RESEARCH OF ELECTRICAL CONTROL SYSTEM FOR FLYWHEEL TIGHTENING DEVICES IN ENGINE ASSEMBLY LINES

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ABSTRACT*: According to the modification requirement for the flywheel tightening device in the assembly line of a well-known automobile manufacturer, this paper designs an electrical control system for flywheel tightening device with the Schneider TXS57 series controller and the XBTGK2330 touch screen as the control core. In order to achieve the precise control over the torque, angle and other parameters during bolt tightening, this paper performs some basic mechanics analysis and experiment on the current bolt tightening methods and techniques, and finally selects the torque-angle method. Under this method, two wrenches are added and tightening is performed according to settings, which makes up for the insufficient capacity of the company, and helps ensure its normal production and operation. The system studied and designed in this paper is of great significance to promoting the application of flywheel tightening devices in automobile engine assembly. It can manage and control tightening data at limited costs, which is an excellent solution for the information construction at factory.*
KEYWORDS*: Bolt, tightening device, flywheel, electrical control system*

1 INTRODUCTION

Bolting is an essential part of mechanical assembly. Nowadays, in the assembly of automobiles, bolting has been widely applied. Bolts themselves are extremely cheap, but they are massively used in automobile production. If any bolt in a key part of a car such as the engine flywheel and crankshaft is damaged or fractures or fails in the course of driving, it is very likely to cause car damages or even a serious traffic accident involving casualties (Bondrea and Rosca, 2015). Therefore, bolts in the key parts of an automobile need to be re-checked for torque in a timely manner. In the bolt assembly process, bolts in the key parts should be tightened with strict control over their tightening torques, angles and other variables. In the past few decades, with the rapid development of high technologies in aviation, military, automobile and other fields, bolting has also been widely applied and given attention to, and at the same time, requirements have also been getting higher for the quality and precision of bolting (Cosma, 2015). As a result, there is a great market need for the R&D of automatic bolt tightening devices. Take the automotive industry as an example (Vilau et al., 2015). At present, there are more than 100 automakers in China and over 500 automotive component suppliers, where a large number of assembly tools and assembly systems with different precisions are required in the production processes. Currently, most of the automatic bolt tightening devices on the domestic market are expensive imported equipment. Due to the high price of the imported equipment, it has become an inevitable trend to localise these technologies and equipment. Designing, developing and modifying automatic bolt tightening devices can save a lot of foreign exchanges and bring significant economic and social benefits (Guo et al., 2016).

In the automobile manufacturing industry, thanks to the mature manufacturing technologies in Europe and over a century of experience in production and assembly, many automobile manufacturers have developed their own unique assembly and manufacturing standards. In Europe, there are Volkswagen, Mercedes Benz, Jaguar Land Rover and PSA Peugeot Citroen, and in the U.S., there are General Motors and Ford Motor, which have another set of assembly and tightening standards. In addition, there are also some high-end truck manufacturers, such as Scania AB Sweden and Volvo, etc., which also employ high-precision tightening tools to manufacture trucks (Bataineh and Taamneh, 2017).

Nutrunner refers to electric wrench. International research papers on this tool are mainly from the United States and Sweden, which are the countries where world-renowned electric tightening tool manufacturers are located (Hedlund et al., 2015). In the past two years, with the widespread of intelligent manufacturing and industry 4.0, more and more people have been paying attention to intelligent manufacturing equipment.

Unlike overseas countries which have mature structure design and control technologies, China is still accumulating experience and developing tightening tools. In the past few years, it has seen some progress in this field, and the research content and direction has also changed from simple applications to the design schemes of tightening tools. In the research of an automatic bolt tightening device, Wei Daozhu (Hefei University of Technology) described in detail how the electric tool accurately controls the torque and angle in the bolt tightening process (Zhao et al., 2015). Huang Gongwei, in the design of an automatic bolt tightening device control system, analysed the control principles of the electric tightening device, including the PLC modular control. Shan Jiping (Dalian Gangbu Electromechanical Co., Ltd.), in the design of an electric multi-shaft nut tightening device control system, described how the host computer communicates with and gives commands to the electric tightening tool through the field bus. Domestic researches on electric tightening tools mostly focus on the secondary development and modification of electric tightening tools and the integration of multi-shaft tightening equipment.

