Safety Assessment and Fatigue Life analysis of Aged Crane Structures

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Abstract The fatigue life of crane steel structure will inevitably decrease in the course of work, which directly affects the work of crane. So the correct safety assessment and fatigue life evaluation is necessary. According to the results of stress testing and non-destructive examination, a framework of assessing remaining fatigue life of crane metal structures is built in this paper based on crack propagation theory. Moreover, in order to descript the analysis process, an example about fatigue life estimation of a shipbuilding gantry crane whose maximum hoist 100 ton was shown.

Keywords Crane, steel structure, fatigue life, crack propagation

1. Introduction

Crane is one kind of mechanics which is of significant characteristics such as repetitive, cycle, frequent brake and large impact load etc. . Especially, there is about 70-80% metal failure accident which is associated with fatigue. So it is very necessary to research the fatigue life estimation of metal structure. When metal structure of a crane reaches its allowable safe life, it must be retired from service. One of the most important life prediction approaches is the stress-life approach [1-2]. As parts of the damage accumulation calculations, rain flow algorithm and Miner's rule were used. However, with no cracks, this could be the ultimate tensile strength or yield strength, depending upon the failure criteria chosen. As a crack forms and grows under cyclic loading, the residual strength decreases. This decrease as a function of crack size is dependent upon material, environment, component and crack configuration, location and mode of crack growth. Considering the crack, a new analysis method based fatigue crack growth is introduced. Compared to the conventional S-N fatigue analysis, crack detection methods, using several different nondestructive inspection techniques and standard procedures, have been developed [3-6]. This paper will present a framework of assessing remaining fatigue life of in-service crane.

2. Principles of fatigue life analysis

2.1. Conventional S-N fatigue analysis

S-N fatigue analysis is a conventional approach which touches on the relationship between applied stress and expected life. And the relationship is characterized by means of the S-N curve so that fatigue life can be predicted (Fig. 1). "S" stands for the cyclic stress range while "N" represents the number of cycles to failure. The core idea of this method is stress change is the main reason of fatigue failure of materials. Of course, the S-N curve is the inherent property and is derived from tests on samples of the material to be characterized (often called coupons) where a regular sinusoidal stress is applied by a testing machine which also counts the number of cycles to failure. The applied stress used to calculate fatigue life can be obtained by tested strain or stress analysis via finite element method.

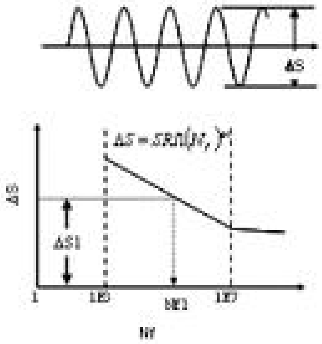

Figure 1. S-N fatigue curve

It should be noted that there are several short comings of S-N fatigue data. First, the conditions of the test specimens do not always represent actual service conditions. For example, components with surface conditions, such as pitting from corrosion, which differs from the condition of the test specimens will have significantly different fatigue performance. Furthermore, there is often a considerable amount of scatter in fatigue data even when carefully machined standard specimens out of the same lot of material are used. Since there is a considerable scatter in the data, a reduction factor is often applied to the S-N curves to provide conservative values for the design of components.

2.2. LEFM based fatigue crack growth analysis

The greatest significance in fatigue crack growth analysis in comparison to the conventional method is the existence of a crack. Cracks can form due to fatigue, or they can exist as a consequence of manufacturing processes such as deep machining marks or voids in welds and metallurgical discontinuities such as foreign particle inclusions. In fatigue life estimation process of metal structure of crane, linear elastic fracture mechanics (LEFM) is introduced to describe and predict fatigue crack growth life and fracture under the basic assumption that material conditions are predominantly linear elastic during the fatigue process. For crack growth or fracture conditions that violate this basic assumption, elastic-plastic fracture mechanics approaches are used to describe the fatigue and fracture process.

In order to perform the life estimation or prediction, several key items are needed: stress intensity factor, maximum and minimum stresses, fracture toughness (KIC), and initial crack size. Of course, environmental conditions, load history, statistical aspects, and safety factors must be incorporated in this methodology for remaining fatigue life assessment.

During the fatigue life estimation process, load history can be finished by the survey of crane usage and statistical analysis. Nondestructive technologies such as magnetic particle testing (MT), ultrasonic testing (UT), penetrate testing (PT) and so on are usually used to detect the size of crack or flaw on the surface of structure. At the same time, the fatigue crack growth behavior is also inspected by these technologies. After idealizing the detected defection, relevant stress intensity factor will be gained via calculation or fatigue handbook. And maximum and minimum stresses can be determinated by means of finite element stress analysis. Certainly, both of them can be tested after typical load test. Furthermore, material properties such as young modulus, tensile strength, yield strength and fracture tough and so on can be obtained via tests. The issued handbooks can also be utilized if common material used in assessing structure. Finally, fatigue analysis can be performed based on measured strains and calculated stresses via finite element method. Prediction of fatigue remaining life can be carried on using professional software.

