failed equipment and returning the equipment to service. The goal of the overall maintenance plan for the Tren Urbano system will be to identify the most desirable balance between preventive and corrective actions. Benefits of such a program include: reduction of unexpected failures, preservation of infrastructure (investment) and passenger security. Moreover, an effective maintenance will keep the vehicles available and not on the repair shop, which is the main goal.

The Puerto Rico Highway and Transportation Authority contracts include the requirements for all train components and maintenance practices; there is also the requirement for Siemens to provide manuals with all repair procedures and preventive maintenance. If the specifications on these contracts are followed, it is more likely that the overall system will be more efficient. As of this point, little, if any work has been done on preparing an infrastructure management process for Tren Urbano. No work has been done on either the facilities maintenance Policy and Procedures Manuals or the Systems Maintenance Policy and Procedures manuals. No attempt to develop an infrastructure management system has begun (Ferretti 1998). On a meeting with other Siemens personnel (Sept. 2000) we were informed that the maintenance manuals are not completed yet and there is work left to do on this area.

Objectives

At the initial phase of our project, we had in mind to investigate the maintenance of the Tren Urbano vehicles as a whole, including operations at the yards and shop facilities. These where the goals we had:

- Analyze the vehicles and maintenance sections of the Tren Urbano contracts
- Study work done by Siemens on its maintenance procedures for truck structures
- Apply Total Productive Maintenance (TPM) and Lifecycle Planning strategies to develop a more efficient maintenance program for truck components
- Gather information from other rail systems which have similarities with Tren Urbano and identify advantages of their maintenance practices
- Make recommendations to existing program

We have now refined our scope within the original objectives. Designing and ideal maintenance plan that combines preventive and corrective actions is not a simple task. However, it is clear that for most components, preventive maintenance can avoid unexpected failures and the cost associated with them. Extensive research is taking place in the development of sensors for monitoring the failure of truck components. Our main objective is to learn about this new sensor technology and explore their application to our rail system. We are also interested in learning about how to improve the overall efficiency of maintenance programs by using information sharing and computerization of maintenance systems.

A good maintenance program incorporating preventive and corrective maintenance can provide many benefits to the rail system. There are many indirect costs related to vehicle failures. First, failures will keep vehicles in the repair shop and not in the rails, where they make revenue. Besides, railroad failure may influence passengers negatively and thus decrease revenue.

Work Done

The progress of our research to this point consists of the study of vehicle contracts involving the maintenance that will be done on them. Also it has been gather recent sensor technology that could be a use as a possible option to a preventive maintenance program to be applies on the rail vehicles.

During the first semester of the academic year '00-'01 we had two meeting with the Siemens personal in charge of the vehicles and its future maintenance program. The Siemens assistant group was form by Joe Ferreti Operations & Maintenance Manager; Ron Mackay, Alternative Concepts Inc.; Christian Fonta, Vehicle Manager and Loraine Lerman, Director of Technology Transfer. In those meeting, they helped us to narrow our research topic to focus in the maintenance that the train's truck or bogie will need when the Tren Urbano is operational. In those meeting we get technical information about the train's truck that it is under their possession and some sketches of it.

Some of the new sensor technology to be use in the rail industry is the Automated Truck Performance Measurement System (ATPMS), Bearing Defect Detection by Vibration Measurements and "Smart-Bolt™" among others. The ATPMS is a series of strain gages that measures the forces in the tracks produce by the vehicle when it is turning in any curve. Those forces are register by a data control system that detect any excessive force and mark the vehicle to be retired for maintenance. The Bearing Defect Detection by Vibration Measurements is an accelerometer that registers a database of vibration of the bearing. The control system alerts the vehicle managers when it registers any vibration readings corresponding to failures of bearings. The "Smart-Bolt™" is temperature sensor that is mounted in the place of the end cap bolt. When this sensor detect a maximum temperature it send a signal to the train engineer and raise an antenna to mark the overheated bearing.

