

# Failure Analysis on Tail Rotor Teeter Pivot Bolt on a Helicopter

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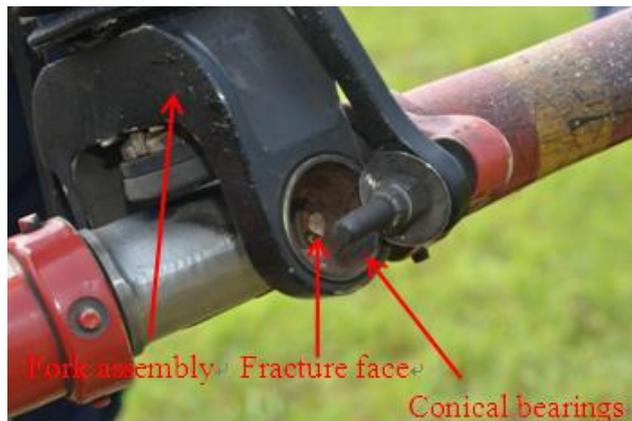
**Abstract.** Tail rotor teeter pivot bolt of a helicopter fractured when in one flight. Failure analysis on the bolt was finished in laboratory. Macroscopic observation of the tail rotor teeter pivot bolt, macro and microscopic inspection on the fracture surface of the bolt was carried out. Chemical components and metallurgical structure was also carried out. Experiment results showed that fracture mode of the tail rotor teeter pivot bolt is fatigue fracture. Fatigue area is over 80% of the total fracture surface, obvious fatigue band characteristics can be found at the fracture face. According to the results were analyzed from the macroscopic and microcosmic aspects, fracture reasons of the tail rotor teeter pivot bolt were analyzed in detail

## 1. Introduction

As the main rotor blades rotate, the fuselage will rotate the opposite direction if unopposed. Tail rotor system of helicopter as one of key components, not only provide anti-torque and achieve directional control, but also keep the helicopter's yaw stability, its working condition directly affects the safety and reliability of the helicopter[1]. Tail rotor teeter pivot bolt as a helicopter tail rotor system of the core force component, need to bear a greater bending moment and experiencing a lot of alternating load. Tail rotor flapping hinge bolt fracture will directly lead to the helicopter yaw control failure, even cause serious catastrophic accidents.

March 2016, a general aviation of domestic was carrying out flight training in field. The helicopter was climbing out when severe vibration prompted the commander to carry out an immediate autorotation landing in a field. The helicopter incurred severe damage during the landing. On inspection, The bolt attaching the tail rotor hub to the rotating fork assembly, about which the rotor is free to teeter, was found to have fractured.



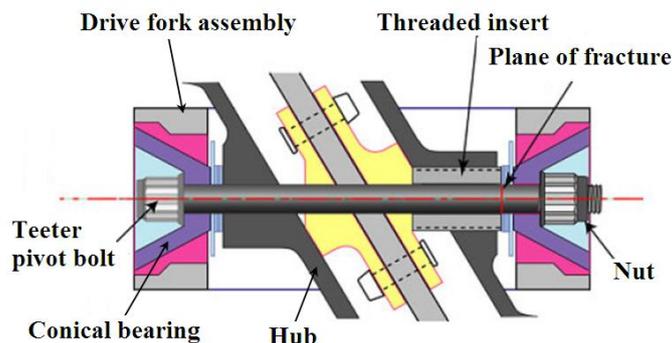


**Figure 1.** Fracture face of the tail rotor teeter pivot bolt

Examination of the fracture face of the teeter pivot bolt showed that it had failed in a plane very close to the exposed face of the threaded insert, allowing the dust shield and washers on one side of the hub to be lost (Figure.1). The thread insert is screwed into the hub forging. The fracture face incorporated a raised angular peak and trough at one edge with a ridge or step extending from the peak across the section separating the two halves of the fracture. Each half occupied a slightly different, though parallel, plane and the two were thus independent fracture surfaces. The paper on the fracture of the teeter pivot bolt were analyzed, the failure mode, analyzes the causes of failure[2].

**2. Structural layout of tail rotor teeter pivot bolt**

The tail rotor, mounted on the tail rotor transmission at the end of the tail-boom, counteracts main rotor torque and controls the heading of the helicopter. The tail rotor system consists of two variable-pitch blades mounted on a teetering delta-type hub assembly which is in turn mounted in a rotating fork. The fork incorporates two conical bearings and a bolt passes through the hub and both bearings. Teetering motion of the rotor is enabled by the presence of the bearings[3]. The bolt, in addition to passing through the bearings and the basic hub trunnion, passes through a shoe, within the hub, which locates the straps holding the two blades against centrifugal force. It also passes through an insert threaded into the hub. Shim washers of various thicknesses bear against the protruding inner races of the conical bearings and enable the pre-load to be adjusted. Two washers of larger diameter, acting as dust shields, are positioned on either side of the hub. structural layout of tail rotor hub components(Figure.2.)



