Integrity Evaluation of Steam Line Using Complimentary NDE Methods (Acoustic Emission and Ultrasonic Testing)

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Abstract

Improvement in continuous run length and reduction in duration of shutdowns are some of the operating philosophies in a continuous process plant like a refinery in this competitive environment. Predictive inspection and planned replacements are a few strategies being followed for achieving this. Various NDE methods and advanced technologies are now available for obtaining a highly reliable inspection report, but need to be selected judiciously for the specific applications. Complimenting NDE methods will help in quick assessment of the equipment integrity and pin pointing the defects. Acoustic Emission Testing can be used for evaluating the integrity of pressure vessels and pipelines. This method also can be used as a screening tool for assessing the entire length of pipelines and identifying defective locations. Conventional NDT can be used to pin point and sizing the defects in equipment. By combining AET with other appropriate NDT techniques, defects can be located and integrity of equipment can be evaluated quickly and effectively.

A 14” steam line delivering steam to main header line burst at a location about 200m from battery limit of the boiler. After restoring the line by repair it was necessary to evaluate the integrity of the remaining portion. This paper discusses how AET was used as screening tool in locating structurally significant flaws in the steam line. Subsequently Ultrasonic method was used to confirm / pinpoint the defective locations. The effectiveness of both methods is improved by using them together, which resulted in putting the steam line back in-service within a short span of time.

1 Introduction

14” steam line which delivers steam at 40 kg./cm$^2$ and 380°C from boiler to the main HP steam header in Kochi Refinery ruptured at a location about 200 meters from the battery limit of the boiler. Fig 1 shows the condition of the pipeline after the rupture. There was no injury to personnel. But the nearby pipe lines viz. 8” steam line and 6” DM water line were damaged (bent) for about 25 meters and 15 meters respectively. The pipe rack structure was also damaged at the burst location. See Fig.2.

2. History

Boiler UB10, which was installed in 2005, delivers 80 MT/hr steam at 40 kg/cm$^2$ and 380°C. A 14” steam piping (Line No.S-14-B-1-14”) delivers the steam from the boiler to the main high pressure (HP) steam header of the refinery. The length of the line from the boiler to the main header is about 473 M which is laid through a pipe rack. The line was designed and laid as per IBR and hydro tested before commissioning. Table 1 shows the design data. The line was in continuous use since it was laid without any problems. A few days before the incident, a small steam leak was reported from the line under insulation.

The steam pressure had never gone above the design pressure of the line. There was a safety relief valve on the header at boiler end and a non return valve at the main header end.

3. Failure Analysis

3.1 Visual Inspection

The failed pipe section was one length of pipe about 5 meters and the failure location was approximately 40cm away from nearest circumferential weld joint. The breaking line was

Table 1 : Design Data

<table>
<thead>
<tr>
<th>Design Code</th>
<th>IBR</th>
<th>Design Pressure</th>
<th>41 kg./cm$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer / year</td>
<td>M/s. SC PETROTUB SA ROMANIA</td>
<td>Design Temperature</td>
<td>390°C</td>
</tr>
<tr>
<td>Outside diameter</td>
<td>355.6 mm</td>
<td>Operating pressure</td>
<td>40 kg./cm$^2$</td>
</tr>
<tr>
<td>Length</td>
<td>473 m</td>
<td>Hydro test pressure</td>
<td>72 kg./cm$^2$</td>
</tr>
<tr>
<td>Nominal thickness</td>
<td>11.12 mm (14” Sch.40)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
almost circumferential in two planes with a small portion of about 15 cm of the breaking on the longitudinal direction in between the two circumferential planes. The broken edges of the line did not show much elongation and failure was like brittle in nature. Thickness survey of the failed sample and random checking of the remaining pipe line was carried out using UT and was found conforming to the thickness of Sch.40 pipe. Random radiography did not reveal any defects in the failed pipe length. The entire 473 meter of the pipe line was stripped off the insulation and 100% visual inspection was conducted. One section of the pipe of approximately 2 M was found to have external defects like opened out laminations at two locations with low thickness. This pipe was cut and removed. Internal inspection of the pipe revealed opened out lamination at inside of the pipe also. The defect was oriented almost longitudinally and oblique to the radius of the pipe.

