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Embedded Electronic Jacquard Guide Bar: A New Approach to Warp Knitting Using the Machine Jacquard Control System

DOI: 10.5604/01.3001.0012.5172

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Abstract

A fluorine-containing acrylate copolymer emulsion was prepared in this study, which was The jacquard control system is one of the crucial parts of a warp knitting machine. In this paper, we present a new jacquard control scheme called the embedded electronic jacquard guide bar (EEJGB). In this scheme, the Micro-Controller Unit (MCU), jacquard driver circuit, DC powers, and communication interfaces are integrated to achieve a simple structure, high reliability as well as ease of installation and maintenance. Specifically an innovative communication strategy with the advantages of fault tolerance and automatic addressing based on the Modbus serial bus is formulated. This paper describes the design of the hardware structure, communication methods of EEJGB, and printed circuit board (PCB), provided to demonstrate the feasibility of the method proposed.

Key words: *piezoelectric jacquard, warp knitting machine, embedded system, automatic addressing.*

Introduction

Warp knitting machines, with their fast speed and high production efficiency, have received sustained attention in academic and engineering circles of the textile industry [1]. In the development of warp knitting machines, flexibility rather than speed increase is prioritised [2]. In recent years, the increased flexibility of warp knitting machines has been achieved by increasing the number of guide bars [3-4], the wide use of electronically controlled drives [5-7], innovative detailed solutions for yarn feeding [8,9], three-dimensional simulation and design of warp knitted structures [10-12], defect detection [13, 14], and so on.

The electricity-control system of a warp knitting machine is a typical kind of flat distributed complex system which can achieve various motion control functions, such as warp yarn let-off and take-up, electronic shogging, and electronic needle selection for jacquard. Piezoelectric bimorph has significant advantages such as low drive current, low power consumption, strong anti-interference ability against the impact of current, low heat production, no harmful vibrations and no electromagnetic interference, and hence it is being widely applied in the textile machinery industry [15]. In the last few years, boosted by advances in computing, communications, and sensing technologies, piezoelectric jacquard has represented a new research frontier for the warp knitting machine to replace the old magnet and mechanical jacquard, and it has recently drawn a great deal of attention. An innovative piezoelectric jacquard selection mechanism is introduced in [15]. The application of flash memory in a computerised jacquard controller was investigated in [16]. In order to raise the efficiency of the knitwear design manufacturing process, [17, 18] studied the knitting and jacquard design process using a textile Computer Aided Design (CAD) system. In [19], a network structure, function and communication protocol for the CAD&CAM system for textile was developed.

Designing piezoelectric jacquard control kernels still remains challenging. Gao et al. [20] designed an automatic jacquard control system for a glove knitting machine using an ARM-based STM32f407 processor. Kumaravelu et al. [21] developed an electronic cardless jacquard for 128 hook handloom weaving apparatus. Li et al. [22] proposed a piezo jacquard control system based on Can-bus. These works give some tentative and enlightening research results, but have potential drawbacks such as that the complex multi-card structure may cause low reliability and maintenance difficulties.

This paper introduces an innovative distributed integrated jacquard control system, i.e., an embedded electronic jacquard guide bar (EEJGB) for a warp knitting machine. The new control method that we describe in this paper incorporates the following three novel contributions:

1) In order to overcome the low reliability and maintenance difficulties of the traditional warp knitting machine's electronic jacquard control system with complex multi-card structure, the EEJGB proposed integrates the Micro-Controller Unit (MCU), driver circuit, DC powers and communication interfaces. Such a structure not only greatly reduces the jacquard control system's size but also improves the reliability and ability of resisting noise interference and vibration.
2) For EEJGB, a hybrid serial communication method combining the bus and ring logic topology architecture is presented to balance the real-time demand, fault-tolerance and reliability. In this way, the addresses of EEJGBs can be automatically and dynamically assigned by a jacquard controller to facilitate expansion and replacement instead of usually using code switches