3. Interpreting methodology for remaining fatigue life assessment

As discussed previously, LEFM is one of the methodologies for remaining fatigue life assessment of metal structure of crane based on fatigue crack growth analysis. The following example shows how the procedures work.

In this example, we researched a shipbuilding gantry crane whose maximum hoist is 100 ton (Fig. 2). Then actual load history data was extracted while referring to the crane usage record. Fig. 3 shows the raw data about one week. Additionally, strains were measured at stress concentration positions, for example, cantilever and boom system. Fig. 4 shows one of the strain measure points at cantilever. All the data was used as the basic input during the estimating residual life process.

Figure 2. The photo of aged crane

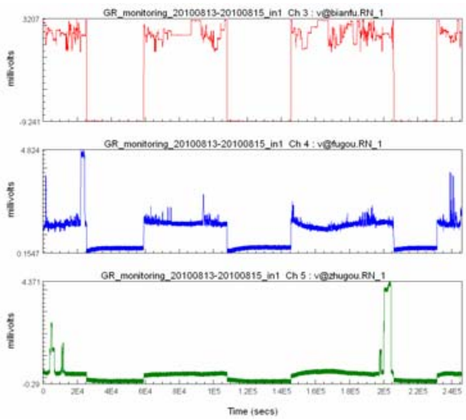

Figure 3. Actual data of load history of crane in less than one week

Finite Element stress analysis provided the primary stress concentration components of the crane. That is, cantilever and boom system. The results can be identified in Fig. 5.

Figure 4. Strain measurement point on cantilever

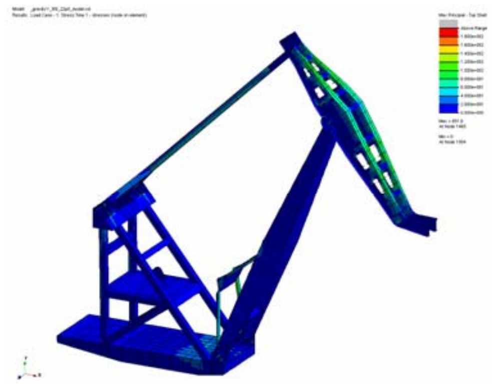

Figure 5. Stress contours of model when lifting 95 ton weight

Nondestructive inspection technology allows parts and materials to be inspected and measured without damaging them. Because LEFM is based on the fatigue crack growth analysis, the technology plays a critical role in inspecting crack or flaw of metalwork structure. During the nondestructive inspection procedure, several defections were found on the cantilever by ultrasonic phased arrays. Defections were inspected by ultrasonic phased arrays such as shown in Fig. 6. Subsequently, these defections were idealized as single edge crack of long atrip and input the fatigue analysis software. The calculation flow can be seen in Fig. 7. The remaining fatigue life of the crane was about 26 years in terms of present damage situation or structural integrity.

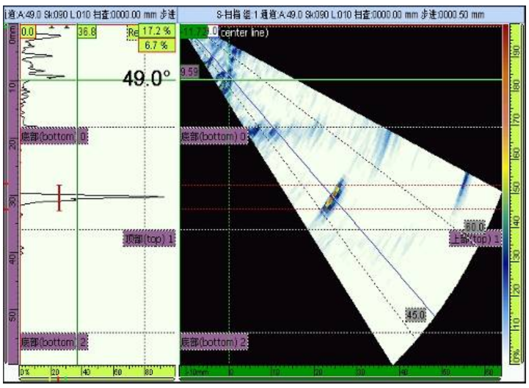

Figure 6. Defection on cantilever via ultrasonic phased arrays

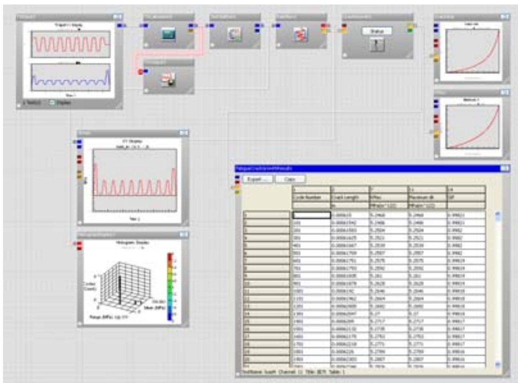

Figure 7. Calculation flow of fatigue life.

4. Conclusions

Based on fatigue crack growth analysis, linear elastic fracture mechanics (LEFM) is introduced to describe and predict fatigue crack growth life and fracture in fatigue life estimation process of metal structure of crane. Especially, the methodology is more suitable for aged crane, which exists some crack or flaw positively. The following example also shows how the procedures work.

Acknowledgments

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