

High Temperature Strain Gaging

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Technical Update, March 2005

EPRI Project Manager

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PRODUCT DESCRIPTION

High temperature resistance strain gages are being evaluated to determine how effective the gages may be for fossil power plant applications over a long period of time. Specifically, the gages are being tested under controlled conditions at elevated temperatures to assess their performance.

Results and Findings

This report serves as an interim report establishing the groundwork that has been laid to begin evaluation of high temperature strain gages. Two types of strain gages have been reviewed herein including resistance and capacitance gages. Resistance gages have been installed on 2-1/4Cr-1Mo test specimens and loaded into a creep test frame for evaluation. Testing is anticipated for up to one year to evaluate the durability of the gages and to determine if the drift with time and temperature can be accurately compensated for, thus permitting accurate measurements even under creep conditions.

Additionally, this report provides the historical background on a failure that occurred in a main steam line girth weld at Southern Company. The girth weld was subsequently machined away, re-welded, post weld heat treated, and returned to service. EPRI will be applying strain gages to the new weldment and pipe to determine if severe bending or fatigue stresses exist at that region of the pipe.

Challenges and Objectives

This report is targeted to utility engineers involved in assessing and extending power plant component life and operation. Use of the technology identified herein will enable power plant personnel to better understand the strains and stresses acting upon a component which could lead to improvement in operational modes or designs wherein the life of the component is extended.

Applications, Values, and Use

Power plant applications wherein bending loads or thermal fatigue conditions exist represent two of the more important areas where high temperature gages could prove beneficial. Potential applications include: ligament damage in superheat or reheat headers, circumferential weldments, affects of desuperheaters, and economizer thermal fatigue.

EPRI Perspective

Strain gage technologies that will enable utilities to better understand and monitor strains and stresses over a long period of time in high temperature fossil equipment are required. The current research which focuses on a new type of high temperature resistance gage could be quite helpful to utilities in addressing equipment where high stresses are anticipated.

Approach

The key goals of this report are to:

- review the state of the art in high temperature strain gage application particularly as it relates to fossil power plant applications.
- Evaluate high temperature resistance gages under controlled mechanical testing conditions to assess gage drift at 1000F operating temperatures.
- To evaluate the same gages within a power plant application for a short and long term.

Keywords

Strain gage

High temperature strain gage

Component stresses

Component strain

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INTRODUCTION

Over the years a number of organizations have attempted to gain a better understanding of the level of residual or imposed stresses on critical components. Stresses can take on a variety of different forms including: thermal, pressure, deadweight, stuck hangers, distortion due to shock, etc. to name a few. Measurement of such stresses, though not easily acquired, can be acquired with good consistency up to approximately 400F (204C). However, beyond this temperature measurement becomes difficult. This stems from the fact that most gages are applied using adhesives; these adhesives tend to break down above 400F (204C) resulting in decoupling of the gage from the component to which they are attached. Higher temperature gages are therefore attached with spot welding equipment.

High temperature strain gages are generally considered those gages that operate in the 800F to 1200F (425C to 650C) range. Such gages are covered by ASTM Practice E 1319-89 *Standard Practice for High-Temperature Strain Measurement*.

Power plant applications wherein bending loads or thermal fatigue conditions exist represent two of the more important areas where high temperature gages could prove beneficial. A few potential applications include assessment of:

- Ligament damage in superheat or reheat headers
- Circumferential weldments
- Affects of desuperheaters
- Economizer thermal fatigue
- Hanger problems and loads

For these reasons, EPRI elected to further examine high temperature strain gage technologies.

This report compares and contrasts capacitance and resistance gages in Section 2. Background information and field experience are provided for each type of gage. Additionally, considerable discussion is provided on a new high temperature resistance gage which may have applicability in fossil power plants.

Next, a discussion of on-going testing of the high temperature gages is provided in Section 3. The testing is aimed at identifying the gage drift with time and temperature at 1000F (538C). Once this is accomplished and compensation is made for the drift, components operating under high strain or under creep conditions can be evaluated.

Finally, background information is provided on a recent failure at Southern Company's Gaston 5 Plant . This information is highlighted since a strain gage installation is planned during the first quarter of 2005.

