"Fastener Troubles, Causes & Solutions" Series

Tire Falling Accident of Large Vehicles Part 3 Proposal of High Precision Fastening Apparatus

by Toshimichi Fukuoka

In most cases, tire falling accidents of large vehicles can be prevented by fastening the bolts connecting the wheels to the hub with a prescribed torque. However, in actual practice, the accidents cannot be completely eliminated as usual. One of the reasons is that it is difficult to rely on human power to fasten all the wheel bolts because a lot of bolts are used in large vehicles. As a countermeasure, we can think of using pneumatic torque wrenches or electric powered torque wrenches. Therefore, the opening part of this article compares the fastening characteristics of wheel bolts between the two cases, i.e., when using manual torque wrenches and pneumatic torque wrenches. Next, referring to the experimental results, I will introduce a "tightening apparatus with four shafts" which has been developed for achieving both high precision fastening and high workability.

Fastening Precision and Workability of Wheel Bolts

The most critical point in bolt fastening is to apply the prescribed axial force. However, in the fastening process using Torque Control Method, the produced axial force is almost in inverse proportion to the coefficient of friction of contact surfaces even if the bolts are fastened with the same torque, which I have explained in my previous article (the third one in the series). The reason that the bolts must be fastened with the prescribed axial force is to prevent the loosening and fatigue failure of threaded parts. My previous article indicates that the stress amplitudes produced in the threaded parts are not so large, even if axial bolt forces reduce to 50% of the expected values. Considering the foregoing phenomenon, we can say that the probability of fatigue failure is almost zero as long as the wheel bolts are fastened with prescribed torques, if a certain degree of scatter in coefficients of friction is involved.

Figure 1

(a) torque wrench

(b) air wrench

Figure 1 (a) is a torque wrench exclusive for wheel bolts. The recommended fastening torque is 600Nm, and its weight is about 72N. The arm length during fastening operation is 1.2m. There exist a few problems when using this torque wrench.

(1) In order to produce a torque of 600Nm, the force applied to the wrench should be 500N, which is quite a large force. This requires physically well-built workers to do the job.

(2) Since wheel bolts of large vehicles need at least 80 times and more of fastening operations, there is a problem to cope with the job by human power.

For problem (1), utilizing simple principles of mechanics, there are torque wrenches that are designed to be capable of producing the same bolt force with 300Nm of fastening torque. In any event, the fastening operation requires a large amount of mechanical energy as usual in relation to problem (2). As a countermeasure, impact wrenches are to be used. Impact wrenches use compressed air to rotate threaded fasteners by means of impact force. Therefore, they have fast fastening speed and high level of workability. On the other hand, they basically cannot control the magnitude of torque, and so the scatter of fastening torque is inevitable. As a consequence, they may cause such problems as insufficient axial forces or over-tightening of the bolts. The former problem leads to loosening or fatigue failure of the bolts; the latter leads to plastic deformation of the bolts. Accordingly, it is required for the fastening method of wheel bolts to possess both axial force precision and high workability.

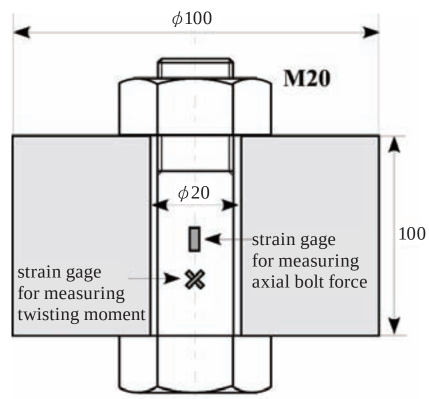

Figure 2

Fastening Experiments Using Torque Wrench and Pneumatic Torque Wrench

In this section, I will evaluate the fastening precision of wheel bolts when using a torque wrench through experiments. In the meantime, I will conduct fastening experiments using a pneumatic torque wrench as a substitute for the torque wrench. ***Figure 1 (b)*** shows a pneumatic torque wrench used in the experiments, which is commonly referred to as an air wrench. Air wrenches are similar to impact wrenches in that they utilize compressed air, and they also have a huge advantage that the magnitude of the torque is controllable . However, the fastening speed is lower than that of impact wrenches, which leads to an inferior workability. Nevertheless, from the point of fastening precision, we should use torque-controllable tools. As shown in ***Figure 2***, a strain gauge and a cross-type gauge are mounted to the bolts used in the experiments for measuring axial force and coefficients of friction. ***Figure 3 (a)*** and ***(b)*** show the relationships between fastening torque and coefficients of friction on thread surface and nut loaded surface, when fastened with a torque wrench and an air wrench. Experimental results are shown with averaged values of 8 experiments and error bars of the standard deviation 1σ.

Air wrenches obviously produce lower scatter, especially in the coefficient of friction on the nut loaded surface. When using a torque wrench, the fastening torque is as large as 600Nm, so it is difficult to fasten smoothly with human power. Therefore, it is presumed that the variation of coefficients of friction have grown larger.

Figures 4 (a) and ***(b)*** are the results of fastening experiments using actual hub and brake drum, which were also shown in Figure 1 in my second article of the series. They show the measured results using a torque wrench and an air wrench, respectively. An experiment of fastening 8 wheel bolts with diagonal pattern was repeated 5 times. The vertical axis is the axial bolt force, and the horizontal axis is the numbers for identifying 8 bolts. The axial bolt forces show the values at the time of fastening the inner nuts and the outer nuts, at which the fastening operation is completed. As in Figure 3, the scatter in axial forces is represented by means of averaged value and error bars of standard deviation 1σ. The air wrench obviously shows smaller scatter in axial bolt forces than the torque wrench. Additionally, since the air wrench generates higher axial bolt forces, it is predicted that the use of air wrench may produce smaller coefficients of friction than that of torque wrench.