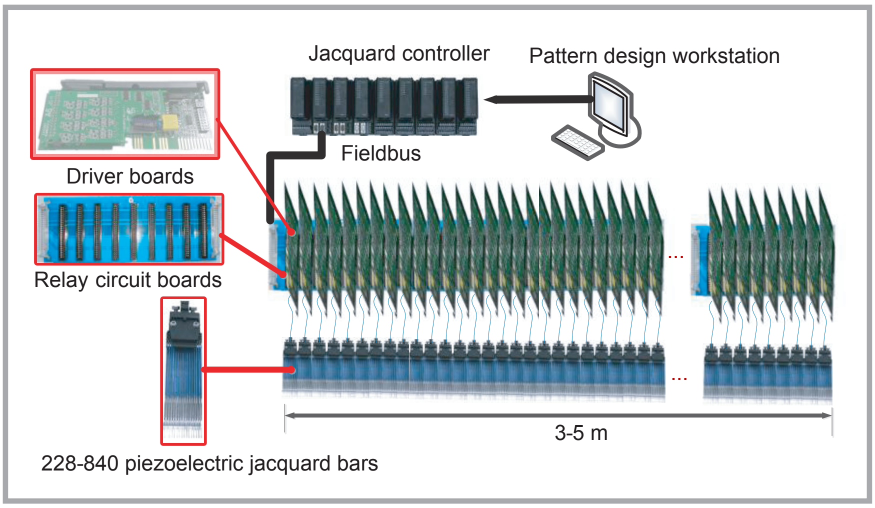

***Figure 1.** Traditional piezoelectric jacquard control system for warp knitting machine.*

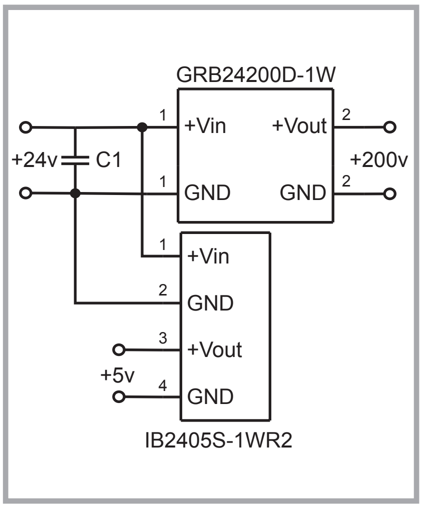

***Figure 2.** Switching power supply of EEJGB.*

or a handheld programmer to assign addresses to EEJGBs.

3) The EEJGB proposed has a distributed control architecture which is of simple structure, convenient maintenance and, at the same time, can run independently.

The rest of this paper is organised as follows: We give a comparative study on the characteristics of the traditional piezoelectric jacquard control system and the EEJGB proposed in Section 2. Section 3 briefly investigates the hardware circuit design of EEJGB. Section 4 introduces the communication architecture of the EEJGB based Modbus serial bus. The dynamic device address configuration mechanism is presented in Section 5. Section 6 shows the feasibility and practicality of our methods. Finally conclusions are drawn in Section 7.

Problem formulation

Rapid drive technology for piezoelectric jacquard

Piezoelectric jacquard applies the converse piezoelectric effect to drive yarn guide deflection. In the modern warp knitting machine's control system, the key technology of piezoelectric jacquard is quickly driving the piezoelectric ceramic. According to the width of the warp knitting machine and knitting gauge, the number of piezoelectric jacquard needles installed on a warp knitting machine ranges from 3640 to 13440. In general, 16 piezoelectric jacquard needles are installed on a piezoelectric jacquard bar. Because every piezoelectric jacquard needle needs to be independently controlled, the control and communication system for piezoelectric jacquard bars will face challenges.