2

BACKGROUND

Selection of a strain gages for a particular application requires the strain gage system to be qualified for the specific conditions under which the gage will operate and for the service conditions it will experience. Available types of strain gages that are suitable for use at high temperatures will be described in this section along with some of the limitations of such gages.

Wire-type or foil-free filament strain gages can be used under static conditions to approximately 750F (400C), and to approximately 2280F (1250C) for certain dynamic applications. Two types of bonding methods are employed to attach these types of gages. These include ceramic cement and flame spray attachment methods. Both methods tend to be cumbersome and difficult to apply on large structures/components, particularly under field conditions. Heat curing is required for ceramic cements. ASTM suggests this attachment method is generally unsuitable for fossil-fuel power generating equipment. (1)

Flame spray type attachment methods are also difficult to employ in the field. As a result, foil-free filament type strain gages are not commonly used outside of the laboratory. In fact, ASTM does not recommend such gages for field applications.

Two types of gages are employed for high temperature field applications including: 1) weldable resistance strain gages and 2) differential capacitance strain gages. Both will be covered below.

2.1 Weldable Resistance Strain Gages

Weldable resistance strain gages are supplied from the manufacturer under hermetically sealed conditions (Figure 2-1) with attached integral lead wires. Such gages may be used under a variety of severe operating conditions at high temperature. The gage itself incorporates a platinum-tungsten alloy wire active strain element and compensating element which form the half-Wheatstone bridge circuit. These are housed in a metal strain tube and are insulated from the strain tube by highly compacted ceramic powder. The powder acts as a strain transfer medium from the strain tube to the active strain element. The gage itself is attached through spot welding wherein a thin mounting flange (attached to the strain tube—Figure 2-2) is attached directly to the component.

Platinum-tungsten alloy gage wires are considered stable up to approximately 930F (500C) at which point they begin to drift (or creep). Long term drift rates are normally below 0.2 microstrain/hour up until this temperature. Above this temperature, the drift rate for typical gages increases with typical values of 1.0 microstrain/hour at 1080F (580C). As a result, such gages are not recommended for “long-term” tests at temperatures exceeding 1080F (580C). (1)

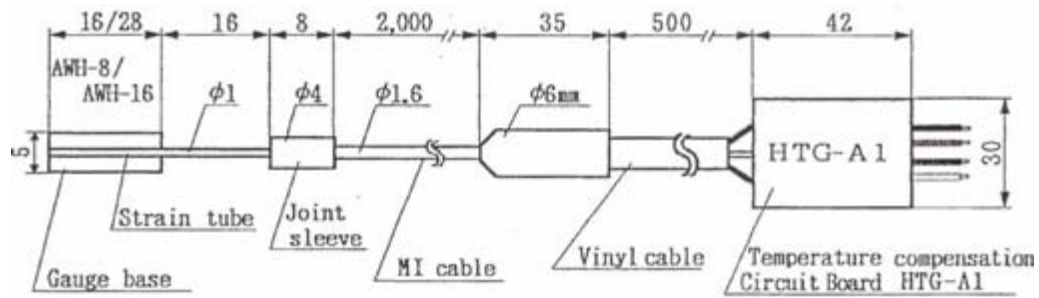


Figure 2-1
Schematic of Weldable Resistance Gage (Source: Tokyo Sokki Kenkyujo Co.)



Figure 2-2
High Temperature Resistance Gage (Source: Stress Engineering Inc.)

