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Fretting fatigue strength estimation considering the fretting wear process

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Abstract

In fretting fatigue process the wear of contact surfaces near contact edges occur in accordance with the reciprocal micro-slippages on these contact surfaces. These fretting wear change the contact pressure near the contact edges. To estimate the fretting fatigue strength and life it is indispensable to analyze the accurate contact pressure distributions near the contact edges in each fretting fatigue process.

So, in this paper we present the estimation methods of fretting wear process and fretting fatigue life using this wear process. Firstly the fretting-wear process was estimated using contact pressure and relative slippage as follows:

$W = K \times P \times S,$

where W is the wear volume (depth), K the wear coefficient, P the contact pressure, S the slippage.

And then the stress intensity factor for cracking due to fretting fatigue was calculated by using contact pressure and frictional stress distributions, which were analyzed by the finite element method. The S–N curves of fretting fatigue were predicted by using the relationship between the calculated stress intensity factor range (ΔK) with the threshold stress intensity factor range (ΔK_{th}) and the crack propagation rate ($\mathrm{d}a/\mathrm{d}N$) obtained using CT specimens of the material. And then fretting fatigue tests were conducted on Ni–Cr–Mo–V steel specimens. The S–N curves of our experimental results were in good agreement with the analytical results obtained by considering fretting wear process. Using these estimation methods we can explain many fretting troubles in industrial fields.

Keywords: Fretting fatigue; Fretting wear; Contact pressure; Fracture mechanics; Threshold stress intensity factor range; Crack propagation rate

1. Introduction

Fretting can occur when a pair of structural elements are in contact under a normal load while cyclic stress and relative displacement are forced along the contact surface. This condition can be seen in bolted or riveted joints [1,2], in shrink-fitted shafts [3,4], in the blade dovetail region of turbo machinery [5,6], etc. During fretting the fatigue strength decreases to less than one-third of that without fretting [7,8]. The strength is reduced because of concentrations of contact stresses such as contact pressure and tangential stress at the contact edge, where fretting fatigue cracks initiate and propagate.

This concentration of stress can be calculated using the finite element method [9] or boundary element method. Methods for estimating the strength of fretting fatigue have been developed that use values of this stress concentration on a contact surface [3,5]. However, the stress fields near the contact edges show singularity behavior, where the stress at contact edges are infinite. Thus, maximum stresses cannot be used to evaluate fretting fatigue strength.

So, in previous papers we present fretting crack initiation estimation method using stress singularity parameters at contact edge [10,11,13], and fretting fatigue limit or life estimation methods using fracture mechanics [7,12,13]. Using these fretting fatigue strength or life estimation method we couldn't estimate the super-high-cycle fretting fatigue troubles in industrial field. For instance 660 MW turbogenerator rotor failed in England during the 1970s as a result of fretting fatigue cracking as shown in Fig. 1 [14].

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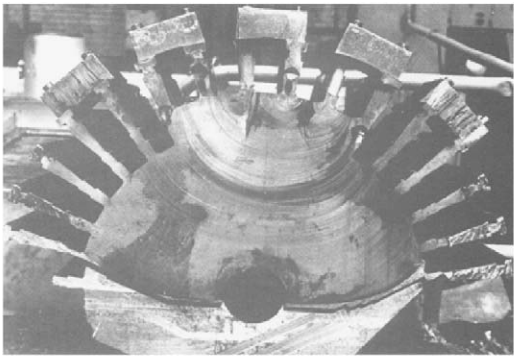

Fig. 1. Fretting fatigue failure example of turbogenerator rotor. After Lindley and Nix (1991) [14].

In this case the loading cycles in just one year is about 1.6×10^9 and this trouble was observed after many years operation. These very high cycle fatigue life can't be explained using only initial stress analysis results. In above mentioned methods we neglect the wear of the contact surfaces near contact edge and change of contact pressure in accordance with the progress of wear.

Here, in this paper we improve these methods on the fretting model where the wear of the each surface near the contact edge is being considered. Finally we can estimate the *S–N* curve in very high cycle fretting fatigue.

