Inspection and Evaluation for wall-thinned pipe due to Liquid Droplet Impingement Erosion in the Secondary Piping System of Nuclear Power Plants

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1. Introduction

Liquid Droplet Impingement Erosion (LDIE) has been known one of the main wall thinning mechanisms as well as Flow Accelerated Corrosion (FAC) in the secondary piping system of nuclear power plants. FAC susceptible components have been able to be predicted with high confidence by adopting CHECWORKS program to secondary piping system since it was developed in 1990s. The FAC prediction logic incorporated in the CHECWORKS program is based on the FAC degradation theory developed by Electric Power Research Institute (EPRI) in America. In spite of using the CHECWORKS program in secondary piping system, quite a lot of pipe leaks generated by wall thinning mechanisms were reported around the world. Among erosion-corrosion mechanisms in nuclear power plants, LDIE has been recently recognized as the degradation mechanism related to wall thinning. To identify potentially FAC susceptible lines, the factors of FAC susceptibility were established by EPRI technical document NSAC-202L. Previously, the factors of LDIE susceptibility have not been completely established. In this study, we have established the factors of LDIE susceptibility. Also, we have inspected potentially susceptible areas on selected components according to the factors of LDIE susceptibility. A number of wall-thinned components were found among the selected samples. Finally, based on Computational Fluid Dynamics analysis (CFD) results, it is concluded that LDIE induced the wall thinning on the components.

2. Methods and Results

2.1 Inspection method

Typically, the area damaged by LDIE is quite small compared to the area damaged by FAC. Therefore, inspection method for FAC, marking grid lines on the components and taking data at the grid intersection points, is not proper to LDIE detection. A UT thickness measuring device producing continuous thickness date was used to find out eroded points due to LDIE. The UT device, Olympus Epoch-XT, equipped with an encoder car which can take UT thickness recoding data; simultaneously saving the distance data from the starting point. With the B-Scanner, we can easily get the continuous ultrasonic thickness data on the line where the encoder passes. Also, we can identify the extent of wall thinning caused by LDIE on the small area based on the continuous thickness data. If the spans are narrower between inspecting lines, three-dimensional thickness data could be acquired with high reliability compared to point thickness data. Considering the short period of plant overhaul, we focused the inspection on the extrados of elbows and the opposite side of tee braches. According to operating experiences and many pieces of literature, wall thinning caused by LDIE occurs in the extrados of elbows and the opposite side of conjunction area of tees. Therefore, with scanning linear wall thicknesses in the extrados of elbows, we can identify whether elbows are thinned or not. Fig. 1 shows an example of the B-Scan thickness profile and the geometric configuration of the inspecting component.

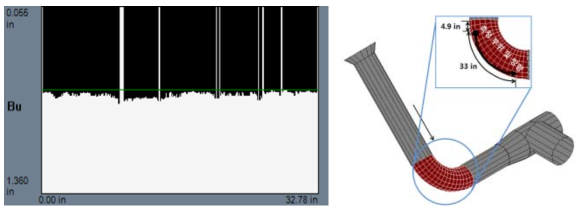

Fig. 1. B-Scan thickness profile (left) and geometric configuration of inspecting component

2.2 Factors of LDIE susceptibility

To determine the inspecting area for wall thinning due to LDIE, we should know the characteristics of LDIE mechanisms based on the operating experiences, experimental studies, etc. Among two phase flows, LDIE primarily occurs in annular and wispy flow However, even if liquid droplets are not found at bubble, slug and churn flow, as these flows pass at the geometrical discontinuity area such as the downstream of control valve or orifice, liquid droplets in these flows could be formed partially. Therefore, when we selected inspection points for searching the damaged pipe components caused by LDIE, all pipe components existing two phase flow were considered as the scope of inspection for determining the factors of LDIE susceptibility. The two phase flow is an important factor of susceptibility to detect the LDIE. To find the inspection points of two phase flows at the scope of pipe component, we used the one-dimensional computational fluid analysis method, Network Flow Analysis (NFA) which is embedded in CHECWORKS program for thermal hydraulic analysis. The liquid velocity in two phase flows is also an important factor to detect the susceptible location for LDIE. Many literatures including LDIE theory [1], [2] show that the droplet velocity is a key factor to determine wear rates caused by LDIE. A geometric configuration according to piping layout is also important factor of LDIE susceptibility. At elbow and tee geometries, where flow direction is changed, liquid droplets in two phase flows collide with the inner surface of these components. Considering the factors of LDIE susceptibility such as type of phase, velocity, geometric configurations, etc., 20 components were selected as inspection points.

