Research and Design of An Automatic Monitoring Technology for Composite Riveting Process

Yu Liu[a], Lin Yang[*], Wei Li, Yun-Long Jia, Long Guo, Xue-Hui Liao

Meishan CRRC Fastening System Co., Ltd., Meishan, Sichuan 620000

[a]yurnd@163.com
[*]Corresponding author Email:475225389@qq.com

Abstract. To solve the problems such as difficulty in inspection and inefficiency of quality inspection in the composite riveting process, this paper studies a method of data monitoring during riveting. According to this method, a pressure sensor and a flowmeter are mounted on the riveting tool using integrated development techniques. During riveting, sensor signals are collected during the riveting to obtain the deformation length and riveting force of the rivets during the rivet forming indirectly, so as to draw the curves of riveting force and displacement during the rivet forming. The riveting curves are analyzed by an empirical threshold method to determine the riveting quality. The results show that this method is suitable for monitoring the composite riveting process and can provide effective quality assurance for its riveting.

Keywords: composite; riveting process; intelligent inspection

1 Introduction

China's urban rail and EMU trains are developing towards lower energy consumption, faster speed, greater passenger capacity and better environmental protection, which requires higher strength and lighter mass of the carbody [1]. To this end, more and more high-quality metallic and non-metallic materials have been used in the carbody and bogie. Components made of different materials, such as carbon fiber material, aluminum alloy, titanium alloy and stainless steel, are combined in the best way for weight reduction and environmental protection [2,3]. Among them, carbon fiber metro trains involve the connection of a variety of materials including carbon fiber reinforced plastic (CFRP), glass-carbon composite, aluminum alloy, titanium alloy, stainless steel, carbon steel and structural steel [3-5]. In these trains, the composite/composite homogeneous components or composite/metal heterogeneous components should be assembled via point connection techniques, of which riveting is an important one for composite/composite or composite/metal connection [6-7].

Nowadays, for trains made of carbon fiber composite, the components are mainly assembled by riveting using pneumatic riveters such as G84-LS and HUCK256. There are a large quantities of rivets in many types and specifications and many rivet-

G. Zhao et al. (eds.), *Proceedings of the 2024 7th International Symposium on Traffic Transportation and Civil Architecture (ISTTCA 2024)*, Advances in Engineering Research 241,
https://doi.org/10.2991/978-94-6463-514-0_72

ing combinations of material types and thicknesses. Different rivets and different riveting combinations are affected by factors such as assembly clearance, hole-making condition and riveting parameters differently. In addition, due to the large number of riveting steps and complex working conditions, the quality of riveted joints easily fluctuates under the impact of factors such as working environment and construction conditions. Thus, it is very important to control the quality through monitoring the riveting process.

To check if the riveting results meet the requirements, traditional riveting quality control mainly relies on manual measurement and inspection, which shows not only disadvantages such as inspection inefficiency and poor result repeatability but also deficiencies including delays in inspection result production and quality result feedback, resulting in adverse impact on the reliability of riveting quality and further serious potential safety hazards [8]. Shanghai Jiao Tong University once installed the pressure and displacement sensors on the riveting machine in its laboratory to analyze the forming process of self-piercing riveting, and analyzed and tested the riveting quantities by monitoring the tolerance zone of the curve of pressure-displacement during riveting [9].

To respond to the problems such as difficulty in monitoring the composite riveting process, few data records of riveting process, difficulty in tracing the riveting quality and lack of digital means to manage the riveting quality, this paper carries out integrated development of hardware equipment and intelligent monitoring system for the riveting process and conducts studies on technology of automatic monitoring of riveting force and displacement during riveting, which is of great significance to bring about the traceability of riveting quality, improve the riveting process quality control capability and the digital management of riveting operation, and realize the automatic monitoring of the riveting process of composite riveted products, thus guaranteeing the safe operation of urban rail and EMU trains.

2 Data Acquisition During Riveting

2.1 Riveting Force Sensor Integration Analysis

Due to the large size, it is difficult to install a force sensor on the piston. Therefore, in this paper, the force was measured by an indirect method, which calculated the riveting force by measuring the liquid pressure on the piston, multiplying the measured value by the area of the piston, and deducting the friction force therefrom. The forces and hydraulic pressures during the riveting were measured by connecting the force sensor in series in the riveting machine. Through comparative analysis, we concluded that the riveting force could be measured with sufficient accuracy by the hydraulic pressure sensor. Therefore, the riveting force can be measured by installing a pressure sensor on the oil inlet side of the pneumatic riveter cylinder.