In order to achieve precise control of the torque, angle and other variables during bolt tightening, this paper performs some basic mechanics analysis and experiments on the bolt tightening technologies and designs a feasible scheme. Based on this scheme, this paper selects the flywheel in the automotive engine as the assembly object in the R&D and design of the automatic tightening device (Viriyarattanasak et al., 2015). With the incorporation of advanced concepts like modular design, the tightening device can be applicable to a wide range of products and satisfy other special requirements.

Based on the current facilities and the technologies of similar advanced products overseas and considering the production conditions of the manufacturers in China, this paper incorporates advanced concepts in the design, including the modular design, and attempts to develop a bolt tightening device with high stability, high efficiency and precise control (Deters et al., 2014).

This paper analyses the tightening device technology from the perspective of structure and chooses the torque-angle method. It designs the electrical control system hardware for the flywheel tightening device with the Schneider TXS57 series controller and the XBTGK2330 touch screen as the control center, writes the control programme and designs human-machine interfaces. The system is implemented and applied in actual practice.

2 BOLT TIGHTENING TECHNOLOGY

Bolts are used to keep the connected parts together, and can overcome the external forces caused by the connected parts. There are totally four kinds of external forces to the bolting connections. When a bolt is in the pre-work state, it is subjected to the preload. If the preload is properly applied, it will make the bolt connection more reliable and tighter. However, if the preload is excessive, the fastener will be overloaded and fractures (Zhai and Xu, 2017). And if the preload is insufficient, it will reduce the tightness of the fastener and weaken its anti-loose performance.

When a bolt is tightened, under the action of the tightening torque, the bolt is subjected to not only the tensile stress σ arising from the preload Q_p but also the torsional shear stress τ due to the torsion of the bolt friction moment. Then, according to the distortion energy theory, we obtain the equivalent stress σ_v at this time:

$$\sigma_{\mathrm{v}} = \sqrt{\sigma^2 + 3\tau^2} \approx 1.3\sigma \tag{1}$$

During tightening, to make the bolt unyielding, the following must hold:

$$\sigma_{\mathrm{v}} = 1.3 \leq S_P \tag{2}$$

S_p—— bolt proof stress, which is generally:

$$S_P \approx 0.9\sigma_{\mathrm{s}} \tag{3}$$

Then we obtain the pre-tightening coefficient:

$$S_{Q_P} = \frac{\sigma}{\sigma_S} \approx 0.7 \tag{4}$$

And there is,

$$Q_P = (S_{Q_P})\sigma_S A_S \tag{5}$$

σ_s——yield limit of the bolt material

A_s——dangerous section area of the bolt

The corresponding preload is obtained by the pre-tightening coefficient, which not only helps maintain the normal service of the bolt but also ensures the reliability of the connection. This solves the problem of inconsistency between the actual preload and the design one.

After the bolt is subjected to an axial work load, the total pulling force on the bolt shall be:

$$Q = Q_P' + F \tag{6}$$

Or

$$Q = Q_P + K_C F \tag{7}$$

Q'_p—— residual preload

F——axial work load of a single bolt

K_c——relative rigidity of the bolt

If the impact of the torsional shear stress is taken into account, the strength condition is:

$$\frac{1.3Q}{A_S} \leq [\sigma] \quad (8)$$

σ——residual preload on the bolt material with small permissible tensile stress. Then we have:

$$Q_{P'} = C_V F \quad (9)$$

C_V is the coefficient. In normal bolting, when the load is stable, C_V=0.2-0.6; and if the load is unstable, C_V=0.6-1.0.

