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Research Paper Engineering

Effect of Strain Hardening Rate on The Clamp Load Loss Due to an Externally Applied Separating Force In Bolted Joints

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ABSTRACT

The present paper deals with the development of the slicing package of two geometry, cone and sphere, in rapid prototyping. Rapid prototyping is the technique of making prototypes with use of special rapid prototyping machines with various technique. It is called Layered Manufacturing or solid freeform fabrication technology also. This is the process of manufacturing prototypes making slices of whole component. As we know that development means to explore for understanding better way. Here cone and sphere two geometry are taken for the development. Through the programming various views of the cone and sphere are created. The aim of creating an explored view is achieved and real development of the slices is seen with uniform slicing.

Keywords : threaded fasteners, clamp load, yield tightening, fastener fatigue, fastener material strain hardening

1. INTRODUCTION:

Despite the many advances in technology of the mechanical joints in recent years, bolted joints are still the most frequently used methods of clamping assemblies together. Bolted joints are widely used in automobile, aerospace and machine tool industry, etc., due to the advantages they offer. These advantages are the ability to develop a clamping force, the ease of disassembly for maintenance and repair. And hence factors affecting the design and integrity of bolted joints are of considerable industrial interest. The key to strong and reliable bolted connections with long service life is a thorough analysis of the joint forces. Of these forces, the initial clamping load and working load carried by the bolt essentially establish the performance of a joint. Ideally, the initial clamping load must be high to compress joined parts, thereby improving resistance to external tensile loads. This clamping force also creates friction between joined parts, providing resistance to shear loads. Normally bolted joints are designed so that the clamped parts are much stiffer than the bolt is. If the joint is highly preloaded, the bolt working load is relatively small. Low working load is especially desirable in dynamic applications to reduce the possibility of fatigue. Thus the effectiveness of the bolted joints is usually measured by its ability to maintain an adequate level of clamping force on the joint surface during service Nassar and Matin [1] have developed a closed form solution for the amount of clamp load loss due to an externally applied separating force for a bolted assembly in which the fastener is initially tightened beyond its proportional limit. The effect of the fastener strain hardening rate on the clamp load loss has been formulated using a nonlinear strain hardening model.

2. CLAMP LOAD LOSS ANALYSIS: FASTENER AND JOINT BEHAVIOR IN BOLTED JOINTS

The key to strong and reliable bolted connections with long service life is a thorough analysis of the joint forces. Of these forces, the initial clamping load and working load carried by the bolt essentially establish the performance of a joint. Ideally, the initial clamping load must be high to compress joined parts, thereby improving resistance to external tensile loads. This clamping force also creates friction between joined parts, providing resistance to shear loads. Normally bolted joints are designed so that the clamped parts are much stiffer than the bolt is. If the joint is highly preloaded, the bolt working load is relatively small. Low working load is especially desirable in dynamic applications to reduce the possibility of fatigue. Thus the effectiveness of the bolted joints is usually measured by its ability to maintain an adequate level of clamping force on the joint surface during service.

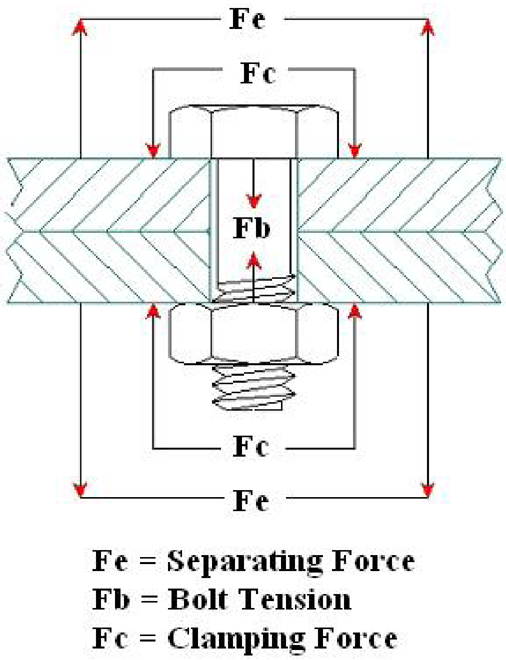

Figure1 : Bolted Joint Model

Figure 1 shows a model of a typical bolted joint, in which the fastener tightening torque creates the fastener tension Fb and the clamping force Fc in the joint. At initial assembly of the joint, both Fb and Fc are equal to some initial value Fi. After initial tightening, the bolted joint is subjected to a separating force Fe that may be static, quasistatic, impact, or cyclic in nature. The separating force increases the fastener tension and reduces the clamp force, simultaneously. As long as the separating force Fe is acting on the joint, the fastener tension and the clamping force will not be equal. They become equal again upon the removal of the separating force. However, the new equilibrium between the fastener tension and the joint clamping force may not necessarily mean that they return to their initial value Fi.[1]

