

Fracture Failure Analysis of Wheel Hub Bolts

Lei Guo^a, Jiasheng Liu and Yan Liu

The 713th Research Institute of CSSC, Zhengzhou 450015, China

^a guol19880418@126.com

Abstract. The hub bolt is a high-strength bolt connecting the wheels of the vehicle, which is used to bear the large torque connection between vehicle hubs and wheels. In view of the fracture phenomenon of the wheel hub bolts of the transfer vehicle during pre-tightening, the causes are analyzed from the bolt material, service load, shear stress and tightening torque, etc., the causes of bolt fracture are clarified and the corresponding strategies are formulated..

Keywords: Wheel; Bolt; Shear Stress; Tightening Torque.

1. Introduction

The transfer vehicle is the equipment used to transport goods on board. The wheel is an important part of the transfer vehicle for driving, steering and braking. It bears the vertical load, transverse force, braking torque and various stresses generated during driving [1]. The wheel of the transfer vehicle is mainly composed of wheel hub, wheel rim and four sets of connecting bolts and nuts (Fig. 1). The wheel hubs and rims are selected from the shelf products of commercial automobiles, and the bolts and nuts are all supporting parts. When pre-tightening the wheel hub bolts during use, a bolt of the right rear wheel hub was found to be broken (Fig. 2). Observing the broken bolt, it is found that the fracture of the bolt is located at the first thread where the nut and the bolt are not screwed together (Fig. 3). In order to find out the reason, the situations that may cause the bolt to break were analyzed.

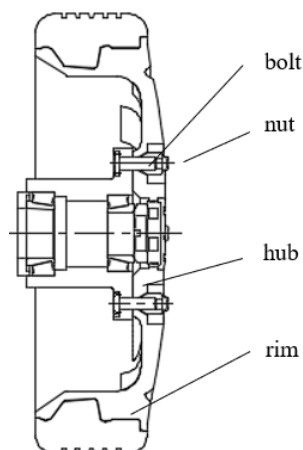


Fig 1. The composition of the wheel



Fig 2. The wheel hub

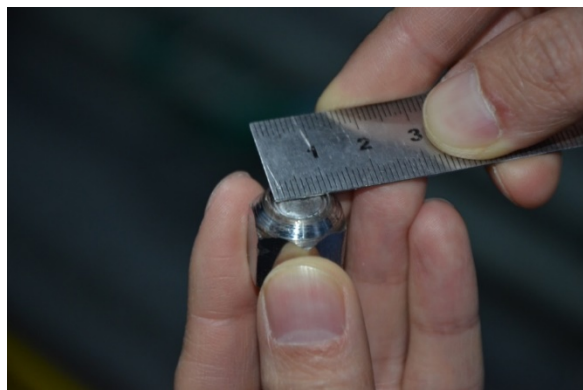


Fig 3. The broken bolt

2. Cause Analysis

2.1 Unqualified Bolt Material

The material of the wheel hub bolt is 08F carbon structural steel, and the diameter of the bolt is M10. Samples were taken from three different positions of the broken bolt and component analysis was conducted. The results are shown in Table 1. It can be seen from Table 1 that the bolt material meets the standard requirements. Therefore, the unqualified bolt material is not the cause of bolt fracture.

Table 1. Comparison of standard requirements and measured results

	C	Si	Mn
08F GB/T 699-1999	0.05~0.11	≤0.03	0.25~0.5
Sample 1	0.072	0.0120	0.386
Sample 2	0.073	0.0139	0.358
Sample 3	0.067	0.0083	0.330

2.2 Excessive Load During Use

In actual use, the total weight of the cargo transferred by the transfer vehicle does not exceed 1t. Taking into account the situation of the three wheels landing on the ground when the transfer vehicle is in the limit position, the single wheel bears half of the total weight at this time, the safety factor is $K=1.3$, and the maximum load of a single wheel is about 6500N. Through the finite element simulation, the stress distribution of the wheel hub under extreme working condition is shown in Figure 4. The wheel hub is made of 45 steel with a yield strength of 355MPa and the yield strength of the bolt is 175Mpa. It can be seen from Figure 4 that the maximum stress of the hub is 36.09Mpa, which occurs at the edge of the hub and the hinged joint between the hub and the bolt. It can be seen that the strength of the hub and bolt far meets the requirements, and the overload during use is not the cause of bolt fracture.

