

## **EVALUATING THE PERFORMANCE OF THE ZAP-LOK CONNECTION SYSTEM**

**Chris Alexander**

Stress Engineering Services, Inc.  
Houston, Texas  
[Chris.alexander@stress.com](mailto:Chris.alexander@stress.com)

**David Roberts**

Zap-Lok Pipeline Systems, Inc.  
Houston, Texas  
[droberts@zap-lok.com](mailto:droberts@zap-lok.com)

**Robert Logan**

Zap-Lok Pipeline Systems, Inc.  
Houston, Texas  
[rlogan@zap-lok.com](mailto:rlogan@zap-lok.com)

### **ABSTRACT**

The Zap-Lok connection system involves a bell, or expanded area, formed on one end of a joint of pipe, and a groove is formed on the opposite end. Both end-forming operations are accomplished with a hydraulic bellling unit and a hydraulic groover, respectively, operated by hydraulic power units. These end preparations are automatically controlled to specifications required for the Zap-Lok joint. In the field, or on the right-of-way, the belled end of one length of pipe and grooved end of another are forced together by the Zap-Lok joining press, with a thin coating of epoxy serving as a lubricant. The Zap-Lok joint is made cold and formed from the pipe itself. This process takes about 10 seconds, and it is normal to average 90 seconds per connection, including driving to the next joint. In the drive to lower costs for oil and gas operators, Zap-Lok is seen as a way to reduce costs of pipeline construction by 25% to 30% on land and by 45% to 60% offshore.

Over the past several years an extensive testing program has been undertaken by Zap-Lok to evaluate the performance of their system, especially in relatively shallow water applications. This paper provides details on specific phases of the research program and the insights that were gained in the evaluation effort.

### **INTRODUCTION**

Many pipeline companies are seeking innovative technologies that improve construction and operational factors such as pipeline integrity, safety, and economics. The Zap-Lok connection has proven itself to be an effective alternative to conventional joining techniques for a range of pipeline applications. This paper provides details relating to the background and history of the Zap-Lok connection systems. Additionally, results are presented from several of the test programs that have been conducted over the past 4 years in an effort to evaluate the integrity of the connection considering a range of onshore and offshore loading conditions.

### **BACKGROUND**

This section of the paper provides a brief history on Zap-Lok, as well as discussions on how the connection works including specific details on how the system functions.

#### **Brief History**

The concept of the Zap-Lok connection was originally conceived to solve a welding problem, i.e. the problem of "burn through" on thin wall pipe to transport low pressure gas to market. It was soon adapted

for joining internally plastic coated pipe and was purchased by a Baker Hughes pipe coating division.

In 1992 Baker Hughes sold the connection rights to a private investor who immediately launched an expansion campaign to broaden the market for the connection beyond low pressure gas, water handling, and internally coated lines. Today Zap-Lok is available for nominal pipe sizes from 2-inch through 12-inch, schedule 80 (0.688-inch wall), either seamless or ERW, up to Grade X60 pipe.

### **The Connection Process**

The Zap-Lok process is simple, but does require making the connection decision early in the pipe procurement process. The first step is to prepare both ends of each joint for the connection. This work can be performed at the company's Houston facility, a pipe mill, or a coating facility. One end of each joint is cold formed (expanded) into a bell shape by the insertion of a hardened steel mandrel. A liquid lubricant is used to prevent galling of the steel pipe surface. The opposite end (Pin End) is grooved and has a slight bevel applied to the end by a tapered roller. This operation should be performed prior to any internal coating and prior to external coating with Fusion Bond Epoxy (FBE) powder. In the case of 3 layer polyethylene or similar coatings, end preparation can be performed either before or after application of the external coating.

Once the coated pipe is delivered to the offshore vessel or onshore location, the joining press, along with a hydraulic power unit and automatic epoxy mixer, are used to join the pipe. For joint assembly, the pin OD and bell ID are coated with a thin film of a catalyzed epoxy resin to prevent galling of the pipe surface. The epoxy soon cures to a solid and allows full joint strength.

