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Evaluation of Wireless Strain Gages for Testing Pipe Hangers

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PRODUCT DESCRIPTION

Out-of-balance pipe support systems can result in significant problems in power plants. To address this problem, this report describes methods and equipment to equip pipe hangers with temporary wireless strain gages. The gages can provide rapid feedback on the maintenance requirements of the hangers.

Results and Findings

Piping systems in power plants are designed to be mechanically flexible, in large part so that they can thermally expand when heated from ambient temperature to operational temperature. To enable this movement, spring hangers are installed to support the weight of the piping system and fluid while allowing displacement. As these piping hangers age, however, they may not operate as designed due to corrosion and other factors. They may then place higher than desired forces on the piping system, resulting in accelerated damage to the piping system. This project was undertaken to investigate a novel method to provide immediate feedback on defective hangers so maintenance or replacement may be performed. Use of wireless technology allows for a cost effective alternative to removing hangers and performing expensive condition assessment tests. After three design cycles, several laboratory verification trials, and three field demonstration tests, a basic design was developed for hanger-rod strain-gage clamps that can be installed by rope access and monitored wirelessly from nearby platforms.

Challenges and Objectives

This report is targeted at plant engineers responsible for maintaining high energy piping systems. It provides a cost effective method to determine issues with operation of pipe hanger systems and schedule required maintenance.

Applications, Values, and Use

Application of high temperature and standard strain gages are becoming commonplace in the assessment of aged components. Use of wireless technology enables cost effective application of these gages by eliminating the cost of running wiring.

EPRI Perspective

EPRI has pursued application of strain gages to monitor plant equipment in many applications. This technology is a cost effective monitoring technique compared to expensive finite element analysis and may allow equipment to remain in service. When applied to hanger rods, this technology provides quick feedback that shows when maintenance is required.

Approach

In order to devise an inexpensive monitoring technique for hanger rods that may have many applications throughout power plants, the project team developed a wireless strain-gage system using off-the-shelf strain-gage sensors that works with a handheld receiver unit. The receiver records the loads from the strain gages in the field and also performs all of the calculations required for averaging and thermal correction due to temperature. The team conducted demonstration tests of the system at three field sites. At each site, tests were conducted on six rods simultaneously on a combination of main steam, hot reheat, and cold reheat constant-support spring hangers.

Keywords
Pipe hanger
Strain gage
Main steam
Hot reheat

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INTRODUCTION

Objectives

The Electric Power Research Institute (EPRI) developed this project as a method to verify the functionality of pipe supports, and then to test the method in the laboratory and in the field. The objective of this project was to demonstrate applicability of wireless strain-gage technology to cost-effectively measure and verify the proper operation of hangers for high-energy piping systems.

Achievements

After three design cycles, several laboratory verification trials, and three field demonstration tests, a basic design was developed for hanger-rod strain-gage clamps that can be installed by rope access and monitored wirelessly from nearby platforms.

Challenges

Initial problems to define the best hardware combination were solved relatively easy. However, design of the strain-gage sensors and clamps was an evolutionary process that may be further refined in the future.

Selection of the wireless hardware is somewhat of a "moving target," since advances in hardware are and will continue to emerge rapidly. Systems are already available that provide improvements beyond the equipment used in this project. However, with new hardware come new problems with integration. The challenge with selecting wireless hardware may simply be the near-constant upgrades to equipment and software, and to avoid changing the hardware and software for as long as practical.

The most significant obstacle to attaining valid data in the field was the presence of electromagnetic interference (EMI) at the power plant. This was successfully addressed by encasing the hardware in a metal enclosure.

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BACKGROUND OF PROBLEM

Pipe-Support Systems

Piping systems in power plants are designed to be mechanically flexible. The primary reason that flexibility is required is that piping systems thermally expand when heated from ambient temperature to operational temperature. To enable this movement, spring hangers are installed to support the weight of the piping system and fluid while allowing displacement.

As these piping hangers age, they may not operate as designed due to corrosion and other factors. They may then place higher than desired forces on the piping system, resulting in accelerated damage to the piping system. This project was undertaken to investigate a novel method to test the function of pipe hangers in place economically to determine if further analysis is required.