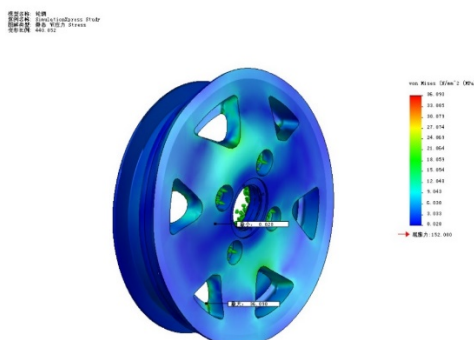


Fig 4. Stress distribution diagram of hub under extreme working condition

2.3 The Shear Stress on the Bolt is Excessive

The rated load of the transfer vehicle is 1t. Considering the limit state of the three-wheel landing, the single landing wheel on the other side of the suspended end of the wheel bears half the gravity (500kg) of the rated load. Taking the wheel hub as the research object, assuming that F is the support force of the tire to the wheel hub, F_m is the friction between the hub and the rim, F_z is the support force of the bolt to the hub, then $F = F_m + F_z$. Taking the friction between the wheel hub and the rim under the extreme working condition as 0N, so the supporting force of bolts to the wheel hub is $F_z = F = 5000N$. Because the holes on the hub are hinged holes and each bolt is stressed evenly, so the shear force of a single bolt is $F=1250N$. The shear stress of the bolt is $\tau = \frac{F_0}{A}$, where A is the cross-sectional area of the bolt[2], and the calculated shear stress is $\tau=15.92MPa$. The yield stress of the bolt is 175Mpa, and the shear stress limit value is $\tau_s = 87.5MPa$ according to the third strength theory, from $S_s = \tau_s/\tau$, $S=5.5$. It can be seen from Table 2[3] that the maximum safety factor of M10 bolt under static load is 4, which is smaller than the design safety factor. Therefore, excessive shear stress is not the cause of bolt fracture.

Table 2. Safety factor S_s of the pre-tightened bolt

Material type	Static load			Variable load		
	M6~M16	M16~M30	M30~M60	M6~M16	M16~M30	M30~M60
Carbon steel	4~3	3~2	2~1.3	10~6.5	6.5	10~6.5
Alloy steel	5~4	4~2.5	2.5	7.5~5	5	7.5~6

2.4 Excessive Tightening Torque during Pre-tightening

For the bolt connection, its tightening torque[4] T is used to overcome the thread resistance torque T_1 of the thread pair and the end face friction torque T_2 between the nut and the bearing surface of the connected piece. When the bolt is coated with thread glue, all the torque of the wrench is applied to the bolt when the nut is screwed by the wrench. The yield limit of the bolt material is 295MPa, so when the shear stress $\tau=147.5MPa$, the yield limit strength of the material is reached. If the shear stress of the bolt is greater than its yield limit for many times, the bolt will break and fail. According to the calculation formula of shear stress[5] $\tau = T_1/W_t$, W_t is the torsional section coefficient, $W_t = \pi D^3/16$, D is the bolt diameter, so $T_1 = \tau \times \pi D^3/16$. After bringing in the relevant parameters, the calculated thread resistance torque T_1 is 28.9Nm.

The calculation formula of carbon steel preload is as follows [6]:

$$F' = 0.7\sigma_s A_s \quad (1)$$

In the formula, σ_s is the yield point of the bolt material, in Mpa, A_s is the nominal stress cross-sectional area of the bolt, in mm^2 , the calculation formula of A_s is as follows:

$$A_s = \frac{\pi}{4} \left(\frac{d_2 + d_3}{2} \right)^2 \quad (2)$$

$$d_3 = d_1 - \frac{H}{6} \quad (3)$$

In the formula, d_1 is the minor diameter of the external thread, d_2 is the middle diameter of the external thread, d_3 is the calculated diameter of the thread, H is the original triangle height of the thread. The pre-tightening force $F=6079N$ can be obtained by bringing in relevant data. According to the friction torque calculation formula [7]:

$$T_2 = \frac{F'\mu}{3} \times \frac{D_w^3 - d_0^3}{D_w^2 - d_0^2} \quad (4)$$

D_w is the width of the opposite side of the nut, d_0 is the diameter of the connected part (bolt diameter). After bringing in the relevant data, the friction torque T_2 is 17.1nm, so the tightening torque of the wrench reaching the yield point of the bolt material is: $T = T_1 + T_2 = 46Nm$.