For onshore applications, the pipe is strung along the ROW just as for welding. The Zap-Lok press is transported along the ROW by a sideboom or other suitable vehicle. The power unit and epoxy mixer are towed behind. At each connection, the bell and pin are centered between the unit's slips and the longitudinal hydraulic rams are used to pull the pin into the bell a specific distance (depending on pipe size). The actual joining process requires only seconds. The slips are released and the press is advanced to the next connection site. Offshore the same equipment is used but the press is stationary and the pipe moves through it to the tensioner. Figure 1 and Figure 2 show the Zap-Lok system being used in offshore and onshore applications, respectively.

In either case normal production rates of 25-30 connections per hour can be expected from a single press and a crew of 3-7 people depending on pipe handling logistics.

### System Functionality

The Zap-Lok connection takes advantage of both the elastic and plastic properties of modern steel alloys by utilizing the particularly flat stress-strain curve under hoop expansion. During belling the internal diameter is increased and the pipe is strain hardened so that its normal yield strength is increased by about 10%. This property will require stress relieving of the bell when pipe must meet sour service standards. The mandrel is sized so that the bell ID will be smaller than the pin OD. This interference insures that the pin will be placed in compression by the additional expansion of the bell during insertion. It is this compressive load applied over the joint engagement area in the presence of steel friction that gives the connection its strength. The connection exceeds the specified minimum strength of the steel pipe so pipelines are not de-rated. The pipe properties of diameter, wall thickness, and grade define the system performance.

The figures listed below capture some of the more important activities that were completed

- Figure 3: Zap-Lok connector pipe assembly load rig
- Figure 4: Application of Zap-Lok epoxy to the box side of the connection
- Figure 5: Application of Zap-Lok epoxy to the pin side of the connection
- Figure 6: Positioning pipe halves in Zap-Lok load rig
- Figure 7: View of assembly after make-up of pipe halves

### TESTING PROGRAM

From its inception, testing has been integral part of the Zap-Lok development process. Testing permits engineers to simulate actual service conditions to determine how a component will perform. Typically, limit state conditions are best understood through destructive testing where the component is loaded in a manner to achieve failure conditions. Zap-Lok has used this approach

Stress Engineering Services, Inc. has performed numerous test programs for Zap-Lok. Listed below are those test programs that have been conducted over the past four years.

1. 12.75-inch x 0.562-inch, Grade X42 pipe to simulate offshore pipe lay operation in water depths of 200 feet and 400 feet (June 2007)
2. 4.5-inch x 0.337-inch pipe to simulate offshore pipe lay operation in water depths of 175 feet (December 2006)
3. 6.625-inch x 0.432-inch pipe to simulate offshore pipe lay operation in water depths of 150 feet (December 2006)
4. 8.625-in x 0.219-in, Grade X52 pipe to evaluate the integrity of the connection under different loading conditions considering different interference levels (August 2008)
5. 10.75-inch x 0.50-inch, Grade X42 pipe tested to evaluate the effects of different pressure and axial tension combinations on the connection integrity (January 2010)
6. Measuring strains during belling and assembly of 10.75-inch x 0.50-inch, Grade X42 pipe (December 2009)

Due to space limitations, results are only presented for two sets of test listed above (Test #4 and Test #6). The sections that follow provide a basic description of the testing methodology and associated results.

### Testing 8.625-in x 0.219-in, Grade X52 pipe

Testing was performed on 8.625-in x 0.219-in, API 5L Grade X52 pipe having Zap-Lok connections. The objective of these tests was to evaluate the integrity of the connection under different loading conditions. Six test samples were made with the Zap-Lok connections having different levels of interference. The interferences of the six connections are listed in Table 1. Three samples were subjected to internal pressure until failure occurred. The other three samples were subjected to axial loading in tension until failure of the connection occurred, with the third sample having internal pressure equal to the maximum allowable operating pressure (MAOP or 72% of the Specified Minimum Yield Strength (SMYS) for the Grade X52 pipe).

The three connections in the pressure test separated at a pressure near the theoretical burst pressure for the pipe. The results for the pressure test are listed in Table 2. The connections in the tension test separated at a load that was higher than the minimum specified yield for the pipe. The failure load for the connection with internal pressure was approximately 70 kips higher than the connections without internal pressure. The results from the tension tests are listed in Table 3.

From both phases of testing it was observed that the stress in the pipe at the time of failure exceeded the yield strength of the pipe. From discussions with Zap-Lok, the target design stress value for the Zap-Lok connection is the SMYS of the respective pipe material.