Numerous papers in the literature have documented the impact of out-of-balance pipe support systems. Pipe support loads have been observed to be disturbed by as much as 23–50%. The resulting stress increases have been up to twice the allowable loading as specified in the ASME B31.1 Code [1,2]. This results in a shorter life for the piping system. Unplanned outages and expensive repairs have been caused by hanger imbalances. The same experience has been repeated worldwide [3].

In the 2005 edition of ASME B31.1 Code, allowable stress has been increased because the factor of safety was reduced from 4.0 to 3.5. This change was enacted to remain consistent with industry trends and other Codes as justified by improved design, manufacturing, fabrication, installation, and NDE methods. However, this change was not enacted for piping operated in the creep regime.

A problem may develop in the industry if improvements in technology are met with the traditional neglect of pipe-support systems. Piping systems are now being designed with more expectation (necessity) that they will function correctly. A lower factor of safety requires better maintenance of piping-support systems, not only improved design, manufacture, etc. Technology to greatly improve the industry's track record is readily available.

Older power plants have been operated significantly beyond their original design life. There is also no reason to assume that newer plants will not be managed similarly. As older units were being pressed into "life extensions," the industry began to learn what is needed for evaluating the remaining life of a piping system. Often, it was found that there was not enough information. An entire industry sprang up to address the issue of aging pipe and approaches to predict remaining life. Much of this information is now practiced and has been added to the ASME B31.1 Code as Chapter VII, Operation and Maintenance [4]. Added in 2007, this chapter requires the Operating Company to develop an operation and maintenance program for their high-energy piping, and to maintain that program for the life of the plant. Piping included in the program is referred to as "covered piping systems (CPS)," and includes main steam, hot reheat, cold reheat, and boiler feed as a minimum. ASME B31.1 Code Non-mandatory Appendix V provides details regarding acceptable plant practices for maintaining power plant CPS systems.

Although some of the information required for an accurate evaluation of a high-energy piping system may still be difficult to obtain, actual pipe-support loads is one parameter that is now practical to measure. In Germany, where a lower safety factor is used, codes require that operators complete Life Expended Calculations. Inspections are then triggered when calculated life expended exceeds 50%. Similar methods are being used in the USA, but are not currently required by the ASME B31.1 Code.

Measuring Pipe-Support Loads

Verifying actual pipe-support loads is becoming more important than ever at a time when the ability to obtain this information is more affordable than ever. There are currently several methods for determining the load on a pipe support:

1. Remove the pipe from service and pull it through its travel. The cost for this typically is similar to replacing the hanger.
2. Attach a dynamometer in place. This approach is expensive (usually prohibitive).
3. Hydraulically weigh the pipe. This can be a cost-effective alternative, but requires erecting scaffolding.
4. Use a load-cell washer. This technique requires extensive rigging and is best implemented during original construction. This approach is not currently used.
5. Use a load-cell pin. This technology is available, but is seldom used due to cost. Obstacles are similar to using a load-cell washer.
6. Use a rod clamp. For this approach, a clamp is attached to the hanger rod to measure changes in load. This can be installed by rope access.

Typically, significant time and expense are required to test pipe hangers for correct operation. Pipe hangers must be removed from service (which requires installing a temporary support) and operated through their full travel. This approach determines if the force exerted by the hanger is correct and if maintenance or replacement is required. Alternatively, the hanger may be tested in place using hydraulic methods; however, this type of test only reveals the force exerted on the pipe in one condition, frequently the cold position.

Strain gages have also been used to measure the force exerted on a pipe. These are typically installed on rods supporting the pipe hanger when no loads are present. Weight of the pipe is then applied and the forces on the hanger are calculated from the strain readings. The change from off-line to operational conditions may then be determined. This technique can also be expensive due to wiring required to connect the strain gages to recording devices.

It is desirable to economically determine the forces transmitted to the pipe during the transition from hot to cold or from cold to hot. This project sought to demonstrate the use of wireless technology whereby strain gages are attached to a pipe hanger support rod and their data transmitted to recording devices without the expense of wiring.

Wireless Transmission of Data

Wireless Internet applications are gaining acceptance in power-plant environments. A wireless application on site may involve any combination of wireless technologies, such as cellular phones, personal digital assistants (PDAs), radio frequency identification (RFI), wireless local area networks (LAN), and the Internet [5]. An obvious and significant advantage of wireless technology is the elimination of wires, which saves time and money. There are a number of different wireless protocols available, and the first step is to select one that is compatible with the site.