**Figure 2.** Structural layout of tail rotor hub components

The teeter pivot bolt is secured and tensioned by a nut which, when the assembly is correctly installed, ensures that the inner races, the nut, bolt, hub, shoe, threaded insert, shim washers and the dust shields all oscillate in unison relative to the fork as the rotor rotates during forward flight.

**3. Analysis of tail rotor teeter pivot bolt**

*3.1. Appearance check*

The whole morphology of fractured tail rotor teeter pivot bolt is shown figure 3. No obvious bending

deformation was found in this section of the bolt. But, at ends of the surface visible obvious signs of corrosion, wear characteristic is not obvious. The fracture section is located on the left side of the bolt. The fracture face is located at the edge of the threaded end bearing, the corrosion feature of the fracture surface of bolt is serious.



(a) Morphology

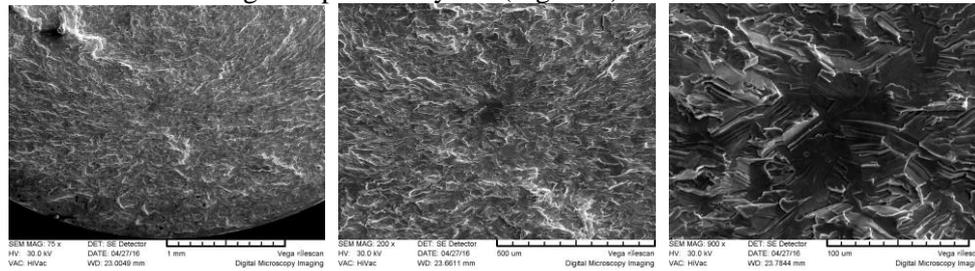
(b) Fracture section

**Figure 3.** Morphology and fracture section of teeter pivot bolt

According to the fracture profile of the bolt. Fracture section height slightly difference, the underside side is relatively flat, upper side is rough. It can be seen from the above figure 3, left and right sides of the lower radiation ridge feature near the surface of the origin of the position, indicates that its source fracture is located in this location.

*3.2. Microscopic observation of fracture*

Scanning Electron Microscope (SEM) examination of the bolt found that fatigue cracking had sourced at the below side surface of the fracture section, no obvious defect on the source location. Fatigue growth from the source area to the left and right sides of the fracture surface, fatigue strip fine, fatigue expansion full. Besides, according to the fracture feature, it can be seen that the cyclic stress of fatigue fracture is small and more fatigue expansion cycles (Figure.4).

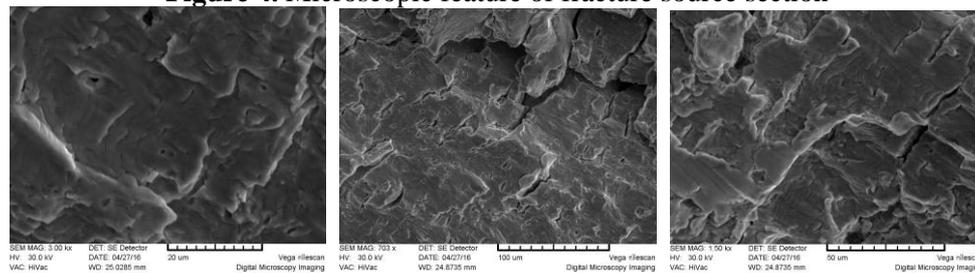


(a) Low magnification

(b) Middle magnification

(c) High magnification

**Figure 4.** Microscopic feature of fracture source section

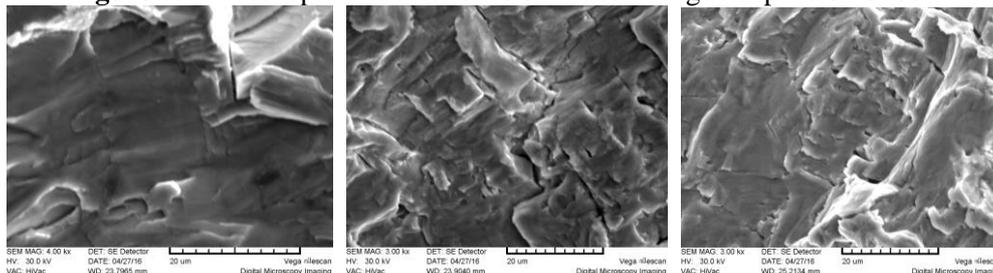


a In initial period

b In middle period

c In late period

**Figure 5.** Microscopic characteristics on the left fatigue expansion of bolt



a In initial period                      b In middle period                      c In late period