The riveting force is calculated with the following formula:

$$F = \frac{12\pi p\left(R^2 - r^2\right)}{1000} \tag{1}$$

where, p is the value of pressure in the riveter cylinder, in MPa; F is the riveting force, in kN; R is the inner radius of the riveter cylinder body, in mm; and r is the radius of the piston rod, in mm.

2.2 Riveting Displacement Integration Analysis

The piston displacement during riveting (i.e., riveting displacement) can be measured by various displacement sensors, such as pull-wire, pull-rod and laser ones. The piston displacement is directly measured at one end of the sensor, and the riveting displacement can be measured by installing a pull-wire displacement sensor. For hydraulic riveters, the piston displacement can be measured indirectly by measuring the volume of the hydraulic oil to reduce the weight of riveters and facilitate the operation of the riveting operators.

A flow sensor is installed on the oil inlet tube of the hydraulic unit to measure the flow during riveting. The volume of liquid entering the piston oil chamber is obtained by integration, and then the piston displacement can be converted on the basis of the incompressibility of the hydraulic oil. The riveting displacement of a hydraulic riveter can be calculated indirectly by the measurements of FRG200 gear flowmeter. In particular, it is calculated with the flow volume and the cross-section area of the inner cavity of the riveter. To verify the accuracy of displacement calculated with the flowmeter measurements, the measurements of a magnetostrictive displacement sensor is used as the standard measurements, which is also used to evaluate the feasibility of measuring riveting displacement with a gear flowmeter. To sum up, the displacement of a pneumatic riveter can be obtained indirectly by measuring the volume of hydraulic oil, and then the riveting displacement can be extracted thereby.

$$V = \int Qdt \tag{2}$$

$$V = A \times \Delta x \tag{3}$$

where, V is the oil volume, in mL and A is the effective action area of piston, in mm^2.

3 Riveter Modification

3.1 G84-LS Modification.

For G84-LS pneumatic riveter, there is a connecting wire between the pulling head and the body, which makes the riveter more suitable for riveting within small spaces, as shown in Fig. 1.

The modified G84LS is shown in Fig. 2. Without any change to the original functions, the followings are added or modified: operating handle, solenoid operated directional control valve button, extended oil tube, quick connector, cylinder valve block, air source connector, joint valve block, pressure sensor, pulse sensor, two-way two-position solenoid operated directional control valve, control cylinder line, box, etc. The modification is made according to the following principles:

1) Use the cylinder valve block as the sealing for the upper end face of the cylinder handle, and connect the oil passages in both the pulling head and the cylinder base handle with those in the original pulling head and cylinder base handle. Connect the oil passage of the cylinder valve block to the joint valve block through a pulse sensor. Install the corresponding quick connector on the joint valve block to match the end with a quick connector of the extended oil tube. Directly connect the other end of the extended oil tube to the pulling head. Therefore, the oil passages of the original pulling head and cylinder handle are connected through the extended oil tube.
2) Use the button on the handle to control the opening of the two-way two-position solenoid operated directional control valve, so that the control cylinder line is connected with the atmosphere. The directional control valve plunger opens due to differential pressure, so that air enters the piston rodless chamber in the cylinder base and pushes the booster piston downward for riveting.
3) Integrate all air circuits into the box, and connect the air intake pipe with the air source connector on the joint valve block to serve as a power source.
4) Install a pressure sensor on the joint valve block and a pulse sensor which is connected with the operating oil to control the back-end program or detect the operating status of the equipment, so that the operation of G84LS-LS can be controlled by the equipment via a single button and the real-time system operating status detection can function.