3.2 Test Results

Failed section was subjected to mechanical tests. The details are given in the Table 2 below. The longitudinal elongation was slightly less (27% instead 30% as required in the ASTM standard) but all other parameters of mechanical properties and chemical composition were meeting the specification. Refer Table 3.

Micro examination on the failed area was carried out and following observations were made. The microstructure revealed ferrite grains in the matrix of pearlite. The grains were more or less equiaxed and fine in nature. No other abnormalities were observed.

3.3 Conclusions

From the mechanical tests and visual inspection it was concluded that the line may have failed due to opening of laminations in the pipe as no abnormalities were noted in any of the tests done.

4. Integrity Analysis of the remaining portion of steam line

The damaged locations of the pipe lines were repaired. However it was necessary to determine the integrity of the remaining portion of the line before taking it in service as the entire line was fabricated from pipes supplied by a single manufacturer and the defect was attributed to processing defect. Moreover it was suspected that the lamination similar to the one observed in the visual inspection may be present, which might have opened up from the inside of the pipe. This had to be ensured within the shortest possible time as meeting the requirement of the steam in the refinery was very important. Since use of conventional NDT methods will be time consuming it was decided to use Acoustic Emission

<table>
<thead>
<tr>
<th>Identification Mark</th>
<th>CSA mm²</th>
<th>0.2% PS kg/cm²</th>
<th>UTS kg/cm²</th>
<th>% Elongation 2° G2</th>
<th>Flattening Observation</th>
<th>Hardness BHN</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.9 mm thk pipe</td>
<td>322.5</td>
<td>44.57</td>
<td>58.14</td>
<td>27.5</td>
<td>Pass</td>
<td>195</td>
</tr>
<tr>
<td>10.8 mm thk pipe</td>
<td>270</td>
<td>31.48</td>
<td>47.69</td>
<td>37.5</td>
<td>Pass</td>
<td>184</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Identification mark</th>
<th>% C</th>
<th>% Mn</th>
<th>% Si</th>
<th>% S</th>
<th>% P</th>
</tr>
</thead>
<tbody>
<tr>
<td>12.9 mm thk pipe</td>
<td>0.22</td>
<td>0.57</td>
<td>0.23</td>
<td>0.014</td>
<td>0.011</td>
</tr>
<tr>
<td>10.8 mm thk pipe</td>
<td>0.21</td>
<td>0.56</td>
<td>0.23</td>
<td>0.015</td>
<td>0.013</td>
</tr>
<tr>
<td>As per ASTM A106</td>
<td>0.3 Max.</td>
<td>0.29 – 1.06</td>
<td>0.1 Min.</td>
<td>0.035 Max.</td>
<td>0.035 Max.</td>
</tr>
</tbody>
</table>
Testing as a screening tool for identifying defective locations like laminations in the pipeline.

5. Acoustic Emission Phenomenon Non-destructive Testing

Acoustic Emission can be defined as the class of phenomenon where transient elastic waves are generated by rapid release of energy from localized sources within a material. It is the elastic energy that is spontaneously released by materials when they undergo deformation.

Acoustic Emission is a wave phenomenon and Acoustic Emission Testing uses the attributes of particular waves to help characterize the material in which waves are traveling. Acoustic emission can be used as a non-destructive testing technology when it was realized that growing cracks and discontinuities in pressure vessels could be detected by monitoring their acoustic emission signals. Piezoelectric sensors can be suitably placed along the structure under test to detect the AE signals. Figure 3 shows the Acoustic Emission testing.