3
LABORATORY TESTS

The basic design concept being evaluated in this project is to measure the stretch of a pipe hanger rod caused by a change in load. To accomplish this, a pair of split clamps was attached to the rod and a pair of strain gage sensors mounted to the clamps. The initial design was constructed of carbon steel and hinged to fit around the rod (Figure 3-1). The strain-gage sensors for the early designs were fabricated in-house by the contractor. This proved to be troublesome because of the venerability of the strain gage sensors and the bulkiness of the clamps.

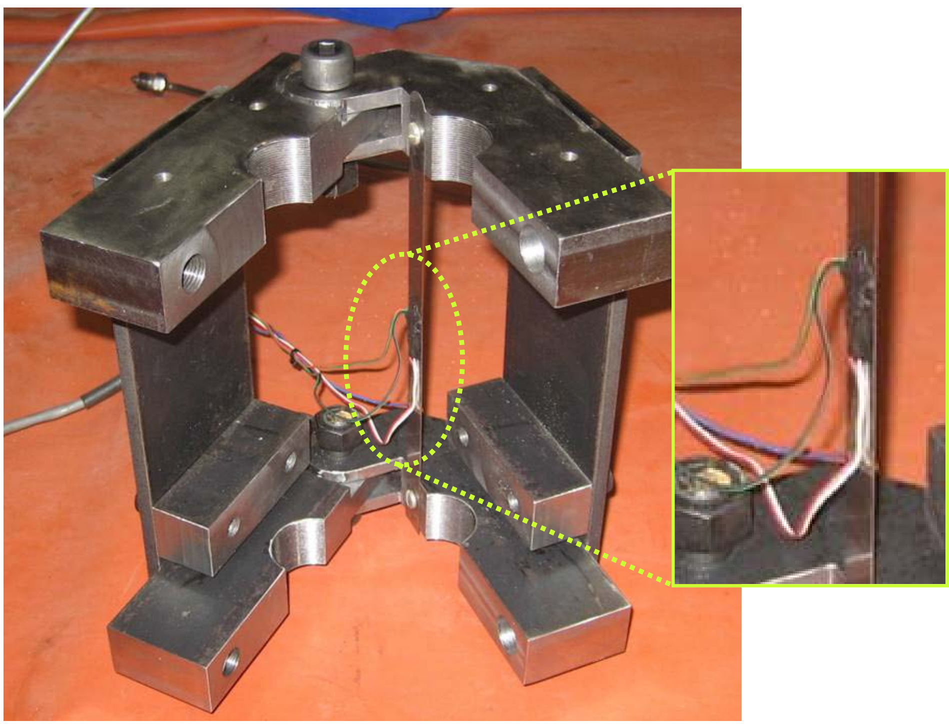

Figure 3-1
Initial design of strain-gage sensor clamp

Another early design of the sensor clamp used a set-screw to attach to the hanger rod (Figure 3-2). This design was more expensive to manufacture.