Characteristics of the traditional piezoelectric jacquard control system

Currently the traditional piezoelectric jacquard control system for the jacquard warp knitting machine is composed of a pattern design workstation, jacquard controller, relay circuit boards and, driver boards, shown in ***Figure 1***. Its working principle is as follows: The pattern design workstation can complete the pattern design of warp knitting fabrics

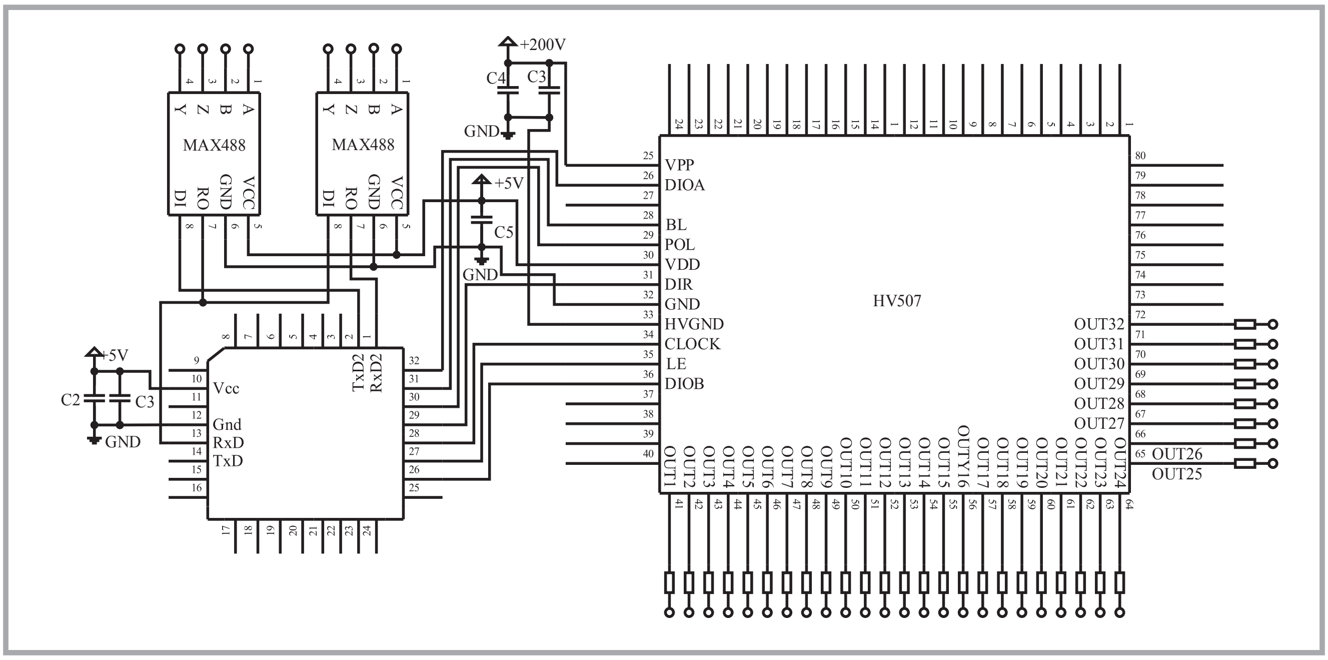

***Figure 3.** Integrated circuit design of EEJGB.*

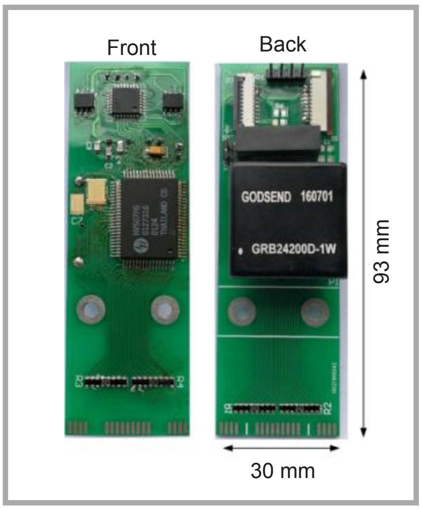

Figure 4. *PCB for EEJGB.*

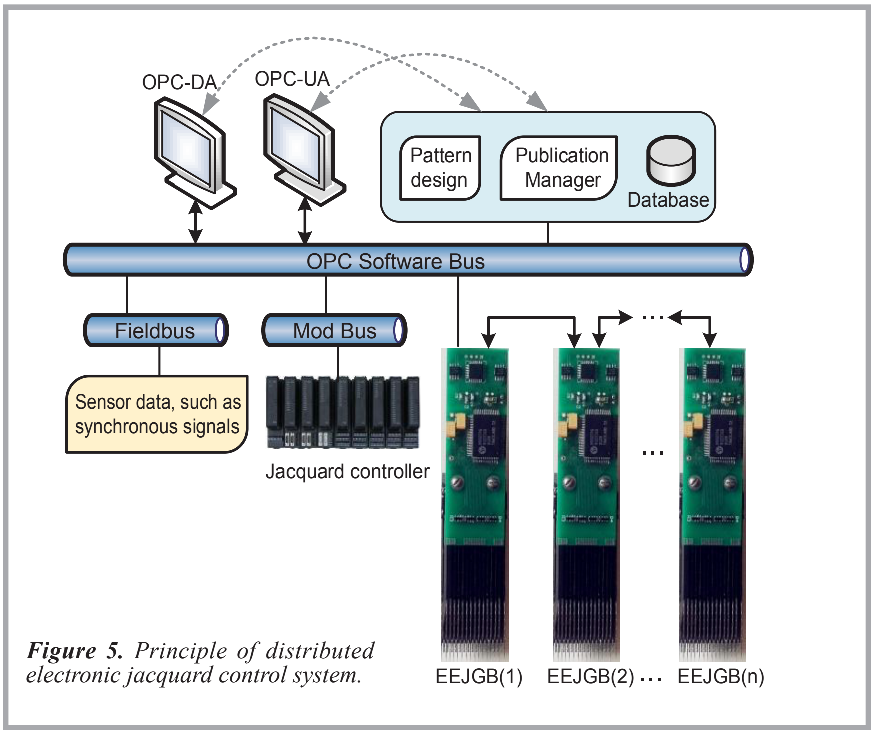

Figure 5. *Principle of distributed electronic jacquard control system.*

though CAD software and then generate pattern data which will be downloaded to the jacquard controller via an industrial Ethernet, flash card, etc. Next the pattern data are transported to the flash memory of the jacquard driver boards through the relay circuit boards. Finally the driver boards control and drive the piezoelectric jacquard bars to move according to the pattern files, as well as synchronise the signal generated by the proximity switch used to detect the run state of the warp knitting machine.

Design of EEJGB

The most appealing feature of the EEJGB is that the Micro-Controller Unit (MCU), driver circuit, DC powers and communication interfaces are integrated into the top of a traditional piezoelectric jacquard bar. The system organisation and workflow of the EEJGB are as follows:

1) The MCU, which is STC15F2K60S2, can receive pattern files from the jacquard controller via the communication interface and store them in internal flash memory.
2) In this paper, two DC powers are integrated into the inside of the EEJGB, which will supply 200V and 5V to the driver circuit and MCU, respectively, as shown in ***Figure 2***. The inputs of the two powers are all 24V.
3) The driver circuit adopts the HV507, which is a low voltage serial to high voltage parallel converter with 64 push-pull outputs. STC15F2K60S2 controls the HV507 to drive the piezoelectric jacquard bars (such as E24) based on the pattern data and synchronising signal generated by the proximity switch, used to detect the run state of the warp knitting machine, as shown in ***Figure 3***.