Then we obtain the preload Q_p:

$$Q_P = Q_P{}' + (1-K_C)F = [C_P + (1-K_C)]F \quad (10)$$

In the past, adhesive was often used to tighten the bolts and prevent them from loosening. The adhesive was applied on the fasteners to form a substantial chemical cohesion between them so that bolt joints will not loosen even if they are not tightened (Zhou and Co, 2016).

In automobile assembly, bolt tightening is carried out to provide a certain amount of preload between the bolt joints. There are currently three main methods to control bolt tightening – torque-angle method, torque method and yield limit control method.

During bolt tightening, when the bolt is tightened to the pre-set torque value, tightening will be stopped. This is called the torque method. Being economical and practical, it is now the most popular and commonly used bolt tightening method in domestic automobile manufacturers. In the torque method, the tightening tools used are very cheap and easy to operate. The disadvantage is that when the control accuracy is determined, the friction coefficient of the fastener will greatly affect the assembly quality.

The torque-angle method is to first set a snug torque at the beginning of bolt tightening, then tighten the bolt to the pre-set snug torque, and rotate the bolt to the set angle. In the torque-angle method, the preload is less dispersed, and the tightening quality is not much less interfered with by the friction coefficient of the fasteners. As a result, the tightening quality of the fasteners is very reliable and the bolt will not fracture even if it is under great preload (Dai et al., 2016). However, the tightening tools used in the torque-angle method are very expensive and also not easy to operate.

During bolt tightening, if the incremental ratio of torque and angle is monitored and tested and then the bolt joints are tightened to the yield point, this is called the yield point control method. Under this method, the preload is the least dispersed among the three methods, and the tightening quality is only affected by the yield strength of the bolt. When the bolt joints are tightened to the yield point, the preload and vibration will have much less impact on the bolt and as a result, the anti-loose performance of the bolt joints will be greatly improved. However, the tools used in the yield point control method is very expensive.

According to the company's modification requirements and the actual conditions, this paper finally selects the torque-angle method, mainly because under this method, the dispersion of the preload is very small, which can greatly improve the utilization of materials, and at the same time maintain high reliability.

3 HARDWARE COMPOSITION OF THE BOLT TIGHTENING DEVICE

The system shaft control unit consists of two units - tightening controller unit 1 and unit 2. The main control unit is mainly used to coordinate the work of all shafts, because when the bolt joints are tightened, the shaft control unit will only control its own tightening shaft unit. The main control unit communicates with each shaft control unit, and at the same time, each tightening shaft also sends data to the main control unit. The main control unit then issues commands to adjust the work of each shaft according to the collected information. The main control unit is mainly used to coordinate the work of each shaft and save the parameters required for the operation of the tightening device, record the tightening workload and quality to facilitate technicians in making adjustments to the tightening device, and test the hardware related to the tightening work. When any failure occurs, it will automatically send out alarm. The shaft control unit is mainly used to control its own tightening shaft according to the commands it receives from the main control unit, receive the signals from the sensor of the tightening shaft, judge the bolt tightening result, issue an order on whether it is qualified, and send the data collected from each shaft and the tightening shaft to the main control unit. The tightening control structure diagram is shown in Fig. 1.