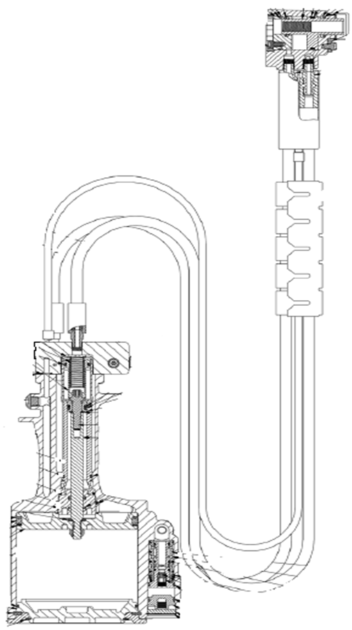

Fig. 1. Original Structure of G84-LS Riveter

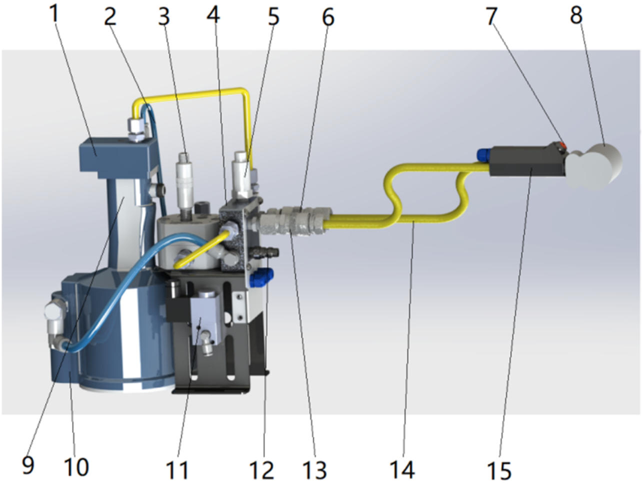

Fig. 2. Modified G84LS-LS

1 Cylinder valve block 2 Control cylinder line 3 Pulse sensor 4 Joint valve block 5 Pressure sensor 6 Quick connector 7 Solenoid operated directional control valve button 8 Original pulling head 9 Original cylinder handle 10 Directional control valve plunger 11 Two-way two-position solenoid operated directional control valve 12 Air source connector 13 Quick connector 14 Extended oil tube 15 Operating handle

The modified equipment is shown in Fig. 3.

(a) (b)

Fig. 3. (a) Computer monitoring system; (b) Modified G84LS-LS

3.2 HUCK256 Modification

HUCK256 pneumatic riveter, in a one-piece design, provides riveting power through air/oil pressure conversion, as shown in Fig. 4.

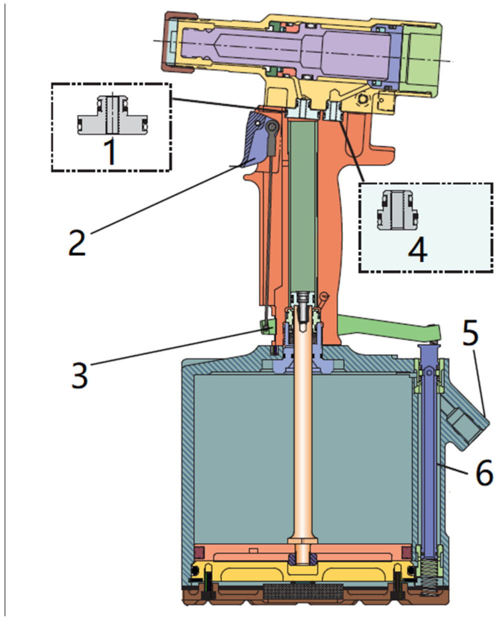

Fig. 4. Original Structure of HUCK256 Pneumatic Riveter

1 High-pressure valve body 2 Button 3 Crank arm 4 Return valve body 5 Air source connector 6 Directional control valve plunger

The modified HUCK256 is shown in Fig. 5. Without any change to the original functions, the followings are added: pulling head valve block, operating handle, solenoid operated directional control valve button, extended oil tube, quick connector, joint valve block, pressure sensor, pulse sensor, plunger control cylinder mounting base, plunger control cylinder, solenoid operated directional control valve, air circuit assembly, box, etc. The principle is outlined as follows:

1) Use the pulling head valve block and cylinder valve block as the sealing for the lower end face of the pulling head and the upper end face of the cylinder handle, and connect the oil passages in both the pulling head and the cylinder handle with those in the original pulling head and cylinder handle. Connect the oil passage of the cylinder valve block to the joint valve block through a pulse sensor. Install the corresponding quick connector on the joint valve block to match the end with a quick connector of the extended oil tube. Directly connect the other end of the extended oil tube to the pulling head valve block. Therefore, the oil passages of the original pulling head and cylinder handle are connected through the extended oil tube.