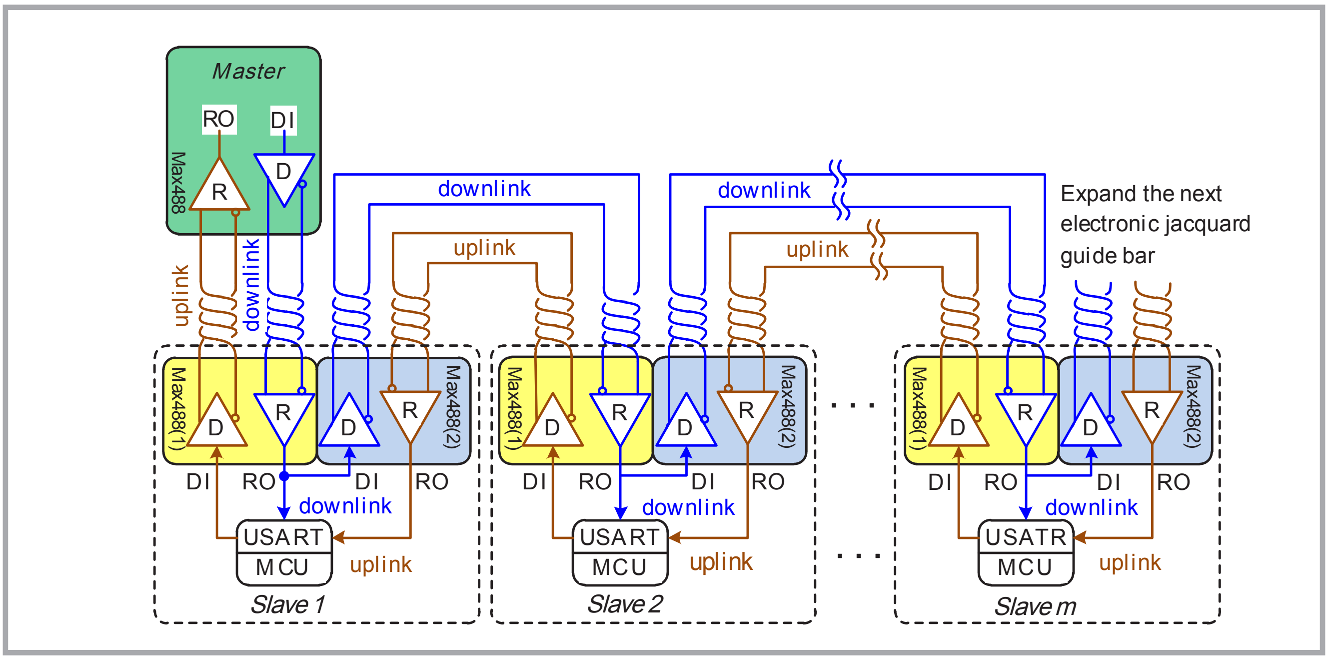

Figure 6. *Physical topology of EEJGB. The blue twisted pair cable is used as the downlink, and the brown twisted pair cable as the uplink.*

Table 1. RTU Message frame.

Device address	Function code	Data	CRC check
1 Byte	1 Byte	n Byte	2 Byte

Table 2. Bit sequence in RTU mode.

Start	Data	Parity/stop	Stop
1 bit	8 bit	1 bit	1 bit

LSB ⟶ *MSB*

Table 3. Example of MODBUS request frame over Serial Line.

Slave device address	Function code	Data			CRC check
		No. of registers	Data start register address	Pattern data	
01 H	15 H	80 H	0000 H	128 Byte	2 Byte

The PCB for EEJGB is shown in ***Figure 4***. Generally the width of a jacquard guide bar (E14-E32) is 25-58mm, which means that the EEJGB proposed can be used to upgrade most traditional jacquard guide bars.

As opposed to the traditional complex multi-card structure of the piezoelectric jacquard control system, the EEJGB presented, shown in ***Figure 5***, apparently possesses the characteristics of simple structure, high reliability, ease of installation and maintenance, and so on.

In order to effectively resolve the problems of integration of distributed and isomeric systems, the OPC client/server architecture scheme is adopted. EEJGB may communicate with CAD software and the jacquard controller through the OPC Software Bus so as to be compatible with traditional systems.

Subsequent sections will provide associated communication architecture details of our design.

Communication architecture of EEJGB

Physical connectivity standard

Physically the EEJGB uses the TIA/EIA-485 (RS485) physical interface [23], which is adopted using the design of the balance transmission driver and differential receiver to strengthen the ability of the restraining common-mode interference. Every EEJGB installed on a warp knitting machine contains two MAX488 chips with a full-duplex and low-power-to-implement serial daisy chain communication mode, as shown in ***Figure 3*** and ***Figure 6***. We will now discuss some advantages of the daisy chain communication model of serial bus topology architecture presented.