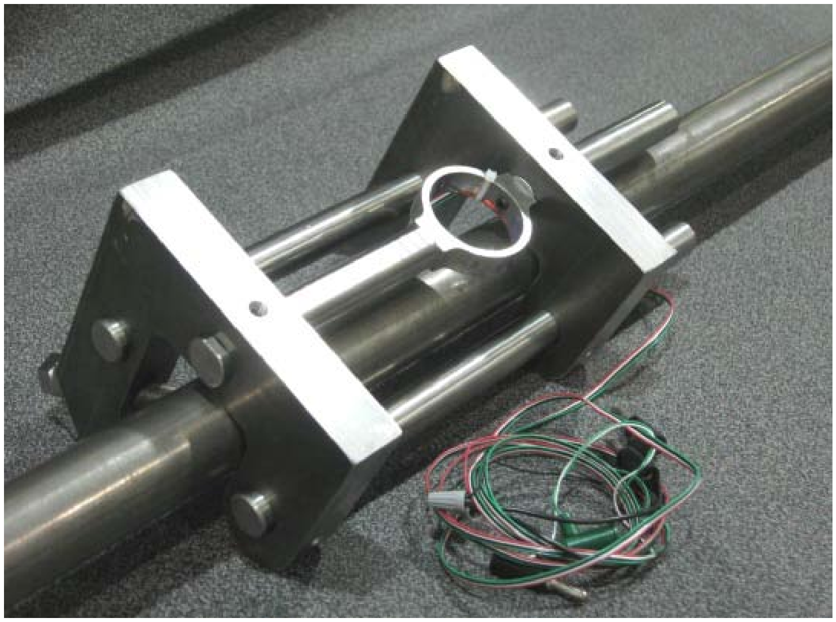

Figure 3-2
Early design of strain-gage sensor clamp

After several clamp designs had been fabricated and tested, the team decided to construct the sensor clamps of aluminum plate bored to fit the rod and designed to be bolted in place. The sensor design was also modified to incorporate off-the-shelf strain-gage sensors. The battery-powered wireless transmitter was sealed in a water-tight box and mounted next to the strain-gage clamps. The components that comprise the latest wireless strain-gage system are shown in Figure 3-3. Orientation of an installed system is shown in Figure 3-4.

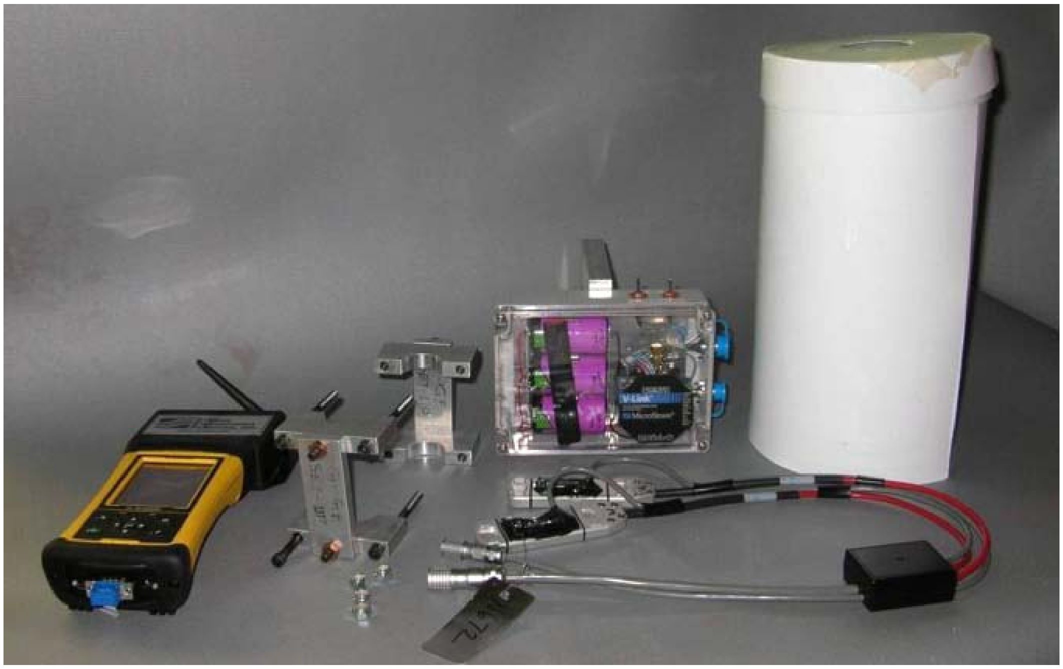

Figure 3-3
Components of system to measure and transmit strain on a pipe hanger rod

