Application of displacement monitoring system on high temperature steam pipe

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Abstract. High-energy piping systems of power plants such as Main Steam (MS) pipe or Hot Reheat (HR) pipe are operating at high temperature and high pressure at base and cyclic loads. In the event of transient condition, a pipe can be deflected dramatically and caused high stress in the pipe, yielding to failure of the piping system. Periodic monitoring and walk down can identify abnormalities but limitations exist in the standard walk down practice. This paper provides a study of pipe displacement monitoring on MS pipe of coal-fired power plant to continuously capture the pipe movement behaviour at different load using 3-Dimensional Displacement Measuring System (3DDMS). The displacement trending at Location 5 and 6 (north and south) demonstrated pipes displace less than 25% to that of design movement. It was determined from synchronisation analysis that Location 7 (north) and Location 8 (south) pipe actual movement difference has exceeded the design movement difference. Visual survey at specified locations with significant displacement trending reveals issues of hydraulic snubber and piping interferences. The study demonstrated that the displacement monitoring is able to capture pipe movement at all time and allows engineer to monitor pipe movement behaviour, aids in identifying issue early for remedy action.

1. Introduction

Piping system of a power plant is subjected to high pressure and high temperature during operation. As the pipe temperature changes from the installation condition to the operating condition, it expands or contracts. Thermal expansion of the pipe due to temperature changes generates enormous force and stress in the system [1]. Piping support systems are critical component in maintaining the forces and stresses within the allowable limit. Considerable stresses can be created in the piping and in the terminal point connections (boiler header and turbine) if the support system is not working properly as designed [2]. Support system malfunction can be caused by transient conditions such as start-up, shut down and water hammer where a pipe can be deflected dramatically and caused high stress in the system. Ignoring this can yield to failure of the system. ASME B31.1, “Power Piping” prescribes requirements for inspection of piping systems in Section VII- Operation and Maintenance, stated “the effects of unexpected piping position changes, and malfunctioning supports on the piping system’s integrity and safety shall be evaluated, significant displacement variations from the expected design displacement shall be considered to assess the piping system’s integrity” [3].

Appendix V, while listed in the code as nonmandatory, contains important information on piping displacement recording, documenting, marking and visual survey [3]. Conventional periodic monitoring and walk down of a pipe system has limitation in capturing pipe position. Very often, pipe
position is recorded only at the time of inspection through hanger reading. Topped or bottomed out hanger will restricted the movement of pipe and the reading remains unknown until the hanger is adjusted to designed hot or cold position. The goal of preventing failure to the piping system can be attained by deploying adequate effective supervision and continuous frequent condition monitoring [4].

This paper provides a pipe displacement monitoring study on the MS pipe at coal-fired power plant to continuously capture pipe movement behaviour at different load by using real-time displacement monitoring using the 3-dimensional displacement measuring system (3DDMS). The deployment of the 3DDMS allows continuous real-time monitoring of the pipe movement. The system also makes capturing pipe movements during hot, transient and cold conditions possible for record and reference data.

2. 3-D displacement measuring system (3DDMS)
The on-line monitoring and measurement system known as 3DDMS was customized by Korea Electric Power Research Institute (KEPRI) and has given the right to Korea Leading Engineering System (KLES) as the sub-supplier to design and manufacture. The system consists of the measurement device (3DMS transducer, see Figure 1) and the control unit or server. The displacement measurement device is the two-link type, which has the ability to measure 3-dimensional displacement of the pipe. Captured pipe displacement data will be sent to the system server known as PLUMBER to be stored. The PLUMBER displays the pipe movement trending on screen for monitoring purpose [5].

3. Displacement measurement transducer set-up
3DDMS transducers were installed on MSP at selected locations where pipe hangers and snubbers are installed. The device link \( l_2 \) end is attached to pipe hanger using a special clamp to prevent any harm on the pipe material. The other end of the device is connected by using jigs to a fix structure to secure its position. Figure 2 shows the location of 8 units of 3DDMS transducer on MS pipe of a power plant. Figure 3 shows the example of 3DDMS transducers installed on MS pipe. The pipe displacement data captured by the 3DDMS devices is transferred to the system server to be processed and visual display.

![Figure 1. Two-link type displacement measurement device.](image-url)
4. Pipe monitoring using 3DDMS

The system is essentially based on measuring pipe displacement. The 3DDMS transducer supplies information about the pipe behavior in x-, y- and z-directions and the magnitude of pipe movement. This is vital when it comes to non-ideal conditions such as over scaled or malfunction hanger where the movement of pipe is restricted. Malfunction hangers can cause high stress in piping system and cause damage development and cracking at base and weldments.

The captured displacement data is compared to pipe hanger design movement where upper and lower movement limits are introduced in the tabulated data trending to monitor the pipe movement in terms of movement direction and magnitude. Displacement measurement device and monitoring system can be directly used for evaluating the design and durability of the piping system [5].
Figure 4. Pipe displacement data monitoring.