Relevant information from the Tren Urbano Contracts

Section 11 of the contract books includes all the design specifications for the truck components. Verifying that these demands are met in the current vehicles is a complex task and is out of the scope of our project. We will pay attention to the contract areas that refer to maintenance and wear of the truck components. The following are sections of the contracts with such information:

The vehicle shall incorporate design standards which minimize MTTR (Mean Time To Repair, including all access time) and costs throughout its intended useful life. The vehicle maintenance program should provide for minimization of maintenance costs and minimization of vehicle downtime. These are the MTTR (in hours) for various components:

- Traction Equipment and Controls 1.75
- Friction Braking 2.03
- Couplers and Draft Gear 1.50
- Trucks & Suspension 1.57

The contractor's maintainability program shall include a detailed plan outlining all schedules and activities for vehicle corrective and preventive maintenance. This plan, along with the proposed maintenance manuals and associated drawings, shall be included in the Master Program Schedule. This plan shall outline each maintenance task, time schedules, recommended tools, personnel and skill levels required.

Trucks, or bogies, are defined as all components from the rail to and including the first components rigidly fastened to the car body. Gear boxes, motors, wiring, brake system components, train control components, and associated mountings brackets for these are not included, except that any mechanical interface requiring welding or drilling on the truck shall be part of the truck.

Surface contact between truck components, except suspension stops, shall be made through fabric reinforced, service-proven, non-metallic materials to impede the transmission of vibration and noise.

The truck structure shall have a service life of 30 years minimum, without the need for structural repairs.

Trucks shall be interchangeable between wither position on the car, and among any vehicles furnished under this Contract, without modification, except for the installation or removal of components unique to their location.

The truck shall be arranged so that the Authority's wheel truing machine will be able to true wheels without removal of trucks form the vehicle or disassembly of any parts from the truck or the car body except end-of-axle ground brush equipment, if used, or the plugs of caps at the ends of the axle.

Provision shall be made in all truck designs for 50 mm of vertical mechanical adjustment to compensate for maximum wheel war and wear or settlement of other truck parts, so that the vehicle floor height can be maintained within tolerances required by this Specification.

A positive mechanical connection shall be provided between the car body and trucks, such that the trucks shall be raised with the car body, without causing any part of the suspension system to disengage or be displaced. These connections shall be detachable by conventional hand tools to permit de-trucking.

Wheel flange lubricators may be installed on each vehicle. Flange lubricators shall use a solid block lubricant to prevent carbody, top-of-rail and right-of –way contamination. The applicators shall include a steel spring assembly that holds the lubricating block firmly against the wheel flange. The lubricant shall not be washed off by rain, and shall be water resistant.

Section 01730 contains the requirements for preparing and submitting the Operation and Maintenance Manuals. It shows the format that the manuals should have and the information that must contain. These sections would be useful for us the next semester when we will examine the preliminary manuals.

Total Productive Management (TPM)

To improve a maintenance program, you need a basic strategy or guideline. This will provide the basis for creating the structure of the program and for decision making. Basically, to make any task efficiently, organization is a must. After studying literature of TPM, we see that it is centered in organization and logical thinking. If correctly applied, TPM concepts can bring benefits to maintenance programs. The following are paragraphs obtained from Gotoh's "Equipment Planning for TPM".

The Japan Institute of Plant Maintenance defines maintenance prevention (MP) as the use of the latest maintenance data and technology when planning or building new equipment to promote greater reliability, maintainability, economy, operability and safety, while minimizing maintenance costs and deterioration-related loss. Put simply, MP means making equipment that is designed from the start for easy maintenance and trouble-free operation.

Often, the technical improvement data gathered by maintenance engineers during daily preventive maintenance activities – data that can improve equipment's reliability and maintainability- are never put to use. The maintenance engineers must not only supply maintenance data as feedback to the design engineers, they should also actively support the design engineers. The design engineers, in turn, should assume greater responsibility for the equipment they design -even after it leaves their hands- by keeping tabs on the life of the equipment.

There are five areas where problems typically arise as MP data are sent to various departments:

1) **Maintenance log**. People in the maintenance department are usually required to fill out a maintenance log sheet for repairs and other operations. When the contents of the maintenance log are inadequate, equipment designers have problems analyzing these records. For example, the log might describe the repair but no the cause or reason for doing the repair, or how effective the repair was eliminating the problem.

2) **MP feedback data.** Even when MP data are passed to the design department, the contents are not always sufficiently coherent. Unless the feedback data are organized

into coded categories, for example, it becomes difficult to search the data, and it may become totally useless.

3) **Design standards and guidelines.** Ideally, all MP feedback data should be analyzed for common problems and solutions and then made generally applicable as equipment standards or guidelines. Quite often, MP data are only filed and not used.

4) **Checklists.** These are useful generally as a means of finding areas where standards are missing from the design, but they are far from foolproof. Whatever omissions eventually become evident should be incorporated to review the various checking methods and checklist contents.