Bolt Stiffness (Kb) - Stiffness of the bolt is the ratio of the load applied to bolt and the deflection produced by it. Bolt stiffness is used to analyze the effects of external loads on bolted joint as well as to determine preload or clamping force. The stiffness of the portion of a bolt or screw within the clamped zone will generally consist of two parts, that of the unthreaded shank portion and that of the threaded portion. Thus the stiffness of the bolt is equivalent to the stiffness of two springs in series. Also it is seen that the stiffness of either a plain or complex body is very much function of the ratio between length and cross sectional area. Thus from the definition of bolt stiffness and equation used to calculate the deflection of a bar in tension or compression, the bolt stiffness is given as;

$$\frac{1}{K_b} = \frac{L_{be}}{EA_B} + \frac{L_{te}}{EA_s}$$

where K_b=bolt stiffness, L_{be} = effective body length, L_{te}= effective thread length, A_s= effective stress area, A_B = cross sectional area of the body, and E= modulus of elasticity.

Case I :Stiffness of the Class 8.8 M10 x 150 bolt

By putting the data L_{be} = 4.62 in, L_{te}= 0.79 in, A_s= 0.0899 in2, AB = 0.1185 in^2,

E= 30x10^6 lb/in^2 in Eq (2.15) the stiffness of class 8.8 M10 x 150 bolt is obtained as;

Kb = 0.6279 x 10^6 lb/in

Case II : Stiffness of the Class 10.9 M10 x 150 bolt

Similarly, by putting the data Lbe = 4.82 in, Lte= 0.59 in, As= 0.0899 in^2,

A_B = 0.1145 in^2, E= 30 x 10^6 lb/ in^2 in Eq (2.15) the stiffness of class 10.9 M10 x 150 bolt is obtained as;

K_b = 0.6165 x 10^6 lb/in

Determination of Clamp Load Loss for Class 8.8 , M10 × 150 Bolt

As such, in this section, the amount of clamp load loss, in terms of strain hardening rate, is determined for class 8.8 M10 x 150 bolt, which is considered to be preloaded beyond its elastic limit. The clamp load loss is caused by subsequent removal of separating force that acts on the joint after its initial tightening. The load deflection curve for class 8.8 M10 x 150 bolt has been determined experimentally, which is used to determine the strain hardening coefficient K and strain hardening exponent n. Experience shows that the stiffness of a "typical" joint (whatever that may be) is about five times the stiffness of the bolt which would be used in such a joint.[22]

As such assume $\frac{K_c}{K_b} = 5$

With K_b = 0.6279 x 10^6 lb/in, the value of K_c is obtained as

K_c =5 x K_b = 3.1395 x 10^6 lb/in.

Substituting the values of K_b, K_c and F_i = 14300 lb, n= 0.281, K=173831 (as obtained from experimental analysis), Ao=0.0899 in2, F_e= 250 lb in Eq (2.13), the clamp load loss, using Ist order approximation, is obtained as

ΔFc = 41.58 lb (184.95 N)

Similarly, by putting above mentioned values in Eq (2.14), the clamp load loss, using IInd order approximation, is obtained as ΔFc = 41.57 lb (184.90 N)

Thus using the same procedure given above and varying separating force Fe (keeping other parameters constant), the amount of clamp load loss, using Ist order approximation as well as IInd order approximation, have been obtained, and the values are given in Table 1

Table 1: Class 8.8 M10 x 150 Bolt - Clamp load loss for various values of Fe

F_e (lb)	ΔFc (lb)	
	Ist order approximation	IInd order approximation
250 (1112 N)	41.58 (184.95 N)	41.57 (184.90 N)
500 (2224 N)	83.17 (369.94 N)	83.14 (369.81 N)
750 (3336 N)	124.76 (554.93 N)	124.71 (554.71 N)
1000 (4448 N)	166.34 (739.88 N)	166.28 (739.61 N)
1500 (6672 N)	249.51 (1109.82 N)	249.42 (1109.42 N)

Similarly,

Table 2 : Class 10.9 M10 x 150 Bolt -Clamp load loss for various values of Fe

F_e (lb)	ΔFc (lb)	
	Ist order approximation	IInd order approximation
250 (1112 N)	41.47 (184.46 N)	41.49 (184.55 N)
500 (2224 N)	82.94 (368.92 N)	82.91 (368.78 N)
750 (3336 N)	124.41 (553.38 N)	124.41 (553.38 N)
1000 (4448 N)	165.88 (737.83 N)	165.91 (737.97 N)
1500 (6672 N)	248.83 (1106.80 N)	248.82 (1106.75 N)