As mentioned above, the use of air wrench will decrease coefficients of friction and also decrease its scatter, which is expected to provide an ideal fastening condition for us.

Development of Tightening Apparatus with Multiple Shafts

In the previous section, I demonstrated that air wrenches are the appropriate tools for wheel bolt fastening. However, they have slower fastening speed than impact wrenches and hence have the drawback of inferior workability. In light of that, I turned my focus on the fastening method that uses multiple air wrenches.

Figure 5 shows the tightening apparatus with 4 shafts using four air wrenches. The apparatus utilizes the high fastening precision of air wrenches and improves workability by using 4 air

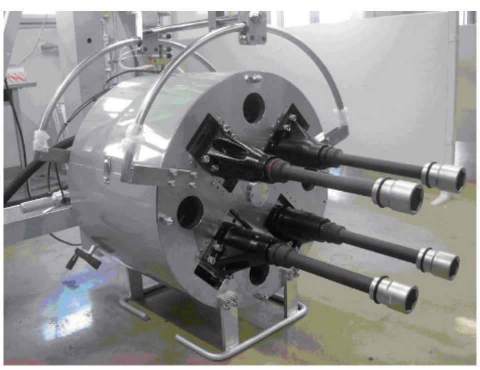

Figure 5

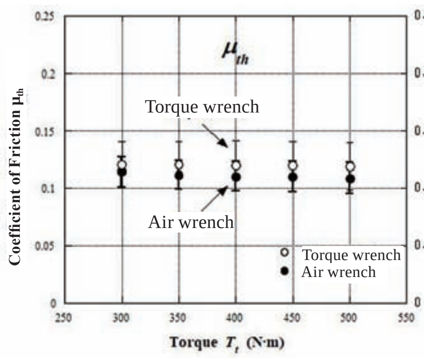

Figure 3 (a)

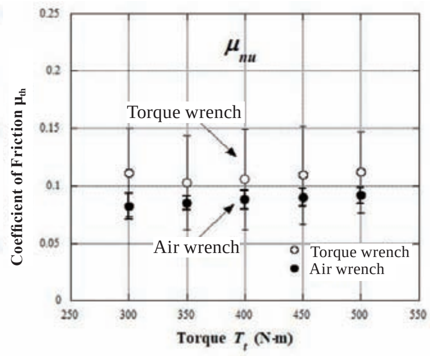

Figure 3 (b)

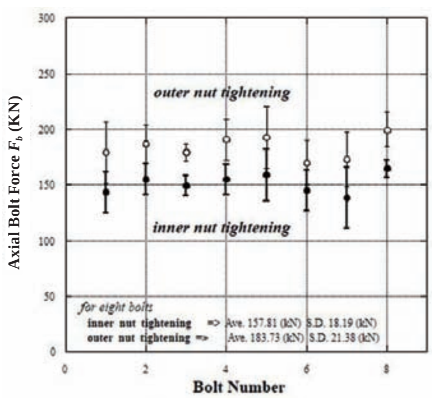

Figure 4 (a) Torque Wrench

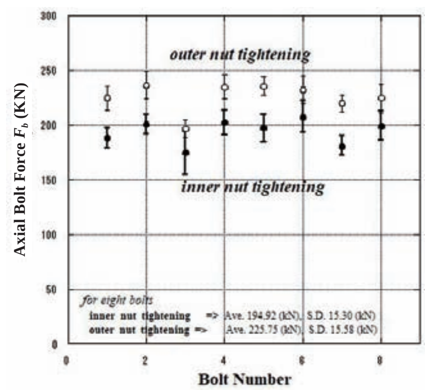

Figure 4 (b) Air Wrench

wrenches. The characteristics of the apparatus are as follows.

(1) Each air wrench stops rotating when reaching the regulated torque of 600Nm.

(2) The apparatus can simultaneously fasten 4 wheel bolts in a single round of fastening.

(3) The apparatus can rotate 45 degrees to the left and right, so it can finish the fastening of 8 wheel bolts by repeating the operation twice.

Using this apparatus, we can fasten wheel bolts within ±5% scatter of the target bolt forces and achieve high level of workability at the same time. Furthermore, since the whole apparatus is to be hung from the ceiling, it is easy to mount 4 air wrenches to the apparatus, even if the floor surface in contact with the tire is not completely flat.

Conclusion

Tire falling accidents of large vehicles can be prevented if we can fasten wheel bolts with the specified torque. To achieve that, I conducted fastening experiments using air wrenches, and introduced a tightening apparatus with 4 shafts that has been developed based upon the obtained experiment results. Although a series of three articles are intended for wheel bolts specified by Japanese Industrial Standards, the wheel bolts of ISO standards, in which 10 bolts are required in sets for fastening, have also caused quite a number of accidents due to fatigue failure. I hope the content introduced in this article will help reduce tire falling accidents of large vehicles occurred around the world.

Reference:

1. Japan National Traffic Safety and Environment Laboratory, Report of the Research Committee on Tire Coming-off Accidents of Large Vehicles due to the Rupture of Wheel Bolts, 2004.
2. Toshimichi Fukuoka, "Threaded Fasteners for Engineers and Design – Solid Mechanics and Numerical Analysis –", pp.264-280, Corona Publishing Co., Ltd. (2015).