Figure 4 shows a window (screen shot) visualizing the pipe movement trending at specified location of the MS pipe. For the pipe isometric view, displacement measurement and history trend may be opened in other tabs as significant information on the hangers’ location and number are shown. In total, 8 3DDMS transducers were installed on the MS pipe.

Compared to the conventional common practice without a monitoring system, the pipe system is significantly improved since:
- Direction of the pipe movement is known.
- Magnitude of hanger movement is known.
- The pipe behavior check is continuous, compared to the common practice of pipe hanger survey and walk down.

5. Results: Pipe displacement trending
8 units of two-link type 3DDMS transducer were installed at MS pipe. Data of actual pipe movement has been obtained in real time and tabulated to compare to the design movement. For the purpose of monitoring the pipe movement, movement upper and lower limits are embedded in the trending graphs.

Based on the pipe displacement trending, it was found that the pipe displacement at all locations are within the control limits and consistent except at locations 7 and 8. Figure 5 shows pipe displacement trending in x-, y- and z-axis at Location 5 near hydraulic snubber location. As it can be seen, the pipe displaced within the upper and lower limits. The z-axis movement however demonstrates that the movement is 25% less compared to that of the design (Figure 6). This signifies that the movement in this particular axis is unusual and not according to the designed. Visual inspection during pipe walk down recorded evidence of hydraulic snubber fluid leaked (Figure 9). As a hydraulic snubber leaks fluid, the dampening capacity of the unit is reduced to the point where it freely slides from full compression to full extension. At this point the hydraulic snubber does not counteract the shock forces generated in the system and translate them back to the equipment nozzle such as turbine [6]. Other pipe displacement data with good condition of snubber such as at Location 1 exhibits movement more than 50% to that of the designed. This shows that the unusual trending of the pipe movement could be due to the performance of pipe snubber.

Figure 7 exhibits the pipe displacement trending at Locations 8 where the pipe movement is inconsistent and have exceeded the limits. Figure 8 shows the pipe movement actual difference between both Location 7 and 8 (north and south pipe) in z-axis are increasing from 18mm in December 2016 to 41mm in March 2017 after the unit re-start-up in December 2016. This demonstrates that both north and south sides of the pipe actual movement difference is more than the design movement difference which is 2.3mm. Visual inspection during pipe walk down found that...
there is anomalous condition of the piping system where a beam structure is seen penetrated into pipe cladding (Figure 10). This signifies that this condition in anyway could affect or disturb the pipe movement behavior. The increasing movement difference between these 2 pipes indicates that the pipes have distorted in the z-axis and this could amplify the risk of high stress on the connection pipe weldment in between (Figure 8). From the displacement trending, it clearly shows that the pipes did not return to its exact original position during cold condition. This is an example of the system degradation as a result of relaxation in the material, the piping rarely returns to its exact position after years in service at high temperature operation. Also, as high energy piping ages, creep deformation results in permanent shifting throughout the system [2].

With the pipe movement monitoring, one can knows pipe actual movement behavior in terms of magnitude and direction and also confirm on pipe hanger and support performance particularly for malfunction hanger or snubber so that remedy action can be taken to secure the piping system safety and reliability. Pipe displacement trending can greatly use in supporting the identification of inspection locations on steam pipe for future condition assessment plans.

![Figure 5](image1)

Figure 5. Pipe displacement trending at Location 5.

![Figure 6](image2)

Figure 6. Location 5 and 6 z-axis displacement trending.
Figure 7. Pipe displacement trending at Location 8.

Figure 8. North and south pipe actual movement difference.

Figure 9. (a) Snubber fluid leaked (b) Magnified view shows hydraulic fluid droplet.
6. Conclusions

This paper provides a real-time pipe displacement monitoring study on the MS pipe at coal-fired power plant. The study demonstrated that the real-time pipe displacement measurement system is able to continuously capture pipe movement and allows engineer to monitor pipe displacement behavior. This aids in identifying issue of trouble pipe hanger/support early so that remedy action can be taken to ensure the piping system safe operation as pipe hanger/support malfunction is the first sign of trouble. This is significantly beneficial for inaccessible and hard-to-reach pipe hangers and snubbers where the condition can be known based on the pipe actual displacement trending captured in the system.

The field inspection at the specified location of abnormal pipe displacement trending reveals the abnormal condition of the piping support system. The pipe snubber at Location 6 found the evidence of hydraulic fluid leaking. This could contribute to the displacement trending less than 25% to that of the design displacement. At Location 8, a beam structure was found penetrated into pipe cladding. It signifies that this condition in any way could affect or disturb the pipe movement behavior and amplify the risk of high stress on the connection pipe weldment in between.

The significant displacement variations from the expected design displacement captured can be considered in piping system integrity assessment as a means to support the identification of critical locations along with the engineering judgement and flexibility stress analysis. This will greatly contribute to the piping system safety and reliability.

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