5) **Judgment of usefulness.** When a vague method is used for judging the feedback data, there is room for ambiguity. Rules should be established for stating the source of information and the method of reasoning.

If you simply gather and file away maintenance reports without further processing, they are practically worthless. Such data gathering cannot be valued as an accumulation of technology. Conversely, technological know-how that exists only in the minds of veteran engineers and is not taught to newer, less experienced engineers is also of little value. Accordingly, a guidebook that presents a standardized compendium of maintenance and other experience-based data will help designers improve their equipment development skills and avoid common pitfalls

LCC, or life cycle cost, refers to the total cost of equipment (or an equipment system) through its life; it is the sum of the direct, indirect, recurring, non-recurring, and other related costs of a large-scale system during its period of effectiveness. The total cost, however, is often difficult to comprehend. The initial (acquisition) costs are easy to see, but the running costs are not. Failure to consider running costs can lead to many problems. The general outline for LCC design follows:

Step 1: Conduct initial cost reduction (ICR) design to minimize initial costs.

Step 2: Calculate LCC

Step 3: Clarify running cost reduction (RCR) needs by examining the highest running cost items.

Step 4: For RCR design, draft improved (alternate) plans that also minimize running costs.

Step 5: Estimate additional IC and RCR effects in each alternate plan.

Step 6: Trade off; apply engineering economics principles to select the alternate plan that offers the best design-to-test or calculated interest.

We had the opportunity to read a report made by Irwin Cohen, the director of Rail Systems Maintenance on the Metropolitan Atlanta Rapid Transit Authority (MARTA). Here he describes his experience on implementing Total Quality Management on this transit agency, the problems encountered and results obtained. Apparently, it is a difficult process, especially when the people in an agency have already a different way of doing things. The maintenance shop for Tren Urbano is not operating yet; this is an advantage since bad maintenance practices can be avoided from the beginning. Here are some relevant statements Cohen presents a bout TQM:

- TQM is not what an organization does, rather it provides the structure for how an organization does whatever it wants to do.
    - **Total** means involving all employees
    - **Quality** means delivery of products and services that meet customer requirements 100% of the time.
    - **Management** involves every manager and every non-manager in planning, organizing, and monitoring processes to deliver the highest quality products and services.
- Everyone is valuable; everyone contributes to the team.
- There is always room for improvement.
- Teamwork is the center of the Quality foundation.
- Involvement is also fostered through open sharing of information

This last point is very important, and several transit agencies are trying to encourage ways of making information accessible to employees and between different companies. Cohen also mentions that many employees associated TQM with downsizing, which meant loss of jobs. If the personnel is not well informed, they can arrive to such conclusions. A scope of our research is to learn about maintenance strategies and procedures from other rail systems. We notice that efficient maintenance programs seem to be closely related with the efficient use of maintenance information data.

Use of Maintenance Data and Information Sharing

The Transportation Research Board conducted a research on innovative maintenance practices being used in transit agencies and implementation strategies for other agencies. The second phase of the project focused on information sharing and better use of maintenance information. Results indicate that transit maintenance would benefit from enhanced interagency communication. Here's a list of commonly asked questions by maintenance managers:

What should be known about special maintenance needs before purchasing a new type of vehicle?

Which vendors stock the cheapest, most reliable parts?

What's the effect of increasing mileage intervals between scheduled inspections?

When should corrosion problems be expected in a particular climate?

In virtually every case, someone else involved in transit can answer the question; the issue is to link both persons. Electronic communication can provide free exchange of information that would benefit transit industry as a whole. The principal point of entry into electronic communication for new users should be via e-mail. To encourage new user into the system there should be a framework in which such use is vital to their functions; there must be a reason to log on. Almost 70% of transit agencies have networked PC's with the capability of sending intra-agency messages. The computerization of rail maintenance systems seems to be the trend for the future, and will help to increase the overall efficiency and reduce waiting time. Maintenance data are useless if they are simply stored and never looked at again. The purpose of this data is to produce information that could give light to some aspects of maintenance practices, evaluate actions and give alternatives. Both data collection and information production are dependent on the capabilities of computer technology.

Sensor Technology

Automated Truck Performance Measurement System (ATPMS)

This automated wayside detector monitors curving performance of individual rail vehicles, alert management to derailment conditions and identifies cars requiring remedial maintenance. This data can also be place in a database for long term maintenance planning and component life cycle costing.