Acoustic Emission differs from other non-destructive methods in two significant respects. First, the energy that is detected is released from within the test object rather than supplied by the non-destructive method. Second, the Acoustic Emission method is capable of detecting the dynamic processes associated with the degradation of structural integrity. Structural system will develop local instabilities long before the structure fails. Dynamic movements associated with plastic deformation, slip or crack initiation and propagation act as source of stress wave and become an active Acoustic Emission source. In the case of steam line opening up of lamination will generate Acoustic waves. By studying the acoustic signals emitted by the laminations their locations can be detected.

Following are the advantages of AET over other non-destructive testing methods in evaluating the integrity of steam line.

1) Acoustic Emission is a dynamic inspection method. If the laminations present are dynamic it can be detected. It is assumed that laminations which are static did not pose a threat to the integrity of steam line.

2) AET can detect and evaluate significance of discontinuities through out on entire structure during a single test. Entire 473 M length pipe line can be evaluated in one go.

3) Pipe lines and other pressure systems can often be requalified during in service inspection that requires little or no downtime. This saves the time required for evaluating the integrity of steam line.

Kaiser effect is used to evaluate the findings of the testing. It can be defined as the absence of detectable Acoustic Emission until the immediate previous maximum applied stress level has been exceeded. This phenomenon lends a special significance to Acoustic Emission investigations, because by measurement of emission during loading a clear conclusion can be drawn about the magnitude of the maximum loading experienced prior to test by the material under investigation. This effect can be utilized to know the maximum load which was subjected by the steam line prior to failure.

6. Procedure for Acoustic Emission Testing

The Acoustic Emission Testing was carried out by M/s. Physical Acoustic Limited using MONPACTM/IPACTM procedures. The following equipments were used.

AE sensors: Sensors used for testing are R151 (incorporating preamplifier circuiting).

Frequency: 100 KHZ to 200 KHZ

AE equipment: Disp Acoustic Emission System

Manufacturer: Physical Acoustics Corporation NJ, USA
6.1 AE Sensor Array on steam line

50 AE sensors were mounted on the steam line with linear zonal location array. Sensors frequency was based on consideration of background noise, acoustic attenuation. Sources are located either by linear source location, zone location or both. Figure 4 shows the AE sensor array.

**Zone location method**

If a continuous signal source develops on a structure bearing a number of sensors, then the sensor with the highest amplitude output will be closest to the source (assuming equal sensor sensitivities). This occurs because the signal detected at the closest sensor is less attenuated than the others.

**Linear zone source location**

Consider the situation where three sources are mounted on a linear structure such as pipe. Stress waves propagate in both directions. The source location would be to note the sensor that received the stress wave first (called the first hit). Let sensor 2 receives the first hit, then source lies half way between sensor 1 and sensor 2 to a point half way between sensor 2 and sensor 3. If the second hit is sensor 1, then source lies between sensor 2 and a point half way between sensor 1 and sensor 2.

7. **Calibration**

An attenuation study is performed in order to determine sensor spacing. This study is performed with the test fluid in the vessel using a simulated AE source. Sensors were located such that a lead break at any location in the examination area is detected by at least one sensor and have measured amplitude not less than as specified by the referencing procedure. The maximum sensor spacing shall be no greater than 1.5 times the threshold distance. The threshold distance is defined as the distance from a sensor at which a pencil lead break on the vessel has a measured amplitude value equal to the evaluation threshold.

Systems Performance Check: A verification of sensor coupling and circuit continuity was performed following sensor mounting and system hookup and again immediately following the test. The peak amplitude response of each sensor to a repeatable simulated acoustic emission source at a specific distance from each sensor was taken prior to and after the test. The measured peak amplitude should not vary more than 4 dB from the average of all the sensors. Any channel failing this check should be investigated and replaced or repaired as necessary. If during any check it is determined that the testing equipment is not functioning properly, all of the product that has been tested since the last. Valid system performance check shall be reexamined.

