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LABVIEW-BASED REMOTE REAL-TIME EVALUATION SYSTEM FOR MOTOR WINDING MACHINES

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Key words: motor winding machine, human-machine interface, real-time information exchange platform.

ABSTRACT

This paper proposes the design and evaluation methodologies for a remote human-machine interface (HMI) system for motor winding machines. An electric motor with an interior rotor evaluates the system performance. The motor winding machine has a 3 degree-of-freedom motion space controlled by a motion control kernel: IMP-2. Real-time data of the motor winding status is crucial for ensuring quality and reliability and detecting malfunction, which facilitates the development and control of mass production of electric motors. Hence, a real-time monitoring interface is essential. This paper presents a LabVIEW-based HMI, which transfers the winding statuses of a winding machine to remote clients through the Internet. A web-based, real-time, and user-friendly graphical interface that employs LabVIEW as the transfer medium is proposed to implement the information exchange platform. Real-time experimental results are published on a website for examination by qualified end users. Illustrative schemes and a demonstration video are provided for comprehensive understanding.

I. INTRODUCTION

Because of demands for pollution-free and quiet operation, electric motors have gradually replaced gasoline engines. Shimizu (1987) reported that the fuel efficiency of electric vehicles is four times higher than their gasoline counterparts under the same conditions (Fig. 1). Because of niche supports, the demand for various types of electric motors is increasing. Automatic winding is a vital technology because it reduces both the motor cost and fabrication time. Consequently, it facilitates the development of motors and is thus increasingly investigated. For instance, Lin (2003) proposed a tension control and estimation approach for a web transport system by employing an observer-based controller; it's performance was nearly identical to that of a conventional tension feedback controller using a tension transducer. A robust control based on H_∞ control theory was employed in the web transport system (Knittel et al., 2003). Benefiting from the H_∞ controller, the system exhibited enhanced winding performance against inertia variations. Li et al. (2012) proposed a new feedback system with a feedforward scheme by using an indirect tension control to achieve high-speed winding. The aforementioned approaches are widely used in webbing applications; however, unlike the webbing system, which increases layers turn by turn, the motor winding machine increases wire layers slot by slot. Consequently, the control should be more complex. More details on control implementation are available in (Su et al., 2012).

The human-machine interface (HMI) monitors the performance and setting functions. Usually, a display platform is set up beside the winding machine, and each winding machine

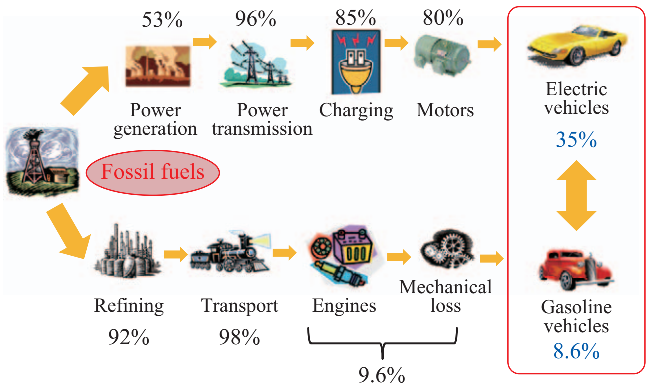

Fig. 1. Comparison of fuel efficiency.

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uses a display panel as its HMI. To adjust or reset the control parameters, the operator must set the parameters one by one. This paper proposes a new web-based HMI that uses the benefits of the Internet and realizes remote parameter control. In addition, the operator can control the winding machines through a personal computer, which economizes human and material resources. The main information is exchanged through a website. Thus, any authorized person can access the website and simultaneously evaluate and monitor the system. Moreover, provided sufficient bandwidth facilitates, a charge-coupled device camera can be connected to enable transmit real-time video of winding quality. Similar ideas have been applied to fuel cell scooters (Hu et al., 2012), electric vehicles (Hu et al., 2010), radio-frequency identification tags (Niktin and Rao, 2009), and exercise bikes (Tsai and Hu, 2007). Unlike these previous systems, this paper proposes a remote-controlled, multimachine monitoring using a web-based HMI, which is the first motor winding machine approach of its kind.