Poor curving performance occurs when trucks do not rotate relative to the car body and the wheel set develops a high angle of attack. This defect increases greatly the potential of derailment and increase wear on track structure, wheels and truck components. Also, this excessive wear results in additional fuel consumption of the system to overcome the added train resistance. Some of the causes to this poor curving performance can be deficiency on the track structure or deficiency in the truck like: side bearing clearance, centerbowl lubrication, friction wedge rise, wheel profile, gib wear, and truck geometry. This sensor accomplished the conventional truck inspection methodology that cannot detect all truck defects cause by poor curving performance.

The Automated Truck Performance Measurement System is design to register the lateral and vertical forces produced by each wheel set as they negotiated the curve where the detector is located. These measurements are done by using strain gages circuits located on the web and the base of both rails in any curve of the track. The gages are place on the rails at the midpoint between two adjacent ties in the area commonly known as the tie crib and thus one set of strain gages is referred as a crib. The analysis of the vertical force data reveals that a wheel passing over the strain gage circuits produces a characteristic "peak". The use of a peak detection processor locates each axle from the train and determines each vehicle type.

The primary uses of the ATPMS are:

- Derailment prevention
- Identify Cars with Maintenance Defects
- Create Database for long term maintenance planning

For derailment prevention, the system primarily looks for two or more defective cars in a row because it has been proven by the rail industries that several consecutive warped trucks or trucks with high lateral wheel set forces are highly causative in rail rollover/gage derailments. To identify cars with maintenance defects, the system looks for high wheel set lateral forces, high wheel set vertical forces, warped trucks and high L/V ratios.

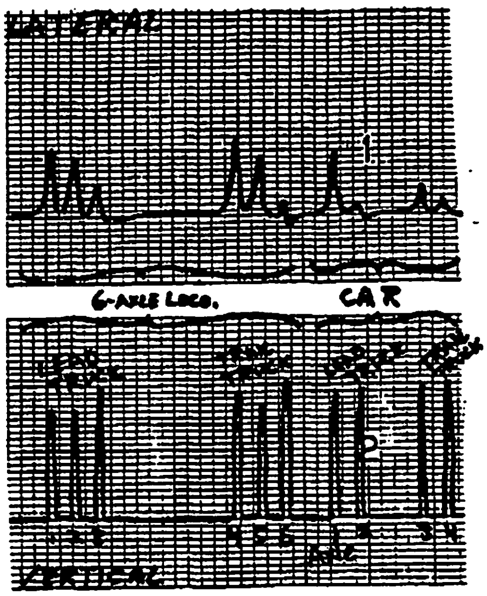

Fig. 1 Lateral and Vertical Wheel Set Force Peaks

In conclusion, finding the cars with poor curve performance allows railroads to minimize two of their biggest cost factors: wheel set replacement and rail replacement. The

ATPMS is definite a correlation between poor curving performance and mechanical defects, also it helps to find cars with mechanical defects some of which are difficult to find with traditional visual inspection techniques. The recommended uses for the ATPMS Technology are those where occurs:

- Captive fleet operations – Operations where the same cars will be seen many times, because it allow management to develop databases of car performance and take corrective action on poor performing cars.
- Passenger/Transit Operations – knowing which of the vehicles is exhibiting poor curve performance, maintenance costs can be minimized and other factors such as curving noise and excessive wear on mechanical parts.

Three Automated Truck Performance Measurement System Installations are currently in operation. One is at Quebec Cartier Mining Company at Port Cartier, Quebec; the other one is located on BC Rail at Clinton, British Columbia and last one is located at the Conrail's coal line in Pittsburgh, Pennsylvania.

Bearing Defect Detection by Vibration Measurements

Of all bearing defect types to be detected, one of the most challenging is that of a bearing with a loose inner raceway commonly referred to as a spun cone. About 50 bearing burn-off occurs each year in spite of important changes to the industry bearings standards and extensive network of hot bearing detectors. For four decades, infrared wayside bearings detectors have been used to notify trains that are close to burn-off temperatures. But if a detector is not in close proximity to the overheated bearing, it will burn-off and cause a derailment. The early detection of internal bearing defects with on-board sensors could avoid some of these derailments. By avoiding those events, it may be possible to apply an efficient preventive maintenance instead of creating costly stoppages.

