自發性鬆脫 & 螺栓接合疲乏

Spontaneous Unfastening Versus Fatigue of Bolted Joints

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Introduction

If we do not take into consideration the destruction of screw connections by excessive static load and corrosion cracking (or hydrogen embrittlement), then their life can collapse in two ways: fatigue fracture of bolts or a spontaneous unscrewing of a nut (Fig.1).

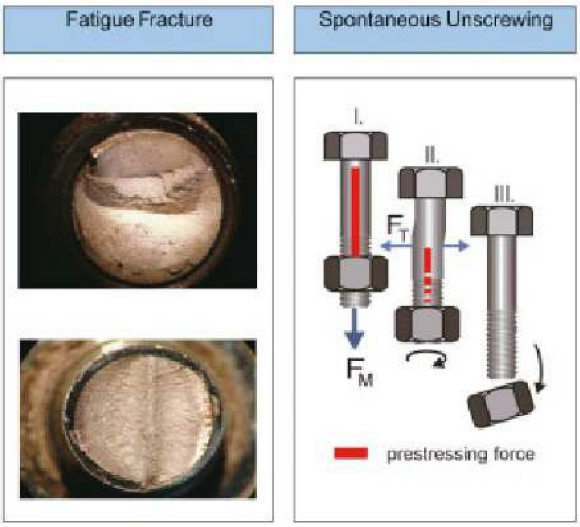

Fig. 1 Disintegration of Bolted Joints Due to Repeated Dynamical Stressing and Vibrations

In both cases, the screw joints lose their ability to function, so both cases are dangerous. When, however, is there unscrewing and when the fatigue fracture? The following contribution will try to give the answer to this question.

Theoretical Problem Analysis

Unlike the destruction of parts from excessive effects of static force, spontaneous loosening is time-dependent gradual process of decline of bolting prestress leading to their complete disintegration with parallel cumulation (Fig. 2) of the fatigue material damage.

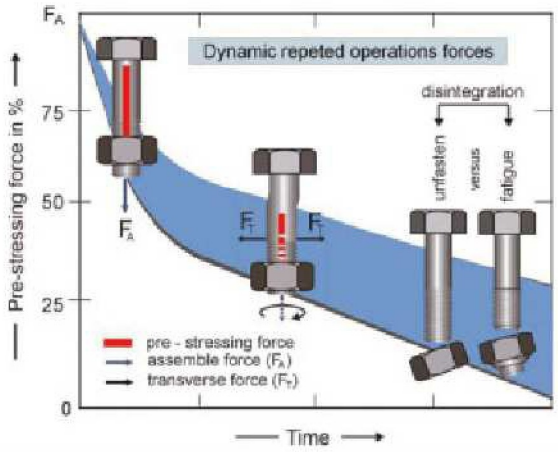

Fig. 2 Disintegration of Bolted Joint

Statistically, it is proven that the joint decay usually occurs when self-unscrewing. However, there are not isolated instances of fatigue fracture of screws after preceding half-way loosening while the joint itself is not completely disintegrated. The reason for this is cyclical repeated dynamic shocks and vibrations transmitted to the relevant nodes.

For functioning it means correctly tightened bolted joint have effect on two types of forces:

a) Internal or assembly induced by tightening the joint forces to a value of prestressing. Internal forces can be defined quite accurately and also applied to the assembly by using of torque wrenches with more or less precision.

b) External forces caused by additional operational loading. External and internal forces are mutually interrelated and

complement one another proportionally and disproportionally or counteract each other. Therefore, we are talking about a superposition of the forces. It is complicated and difficult to control. It is often a random process depending on many factors. In most cases, it is a combination of statically and dynamically operating axial, radial or torsional forces which can be hard to predict.

For absence of exact data on the operating conditions, designers usually offset by increasing the safety coefficient by sizing of bolted connections, increasing the coefficient of friction on the contacts surfaces, choice of fine pitch thread or by other measures. However, the designer can never guarantee 100% operational safety because he is not responsible for the installation and subsequent handling. The mentioned superposition of forces causes that the original, i.e. assembly prestressing may not be preserved but by improper installation and adverse operating conditions it gradually decreases, in extreme case right to zero.

Precondition for the right working of bolted connections is assembly prestressing that achieves by required tightening torque. During operation the prestressing serves as reservoir of assembly forces and it may not drop below a certain critical value. On the contrary, it may not exceed the strength characteristics of material even for short additional operational burden. Fig. 3 shows that just a little proportion of energy supplied in form of torque (M_{ef}) is used effectively for preloading required to maintain associated parts in the tightened state. The rest of energy (M_{fr}) is used for overcoming friction between threads and under the head of the screw and under the nut and is converted into reactive heat. Here is valid:

$$M=M_{fr}+M_{ef} \Rightarrow M_{ef}=M-M_{fr}$$

In terms of safety it is not torque what is important, but the prestressing that causes it. The higher friction between the screw and the head of screw and the nut entails the lower constant M prestressing, it means that the connection will be sufficiently tightened. Untightened or ragged although not fully disassembled screw connection represents a significant security risk because in a short period of time, there is a bore to discharge mounting holes with subsequent spontaneous disintegration service or fatigue fracture of screws and it occurs preferably in locations of the biggest stress concentration, in this case, in the interface of external and internal thread.