The following observations are made in reviewing the test results:

- The samples in the pressure test failed in the connection near the theoretical burst pressure (< 10% difference for these samples).
- Interference in the Zap-Lok connection does not appear to affect the pressure at which the connection fails.
- The samples tested in tension failed at a higher load than the minimum specified yield load.
- The tension sample with internal pressure equal to the maximum allowable operating pressure failed at a higher load than the samples without internal pressure.
- Internal pressure energizes the Zap-Lok connection.

Figure 8 and Figure 9 are photographs of two burst and tensile samples after failure, respectively. The primary conclusion based on the above observations is that the tested Zap-Lok connections all failed at loads exceeding the Specified Minimum Yield Strength of the Grade X52 pipe for the respective modes of loading.

### Belling and Assembly of 10.75-inch x 0.50-inch, Grade X42 pipe

A small number of samples were instrumented prior to the belling and assembly operations. Instrumentation included strain gages, displacement transducers, and pressure transducers. Data were recorded at a rate of 1 scan per second during the belling and assembly operations. Detailed measurements were not conducted for all phases of work in evaluating the Zap-Lok connection. However, in this particular section results are presented for tests associated with the program identified as Item #5 listed previously for work completed in January 2010 on 10.75-inch x 0.50-inch, Grade X42 pipe (see listing provided in the *Test Program* section of this paper).

The sections that follow provide specific details on these two phases of work.

**Belling Operations** Belling is the process by which one end of the Zap-Lok assembly is expanded prior to assembly. As expected, a certain level of plastic deformation occurs during this forming process. Strain gages were installed on Sample A1 as shown in Figure 10 prior to belling. In addition to the strain gages, a displacement transducer was installed to measure the circumferential expansion of the bell past the operating range of the strain gages. A cable and spring assembly was used to translate the expansion of the bell into a linear displacement measured by the displacement transducer. The displacement transducer set-up is shown in Figure 11. The circumferential displacement measured during mandrel insertion and removal is shown in Figure 12. Hoop strains measured by the strain gages and calculated using the displacement are plotted in Figure 13. As noted in this figure, the strain gages did not provide hoop strain measurements exceeding 2%; however, the displacement transducer recorded strains in excess of 7%. The residual strain after belling calculated from the circumferential displacement was 7.5%.

**Assembly Operations** Two sets of bells and pins were instrumented prior to assembly of the connections (results are only presented for one set). The locations of the strain gages are shown in Figure 14, and a photograph of a connection during assembly is shown

in Figure 15. Hoop strains measured during the assembly of C22 and B11 are shown in Figure 16. The maximum strain was measured by Gage 4H, which is near the end of the pin, and was found to be approximately 13,000 microstrain (or 1.3%).

## CONCLUSIONS

The Zap-Lok connection was originally conceived to solve a welding problem that involved “burn through” on thin wall pipe used for transporting low pressure gas to market. It was soon adapted for joining internally plastic-coated steel pipe for a larger number of applications. Full-scale testing has been used to validate the design of the Zap-Lok connection and ensure that it meets the minimum requirements set forth by pipeline companies. The general observation from the multiple test programs that have been completed is that the tested Zap-Lok connections are able to achieve loads equal or exceed the Specified Minimum Yield Strengths of the tested pipe grades. Additionally, the integrity of the Zap-Lok connection is able to withstand loads associated with offshore pipe lay operations in water depths up to 400 feet.

**Table 1 - Test Sample Configurations**

Sample	Test	Interference	Bell ID (in)	Heat	Pin OD (in)	Heat
A	Pressure	Minimum	8.519	44536	8.603	44536
B	Pressure	Maximum	8.496	44537	8.652	44536
C	Pressure	Nominal	8.508	44281	8.626	44281
E	Tension	Minimum	8.519	44537	8.606	44538
F	Tension	Maximum	8.485	44537	8.658	44281
G	Tension & Pressure	Maximum	8.500	44537	8.659	44280

**Table 2 - Pressure Test Results**

	Burst Pressure (psi)	Theoretical Burst Pressure (psi) *	% Difference**
Sample A	3,344 (125% SMYS)	3,651	8.41%
Sample B	3,394 (128% SMYS)		7.04%
Sample C	3,453 (131% SMYS)		5.42%