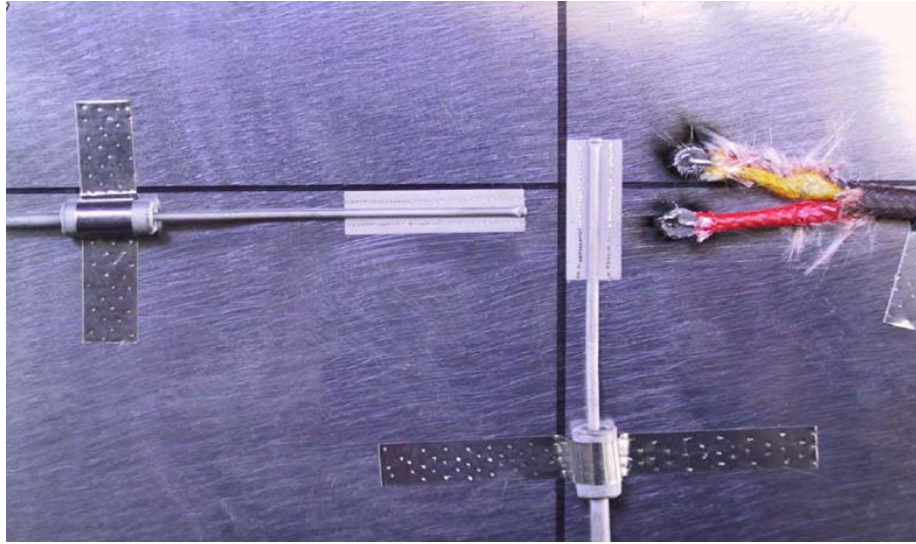


Figure 2-3
High Temperature Resistance Gages spot welded into place at 90 degrees apart (Source: Stress Engineering, Inc.).

Furthermore, they are recommended mostly for dynamic strain measurements and relatively short-term applications.

During the investigation of resistance gage technologies, it was brought to EPRI's attention that a new high temperature resistance gage had recently been introduced to the market. (2) The gage, which is manufactured by Tokyo Sokki Kenkyujo Co., Ltd., is referred to as a *TML Capsulated High Temperature Strain Gage AWH-8/AWH-16*. (3) The gage can be considered for use up to 1112F (600C) for static applications and to 1202F (650C) for dynamic applications. The sensing elements and the lead wires are hermetically sealed within an Inconel alloy 600 tube which according to the manufacturer allows the gage to be employed in various environments, even under water. Similar to other resistance gages, gage attachment is accomplished through spot welding.

As noted above, resistance gages are typically not recommended for "long-term" tests at temperatures exceeding 1080F (580C) by ASTM. The TML gage provides increased temperature performance, which should cover most fossil applications. *More importantly, the gage is stated (by the manufacturer) to exhibit a "linear drift" up to the 600C (1112F) temperature. If this is the case (unlike previous resistance gages), the TML gage may be useful for long-term fossil power plant applications.* Long-term performance where "creep" may be an issue has long been the "Achilles-heel" of resistance gages. Capacitance gages (discussed below) provide much better stability over the long-term and are able to measure strain even under creep conditions. If indeed the drift of the gage is linear, compensation could be made for the drift and accurate strains could be predicted even at higher temperatures. To validate the manufacturer's claims/specifications, EPRI has contracted Stress Engineering, Inc. to perform creep tests within a load-frame with strain gages attached to the test coupon (more on this subject in Section 3). Additionally, an in-situ installation of the gages will be performed at Southern Company in early 2005 (see Section 4).

2.2 Differential Capacitance Strain Gages

The second form of gage is the differential capacitance strain gage. This gage has found much wider use in fossil-fuel power plant applications (4,5,6,7) due to the fact that it is unaffected by temperature excursions and that it normally provides good stability over long periods of time. Differential capacitance strain gages (as shown in Figure 2-3) include a compensating rod normally made of the same material as the test component and cylindrical excitation plates which are mounted coaxially on (but insulated from) the compensating rod. A sensing ring is also mounted coaxially with the excitation plates and separated by an air gap.

Similar to resistance gages, capacitance gages are welded to a component via spot welding. This is accomplished with the assistance of attachment ribbons (Figure 2-4) which provide a means for welding the gage to the test component. Alignment flexures (again see Figure 2-4) provide the coaxial alignment of the sensing ring relative to the excitation plates and the compensating rod. Lead wires are attached from the capacitor plates to a terminal which is also attached to the test component.

Capacitance gages work on the principal wherein strain in the test component causes linear movement of the excitation plates relative to the sensing ring. Changes in capacitance result when the sensing ring overlaps the isolation plates; the linear gap between the excitation plates and the annular gap between the excitation rings and the sensing rings remains constant. Compensation for temperature changes is achieved by using a similar material for the compensating rod to that of the component material. Thermocouples are also attached to the gage and the component for computing any required corrections.