**Figure 6.** Microscopic characteristics on the right fatigue expansion of bolt

The microscopic characteristics of fatigue expansion at the left and right sides, from the front, middle and late stages of the fatigue source of the bolt fracture, the fatigue characteristics of fracture are obvious, fatigue strip fine, fatigue expansion full (Figure.5 and Figure.6). The fatigue had the characteristics of torsional shear stressing applied in two distinct directions. However, the torsional evidence was, not orientated about an axis coincident with that of the bolt. Therefore, it can be concluded that the fracture property of the bolt is fatigue fracture.

### 3.3. Material analysis of teeter pivot bolt

Energy spectrum analysis of the tail teeter pivot bolt, shown that the material for Ni-Cr alloy, contains Ni, Cr, Fe and other elements.

## 4. Analysis and discussion

### 4.1. Fracture property of bolt

The fracture face of tail rotor teeter pivot bolt at the thread root, originated in the near surface position of the bolt fatigue fracture, Obvious fatigue band characteristics can be found at each location of the fracture face, fatigue area is over 80% of the total fracture surface[4]. Therefore, it can be concluded that the fracture property of the bolt was high cycle fatigue fracture.

### 4.2. Analysis of causes

Reference to the maintenance manual of the aircraft revealed that a requirement exists for the preload in the teeter pivot bolt to be ascertained at regular intervals. An alternative method of tightening the nut, involving achieving a measured stretch in the bolt, was also available when installing bolt. The tightness of the teeter pivot bolt in its housing found during sectioning of the hub could have been caused by an unfavourable combination of manufacturing tolerances. The bolt was not, however, measurably different in diameter from another sample bolt measured. It was not possible to measure accurately the internal diameter of the threaded insert or the shoe due to the necessarily destructive method used to separate them.

Considering the bolt in the work not only bear the alternate load of the tail rotor, but also subjected to torsion of tail rotor transmission component, combined with the analysis of the bolt fracture characteristic, analysis that causes of the bolt fatigue fracture has the following 3 possible:

(1) The tail rotor fork bolt failed in fatigue after a period of operation with no pre-load present in the bolt/nut assembly. The lack of pre-load was probably a consequence of failure to establish the correct tension in the bolt at the time of last assembly. Failure to establish the correct tension may have resulted from a tight fit of the bolt within the threaded insert, disguising the fact that the bolt head was not correctly seated as torque was applied.

(2) The bolt is not fitted with appropriate thickness of shims when it was installed. The bolt in installation, failed to effectively measure fork assembly inner diameter, outer diameter and the teflon dust thickness of tail rotor hub, The fork assembly cannot eliminate the loose of conical bearing ends and the axial clearance of bolt, which lead to the normal flapping motion of the conical bearing to be blocked.

(3) Contamination of the bore of the threaded insert. Contamination of the bore of the threaded insert with teflon dust may have caused the tight fit of the bolt within the threaded insert, which leads to fatigue torsion of the bolt during installation.

It seems reasonable to analysis that the bolt failed as a result of a fatigue mechanism which, although not fully explained, nonetheless resulted from operation with a bolt which was not carrying the correct end-load consistently throughout its length. The installation irregularity responsible for this condition was most probably excessive friction of the bolt within the bore, shoe or threaded insert in the hub, experienced at the time of assembly, resulting in the bolt failing to seat fully.

## 5. Conclusion

The fracture face originated in the near surface position of the bolt, no obvious defect on the source location the fracture extends from the source area to the left and right sides, fatigue banding closely. The fracture of tail rotor teeter pivot bolt is caused by fatigue fracture, high cycle fatigue fracture due to high original stress and fatigue fracture development is more adequate. It shows that the fatigue crack has experienced a long time process from the initiation to the final fracture.

## 6. References

- [1] Wang Qiang. Failure Analysis on Tail Rotor Teeter Hinge Bolt Fracture for a Certain Type of Helicopter[J], *Aviation Maintenance & Engineering*,2017,5:98-100.
- [2] LI Chun-guang, SHU Ping, MA Xiao-ming, etal. Failure Analysis on Tailor Rotor Rod Components of a Helicopter[J], *Failure Analysis and Prevention* ,2013,8 (6):346-349.
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