\* Based on the ultimate tensile strength from the Mill Test Report (MTR)

\*\* Percent difference between the actual and theoretical burst pressures

**Table 3 - Tension Test Results**

	Failure Load (kip)	Internal Pressure (psi)
Sample E	334 (111% SMYS)	0
Sample F	339 (112% SMYS)	0
Sample G	407 (135% SMYS)	1,901



**Figure 1 – Offshore installation using the Zap-Lok system**



**Figure 2 – Onshore installation using the Zap-Lok system**





**Figure 3 – Zap-Lok connector pipe assembly load rig**



**Figure 4 – Application of Zap-Lok epoxy to the box side of the connection**

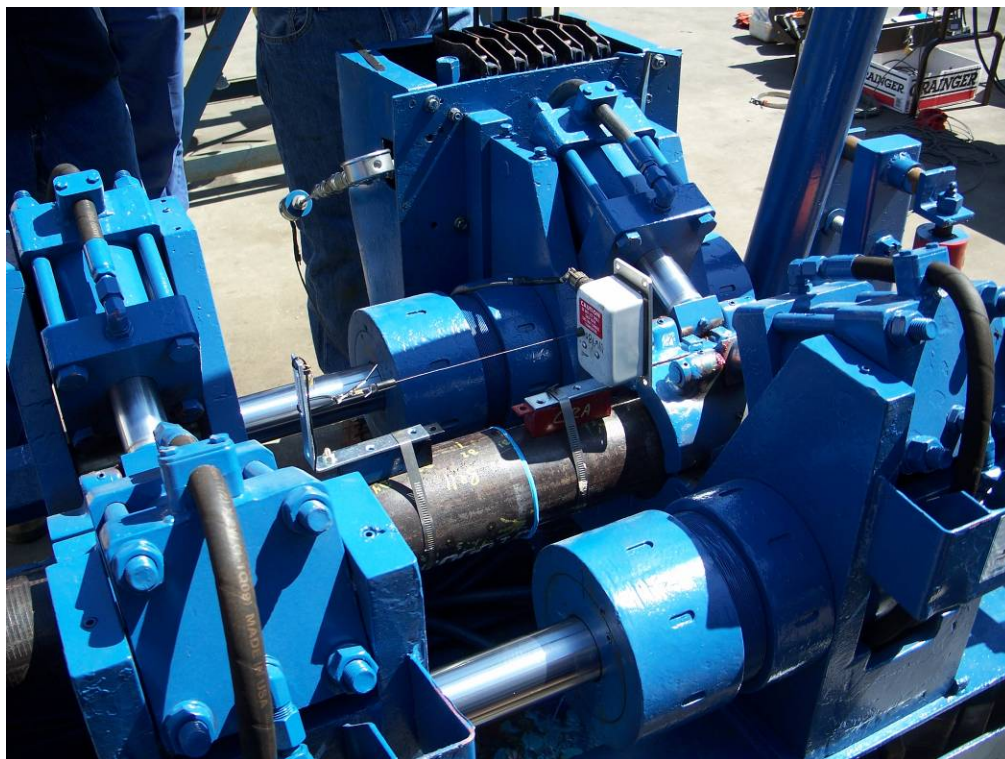


**Figure 5 – Application of Zap-Lok epoxy to the pin side of the connection**



**Figure 6 – Positioning pipe halves in Zap-Lok load rig**





**Figure 7 – View of assembly after make-up of pipe halves**



**Figure 8 - Sample B after burst failure**



Figure 9- Sample E after tensile failure

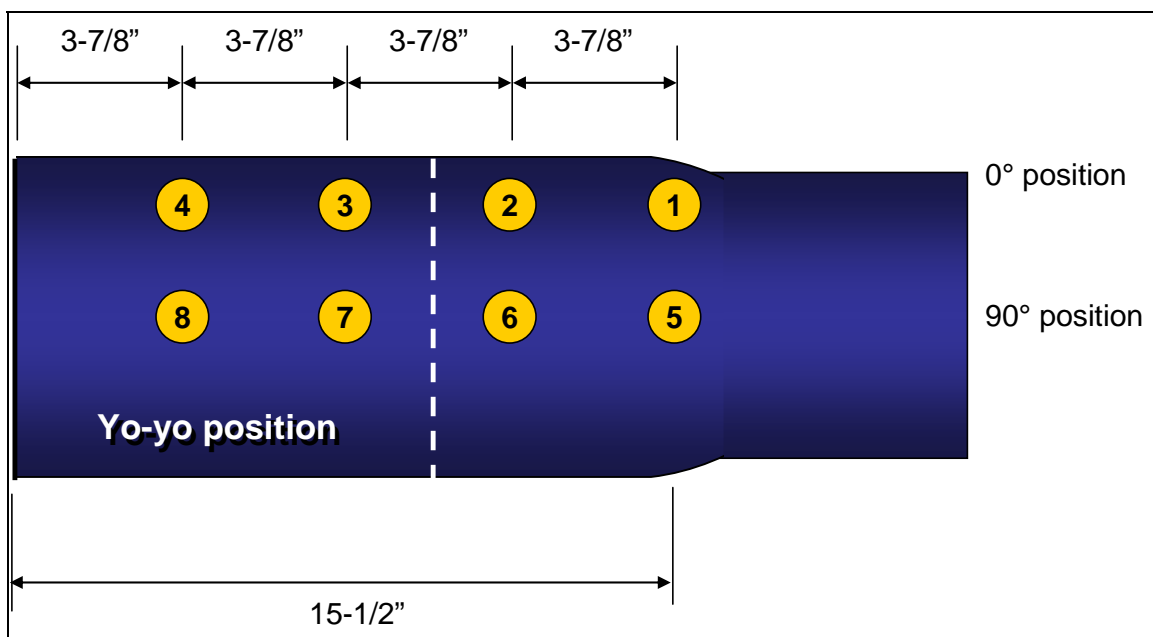
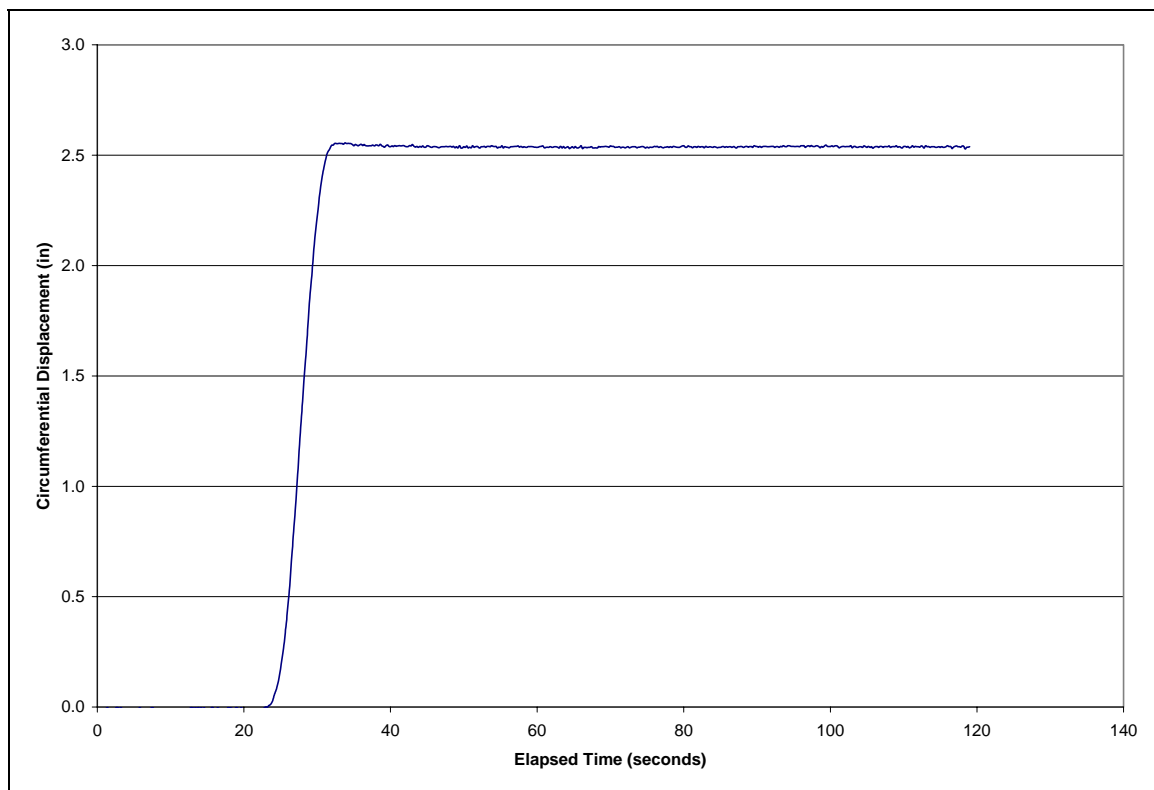