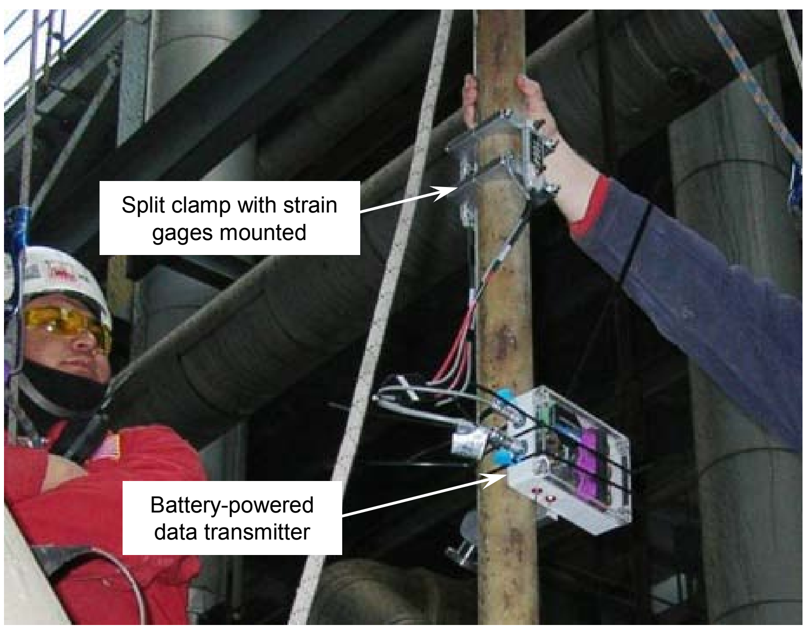

Figure 3-4
Split sensor clamp attached to hanger rod

The strain sensors used in this system are manufactured by BDI (Bridge Diagnostics, Inc.) and are typically used to measure strain on highway bridges. These sensors can be rapidly and easily installed on structures. Their primary disadvantage is that the sensing element is manufactured from aluminum to increase its sensitivity when measuring very small strains. Unfortunately, the thermal coefficient for aluminum is different from that for steel. This causes a change in the relative response of the gage as temperature of the system (steel structure being monitored plus aluminum gage) changes. When applied on bridges etc., these sensors are zeroed immediately before a loading cycle to minimize the effects of temperature changes.

To use these gages on hanger rods in a plant environment, a temperature sensor was developed that was added to each BDI sensor. (In the future, BDI will install this temperature sensor inside their sensor assembly to reduce wiring and produce a cleaner package.) The temperature sensor allows monitoring the changes in temperature as compared to conditions when the sensors were installed. Based on this information and calibration curves for each sensor, strain readings are then corrected for the current conditions.

The team developed correction curves for each sensor tested by heating it in a thermal oven in the laboratory. An example correction curve for one pair of sensors is shown in Figure 3-5.

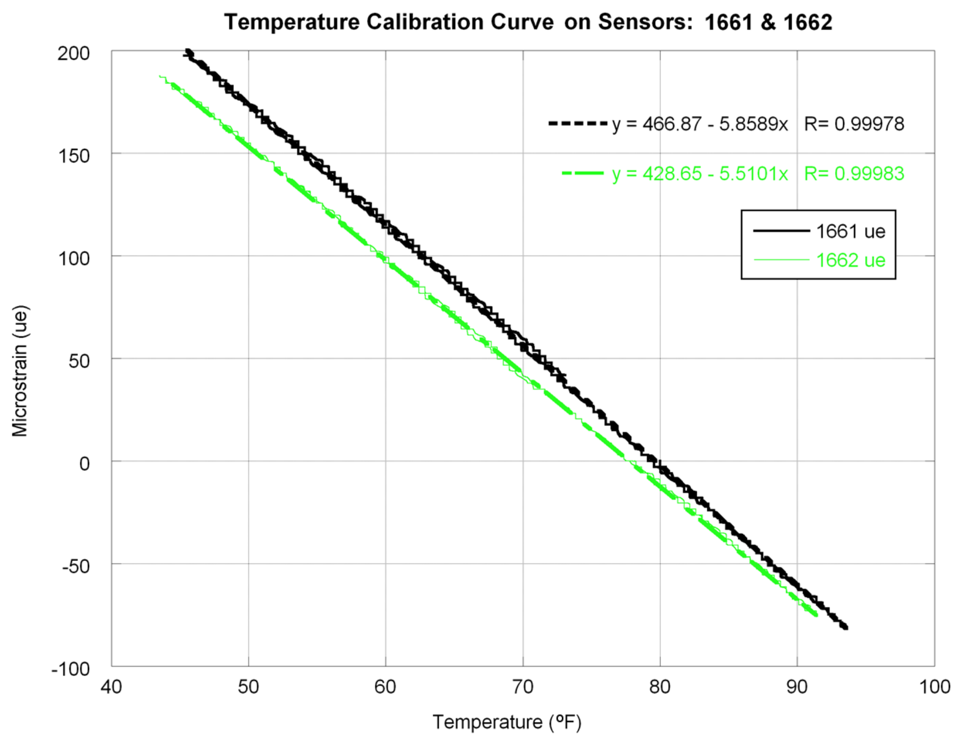

Figure 3-5
Temperature calibration curve for strain-gage sensors

A layer of thermal wrap was applied in the field to reduce the effects of wind eddies etc. and increase accuracy of the measurements. The insulation also had the benefit of maintaining the hanger rod and sensors at the same temperature.