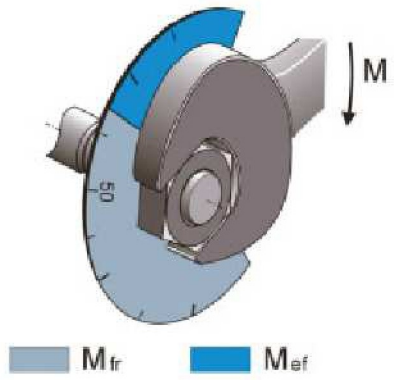

Fig. 3 Moment Distribution

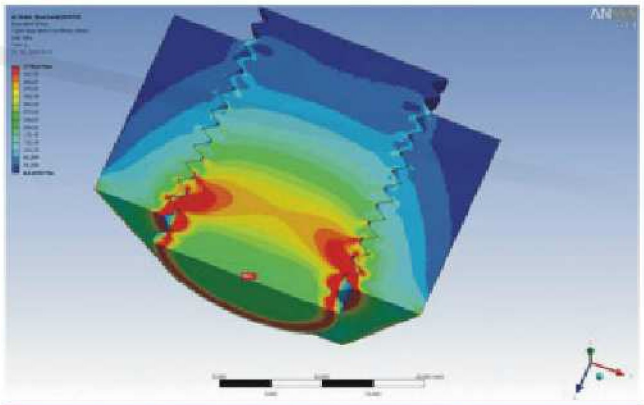

Fig. 4 Course of von Mises Stress in Bolted Joint

Spontaneous Unfastening (Release) Versus Fatigue Fracture

As it was already mentioned, if we omit the brutal congestion, then bolted joint can collapse either due to spontaneous release or fatigue fracture (Fig. 1 and 2). Both cases are, equally, dangerous and the causes are also the same - the vibration and repeated dynamic stress. But when is there the spontaneous release, when the fatigue and when fracture? The answer is not so simple, but on the knowledge about the behaviour of bolting, we can, at least, formulate a core argument.

As it is generally known, the process of spontaneous release is proceeding in three known phases: 1. the relaxation, 2. the spontaneous unfastening and 3. the decay (or disintegration). The relaxation occurs without the nut/screw turn over. The cause lies on aligning the contact surfaces and on inequalities of microplastic deformation in these areas. The second stage begins with gradual of scrolling matrix and/or screws in assembly dependent current downturn which results

into the third stage - total separation from the nut screws. The case of total unscrewing is clear. But what will happen if the prestressing falls to zero and the nut is not detached from the screw? Will the first two stages occur? This state may occur due to using of the lock nut with nylon ring according to DIN 985, or another safety element with similar properties. If the dynamic loading exposition continues, after certain number of cycles, the critical cumulation of fatigue damage and subsequent fatigue fracture will occur, which is, from the point of safety, certainly worse state. The reason is simple. While a loose screw can be checked and possibly tightened, fatigue failure comes suddenly, without warning.

Fatigue Failure and Actions to Increase the Bolt Capacity

Fatigue failure develops in parts loaded by variable loads mostly in areas of stress concentration although the value of the nominal stress is far below the ultimate strength. Statistics confirm that from the total number of observed standardized bolts which have been damaged by fatigue fracture, the fatigue failure occurred in 65% of the bolts in the first support thread, 20% in the thread run-out and 15% in transition from the shank to the bolt head. From the given statistics if fatigue failures, there are apparent areas which need to be focused on when constructing dynamically loaded bolt connections.

1. The reduction of the notch coefficient in thread run-out by rounded transition to bolt shank.
2. The radius transition increase from head to bolt shank.
3. If possible, do not use bolt with fine pitch thread.
4. If possible, do not use bolts with large diameters. Prefer two smaller bolts to one large.
5. Use suitable structural design of joints with studs.
6. Use cross-thread bolt design for through-hole
7. Use stud with nut cross-thread bolts for dead hole. For dead hole is preferred to use stud with nut, based on the bottom of the hole, instead of the standard bolts. The best stud is with ball end, or with inserted ball.

We also note that the dynamic load of bolted joints must be designed bolt satisfying "static" control with regard to yield strength for the load from maximal axial force.

Conclusion

The loosening of bolts causes improper assembly, followed by the loss of their self-locking during the operation. Then, it depends on the particular circumstances whether a classical breakdown of bolt joint occurs or its destruction occurs by material fatigue. Statistically, it is proven that the most frequent spontaneous release of bolted joints occurs after the first loaded cycles. Therefore, it is important in their current monitoring, especially in that interval.