Figure 10 - Strain gage locations for bellling operation





**Figure 11 - Displacement transducer used during belling operation**



**Figure 12 - Circumferential displacement measured during belling operation**

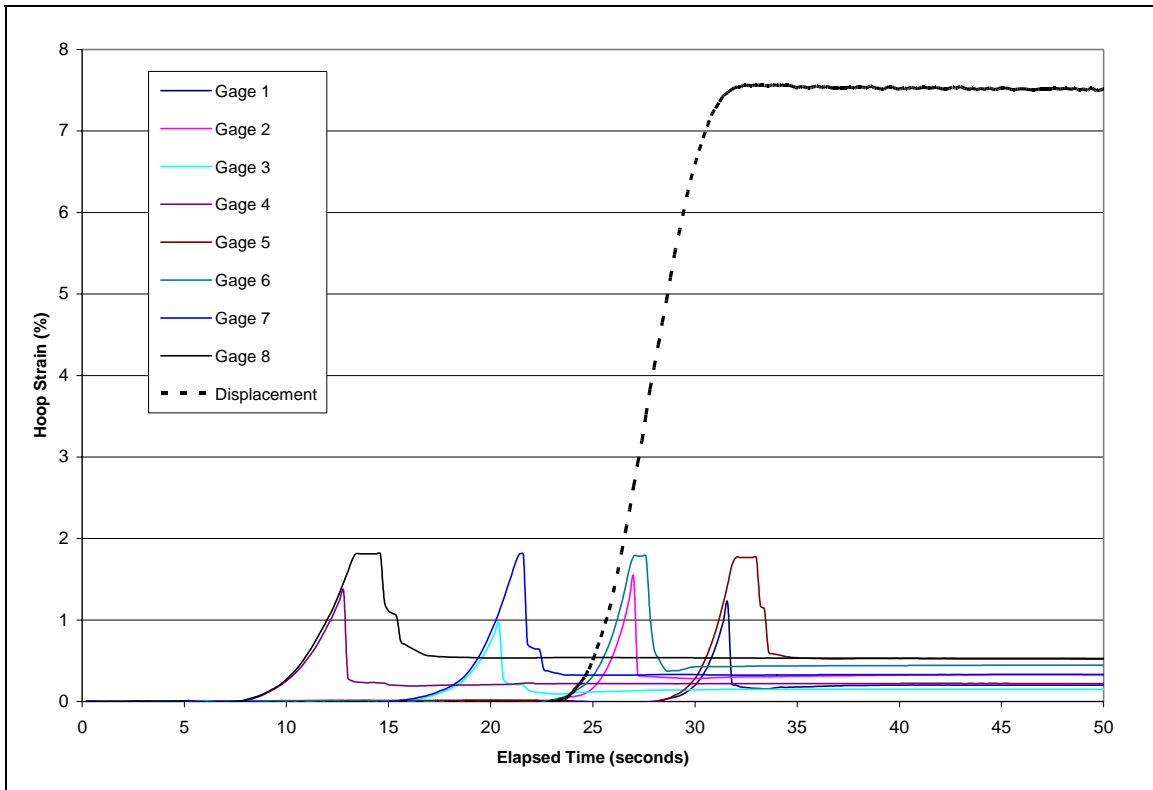


Figure 13 -- Hoop strain measured during belling