Capacitance gages have been shown to operate effectively over 800F to 1200F (425C to 650C), with average drift rates of 0.01 to 0.05 micrometers/meter/hour at 1180F (640C) for long term tests (2000 to 12000 hours). Short term drift rates can be up to 1 micrometer/meter/hour. Other data on thermal compensation and transients can be acquired from ASTM 1319-89.(1)

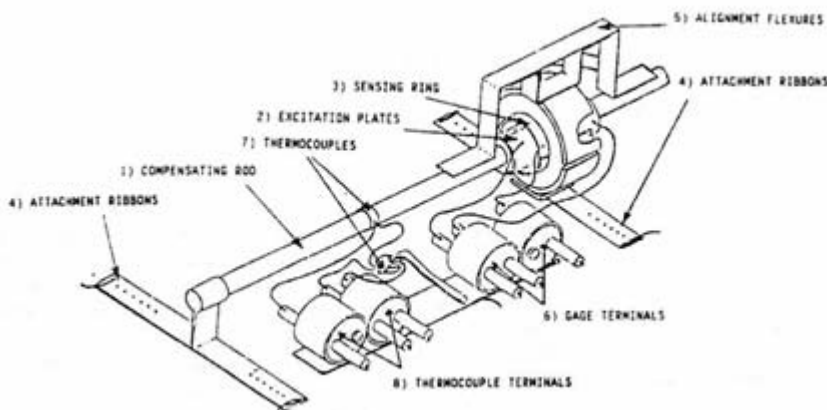


Figure 2-4
Schematic of Capacitance Strain Gage (Source: ASTM Standard E1319—89)

3

RESISTANCE GAGE ASSESSMENT

As introduced above, resistance gages are not commonly employed for “long-term” high temperature service applications. With the introduction of the “linear-drift” *TML Capsulated High Temperature Gauges-TML AWH-8*, longer-term high temperature measurement may be possible. Such gages may permit an engineer to accurately compensate for the drift with time (and temperature), thus permitting accurate measurements even under conditions where creep is involved.

With this in mind, EPRI has contracted Stress Engineering Services to perform a “long-term” creep test wherein the TML AWH-8 gauges are applied to large diameter 2-1/4Cr-1Mo test specimens. During the tests, gage drift will be measured with time and correlated against extensometer measurements performed on the test specimens. Tests are planned for up to 8000 hours (1 year) to evaluate the performance and drift of the gages. Strain gages will be used to measure drift, creep, apparent strain error, and load-induced strain during periods when the load and temperature are held constant.

All measured strains will be corrected for apparent strain error due to temperature. This includes an error in reading and an error in gage factor using the data as supplied by the manufacturer for each specific gage. At a constant temperature, this error can be zeroed-out at the beginning of each test.

As mentioned above, drift has been documented to be a linear function of time for specific temperatures by the manufacturer. Using this information, a correction factor will be included in the data processing program employed to account for time at temperature and applied to the temperature corrected reading. *The remaining strain, once this correction has been made, is due solely to creep and load.* The initial value when the specific load level is first achieved will be used as a reference. Any changes in load will be included as an adjustment. This leaves only the test sample creep strain as a function of time at specific temperatures.

Drift data provided by the manufacture is shown at 1112F (600C) for exposure times at 8000 hours. The drift rates are shown in Table 3-1

Table 3-1 Drift data supplied by the manufacturer at 600C (1112F) for exposure times up to 8000 hours.

Exposure Time (hours)	Measured Drift ($\mu\epsilon$ /hour)
0-200	1.25
2400-2600	0.30
5000-5200	0.30
7800-8000	0.15

Actual high temperature strain gage testing was initiated in late 2004 with final test results anticipated in late 2005.

4

GAGE ASSESSMENT AT SOUTHERN COMPANY

Concurrent to the testing of the high temperature resistance strain gages described in the previous section, EPRI wanted to field test several of the gages. Southern Company contacted EPRI indicating they would like to work with our staff to install gages on a main steam line girth weld at the Gaston 5 plant. The installation is planned during an extended outage in late March 2005.

The installation will be performed along the girth weld region of a main steam line wherein extensive damage was discovered in February 2004 and subsequently repaired. It is believed that short-term cyclic and/or thermal stresses may have contributed to the failure. As such, a better understanding of the local stresses imposed upon this weld may provide more information on why it failed.

