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# Bolt assembly optimization and life prediction based on creep curve

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**Abstract**

This paper research the phenomenon that the engine bolts would creep under the preload and the high temperature in the operation process, and creep could cause the degradation of preload leading to engine failure. Through the high-temperature creep test and the stress relaxation test, the creep curve and stress relaxation curve are obtained. With the data of creep test, a method is proposed to find the turning time from the rapid stage to the steady stage of creep process more accurately. Then the retightening operation is applied at the turning time under the same test conditions to optimize the bolt assembly and the new stress relaxation curve could be obtained. According to the data before and after optimization, the life distributions of bolt could be estimated by the method of mathematical statistics.



*Keywords:* Bolt assembly optimization; Creep curve; Stress relaxation; Life distribution.

## 1. Introduction

Bolted joint is the most widely used assembly method in mechanical products and it is also widely adopted in aviation engines. Some important bolted joints have a significant impact on the reliability of the engine working. In the assembly process of the engine rotor bolts, the axial preload should be applied to bolts. In the operation process, the bolts would creep under the preload and the high temperature. Creep could cause the degradation of preload, leading to engine failure.

Creep is an irreversible plastic deformation. The typical metal creep could be divided into three stages: rapid stage, steady stage and acceleration stage [1]. The rapid creep process will cause the early failures of bolts. So the bolts we need are in the steady stageit as long as possible and the retightening operation should be applied at bolts after stress relaxation. Some researchers [2~5] have demonstrated that it is useful to retighten the bolts to decrease the preload degradation rate. Through temperature tests on kinds of bolts with different diameters, they described the degradation curves of the preload and the curves of bolt's retightening operation and demonstrated that there are some potential benefits from retightening the bolts. But they rarely think about the relationship between creep and stress relaxation and do the research about the retightening operation time.

In our previous study, in order to prevent the effect of bolt creep on the degradation of preload, the authors proposed a method that the best way to weaken the degradation rate of preload and improve reliability of bolted joint is that the bolt is retightened at the time when the bolted joint has just reached the steady stage of creep behavior, and the test results validate the effectiveness of this method. Although the time for retightening was offered by the intersection of the first stage curve and the fitted line of the gradient of second stage, the turning point from the rapid stage to the steady stage was not accurate by this method, which is highly dependent on the accuracy of shape of curve. If the increment of axis is changed, the result will change too, resulting in inappropriate time of retightening and affecting the quality of optimization.

This thesis centers on the creep defect of bolts, and proposes a mathematical method to find the turning time from the rapid stage to the steady stage more accurately on the basis of high-temperature creep test and stress relaxation test. According to the obtained turning time, the optimal time for applying retightening could be chosen. Finally, the life distributions before and after optimization were estimated by the method of mathematical statistics.


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## 2. Test overview

In the actual operation process, due to the combined effect of the preload and high temperature on the bolt, the bolt would creep, causing the stress relaxation of bolted joints structure and failure. Therefore, the tests simulate actual operation process of bolts, the amount of stress relaxation was set as the characterization value of bolt performance; temperature was set as the strengthening factor. Through the high-temperature creep test and the stress relaxation test, the creep curve and stress relaxation curve were obtained.

### *2.1. Test conditions*

The specimens is machined with the simplified model shown in Fig. 1. Referring to the actual engine conditions, the material of bolt was 1Cr11Ni2W2MoV; nut material was bronze and the connector (that is the fastener in the actual bolted joint) was the rigid structure. The initial preload was applied to 15kN; the test temperature was set at 500℃. The high-temperature creep test time was 1200h and the stress relaxation test time was 1000h. The test results were collected with every 30 minutes.