The new sensor system was calibrated in the laboratory on a universal test frame by applying loads to a dummy hanger rod. A typical calibration curve for a pair of sensors is shown in Figure 3-6. Note the effects of bending on the sensors. In practice, a pair of sensors is mounted at a relative orientation of 180°, and their results averaged to eliminate the effects of bending. For comparison, strain was also measured with weldable strain gages and glue-down CAE-type strain gages. These data are also shown in Figure 3-6, and illustrate the challenges associated with data from only one gage. In multiple tests in the laboratory test frame, the combination of two BDI sensors mounted at 180° always yielded calculated loads that were within 1–2% of the actual loads.

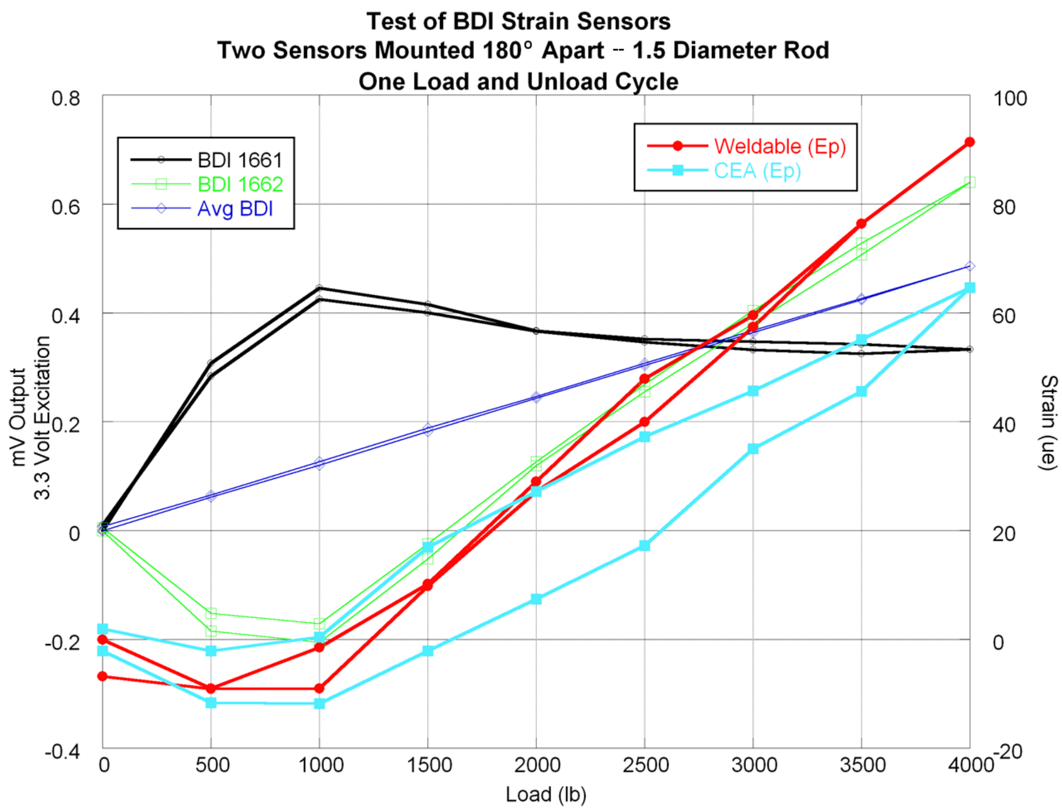

Figure 3-6
Response of strain sensors to changes in load

The handheld receiver unit used to record the loads in the field also performs all of the calculations required for averaging and thermal correction due to temperature.

4
FIELD TESTS

After laboratory testing was completed, the team conducted demonstration tests of the system in the field. Three field sites were visited:

1. TVA's Shawnee Unit 6
2. Entergy's Lewis Creek Unit 1
3. NRG's W A Parish Unit 5

At each field site, tests were conducted on six rods simultaneously on a combination of main steam, hot reheat, and cold reheat constant-support spring hangers.

Results from the first trial (Shawnee Unit 6) indicated that the strain-gage sensors and clamps needed to be improved. The strain-gage assemblies were installed by engineers from scaffolding while the unit was down. Readings were then taken when the unit was hot via a lap-top computer configured with a plug-in antenna. This provided data representing a change in load from cold to hot. There was some inconsistency in the wireless signal that, at the time, was attributed to sensor design.