2) Install a single-action cylinder plunger above the directional control valve plunger on the cylinder base. Use the button on the handle is used to control the opening of the two-way two-position solenoid operated directional control valve, so as to control the extension of the single-action cylinder and push down the directional control valve plunger, so that air enters the piston rodless chamber in the cylinder base and pushes the booster piston upward for riveting.

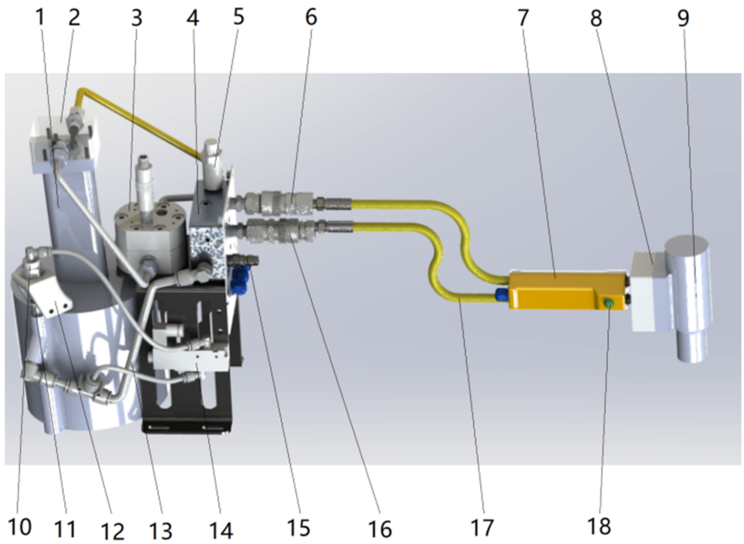

Fig. 5. Structure of Modified HUCK256

1 Original cylinder handle 2 Cylinder valve block 3 Pulse sensor 4 Pulling head valve block 5 Pressure sensor 6 Quick connector 7 Operating handle 8 Pulling head valve block 9 Original pulling head 10 Plunger control cylinder 11 Directional control valve plunger 12 Plunger control cylinder mounting base 13 Air intake pipe of solenoid valve 14 Two-way two-position solenoid operated directional control valve 15 Air source connector 16 Quick connector 17 Extended oil tube 18 Solenoid operated directional control valve button

3) Integrate all air circuits into the box, and connect the air intake pipe to the air source connector on the joint valve block, and then with the two-way two-position solenoid operated directional control valve when the air intake pipe passes through the cylinder base valve block. Use the button on the operating handle to control the air intake of the plunger control cylinder through the directional control valve.
4) ©Install a pressure sensor on the joint valve block and a pulse sensor which is connected with the operating oil to control the back-end program or detect the operating status of the equipment, so that the operation of HUCK256 can be controlled by the equipment via a single button and the real-time system operating status detection can function.

The modified equipment is shown in Fig. 6.

(a) (b)

Fig. 6. (a) Computer monitoring system; (b) Modified HUCK256

4 Intelligent Monitoring System

The main interface of the upper computer software programmed by VS is shown in Fig. 7. This system is mainly used for sensor information acquisition, data recording and generation of real-time riveting process curve.

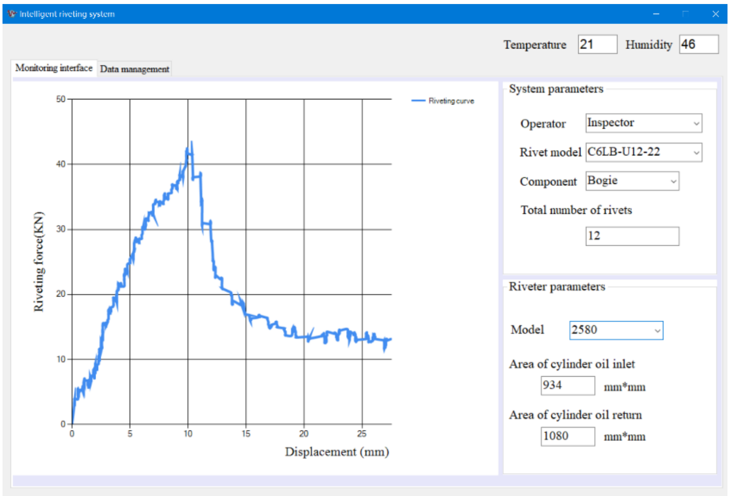

Fig. 7. Main Interface of Monitoring System

As shown in Fig. 8, the data management mainly includes quality judgment and data reports. During the riveting, data are continuously collected and added into the database. The accuracy of quality judgment algorithm can be effectively improved through off-line training.