4.1 History of Girth Weld Damage

The girth weld damage was located in a SA335 Grade P22, 30.5" OD x 6.0" wall main steam pipe section at a pipe-to-tee weld (Figures 4-1 and 4-2). The design pressure and temperature for the system was 3900 psi and 1000F respectively. The estimated service hours were 195,600 hours and the date of commercial operation was August 8, 1974. Since 1982, until the damage was located, the system was estimated to have experienced 578 cycles with a total number of cycles over its lifetime of over 1000 cycles.

A photograph of the actual damage is shown in Figure 4-3. A large crack encompassing approximately 70% of the circumference of the pipe weld was identified, subsequently removed via machining, re-welded, and post weld heat treated before returning the unit to service. Ultrasonic examination and metallography concluded 3-4" of the crack penetrated 100% of the wall of the weldment.

A preliminary stress analysis of the girth weldment calculated the stresses in the region of the failed weld at 5491 psi (sustained) with expansion stresses of 2450 psi. Hoop stresses were estimated at 7486 psi. Based upon these observations, the thermal expansion stresses do not appear sufficiently high to cause failure.

Metallographic examination provided the following conclusions:

- A B2 weld wire was likely used for the shop submerged arc weld
- A significant number of MnSi inclusions were noted in the submerged arc weld which is usually indicative of a weak acid flux.
- Minor creep damage was also evident, though it was not severe.

- Temper embrittlement was also indicated as a possibility.
- Thermal expansion stresses do not appear to be sufficiently high to cause problems; however, features of the fracture surface were typical of high bending loads.
- Fatigue interaction is believed to be a factor due to a high number of startup and shutdown cycles and reduced load cycling history of the plant.

The final two conclusions led Southern Company and EPRI to believe this piping system would be a good candidate for high temperature strain gage application.

4.2 Strain Gage Installation

High temperature strain gage installation is planned for March 2005 at several locations around the diameter of the pipe girth weld. It is believed the high temperature resistance gages can provide information on the stresses/strains for this weld under cyclic loading conditions which will hopefully point to the cause(s) behind the failure.

Information on this analysis will be reported later during 2005 as information becomes available.



Figure 4-1
Girth Weld Damage in a SA 335, Grade 22 Main Steam Pipe Section at Gaston 5.