2.3 Thickness measurement

Among the selected 20 components, a wall-thinned point was found at the elbow connected to the condenser nozzle and estimated as LDIE degradation. Fig. 2 shows the piping layout including the inspecting elbow marked with circle.

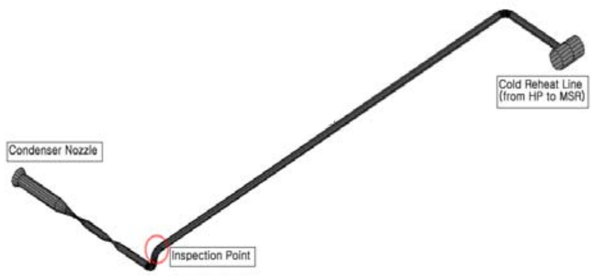

Fig. 2. Piping layout including inspection area

Fig. 3 shows the three-dimensional thickness contour and thickness data measured at 4 circumferential points (A, D, G, J) as the space interval of 90 degree and 16 longitudinal points (1~16). In the middle of wall thickness data, the extrados thickness data (A) are selected to evaluate the effect of LDIE.

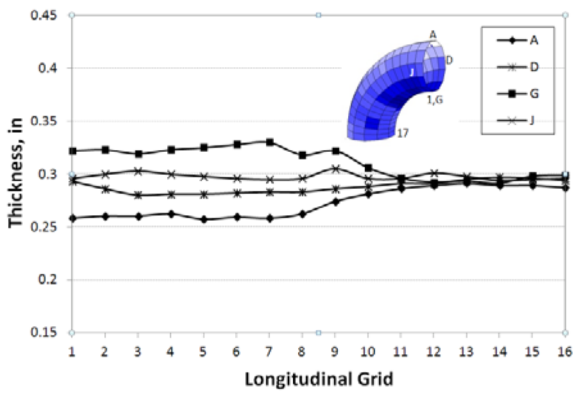

Fig. 3. Wall thickness data and contour at inspection point of elbow.

2.4 Numerical analysis for wall-thinned point

Among the factors of LDIE susceptibility, the liquid velocity is a dominant key factor. According to the literatures of Heymann and Sanchez [1], [2] the wear rate of carbon steel due to LDIE is proportional to the 5th power of velocity. In this study, in order to distinguish between LDIE and other wall thinning mechanisms such as FAC. we considered the droplet velocity at elbows. Based on the relation between the fluid velocity and wear rate as described in Heymann and Sanchez's research, we compared the normalized values of wear rate and velocity at extrados. Fig. 4. shows that the curve of normalized wear rate of elbow is closest to that of the 5th power of velocity. Therefore, we can conclude that the wear of elbow is caused by LDIE.

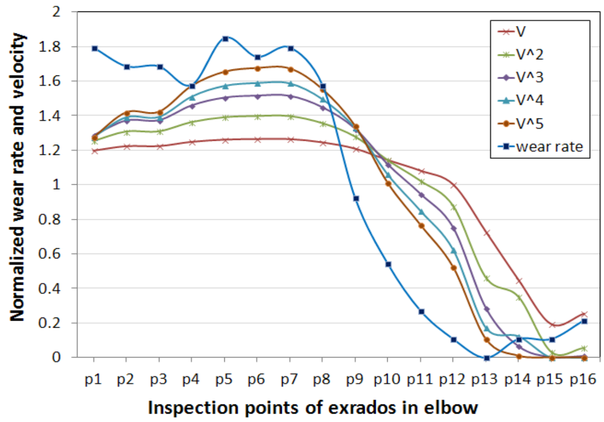

Fig. 4. The comparison between normalized wear rate and velocity magnitude at inspection points.

3. Conclusions

LDIE is a newly issued wall thinning mechanism in the secondary piping system of nuclear power plants. Although a lot of investment has been put into managing FAC in secondary piping system, many leakages have occurred. It has been known that LDIE is the main or partial cause of those leakages in nuclear power plants. In this study, we identified the cause of wall thinning in elbows based on CFD analysis and concluded that the factors effecting on the LDIE susceptibility are reasonable to be adopted in nuclear power plants. In future studies, further cases will be analyzed to verify the above methodologies.

Acknowledgement

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