The second field test (Lewis Creek Unit 1) used modified off-the-shelf strain-gage sensors and an improved aluminum clamp design. For this test, the strain-gage assemblies were installed from ladders by an engineer and a technician. The data were recorded wirelessly by the use of a hand-held receiver. This new system proved to be a much better arrangement. However, the inconsistencies in the wireless signal were still present.

The third field test (W A Parish Unit 5) addressed the problems in the quality of the wireless signal. The problem was suspected to be caused by EMI. The transmitter enclosure was originally constructed of plastic. For this test, one of the six hanger assemblies was modified to incorporate a metal box to replace the plastic enclosure. Based on field results, this change appeared to solve the signal problems.

The third field test installation was accomplished entirely by inspectors via rope access (Figure 4-1 and Figure 4-2). This ability represented a reduction in installation labor costs. Once the three-man team became familiar with the installation process, the process was completed faster. For this test, six rod-clamp assemblies were installed in half of a day. A rough estimate for the expense for a three-man crew is $4000 per day. After the sensor clamp assemblies are installed, a technician can return to each hangers and acquire the readings from a nearby platform.

Figure 4-1
Installation of wireless sensor assemblies at NRG's W A Parish Unit 5

Figure 4-2
Installation of cover over wireless transmitter at NRG's W A Parish Unit 5

After the completion of the field trials at W A Parish Unit 5, the plant asked for assistance to help determine the actual load on Hot Reheat hanger HRH-25 (Figure 4-3). This was a Figure 81H-E size 70 Grinnell constant support hanger with a load rating of 25,000 lb. The hanger had been adjusted with out weighing the pipe several years prior and the plant wanted to measure the actual load due to concern about turbine nozzle loading. Rigging was in place to adjust the hanger, and timing was coincident with contractor being on site.

The hanger of interest was unloaded and the strain-gage clamps were installed. The rod was then reloaded and the actual load was successfully measured. The load was measured to be 21,439 lbs, over 14% lighter than the desired load. With the rod clamp still in place, the hanger was adjusted to the desired load. Confirmation of pipe support load allowed increased confidence in the stress analysis results that were used to set inspection interval. The advantage over the traditional chain fall/dynamometer combination was evident by the reduced man-hours required to measure actual hanger loads.