Building a graphical and compact HMI is difficult. In this study, LabVIEW (National Instruments) was used to build the corresponding panel. An HMI employing LabVIEW provides the operator and hardware interfaces and enhances the flexibility and simulating hardware in the loop. LabVIEW can be embedded in the website program and is convenient for transmitting real-time testing results visually. The user-friendly functions and graphical interface make LabVIEW acceptable as a flexible toolkit adopted under the framework of the World Wide Web (WWW). Moreover, by implementing authorized access, the end user can control the LabVIEW program remotely over the Internet. For instance, Pecen et al. (2004) presented an instrumentation system for a wind-solar hybrid power station, Zhang et al. (2012) presented the temperature control of a hollow fiber spinning machine, Wang et al. (2013) demonstrated an automatic test system for sieving chips, and Jin and Ho (2009) presented a fuzzy control for lighting systems, all of which are LabVIEW-based systems. The use of LabVIEW as a real-time data processing platform is thus highly recommended. Therefore, this study employed LabVIEW to construct a website with rich, real-time, and interactive information-revealing functions.

The proposed system utilizes the advantages of the WWW and the Internet to develop a real-time HMI for motor winding machines. The paper is structured as follows. Section II describes the system constructions and its corresponding setup. Section III details the motor winding processes. Section IV provides discussions and practical examples for evaluating the proposed approach. Finally, Section V presents the concluding remarks.

II. SYSTEM CONSTRUCTION

Fig. 2 is a photograph of a motor winding machine used to test the feasibility of the proposed design and evaluation methodologies. This motor winding machine equips three motors in different axes, that is, it works in a 3 degree-of-freedom motion space. Depending on the spindle motor, the winding speed can exceed 200 rounds per minute. The entire system is controlled using a single motion control kernel, IMP-2 (Fig. 3), which is manufactured by the Industrial Technology Research Institute, Taiwan. The relevant specifications of IMP-2 are presented in Table 1. Because of the demands for the automation of electric motors, the automatic winding machine has its potential niches. Several studies have focused on increasing the winding speed in the manufacturing process. High-speed winding enhances the manufacturing process quantitatively but not necessarily qualitatively. To monitor and maintain the quality to an acceptable level, an HMI is important. In particular, a remote, real-time, and multima chine interface is critical.

Table 1. Specification of IMP-2.

ADC Interface	14 bit, 8 Channels
DAC Interface	16 bit, 8 Channels
Encoder Interface	32 bit, 8 Channels
CPU	32 bit RISC, 400MHz
Timer	32 bits
Flash	32MB
RS232	1 Set
USB	1 Set for USB 2.0
Ethernet	1 Set for 10/100Mbps
PCI Interface	1 Set (32bit)

Fig. 2. Experimental motor winding machine.

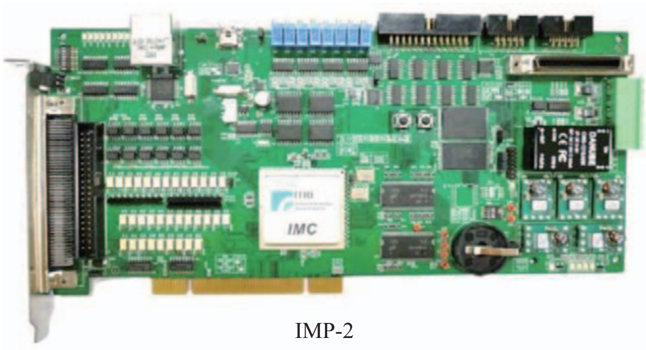


Fig. 3. Motion control card: IMP-2.

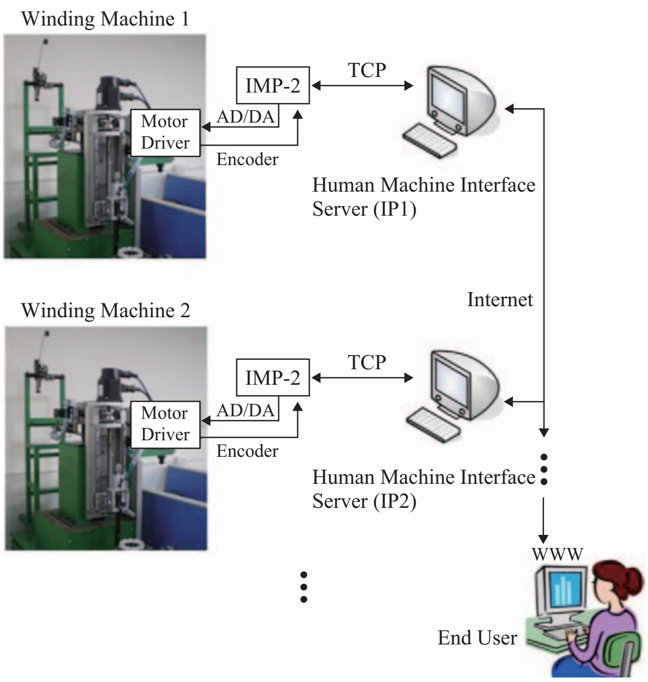


Fig. 4. Proposed micronet HMI system.