Downlink implementation

The downlink is used to transmit pattern data or synchronizing signals. By adopting the step-by-step excitation mode, i.e., relay transmission, the pattern data or synchronising signals are carried though the downlink from the jacquard controller to the first EEJGB, then until the final EEJGB. It is worth noting that the MCU is not intended to intervene and control the communication process; it is there to improve reliability without reducing the transmission speed. Therefore we logically treat the downlink as bus topology. Before the warp knitting machine begins to run, the jacquard controller downloads pattern data to every one of the EEJBGs using the downlink. When the warp knitting machine is running, the jacquard controller only needs to transmit synchronising signals to the EEJGBs, which can ensure real-time communication.

Uplink implementation

The jacquard controller may collect the response signals of EEJGBs via the uplink. A very important feature of our RS485 uplink implementation is that the response signals are controlled and interacted by MCUs. In the line RS485 network for EEJGBs, the only final node is used as a communication node, but has no jacquard function, as shown in ***Figure 5***. The topology of the uplink is similar to ring topology.

Modbus serial data link protocol based on RS485 for EEJGB

We adopt Modbus protocol to implement the data link and application. The Modbus standard defines application layer messaging protocol, positioned at level 7 of the OSI model, that provides "client/server" communications between devices connected on different types of buses or networks. It also standardises specific protocol on a serial line to exchange the Modbus request between the master node and one or several slave nodes. In this paper, the master node may be a jacquard controller or EEJGBs, and slave nodes are EEJGBs.

RTU transmission mode

We use the Remote Terminal Unit (RTU) mode, whose advantage is that its greater character density allows better data throughput than the ASCII mode for the same baud rate. A typical RTU message frame is shown in ***Table 1***. The maximum size of a Modbus RTU frame is 256 bytes. According to Modbus protocol, the Modbus master node has no specific address; only the slave nodes must have an address that has to be unique on a MODBUS serial bus. This means that each EEJGB, as a slave node, must have a unique device address (from 1 to 247 decimal) so that it can be addressed independently from other nodes on a Modbus serial bus, as shown in ***Table 1***. Address 0 is used for the broadcast address, which all slave devices recognise. The RTU function code field of the message frame tells the slave what kind of action to perform when a message is sent from a master to a slave device. Valid codes are in the range of 1-255 decimals. A data field is constructed using sets of two hexadecimal digits, in the range of 00 to FF hexadecimals. The data field of messages sent from a master to slave devices contains additional information which the slave must use to take the action defined by the function code. The RTU mode includes an error-checking field that is based on the Cyclical Redundancy Checking (CRC) method performed on the message contents. In the RTU mode, messages start with a silent interval of at least 3.5 character times. The entire message frame must be transmitted as a continuous stream. If a silent interval of more than 1.5 character times occurs before completion of the frame, the receiving device flashes the incomplete message and assumes that the next byte will be the address field of a new message.

When messages are transmitted on standard Modbus serial networks, each character or byte is sent in this order (left to right): Least Significant Bit (LSB).... Most Significant Bit (MSB), as shown in ***Table 2***. Devices may accept by configuration either Even, Odd, or No Parity checking. If No Parity is implemented, an additional stop bit is transmitted to fill out the character frame to a full 11-bit asynchronous character.

RTU message of pattern design data in unicast mode

An EEJGB usually includes sixteen knitting needles. Before the warp knitting machine begins to run, the jacquard controller issues a Modbus request message including pattern design data to every EEJGB in the unicast mode through the downlink. Large pattern design data can be sent multiple times. Apparently this mode of offline downloading and step-by-step excitation of pattern design data can not only effectively reduce real time data traffic but also increase the maximum number of slave nodes in the Modbus serial bus.

Firstly the jacquard controller addresses every individual EEJGB sequentially. ***Table 3*** shows an example of a Modbus query message in hexadecimals from a jacquard controller. The query contains a standard Modbus slave address, function code, byte count, starting address and error check fields. The jacquard controller query is a *Write General Reference* (i.e., the value 15 Hex) request that can write multiple groups of references to slave device address 01Hex. The message requests pattern design data to 128(80 Hex) registers of an EEJGB. Note that the message specifies the starting register address as 0000 Hex. The available quantity of Memory depends upon the size of Extended Memory installed in the slave EEJGB. In this paper, the STC15F2K60S2 has 60K storage space for pattern design data.