8. **Pressurization sequence**

0 to 50%, hold for 10 minutes, 50 to 60%, hold for 10 min, 65 to 85%, hold for 10 min, 85 to 100%, hold for 30 min, and depressurise to 50% and repressurise as follows: 50 to 60%, hold for 10 min, 65 to 85%, hold for 10 min, 85 to 98%, hold for 30 min. End of test. Initial loading is to identify and eliminate noise due to spalling of scales, valve gland leakages; movement of pipe lines with respect to structures/neighboring lines etc. during the second phase of loading AE signals are monitored. The pressure was maintained as above and the test was carried out.

9. **AET Results**

The MONPAC™ Intensity chart is used to determine the MONPAC™ grade of individual sensor channels. The grading is based on severity & history of the acquired acoustic emission hit data. The intensity data is only valid for tests run with MONPAC™ certified instrumentation to MONPAC™ procedures.

Severity Index- Is a function of the energy received on the particular channel.

Historic Index- Is a function of how the severity varies with time & pressure throughout the test.

MONPAC Grading and standard recommendations are:

- “N” Black insignificant emission No further Action
- “A” Green Very Minor Source No Further Action
- “B” Dark Blue Minor Source Visual External (possible corrosion)
- “C” Purple Source Further Evaluation possible NDT
- “D” Yellow Active Source Follow-up NDT
- “E” Red Intense Source Immediate Follow-up NDT

**Table 4: AE Test Results**

<table>
<thead>
<tr>
<th>MONPAC/IPAC GRADES</th>
<th>1st Loading</th>
<th>2nd Loading</th>
</tr>
</thead>
<tbody>
<tr>
<td>“A” grade channels: None</td>
<td></td>
<td>43</td>
</tr>
<tr>
<td>“B” grade channels: 13,16,25,30,40,43,21,31</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>“C” grade channels: 2,11,29,33,34</td>
<td>38,50</td>
<td></td>
</tr>
<tr>
<td>“D” grade channels: 28,32,35,37,39,41</td>
<td></td>
<td>None</td>
</tr>
<tr>
<td>“E” grade channels: 1,38,50</td>
<td></td>
<td>None</td>
</tr>
</tbody>
</table>

**1st Loading**

Activity received & located through out the test from zones covered channels 37-38-39. Also activity received from Channel 1&2, channels 49 & 50, channels channels 27-28-29, channels 32-33, channels 40-41. Please see location graphs for correct locations. No significant activity during Load Hold periods. Please note the energy levels shown in Fig. 4

**2nd Loading**

Minor Activity received from zone covered by sensor 38 & 50. No activity during Load Hold periods. Please note the energy levels shown in Fig. 5
Fig. 4: 1st loading

Fig. 5: 2nd loading

Fig. 6: 1st loading

Fig. 7: 2nd loading
10. Evaluation

No activity during Load Hold during 1st and 2nd Loadings. Minor activity received during second loading, which conforms no severe damage or no crack like activity. Activity during 1st loading has picked up after 40 Kg/cm², which confirm the Kaiser effect. This activity during 1st loading can be from weld or actual pipe-line laminations. Activity from zone covered by Sensor 50 was due to noise generated from boiler side. So, it was not considered for further NDT. Zone covered by channel 38 is to be inspected using follow up NDT. It was suggested to perform UT flaw detection in this zone to confirm possible de-lamination.

11. Ultrasonic Testing

Based on the observations obtained from AE Testing, UT scanning was carried out at the affected area i.e. zone 38. The area scanned was of about 14M length. Indications were obtained for about 3M. The indications were continued to be off lamination during internal inspection. The defective locations were replaced and line was successfully hydro tested.

12. Conclusion

By effectively combining both AET and conventional UT method accurate /complete determination of structurally significant flaws were carried out with in the shortest possible time and effort. This resulted in putting back steam line in service quickly.

References

2. www.ndt.org