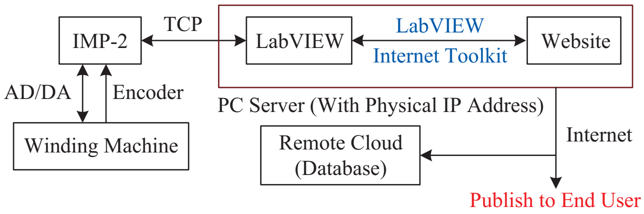


Fig. 5. Scheme of proposed data exchange.

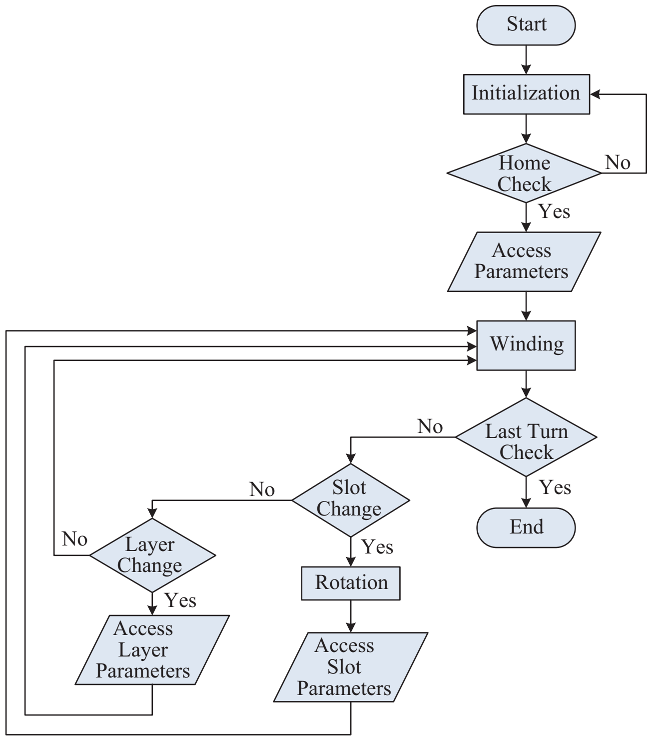


Fig. 6. Flowchart of winding process.

Fig. 4 illustrates the proposed monitoring strategy, which employs a micronet to manage all the HMIs. The distinguishing characteristic of this approach is its convenience and reliability in controlling and monitoring all process variables simultaneously. During the winding process, the IMP-2 and HMI exchange information in real time. Subsequently, LabVIEW coordinates the data acquisition for logging. The performance data can thus be monitored in real time and can be extensively analyzed through data logging.

Fig. 5 depicts the proposed data exchange strategy. A computer server remotely collects and stores data through a micronet. LabVIEW serves as a file manager and stores the received data in a spreadsheet database. The useful information is copied using a graphic interface for comprehensive analysis. Thus, an alternative program developed by LabVIEW establishes the graphical interface for displaying the real-time status of the remote winding machine. This program can be embedded into a website program. Consequently, all end users can assess the actual testing data of a winding machine on an interactive, graphical, and user-friendly platform. It is very convenient for all end users to browse the testing data through the website. WWW use is prospering as Internet penetration increases; this study utilizes this advantage to realize remote management of winding machines. The maximal load that the presented system can sustain depends on the bandwidth available for use between IMP-2, the PC server, and the end user. The academic contribution of this paper is that it enables the monitoring of real-time winding by using a portable device and the associated data can be accesses remotely through the Internet. In addition, the operator can analyze the data stored in the cloud to inspect and evaluate the winding quality. This is an innovative proposal—the first of its kind—which connects all winding information to a remote database for system inspections.

III. WINDING PROCESS

To control automatic motor winding using the proposed

Table 2. Specifications of the employed motors.