Then after receiving and processing the request, every EEJGB returns a message (a ‘reply’) in hexadecimals to the jacquard controller. If the action requested is without error, it returns the same address, function, byte count and starting address code in its response. It means that the slave simply echoes the original function code as a normal response. As an exceptional response, the slave returns a code that is equivalent to the original function code, with its most significant bit set to *logic* “1”. For example, if an exception occurs, the EEJGB must return the following function code: 95H. In addition to its modification of the function code for an exceptional response, the slave also places a unique diagnostic code into the data field of the response message. ***Tables 4*** and ***5***, respectively, illustrate an example of a normal and exceptional response by an EEJGB. The diagnostic code 00 Hex and 01 Hex indicate ‘normal’ and ‘error’, respectively. The jacquard controller’s application program has the responsibility of handling exceptional responses. Typical processes are to post subsequent retries of the message, to try to send diagnostic messages to the EEJGB, and to notify operators.

Table 4. *Example of MODBUS normal response frame over Serial Line.*

Slave device address	Function code	Data			CRC check
		No. of registers	Data start register address	Diagnostic code	
01 H	15 H	80 H	0000 H	00 H	2 Byte

Table 5. *Example of MODBUS exceptional response frame over Serial Line.*

Slave device address	Function code	Data			CRC check
		No. of registers	Data start register address	Diagnostic code	
01 H	95 H	80 H	0000 H	01 H	2 Byte

RTU message frame of synchronous data in broadcast mode

Once the warp knitting machine is up and running, the jacquard controller can receive a synchronous data message in real-time from the proximity switch and then broadcast it to all EEJGBs to decide whether to move. The synchronous data message includes the sequence number of current steps of EEJGB (one byte) and the synchronous control signal (two bytes) (***Table 6***).

After receiving the synchronous data message, every EEJGB will send a response signal to its own upper node via the uplink. Every upper node applies the synchronous data message from the lower node to verify its own and no longer transports it upwards to effectively avoid the uplink jam in real-time (***Table t***).

Dynamic device address configuration mechanism

In the traditional jacquard control system of a warp knitting machine, each EEJGB is assigned a fixed address by the code switch or handheld programmer. In this way, when the physical location of an EEJGB is changed, we need to re-configure addresses for EEJGBs each time, which is a burden to operators. Therefore we proposed a new dynamic configuration method of EEJGB addresses which incorporates the following key features:

- the unique identification (ID) number of each EEJGB is sent to the jacquard controller in the unicast mode;
- all the ID numbers of EEJGB are mapped to an address table according to the chronological arrival order of ID numbers;
- the jacquard controller sends the address table to all EEJGBs in the broadca st mode;
- by using the methods of address table lookups, every EEJGB can obtain a unique address based its own ID number.

The dynamic device address configuration mechanism above represents an important contribution of this paper.

Real-time communication testing and analysis

For a jacquard warp knitting machine, guiding needles are required to complete the lateral movement while completing the offset action. Take E32 for example, the width of an EEJGB containing 16 needles is 25.4 mm, and their offset is 0.79 mm. Each revolution of the warp knitting machine spindle allows the offset angle to be 70° before the needle and 160° after the needle, as shown in ***Figure 7***. According to document [24], the allowable time range for deflection of the piezoelectric ceramic guide needles is $18ms \le t_{DE} \le 43ms$.

The spindle speed of the warp knitting machine can be calculated by

$$v = \frac{500\theta}{3\left(t_{DE} + t_{\Delta}\right)} \quad (1)$$

where θ is the rotation angle of the spindle t_{Δ} the communication time, and t_{DE}