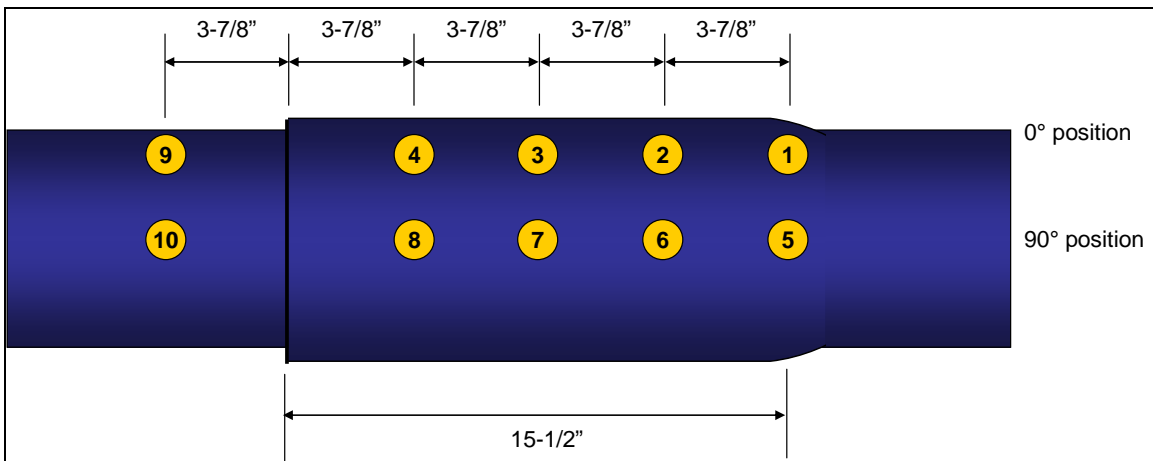
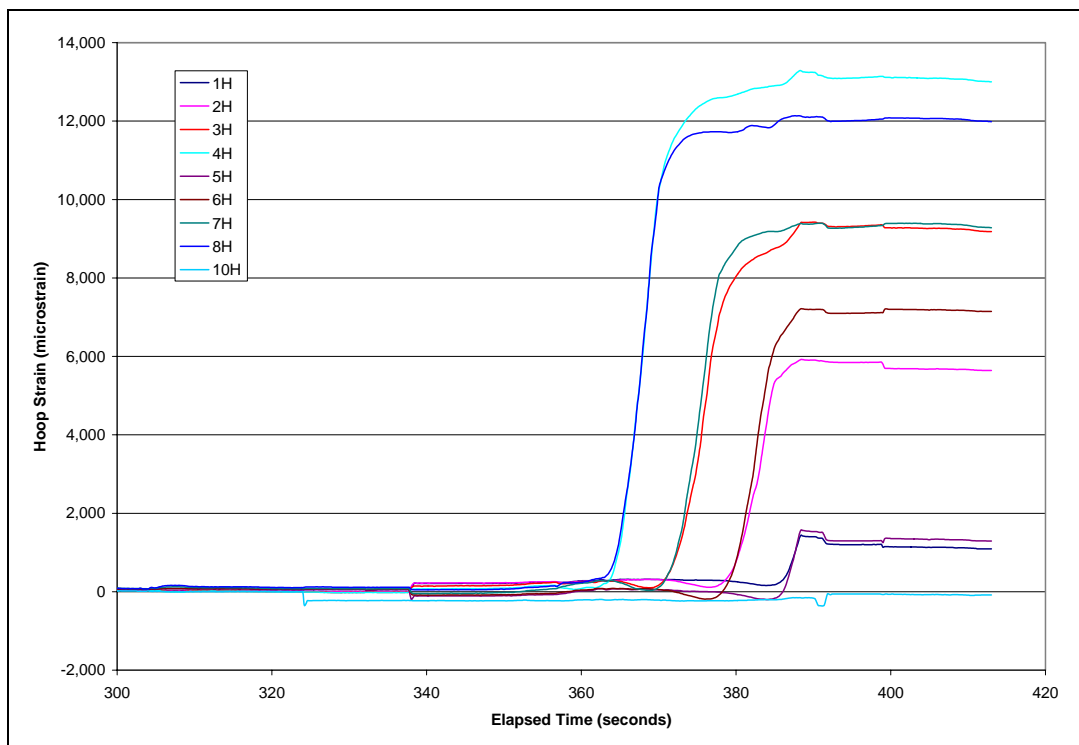


Figure 14 - Strain gage locations for connection assembly



**Figure 15 - Connection assembly**



**Figure 16 - Hoop strains measured during assembly of C22 and B11**  
 (Strain gage data listed in legend corresponds to "Hoop" gages numbered in Figure 14)