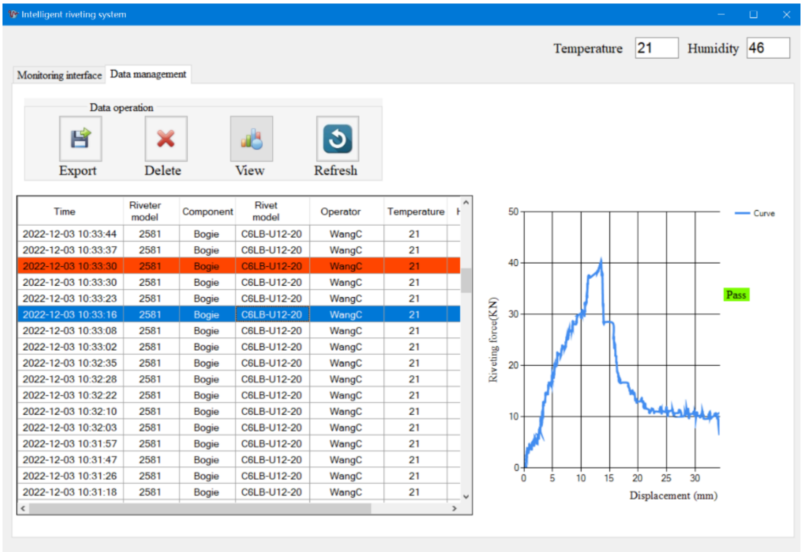

Fig. 8. Data Management Interface

5 Conclusion

In this paper, the composite riveting machine is modified so that it can collect the curve of rivet forming during riveting. The riveting curves are analyzed by an empirical threshold method to determine the riveting quality. which is of great significance to bring about the traceability of riveting quality, improve the riveting process quality control capability and the digital management of riveting operation, and realize the automatic monitoring of the riveting process of composite riveted products, thus guaranteeing the safe operation of urban rail and EMU trains.

References

1. Chen Weirong, Wang Yingmin, Li Bingxun, et al. Overview on Current Research Status and Development Trends of Hydrogen-powered Rail Transit [J]. Electric Drive for Locomotives, 2023, (03): 1-11.
2. Shi Hongwei, Cui Changjing, Wei Tao, et al. Behaviours and Protective Measures of Galvanic Corrosion on Dissimilar Materials of Typical Aircraft Structure in Harsh Environment [J]. Equipment Environmental Engineering, 2020, 17 (05): 52-57.
3. Ming Xin. Research on the Application of Carbon Fiber Composites in Structure of Car Body [D]. Dalian Jiaotong University, 2023.
4. Wang Xinmin. Research on Replacement of Metal Materials with Carbon Fiber Reinforced Plastics for Rail Car Bogie Components [J]. Synthetic Materials Aging and Application, 2022, 51 (04): 115-117.
5. Qin Mingze, Zhang Weitao, Ji Xiaochen, et al. Research on Application of Composites in Aerospace and Rail Transit in China [J]. Hot Working Technology, 2024, 53 (06): 6-9.

6. Cao Zengqiang, Zhang Minghao, Tan Xuecai, et al. Overview of Riveting Technology for Aviation Composite Structure [J]. Aeronautical Manufacturing Technology, 2023, 66 (Z1): 26-37.
7. Cheng Hui, Fan Xintian, Xu Guanhua, et al. State of the Art of Precise Interference-fit Technology for Composite Structures in Aircraft [J]. Acta Aeronautica et Astronautica Sinica, 2021, 42 (10): 55-73.
8. Liu Ning. Development of New Intelligent Riveting Equipment and Quality Monitoring System for Freight Wagons Bogies [D]. Southwest Jiaotong University, 2018.
9. Huang Shuyan, Li Yongbing, Lou Ming, et al. On-line Monitoring the Self-pierce Riveting Joint Quality by Force and Displacement Signals [J]. Machine Design & Research, 2011, 27 (03): 86-90.