2. Fretting fatigue process

Here, we present fretting fatigue process model as illustrated in Fig. 2. Cracking due to fretting fatigue starts very early in fretting fatigue life. We used stress singularity parameters at the contact edge to estimate the initiation of these cracks [10,11,13]. During this early period, fretting fatigue cracks tend to close and propagate very slow, due to the high contact pressure acting near this contact edge. But wear on the contact surface reduces the contact pressure near the contact edge, and cracks gradually start to propagate. Hence, fretting fatigue life will be dominated by the propagation of this small cracks initiated at the contact edge. So to estimate the fretting fatigue strength or life, the precise estimation of the fretting wear progress is indispensable. The propagation life in long crack length region can be estimate using ordinal fracture mechanics. In this paper we discuss the estimation method of wear extension on contact surfaces near the contact edge, and present the fretting fatigue crack propagation estimation method considering fretting wear extension.

3. Fretting fatigue life analysis considering fretting wear

In Fig. 3 the flow of fretting fatigue life analysis considering the extension of fretting wear. Firstly the fretting wear amount is estimated using contact pressure and relative slippage on each loading condition [15]. Then the shapes of contact surfaces are modified following the fretting wear amount. And finally fretting crack extension or arrest evaluation is performed using fracture mechanics, if the operating ΔK is higher than the threshold stress intensity factor range ΔK_{th} we can estimate this load cycle as fretting life, and if the operating ΔK is lower than the threshold stress intensity factor range ΔK_{th} fretting wear amount is estimated using new contact pressure and new relative slippage and repeat these process until operating ΔK reach to the threshold stress intensity factor range ΔK_{th}.

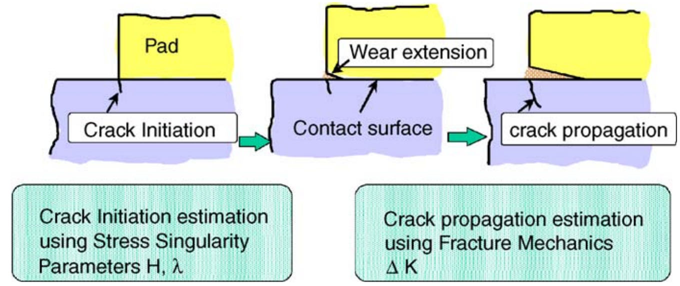

Fig. 2. Freeting fatigue mechanisms in various processes.

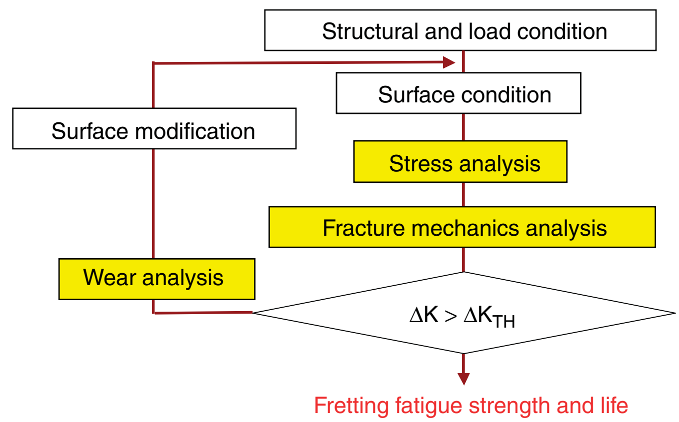

Fig. 3. Flow chart of fretting fatigue life analysis.

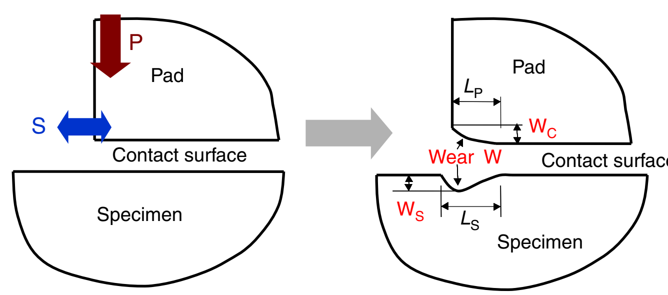

Fig. 4. Wear analysis using contact pressure and slippage.

4. Fretting wear analysis

4.1. Fundamental equation

Using classic Archard's equation, the wear extension on contact surfaces can be expressed as follows (Fig. 4):

$$W = K \times P \times S, \quad (1)$$