THE APPLIED RESEARCHES OF THE LEAK BEFORE BREAK (LBB) ON THE MARINE PRESSURE PIPES

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ABSTRACT

This paper firstly describes the backgrounds, basic concepts and main contents of the LBB analysis technology, then lays special stress on probing into several special problems in the LBB technological applications in the marine pressure pipes, and finally brings forward the critical technologies and research approaches for the LBB technological applications in the marine pressure pipes.

INTRODUCTION

In developing processes of high-pressure pipe (container) technology, much weight is always attached to the safety and reliability. To guarantee the structural reliability, people more often than not regard Double-Ended Guillotine Break of the pressure pipes as standard design accidents in the pressure pipe design before 1980s. The Double-Ended Guillotine Break refer to abrupt complete pipe breaks caused by high-pressure, stress and so on, and creating severe leakage accidents. The leaking high-pressure liquid and gas create mighty jet power, endangering the structures and equipments around. To tackle this kind of accidents, safety injection system, pipe anti-toss system and liquid jet shielding system and so on are more often than not set up in order to guarantee the safety of nuclear power plant.

The invalidation mode of pressure pipes discovered in theoretical researches and experiments since 1980s are more often than not crevasse leakage, namely, so-called Leak Before Break (LBB). If the LBB analysis technology is conditionally applied during designing on marine pressure pipes, it is possible to avoid the dynamic effects of Double-Ended Guillotine Break on pipes, simplify complex designs of relative systems and equipments, reduce complex extents of piping structures and construction, operation, maintenance costs and so on. At the same time, it is possible to reduce in-service checks and crack detection times of pressure pipes, reduce rigor extent of piping safety assessments, extend its service life, and heighten economy. In a word, it will certainly create huge economic benefits to deeply and systematically carry through the LBB analytical researches on marine pressure pipes and apply in designs, constructions and operations.

THE DEVELOPMENT STATUS LBB AT HOME AND ABROAD

After having brought forward by Italian nuclear power experts, the idea of LBB was soon recognized by all countries across the world. The United States, Britain, Japan, German, France, Canada, Russia and other countries have carried out a great deal of theoretical and experiment researches on LBB analysis technology, developed some LBB analysis methods easy to apply in engineering, for example: Two-criterion Assessment Method (R6 Assessment Method) in Britain, EPRI Method in the United States, Limit Load Method and Maximum Stress Method in German, etc. They have accumulated some important data, incorporated some research achievements into nuclear reactor design criteria, and obtained recognitions of international nuclear energy industries on some problems.

At home, some experts also recognized the importance of the LBB technology, and obtained some important research achievements on defect assessments for pressure containers. Some LBB analysis researches were also carried out during designing, constructing and operating of Guangdong Nuclear Power Station and so on. In processes of research designs of the high-temperature air-cooling reactors, Institute of Nuclear and New Energy Technology of Tsinghua University applied the LBB analysis technology and brought forward Two-parameter Evaluation Method reached international advanced level.

BASIC CONCEPTS OF LBB ANALYSIS

Assuming there is a surface crack on pipe (or container) wall, whose initial length is a_i and depth c_i, the crack will simultaneously enlarge along length direction and depth direction respectively under the effect of external loads. If critical length that the structure creates overall unstable invalidation is a_{crit} under the effect of a certain load, corresponding length which the crack penetrates wall thickness is a_{leak}, this structure will only cause penetrating leakage when $a_{leak} < a_{crit}$, not cause instable overall breakage. But under the effect of external load, the penetrating crack length is a_{leak} will continually enlarge until the structure causes overall breakage when the crack length reaches a_{crit}. This invalidation process is called LBB. People can discover leakage via various methods and measures in this process, and immediately take measures to prevent occurrence of catastrophic overall breakage accidents.

The LBB invalidation process can be divided into four phases: subcritical enlargement of surface crack, local instability (crack penetration), subcritical enlargement of penetrating crack and overall instability. The LBB analysis requires that the crack produces enough liquid leakage before overall instable breakage in order to guarantee it detected as soon as possible, and there is enough time to take measures (such as pressure discharge and maintenances) before leakage detected to crack instability.

The LBB criterions are used to differentiate whether a certain initial crack on pressure pipes (or containers) causes LBB under the effect of operating load and environmental factors. The LBB criterions usually include following requirements:

(1) Load requirements: The load should include static strength and static bending moment under normal operating conditions, strength and bending moment pertinent to earthquake and shock. Assuming that the crack is positioned at the point where the combination of stress and material quality is worst, where the stress is highest while the ductility and intensity of the material are lowest.

(2) Crack dimensions and positions: Assuming that the dimensions of the crack are large enough in order to guarantee the leakage measured as soon as possible. The crack leakage rate under normal operating loads is commonly required to be at 10 times of minimum leakage quantity detected by leakage detection system.

(3) Crack stability conditions: While determining crack stability, add the normal operation loads to earthquake and shock loads, and then multiply a coefficient of safety (according to different load calculation methods, commonly take $\sqrt{2}$ or 1.0), and the crack is required to be stable under this load.