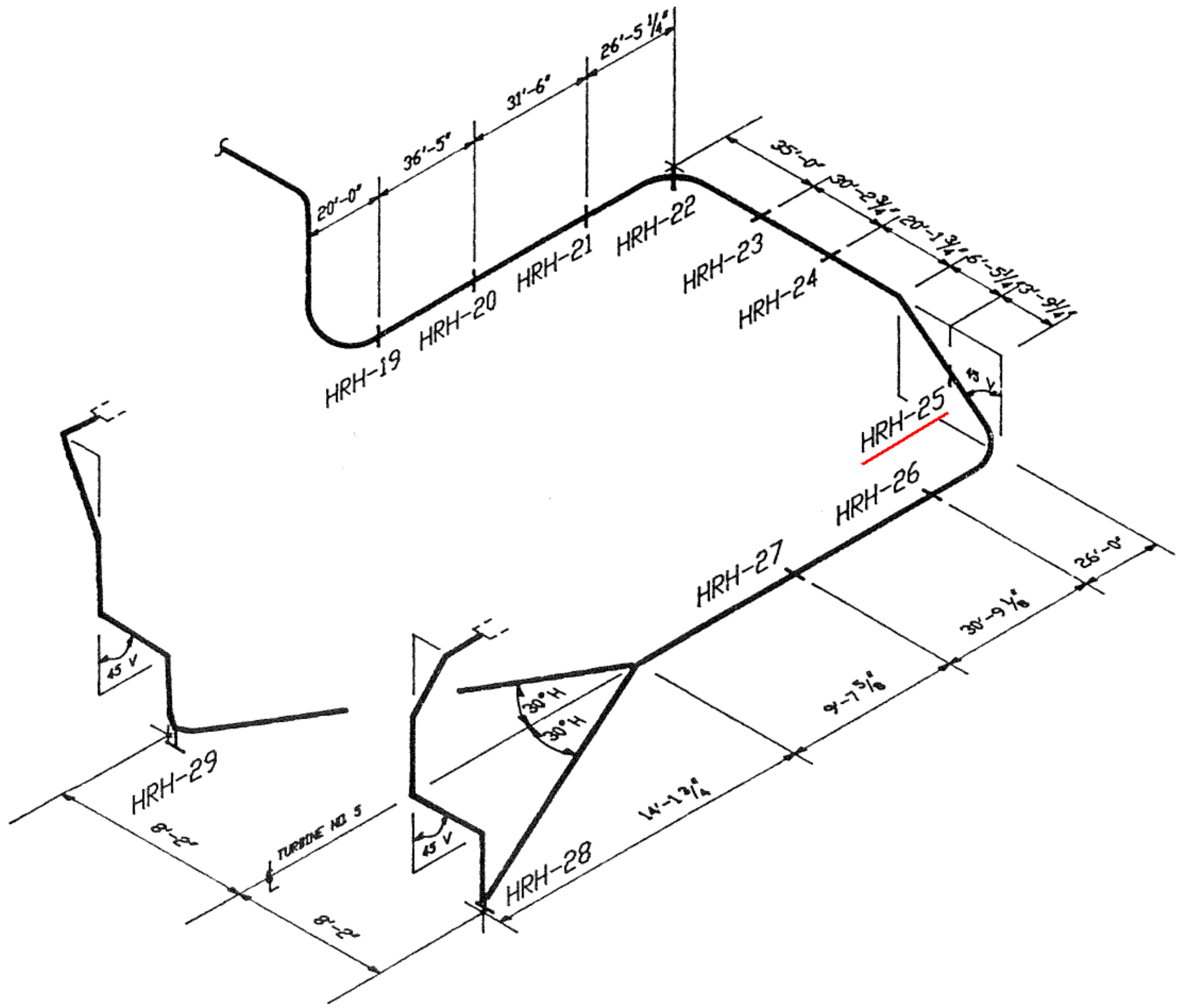

Figure 4-3
ISO of WA Parish Unit 5 Hot Reheat system

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DISCUSSION

A number of utilities are currently developing methods to measure pipe-support travel and load changes using both wired and wireless configurations. This information is being used in "as-found" pipe-stress analysis as well as creep-stress analysis. These are two separate types of analyses that yield different information. An "as-found" analysis typically provides highest Code stress locations, while a creep-stress analysis highlights the location with the highest life expended, considering the properties of the aging material. The wireless system developed during this project is an important tool for both approaches. The importance of measuring actual pipe support loads is becoming more widely understood throughout the industry.

The option to use rope access coupled with convenient wireless readings via a hand-held receiver, provides a cost-effective alternative to other methods for determining actual hanger loads. It should be noted that most of the hangers monitored during these field tests were not unloaded prior to the installation of the strain-gage clamp. Therefore, only *load changes* were measured. This approach, while limited, provides a quick check of the functionality of a constant-spring pipe support. The significance of the pipe hanger data needs to be evaluated with pipe elastic (design) and creep-stress analyses. Measured and calculated hanger loads and travel should be compared for agreement. Coupled with observations of whether hangers have bottomed out, these comparisons can provide an adequate basis for piping assessment.

Pipe supports have been successfully adjusted via rope access. The rigging required to adjust a support is much less than that required to pull the hanger through its travel. During the set-up for an adjustment, the rod load can be zeroed out and the clamp installed. This will allow the operator to determine the actual hanger load. Actual load should be used in performing "as-found" stress analysis and creep-stress analysis.

It is useful to pull the spring through its total travel several times, since this is the only way to determine its actual performance. This may be important in some situations. For the purpose of analysis, i.e., to determine the conditions to which the pipe has been subjected during the previous several years, the actual hot and cold loads are more important.

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CONCLUSIONS

Conclusions from this project are as follows:

1. A wireless strain-gage-based system can be used to monitor changes in loads on hanger-rod supports in high-energy piping systems.
2. The use of strain-gage clamps for hanger weighing and adjustments offers the potential to reduce installation and monitoring costs.
3. Wireless rod clamps are easier and faster (rope access, temporary or permanent) to install than alternatives.
4. Traditional methods to measure hanger loads may sometimes be more cost-effective, depending on the total work scope.
5. Accurate data describing hanger loads or load changes, along with hot and cold walk-down information and piping-stress analysis, allow reliable assessments of expected life and identification of potential problem areas.
6. The use of wireless strain-gage rod clamps can provide power plants with improved and cost-effective methods for supporting a fitness-for-service program (Chapter VII, B31.1, ASME Power Piping Code).

7
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