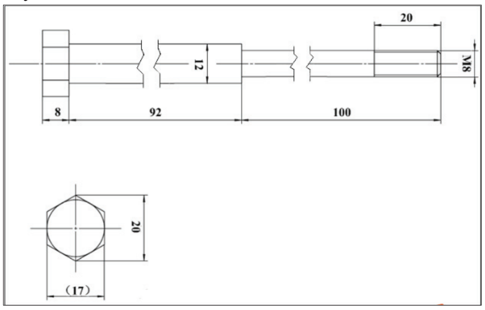


Fig. 1 The size of bolt

### *2.2. Test results*

At a temperature of 500℃, the high-temperature creep test and the stress relaxation test were applied to the same kind of bolts. The high-temperature creep curve and the stress relaxation curve were obtained as Fig. 2 and Fig. 3.

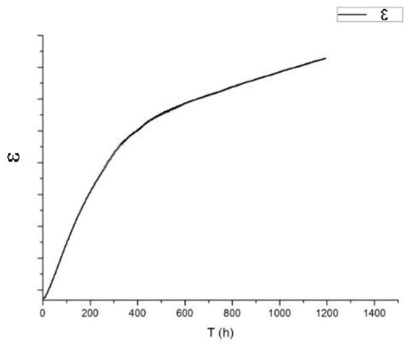


Fig. 2 The curve of bolt creep

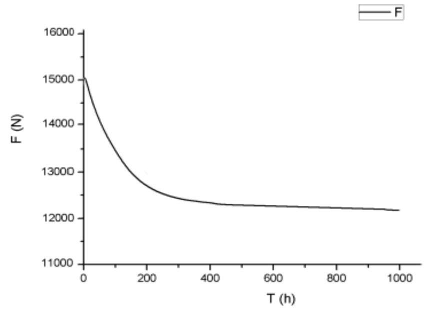


Fig. 3 The curve of bolt stress relaxation

## 3. Data processing

### *3.1. High-temperature creep test*

Creep mechanism is very complex and there are many empirical formulas to describe the creep with time, but it has not been unified [6]. This article need to find the turning time from the rapid stage to steady stage of creep according to the creep test results. However, the rapid stage and the steady stage have not been expressed separately by these empirical formulas. So this paper carried on the rapid curve fitting and steady curve fitting separately, and adopted a simultaneous equation group to figure out the turning time. The proposed solving procedure will be graphically depicted in Fig.4 and the detailed steps will be also given as follows:

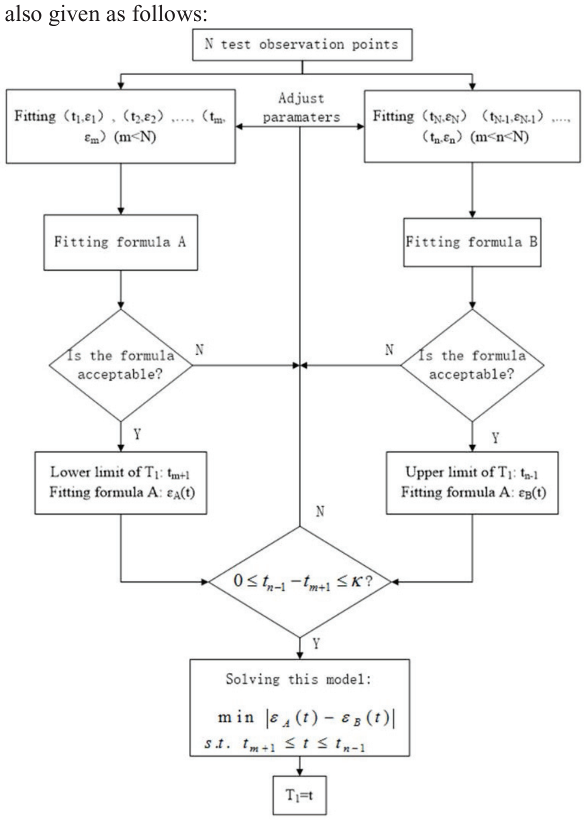


Fig. 4 The flowchart of the proposed solving procedure