	X Axis	Y Axis	Z Axis
Rated Power (kW)	5	1	0.75
Rated Torque (Nm)	15.9	3.3	2.39
Maximum Torque (Nm)	39.7	9.9	7.16
Rated Speed (rpm)	3000	3000	3000
Maximum Speed (rpm)	4500	5000	5000
Encoder Resolution (pulse/rev)	2500	2500	2500
Rotor Inertia (kg/m^2)	12×10^{-4}	2.6×10^{-4}	1.08×10^{-4}

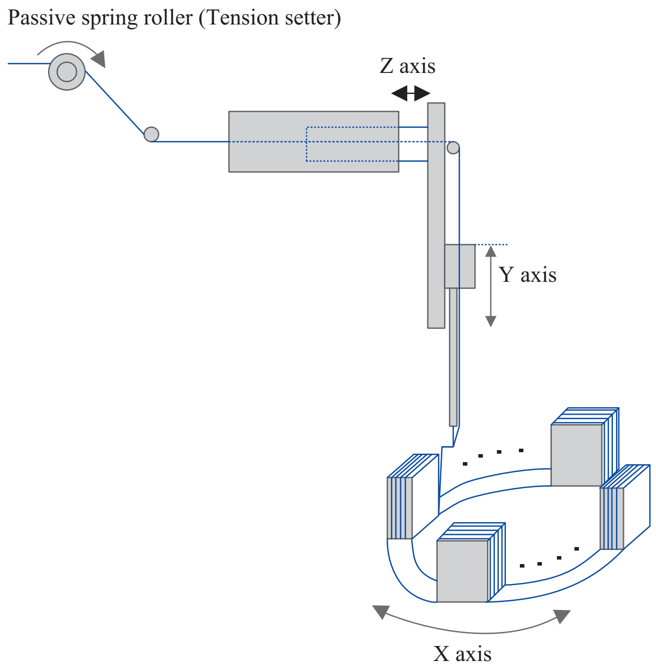


Fig. 7. Three axes motion scenario.

micronet HMI system, understanding the employed winding process is essential. The automatic motor winding process facilitates mass motor production and cost reduction. With proper control, each motor winding process can be completed within 5 minutes. Quality management is crucial; the presented HMI program can continually update and store real-time testing data to a spreadsheet database. The technical operator can examine the performance by reviewing the stored data. Fig. 6 is the flowchart of the winding process for the presented system. The "Home Check" function ensures that the winding pin starts from the designated origin. In the winding process, the control kernel IMP-2 coordinates with the machine's axis motor to achieve a particular winding. Wire winding is achieved through an s-curve position control. Fig. 7 illustrates the three-axes motion scenario. Motion control is implemented in a three-dimensional work space. Consequently, three servo motors were used to facilitate the winding process. The specifications of the employed motors are mentioned in Table 2. The machine winds the wire according to the shape of the motor. Different slots and air gap requirements substantially influence the winding speed. Moreover, to maintain identical impedance for all motor parameters, tension control of the winding machine is required. The winding s-curve command is predesigned for various motor geometric specifications. During winding, the control kernel governs the three-axes motors to wind the motor wire layer by layer and then slot by slot, respectively. The motor winding stops when the process is complete. The quickness of this process makes it difficult for the operator to differentiate between minute changes in the real-time process. To assist engineers in updating, adjusting, and fine-tuning winding performance, IMP-2 transfers the monitoring data to an HMI program through the micronet. Thus, winding speed and motor quality can be maintained efficiently.

In practical production, wire tension control is also essential. Without optimal tension control, the wire can break or become thin because of heavy tension stress, thus altering wire impedance. This phenomenon causes the mass production motors to produce inconsistencies in performances, such as maximum power, back electromotive force, and efficiency. Data acquired from an HMI can assist the operator to maintain and monitor the required quality. As stated, the proposed HMI is embedded in a web program; hence, the end users can access and examine the latest results from anywhere. Therefore, under the proposed scheme, an executive operator can act as a remote end user to evaluate and improve the process.

IV. EXAMPLE AND DISCUSSION

In this section, the proposed LabVIEW-based real-time evaluation system for motor winding machine illustrated using an example. Fig. 8 is a screenshot of the proposed LabVIEW-based micronet HMI system. Fig. 8(a) shows the LabVIEW program displaying information. The end user can assess the testing data and winding information, such as position, speed, and wire tension, in real time using this interface, which is embedded in the website program. Fig. 8(b) displays the "Jog setting" interface, which allows the operator to test and adjust the sensitivity of each actuator. Under acceptable settings, the performance can be estimated in advance. Fig. 8(c) shows the "parameter accessing" interface. All setting parameters can be set using this interface. In addition, the experimental results built by LabVIEW can be acquired using this control panel. Fig. 8(d) shows practical remote monitoring; the end user can quickly determine the current winding performance from the graphical and numerical data. This HMI uses graphical tools to present winding performance in an easy to comprehend and user-friendly manner.