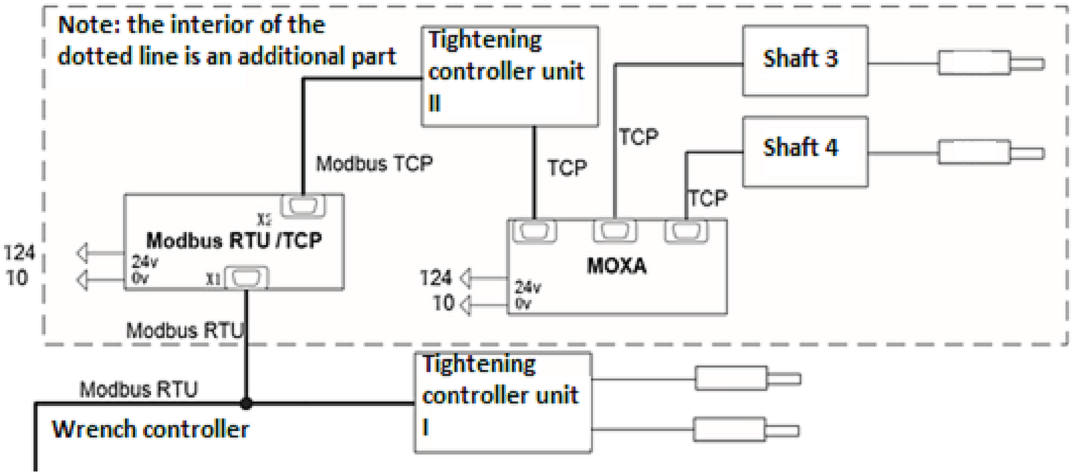

Figure 1. Tightening control structure diagram

This paper selects the model and specification of the controller according to field conditions. The main control system consists of various modules, namely power module, main control module, input and output module and auxiliary communication module, as shown in Fig. 2.

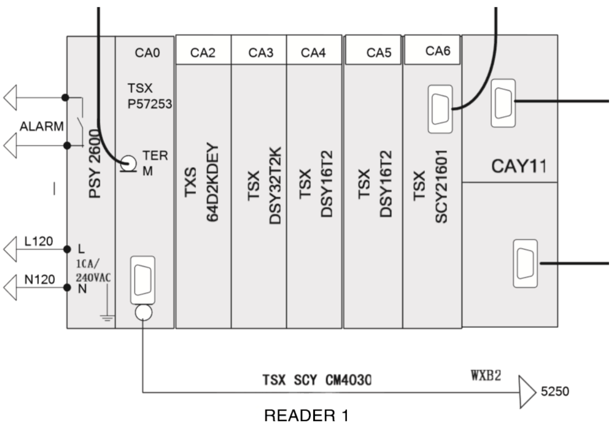

Figure 2. Controller composition diagram

4 SOFTWARE DESIGN FOR THE BOLT TIGHTENING DEVICE

After analysing the principles of the tightening device and considering the actual conditions of the project, this paper decides to use the programming language LAD. In the programme design, the author first draws an overall programme flow chart, and then writes the programme according to the flow chart. Comments need to be given during the programming.

After the touch screen is activated, the programme will be initialized and then choose the operation mode. It will keep running until the production is completed (De Oliveira et al., 2015). The flow chart of the automatic operation programme is shown in Fig. 3.

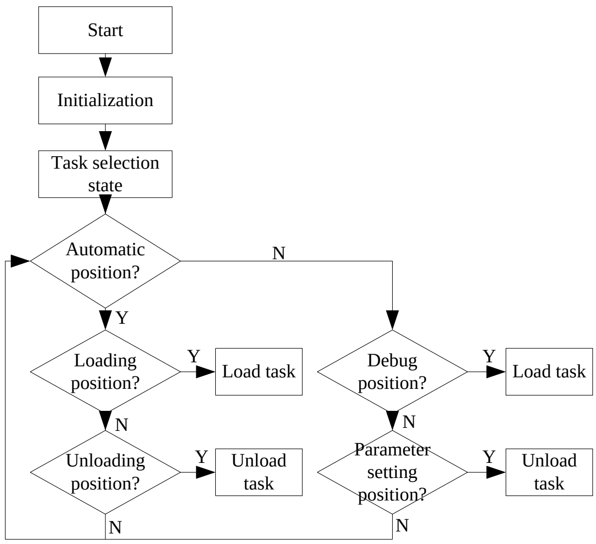

Figure 3. Flow chart of the automatic control programme

In the wrench tightening cycle, if the tightening is not qualified, the slipway will stop at an unqualified angle and send out alarm. The solution is to switch the position to the manual mode, manually loosen the bolt, change it and get the slipway back in place, and erase the memory, and then restart the cycle. Another solution is to execute the automatic loosening programme – keep the position status unchanged, find the “ action by step” on the “home screen”, click the “action by step” button to make it turn dark green, and then find “loosen the unqualified” and click “work control”; after the slipway gets back in place and the servo returns, start the loosening programme; after it is finished, the position gets back in place, and the cycle start indicator flashes, waiting for bolt change (remember to click the “action by step” button to make it colourless). At this time, the cycle start indicator flashes, but the position is still in the automatic cycle. Click “start the cycle”, and the indicator turns normally on and the position starts the new cycle (Pietraszek, 2012). In this new cycle, the programme does not writes the card or reread the card. After the automatic operation of the position is completed, the programme will automatically write the card and release the alarm. After the loading task is selected under the auto mode, the tightening system will start the loading task (Zhao et al., 2015).