(4) Crack dimension margin: Satisfy the minimum crack length prescribed in condition (2) i.e. $2a_{leak}$, satisfy the crack length of critical instability enlargement prescribed in condition (3) i.e. $2a_{crit}$. The LBB criterions require:

$$a_{crit} \geq S_a a_{leak} \tag{1}$$

of which, the safe margin factor of crack length S_a commonly takes 2.

(5) Other requirements: enough time is required to implement leakage detection and safe protective measures, that is:

$$t_{LBB} > S_t T \tag{2}$$

of which, t_{LBB} is the time of penetrating crack from the detectable leakage beginning to unstable enlargement, T is the responding time of leakage detection system, including the time required to detect leakage under normal operating conditions and to take necessary measures, S_t is safe margin factor of crack enlargement time.

THE LBB RESEARCHES ON MARINE PRESSURE PIPES

The following characteristics of marine pipes must be fully considered during carrying through the LBB researches on marine pressure pipes:

(1) The impact of bad conditions for ocean navigation and suddenly changing environmental conditions on marine pressure pipes is much more complex than on land pressure pipes. The marine pressure pipes and containers must endure shocks of instant loads caused by swing, ups and downs, undulation and other anomaly movements.

(2) The operating conditions of marine power plant change suddenly and frequently during navigation. The changing amplitude and frequency of pipes inside medium parameters are great. The pressure pipes' vibration alternate stress and cyclic heat stress are great, too.

(3) Because the cabins are narrow and small, the pressure pipes are compactly laid out, there are many winding pipes and the stress distribution on pipe walls is complex, so these all set more strict requirements on the LBB researches.

(4) The marine equipments are light in weight and small in volume (contrary to land equipments), so the pressure pipe diameters are commonly small and pipe walls are rather thin. These are all matters needing attention during the LBB researches into marine pressure pipes.

All abovementioned characteristics make the LBB researches on marine pressure pipes much more complex and difficult.

The designers will use the research achievements of the LBB technology at home and abroad for references during conducting the LBB researches on marine pressure pipes, develop the LBB analysis and computation procedures according to the practical conditions of ships and accomplish experiments and validations, and conduct the LBB analysis evaluations on marine pressure pipes. The specific research items are:

(1) Apply the ANSYS procedures to analyzing loads and stresses of selected piping systems; determining various loads under normal operation operating conditions and vibration shock conditions, including bending moment, internal pressure, axial force, heat stress and so on; calculating relative stress distributions; and differentiating which stresses have impacts on crack plastic instability.

(2) Apply material testing machines to conducting material fracture performance tests; determining material properties of selected pipes, such as stress-strain curves, yielding limit and intensity limit stress, critical stress intensity factor K_c, J resistance curves and so on.

(3) According to the stress conditions, manufacturing engineering and operating conditions, determine position and shape of the crack, and analyze annular and axial surface and penetrating cracks. The annular crack is more dangerous under majority conditions, so the analysis and computation procedures emphasize researches on annular penetrating cracks and surface cracks, and consider the particularity of winding pipe cracks.

(4) The analysis of leakage detection system includes leakage detection method, sensitivity and so on. The analysis of leakage detection system should be based on experiments and measured data of equipments, consider the impacts of open area of

the crack, surface roughness, two-phase flow and other factors, determine minimum crack dimensions $2a_{leak}$ detectable by leakage detection system, commonly take 10 times of safety margin.

(5) Develop the computation procedures for open area of the penetrating cracks, leakage rate and enlargement velocity under marine conditions, determine critical crack dimension $2a_{crit}$ of instability enlargement; analyze the relations among enlargement stability, critical crack length and loads of surface penetrating crack under marine conditions, and calculate the time t_{LBB} from leakage beginning to crack instability.

(6) Consider the influences of geometry conditions of pipes, stress strain relations of materials, ocean environments and other factors on the LBB characters; analyze overall stability of selected pipes; and determine whether plastic unstable breakages occur on the pipe with cracks. Then, analyze local stability, determine whether the crack causes instable brittle fracture, and conduct fatigue enlargement analysis of surface crack as necessary.

(7) Conduct complete assessments on abovementioned analytical results, accomplish the LBB analysis and evaluation of the selected piping systems, and provide basis for safe evaluations and optimizing designs of the selected piping systems.

CONCLUSION

The LBB technology is a new kind of method arisen in recent ten and more years, which can guarantees high reliability of the pressure pipes, pressure container and other equipments. Compared with the design idea that traditionally regard the Double-Ended Guillotine Break of nuclear power plants as standard design accidents, the LBB method more uses achievements of spring-ductility fracture mechanics researches, make the best use of plastic deformation and strain enforcement characters of ductile materials, fully reduce design redundancy as well as guarantee high reliability of structures.

Developing the LBB researches on marine pressure pipes have not only provided a kind of method on safe analytical evaluations for marine pressure pipes, heighten the reliability of pipes and guarantee safe operations of marine power plants; but also established the technological basis for applying the pipe design criterions based on the LBB technology in the future, simplifying pipe structures, reducing construction, operation and maintenance costs for marine power plants. Therefore, the LBB researches on marine pressure pipes are of momentous significance on heightening safety and economy of marine power plants.

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