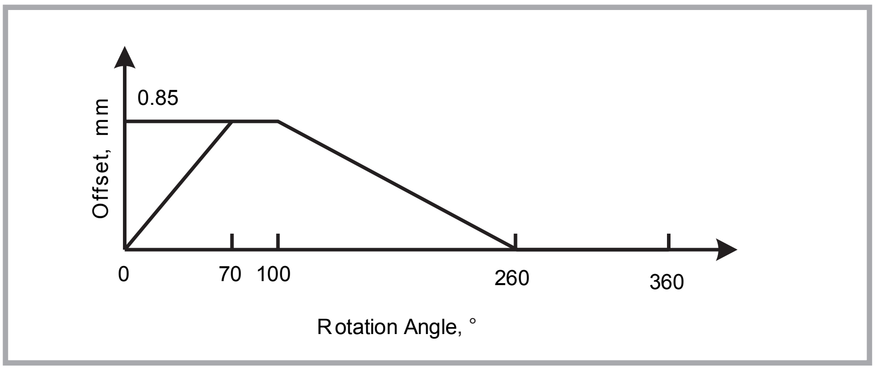

***Figure 7.** Migration movement diagram of jacquard guide needle.*

the time allowable for deflection of the piezoelectric ceramic guide needle.

The serial communication time model can be expressed as

$$t_{\Delta} = t_T + t_{PD} + t_{PD}^{*} \qquad (2)$$

where $t_T = N\sigma/B$ is the data string transmission time, where N is the number of characters of a data frame, σ the data digits in each character, B the baud rate, $t_{PD} = \alpha\beta t_{(PLH/PHL)}$ the data transmission delay time of the downlink, where $t_{(TLH/PHL)}$ is the MAX488 transmission delay time, α the number of EEJGB in the downlink channel, β the number of MAX488 in an EEJGB, and t_{PD}^{*} the uplink channel data transmission delay time, which can be described as

$$t_{PD}^{*} = \left(\sum_{i=1}^{\alpha} i\right)^{\kappa} \beta t_{(PLH/PHL)} = \left[\alpha(\alpha+1)/2\right]^{\kappa} \beta t_{(PLH/PHL)} \qquad (3)$$

when using the traditional communication architecture, $\kappa = 1$, and the serial heterogeneous communication architecture proposed in this paper, $\kappa = 0$.

In this section, we consider the following examples: $N = 7$, $\sigma = 7$, $\alpha = 208$, $\beta = 2$. Through testing, the average value of $t_{(PLH/PHL)}$ is 0.8*us*. According to ***Equations (1), (2)*** and ***(3)***, we have $v|_{\kappa=1}^{\theta_F} \in [149, 220]$ *r/min*, $v|_{\kappa=0}^{\theta_F} \in [267, 627]$ *r/min.*

From the above testing and analysis, it can be seen that the factors restricting the spindle speed of a warp knitting machine by the traditional communication mode are not only controlled by the offset speed of the piezoelectric jacquard needle, but also by the communication rate. After the distributed heterogeneous communication architecture proposed, the spindle speed of the warp knitting machine is mainly controlled by the offset speed of the piezoelectric jacquard needle.

Conclusions

FPAE emulsion with a core-shell structure was synthesised by semi-continuous seed emulsion polymerisation. Then linen fabrics weh resistance was excellent and the wear-resistance of the finished linen fabric was better than for the unfinished linen fabric; however, it had a negative effect on bending rigidity as well as the air and moisture permeability.

In this work, taking into account using a Modbus serial bus, a new integrated control strategy, i.e., EEJGB, is proposed for warp knitting machines. The EEJGBs, with their compact structure and small bulk, can be embedded into various warp knitting machines in a quick and convenient way. The feasibility is shown in the 3D PCB board constructed by means of Altium Designer (version 14.3.12) soft.

***Table 6.** Example of synchronous data frame over Serial Line.*

Slave device address	Function code	Synchronous data	CRC check
01 H	16 H	3 Byte	2 Byte

***Table 7.** Example of synchronous data response frame over Serial Line*

Slave device address	Function code	Diagnostic code	CRC check
01 H	96 H	01 H	2 Byte

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgements

This work was supported by the National Natural Science Foundation of China (Grant No. 51576114), the Natural Science Foundation of Fujian Province of China (Grant No. 2015J01667), The Key Industry Project of Fujian Province (2015H0034), and the Science and Technology Program of Sanming of Fujian Province, China (Grant No. 2015-G-5).

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Received 03.08.2016 Reviewed 23.07.2018