The loading task is a core part of the whole system and designed to control the tightening device to complete the whole bolt tightening process. This action is divided into the torque control stage and the angle control stage. In the angle control stage, the tightening torque is monitored to facilitate the tightening process (Deters et al., 2015). The flow chart of the loading task in the software design is shown in Fig. 4.

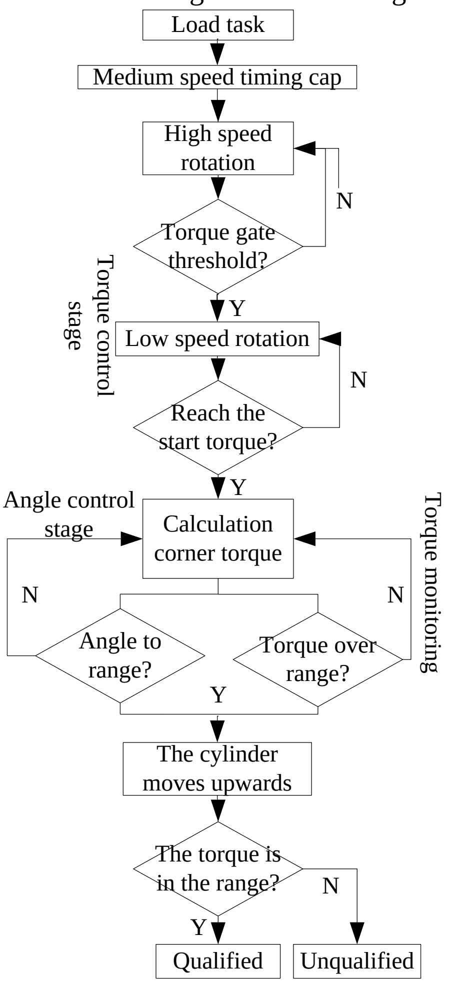

Figure 4. Flow chart of the loading task

Unloading tasks coexist with loading tasks, but with exactly the opposite work process. An unloading task is executed to loosen the bolt, which generally involves the low-speed and high-speed tightening stages (Sedighnejad et al., 2014). The flow chart of the unloading task in the software design is shown in Fig. 5.

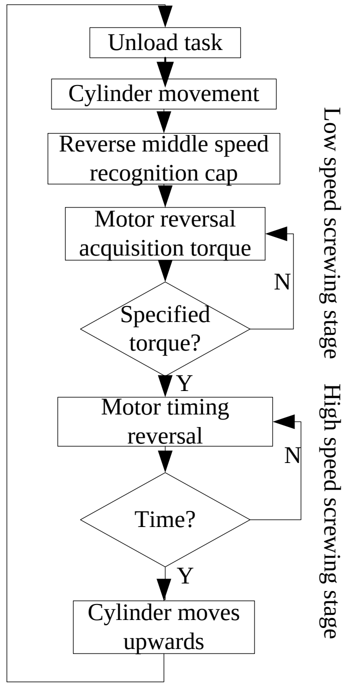

Figure 5. Flow chart of the unloading task

5 CONCLUDING REMARKS

This paper designs the tightening device used to automatically tighten the flywheel bolts in an engine assembly line with Schneider TSX P572635M. This tightening device uses four wrenches instead of the originally two, and designs the human-machine interfaces with the XBTGK2330 touch screen. This system solves the insufficient capacity problem and improves the productivity of products and the production efficiency of the company.

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