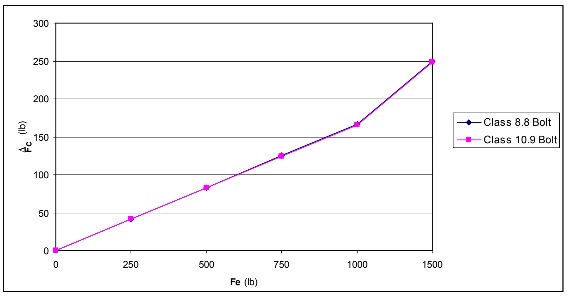

Figure 2: Clamp Load Loss vs. Separating for Class 8.8 and Class 10.9 Bolt Together

3. EXPERIMENTAL ANALYSIS

Experimental determination of the clamp load loss in a typical bolted joint using two types of bolts, for different values of separating force has been carried out to take in to consideration the effect of strain hardening on amount of clamp load loss.

For this purpose, two specific cases of bolted joints using

i. Class 8.8 M10 × 150 size bolt and
ii. Class 10.9 M10 × 150 size bolt have been tested.
Using Universal Testing Machine, the load-deflection curves for the above mentioned bolts have been obtained, from which the values of strain hardening coefficient, strain hardening exponent and elastic limit have been determined. These parameters are used in theoretical analysis to determine the clamp load loss in above mentioned specific bolted joints.

An experimental set-up was planned with the strain gauge load cell developed for the same to measure the clamp load loss. The separating force has been applied to the bolted joint by pulling the sleeves, which have been joined together by the bolt under testing, with the help of Universal Testing Machine with appropriate bolt holding system. The corresponding values of clamp load loss have been recorded and analyzed.

The Specifications of the above mentioned bolts are given in Table 3

Table 3: The Specifications of the Test Bolts

Bolt Type	Nominal Diameter (mm)	Pitch (mm)	Length (mm)	Threaded Length (mm)
Class 8.8 M10 × 150	9.860	1.5	150.6	34.7
Class 10.9 M10 × 150	9.700	1.5	149.7	29.7

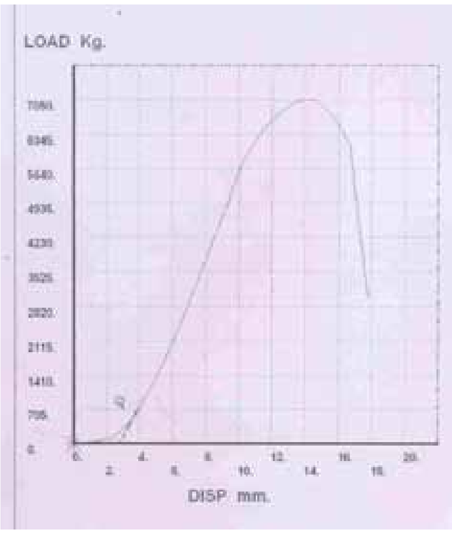

Figure 4: Typical Load-Deflection Curve for Class 10.9 M10 x 150 Bolt

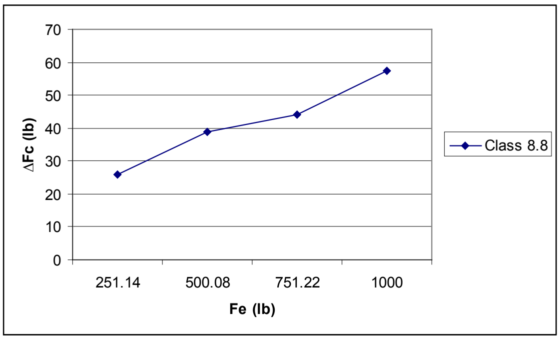

Figure 5 : Experimental Clamp Load Loss vs Separating Force for Class 8.8 M10 x 150 Bolt

4 CONCLUSIONS

(1) From the theoretical and experimental studies, it is seen that the amount of clamp load loss is significantly affected by the separating force and the values of strain hardening coefficient K and strain hardening exponent n.
(2) From the theoretical analysis, it is seen that the amount of clamp load loss is almost inversely proportional to joint-to-fastener stiffness ratio.
(3) For fastener material with low strain hardening rate, it is seen that the initial preload level past the elastic limit has a little or no effect on the amount of clamp load loss.
(4) Also for fastener material with high strain hardening rate, there is some effect on amount of clamp load loss. Thus as the strain hardening rate increases the clamp load loss decreases.
(5) If in an existing design of a bolted joint, the clamp load loss is increased beyond the expected value, due to the external tensile load, in that case, the bolts of the existing design can be replaced by the bolts with higher strain hardening rate material so that the clamp load loss can be minimized to avoid failure of the bolted joint.

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