Some bearing defects as spun cone, broken rollers and water-etched surfaces can be identify from a normal operations by vibrations measurements made by accelerometers located directly over the bearing. All vibration data is processed using a technique referred to as envelope detection. This technique consists of extracting the lower frequency defective bearing information from the higher frequency carrier vibrations. Envelope processing is an effective diagnostic tool that has the capability of revealed the presence of very small modulating signals even when large amounts of noise are present.

From experimental data, bearings with spun cone defects vibrate at higher levels than good bearings in the range of frequencies from 0–187Hz. Also, occurs an increasing trend of vibration with increasing speed to all the three bearing defect type examined on-board. As expected, higher train speeds provided hotter outer race operating temperature and an increasing trend in temperature in the bearing.

On-board sensing has several advantages over wayside detectors as:

- Continuously monitoring rather than intermittently.
- Evaluate much longer defect related signatures.
- It can evaluate structure-born sources of data.
- Notification of immediate danger when the condition is occurring.
- Integrate multiple transient "danger signals" for eventual fault announcement.

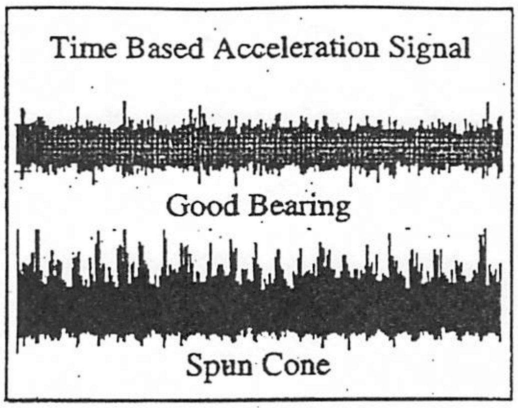

Fig. 2 Vibrations from Bearing Mounted Accelerometers

The disadvantage of on-board devices is that they have to be rugged enough to continuously operate in a high vibration impact environment. Since each railcar or bearing would require it's own detector any developed sensor would have to be very inexpensive to deploy and required little or no maintenance.

"Smart-Bolt™"

Currently in the United States rail industry, is common practice to use wayside infrared detection devices for automatic monitoring of defective hot journal bearing. This wayside detector is place every 15 miles or more as standard practice on the railways throughout the U.S. However test report has shown that bearing can heat up and catastrophically fail in relative short distance compare with the distance among sensor. In a series of test conducted by Burlington Northern Railroad in 1987-88, a catastrophic heat-up and failure of a defective bearing can occur within 30-60 seconds of operation. After the train it is alerted of a bearing problem, the crew walking along the train accomplishes the identification of the overheated bearing. Once the bearing is located it is measured it's temperature. The disadvantage of this procedure is that the bearing often has time to cool while the crew is walking, making it a wrong guess of the actual temperature it reach.

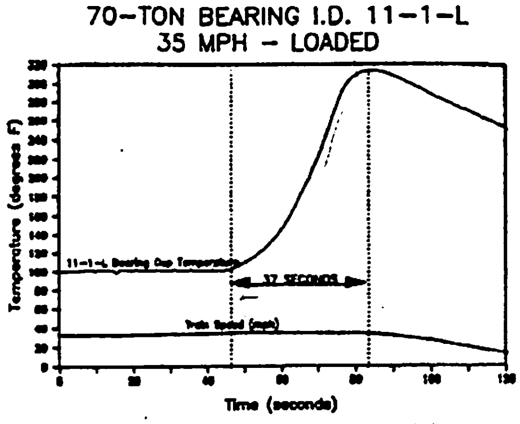

Fig. 1 Thermal Runaway of Bearing at Pueblo

Fig. 3 Thermal Data Registered in Failure

The "Smart Bolt™" is a thermal sensor-bolt that monitors real time data of the bearing temperature. Its primary functions are:

- Secure the end cap in place.
- House the sensor and electronics.
- Supply a visual indication for help in locating the failed bearing.

The thermal sensor replaces a standard bearing end cap bolt at each end of an axle. It is contained along with the transmitter in the body of the bolt. The main function is to transmit a signal to the engineer in the locomotive when activated by the alarm temperature.