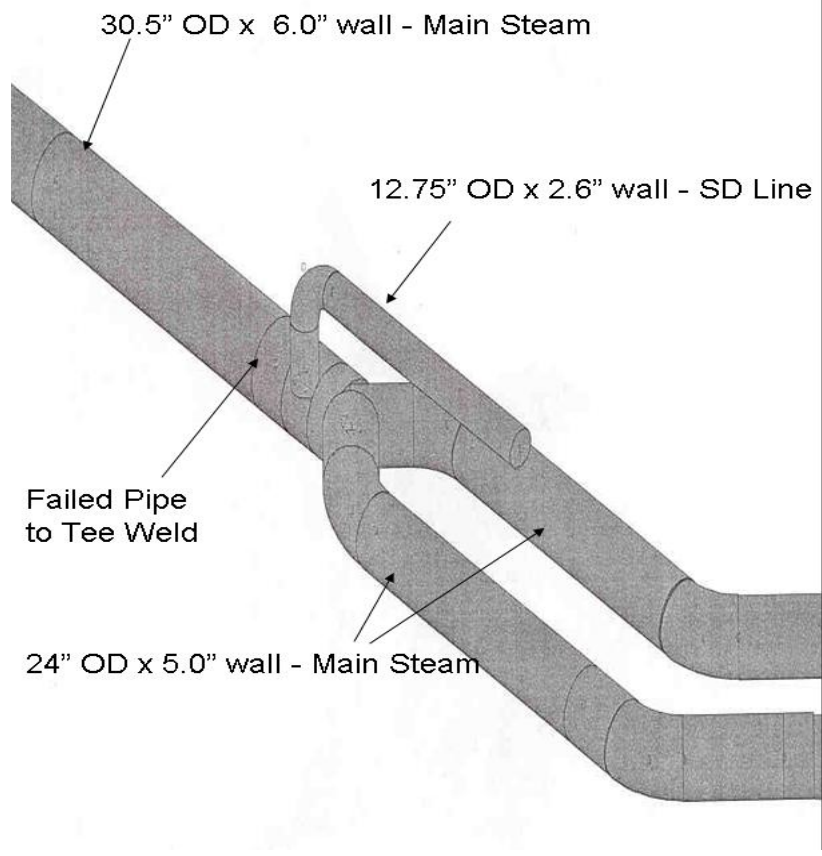


Figure 4-2
Girth Weld Failure Location

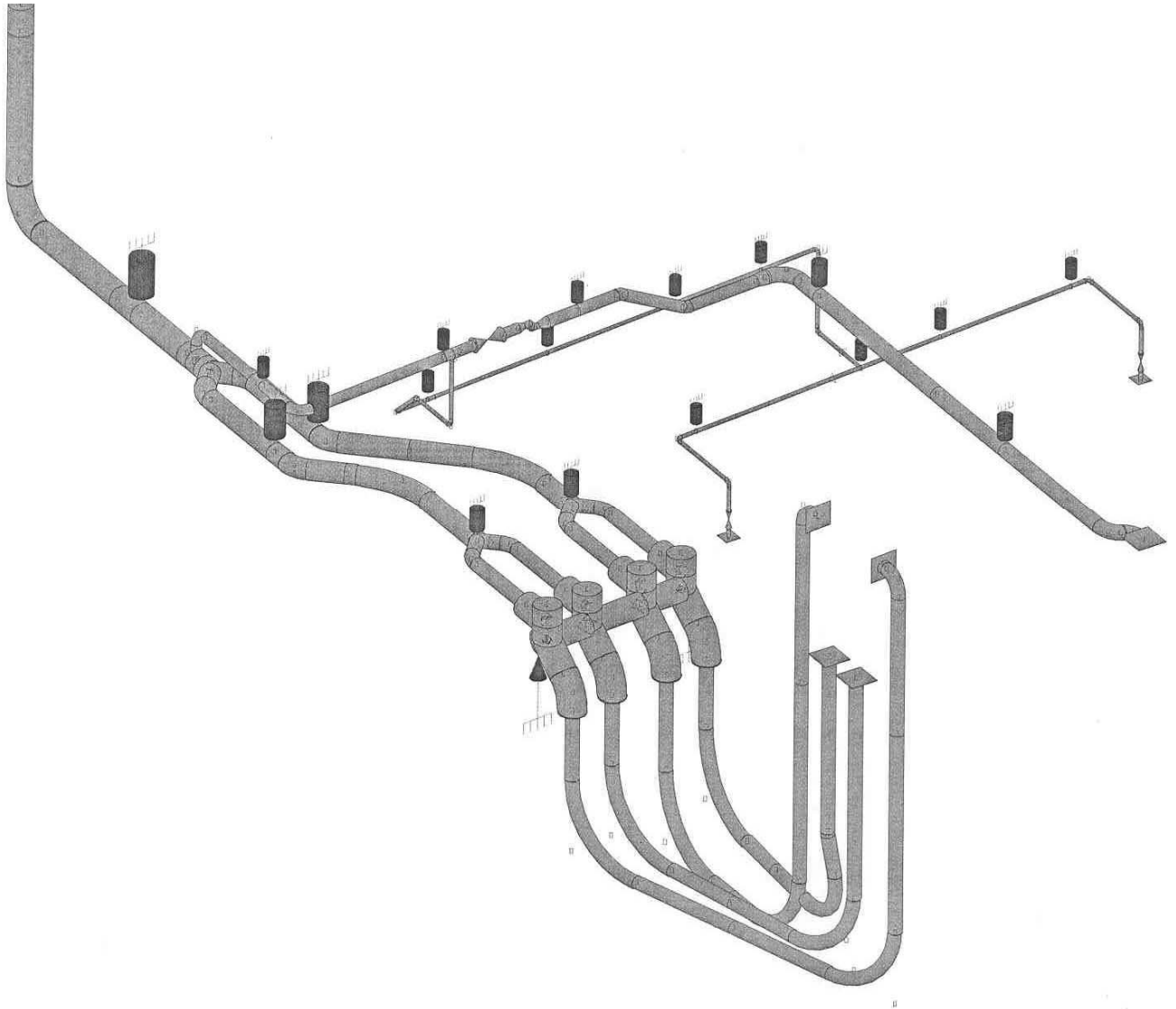


Figure 4-3
Schematic of Piping System Where The Girth Weld Failed.

5

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