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Short communication

Failure analysis on fracture of worm gear connecting bolts

Ling Li *, Rong Wang

Shanghai Key Laboratory of Engineering Materials Application and Evaluation, Shanghai Research Institute of Materials, Shanghai 200437, China

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ABSTRACT

The worm gear connecting bolts of refueling machines of a nuclear power plant, with implementing standard of ANSI/ASME B18.3 and ASTM A574-08 and strength grade of 10.9, fractured at the thread neck position after running for about 10 years, and means such as macro examination, chemical compositions analysis, hardness testing, metallographic examination and fracture analysis, were used to analyze the fracture property and reasons of the bolts. The results show that the fracture of the bolts is due to two-way bending fatigue fracture. Surface decarburization of the bolts and stress concentration at the bolt thread neck decreased the fatigue strength of this position and resulted in the initiation of fatigue cracks. By comprehensive analysis and stress estimating, it was concluded that the main reason for fracture of the bolts is that there was a big gap between the bolts and the bolt holes, which resulted in fatigue fracture of the worm gear connecting bolts.

0. Introduction

Worm-gear transmissions can change the high speed rotation output from the power generators or internal combustion engines into low speed and stable work output which suitable for varieties of specific operation, and they are widely used in the feed mechanisms for mining and steel mills, as well as elevators. An important characteristic of the worm-gear transmissions is that it can increase the torque, but it also means that the large axial force of the worm would be converted to a large circumferential force of the gear [1]. Refueling machine is an important device for adjusting the radioactive fuel in nuclear power reactors, and it completes the fuel delivery and removal by a push rod (or a wire rod) under the control of worm-gear transmission system. There are two sets of push rods driving the worm gear for a refueling machine and each set of driving worm gears was focused by 6 connecting bolts. It was found that all the 6 connecting bolts of a set of driving worm gears fractured during maintenance after about 10 years. After fracture the bolts partially prolapsed and made the worm gear and the internal gear could rotate relatively, see Fig. 1(a). Fig. 1(b) gives the morphology after dismantling the driving worm gear from the internal gear, and it can be found that all the bolts fractured in the bolt holes of the internal gear and screw threads can be seen on inside walls of the bolt holes. According to the design paper, the bolt holes of the internal gear consist of two parts, and the lower part has screw threads and the upper part is unthreaded hole. However, the actual spot inspection results show that the upper part of the bolt holes also had screw threads, and only the thread tooth tips were worn. The connecting bolts fracture phenomenon was also found for all the 4 refueling machines with the same type and being bought at the same time, and there was no loose phenomenon for the un-fractured connecting bolts. It was also known that wire rod deadlocking phenomena occurred occasionally during operation of the refueling machines. The implementing standard of the fractured bolts is ASME B18.3:2003 "Socket Cap, Shoulder, and Set Screws, Hex and Spline Keys (Inch Series)" and ASTM A574-08 "Standard Specification for Alloy Steel Socket-Head Cap Screws" with bolt shank diameter of 5/16 in (7.94 mm), bolt thread portion external diameter of 1/4 in (6.35 mm), and strength grade of 10.9. To find reasons for the fracture of

* Corresponding author.
E-mail address: sctliling@163.com (L. Li).

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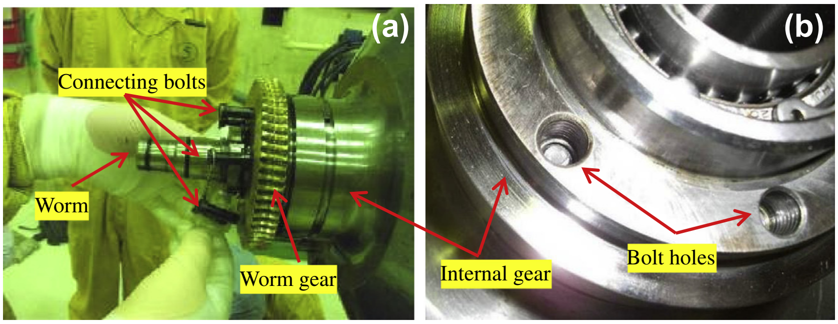

Fig. 1. Failure scene of the fractured worm gear connecting bolts (a) before dismantling and (b) after dismantling.

the connecting bolts and prevent similar failure accidents reoccurring, a great deal of analysis work was carried out to the fractured bolts.

1. Physical testing and chemical analysis

1.1. Macro examination

Fig. 2 is one part of the fractured connecting bolt. It can be seen that the bolt fractured at the transition arc position near the bolt thread neck, with the fracture surface being approximately perpendicular to the bolt axial direction. The bolt surface was covered with black oxide film except the part close to the fracture surface, where the black oxide film was damaged and distributed in equidistant parallel just like the screw threads, and it is considered the result of repeated contact between the bolt and the bolt hole of the internal gear.

As shown in Fig. 3, most of the fracture surface of the connecting bolt is smooth, and only a relatively small area is rather coarse and it is the final instant fracture zone. There are a lot of small steps at outer circumference of the bolt fracture and they are fracture sources, and two sides of the final instant fracture zone are both fatigue propagation zones [2–4].

Fig. 4 is the morphology of the same batch of un-fractured connecting bolts, with total length of 41.80 mm, bolt shank diameter of 7.86 mm, bolt thread neck diameter of 4.74 mm, bolt thread portion external diameter of 6.26 mm, and transition arc radius of 0.86/2 = 0.43 mm. According to ASME B18.3:2003, the transition arc radius should be in the range of 0.022–0.028 in (0.56–0.71 mm), so the actual transition arc radius of the bolt is less than the required value. Measuring was also done to the 6 fractured bolts, and the measured bolt shank diameters are all 7.86 mm which meets the standard requirement of (5/16 ± 0.005) in [(7.94 ± 0.13) mm)]. The bolt hole diameters of the worm-gear corresponding to the bolt shank part are 7.90–7.92 mm with the requirement of 7.91–7.92 mm, the hole diameters of the seals are 7.92 mm with the requirement of 7.91–7.92 mm, and the hole diameters of the internal gear matching to bolt shank part is 7.94–8.00 mm with the requirement of 7.91–7.92 mm. From the above results it can be found that there is a gap with size of 0.08–0.14 mm between the bolt shank parts and the bolt holes of the internal gear. However, the design allowed gap size should be in the range of 0.025–0.09 mm.

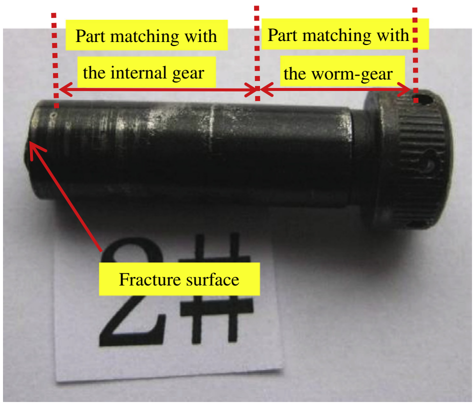

Fig. 2. Macro morphology of one part of the fractured bolt.