The "Smart Bolt™" is an board device which provides instantaneous warning and identification of an overheated bearing to the operating crew at all times and at any speed without the need for wayside equipment. The location of the thermal sensor near the bearing race insures an accurate temperature monitoring and the elimination of false alarms. That accuracy is obtained because the location of the sensor reduces the effect of temperature gradients around the bearing due to heating and cooling effects. The installation of the sensor in the bearing does not need any modification in the rail vehicles because it is contained in the body of the bolt and reduce cost of its installation. The basic operation of the "Smart Bolt™" consists of a passive thermo-mechanical sensor that extends a piston when the alarm temperature is sensed. This action deploys an antenna and activates the transmitter that sends a radio signal to a receiver in the vehicle. The extended antenna also acts as a visual indicator to help locate the damage bearing.

One of the parameter that defines the sensor was the alarm temperature that was selected. The decision was based on the maximum temperature a bearing can withstand without occurring failure. This maximum temperature is control by the weakest component of the bearing, that is the seal made of "Nitrile", a synthetic elastomer that suffers damage at temperatures above 250°C. To support the mechanical load and vibrations the bolt end cap of a bearing take, the "Smart Bolt™" have an equivalent strength of a solid SAE grade 2 bolt. That is accomplished by increasing the material strength because the cross section has been reduced. The sensor works on band frequency of 902-928MHz. This band allows for spread spectrum transmission, which is virtually interference free and is easily achieved with a rugged non-crystal oscillator and compact antenna. The most important advantage of transmitter is the excellent noise immunity and jam resistance with the ability of the signal to get through many transmitting sources within the same bad-space in a range of 1 mile.

The main porpoise of the "Smart Bolt™" is to inform the crew that a problem exists and that action must be taken to avoid an impending accident. The averting of derailment will save the railroads millions of dollars in capital equipment. Other savings related to preventive of derailment are a reduction in the number of false stops and the stop duration because of the ability of the system to identify the hot bearing. These reductions will result in less fuel waste, fewer maintenance calls, improved schedule adherence and greater customer satisfaction.

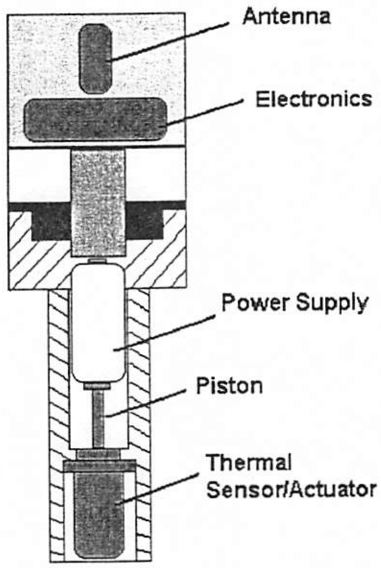

Fig. 4 Schematic Diagram of Device

Conclusions and Further Investigation

All the research done and the information gathered confirm the fact that maintenance is one of the most important factors to ensure that a rail system keeps operating for a long period with high quality. During this first semester, we accomplished the goals we had, with reference to the work plan we established. These activities are described in the "work done" section.

One of the possible problems that may afffect Tren Urbano is the high wheel and rail wear as a result of the sharp turns in the alignment. Figures 5 and 6 show important aspects of the wheel rail interaction. The sensors we have studied can monitor the performance of the trucks and indicate when to repair the components in order increase the curving performance and consequently reduce wheel wear. We will give suggestions on what sensors or systems to use and where to locate them.

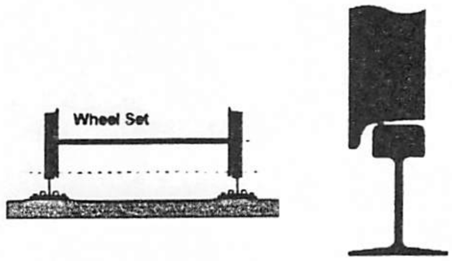

Fig. 5 Wheel Rail Interaction

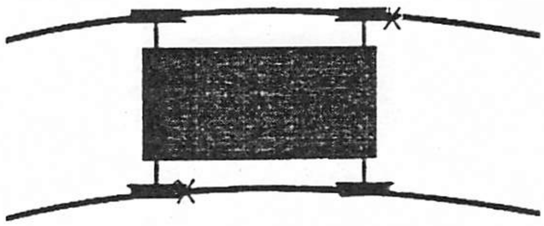

Fig. 6 Points of Increased Friction in Turns

We also keep an interest in exploring how maintenance systems can be improved by the use of computers and TPM strategies. We plan to get information on how other rail systems are incorporating sensor technology and computerized maintenance programs on their daily activities.

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