The torque arm length of the wrench used for pre-tightening is 200mm. According to the torque required at the yield point, the operator only needs 230N to reach the yield limit of the bolt material. The position of the wrench when tightening the bolt is shown in Figure 5 and Figure 6. When the force is applied in the horizontal direction, the height of the force application point is 420mm. According to the standing right arm tension calculation formula (Formula (5)) and standing right arm tension value (Table 3) in “Gunner Operating Force” (GJB 703-89), when the nut is tightened horizontally, the vertical tension is 341N, which is greater than the force required to break the bolt (230N). Tightening the bolt in this position can cause bolt fracture. Therefore, the cause of bolt failure is overload fracture caused by excessive pre-tightening force.

$$Y = 357.2 - 0.04361X - 0.007829X^2 \quad (5)$$

In the formula, Y is the tensile force, in N; X is the height of the force application point, the value ranges from 40 cm to 160cm.

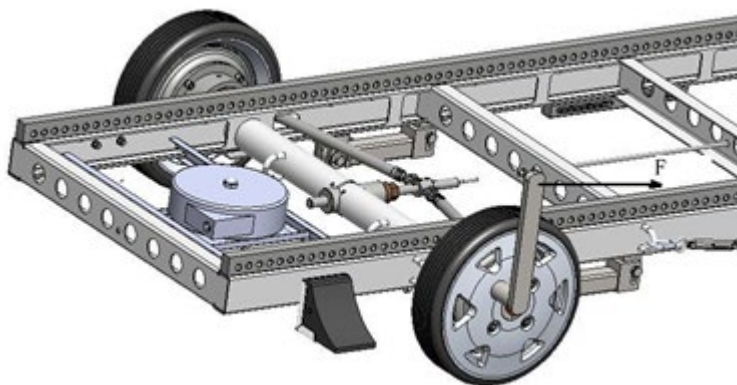


Fig 5. Apply force horizontally when tightening the nut

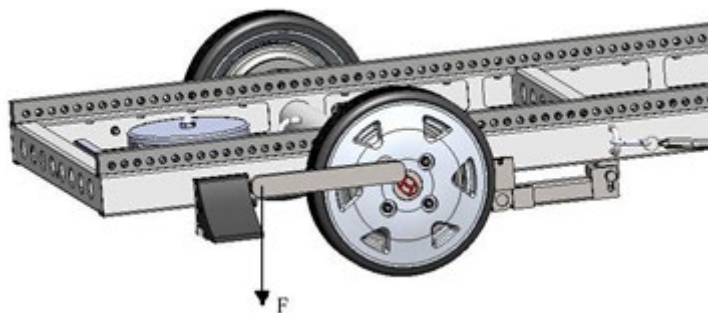
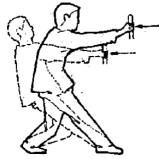


Fig 6. Apply force vertically when tightening the nut

Table 3. Standing right arm tension value

	height of the force application point(cm)							Posture of exerting force
	40	60	80	100	120	140	160	
Standing right arm tension (N)	343	326	304	275	239	198	150	

3. Conclusion

Through the analysis, it can be concluded that the bolt fracture is the overload fracture when the bolt is tightened. In order to avoid bolt fracture in subsequent use, the following measures are mainly taken:

- (1) Replace the high-strength thread glue originally applied on the bolts with medium-strength thread glue to avoid excessive initial tightening torque during pre-tightening;
- (2) Mark and locate the nut matched with the bolt, and tighten it when the scale deviates;
- (3) Change the bolt material to 304 stainless steel, which has higher yield strength and better corrosion resistance than 08F.

References

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