Fig. 9 illustrates the data acquired for technical inspection from the HMI in a practical experiment. Fig. 9(a) is a plot of the wire location displacements in a single layer of the winding. Under appropriate s-curve regulation, the wire quickly and precisely fell into rank. Fig. 9(b) reveals the real-time wire

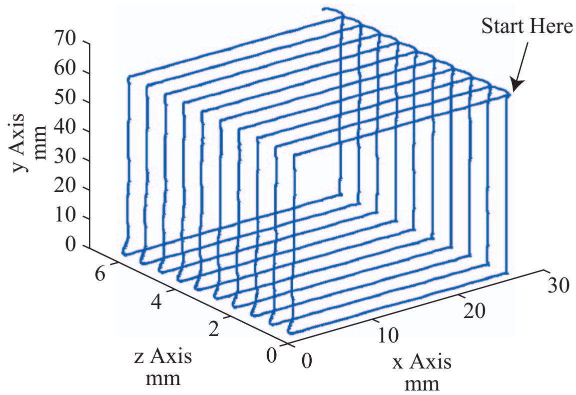
(a) Main display of human machine interface.

(c) Parameter accessing interface.

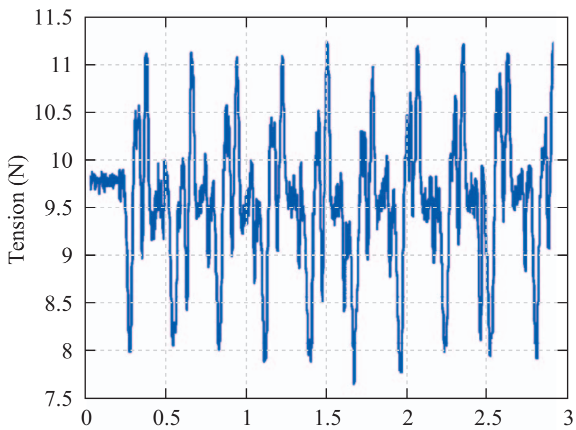
(b) Jog setting interface.

(d) Real time winding experiments.

Fig. 8. LabVIEW-based micronet HMI system.



(a) Position curvatures of winding pin in Cartesian coordinate system.



(b) Experimental data of wire tension.

Fig. 9. Experimental results.

tension. An experienced operator can approximately assess the winding quality by using the tension information. Usually, the tension waveform is monitored to inspect broken wires. In addition, winding tension considerably influences wire impedance. Consequently, the operator can observe the impulse peak to estimate the winding quality. The more enhanced the tension consistency is, the superior the winding quality is; this judgment algorithm can be embedded in the HMI, consequently making the winding process more intelligent. Finally, the operator must decide when the alarm functions of the HMI must be activated.

To summarize the functions of the presented system, technical staff can remotely and easily monitor winding machine parameters, such as position, speed, and tension, simultaneously using a web browser. By examining practical testing data, engineers can verify the performance remotely and investigate the enhancement. Because data are published on the website, the performance and reliability of the proposed winding machine are convincing. A video of the practical demonstration of the presented HMI is available at https://goo.gl/LC0pLE. The experimental results indicate that the proposed system is reliable and stable. Authorized end users from any location can voice their evaluative comments to the design team. Because the website can be accessed the general public as well, some security control for exploring the HMI is essential. The presented system is based on the expedited information exchange enabled by web-based platforms, which grants each mobile device a convenient opportunity to appreciate wire dancing.

V. CONCLUSION

An HMI is essential for the maintenance and control of machines, including motor winding machines. For contemporary applications, electric motors are preferred because of their quiet and pollution-free operation. Automatic winding technologies have facilitated mass motor production. This paper proposed design and evaluation methodologies for building an HMI for winding machines. The presented system uses the Internet to achieve remote monitoring through a web-based, real-time evaluation system with embedded LabVIEW software as the end user interface. All winding parameters, such as speed, position, and tension, can be accessed using a web browser. The real-time experimental results indicate that the proposed system functions efficiently. All testing results prove that the proposed LabVIEW-based HMI for automatic motor winding machines is cost effective and responds quickly.

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