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PC-based data acquisition system for PLC-controlled linear switched reluctance motor

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Abstract: In this study, a linear switched reluctance motor (LSRM) with 250 W, 6/4 poles, 3 phases, and 24 V was controlled with a programmable logic controller (PLC). Some parameters of the LSRM were set, and for PC monitoring, software developed by the authors was used. A serial port was used for communication between the PC and the PLC. The software was developed with Visual C#.Net 2008 for monitoring and controlling. This user interference allows for controlling of the motor's travelling distance with a running strategy. The first and second destination can be defined and the system provides that the motor operates between these points continuously. The phase and velocity currents of the motor were shown and curved with the software. The existing position of the motor and the number of pulses were determined and displayed with a linear incremental encoder. The windings of the motor phases were energized depending on their position using a classical bridge converter. This PLC-controlled LSRM study leads industrial practices and the educational sector to highlight the importance of linear motion, which is used in many implementations. Furthermore, all types of LSRMs can be used in the developed system.

Key words: Linear motor position control, linear switched reluctance motor, LSRM, monitoring software, programmable logic controller, PLC

1. Introduction

Many applications in industry require a linear motion control system. Most advanced manufacturing processes require high-speed and high-precision assembly machines for material transfer, packaging, assembly, and electrical wiring [1]. In recent decades in particular, robotics and computerized numerical control applications require high-precision use of linear motors with less vibration. In the miniaturized world, more and more attention has been drawn to the related device constructions by employing machine concepts such as microelectromechanical system (MEMS) application requirements on micropositioning stages, microfluidic devices, minimally invasive surgery, relays, and switches [2]. Generally, rotational motors were used for providing linear motion with a wheel, belt, and gear. This additional equipment decreased the efficiency of the system, required maintenance, and caused some mechanical problems. Linear motors eliminate the need for rotary-to-linear mechanical interfaces, resulting in simpler and robust conversion of electrical input into linear motion. There are also the additional benefits of quietness and reliability.

The linear switched reluctance motor (LSRM) has never been appreciated for its direct-drive linear motion control system in industry. In comparison to the linear AC permanent magnet (PM) motor or the linear AC

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induction motor, the LSRM has many advantages that other actuators do not have. First, the manufacturing of a LSRM is simple, and it is very suitable for high-precision travel over long distances. Second, unlike in other types of motion actuators, mechanical couplings, lead screws, magnets, and brushes are not required in the LSRM. Special mechanical adjustments or alignments are also not necessary. Third, the windings are concentrated rather than distributed, making them ideal for low-cost manufacturing and maintenance. Finally, in comparison with PM linear motors, the proposed actuator has a much simpler structure and is less expensive. It is also more robust and more fault tolerant, there are none of the demagnetization effects of PMs, and it has fewer overheating problems [3–5]. Therefore, the LSRM is a potential candidate for high performance linear motion drive [5,6].

Studies of the LSRM have focused on the converter, driver, and control of the motor; research on usage in different industrial areas and mechanical/geometrical structure; and increasing efficiency. The design schemes and analysis for the LSRM are presented in [5,7–10], and the speed control for the LSRM is discussed in [11–14]. In terms of application area, longitudinal-flux LSRMs have been proposed for applications such as precise motion control [15,16] and as propulsion systems for railway vehicles [17] or vertical elevators [18–21]. In [22], a high-force longitudinal-flux double-sided double-translator LSRM was analyzed. Some papers presented a detailed sensitivity analysis of the effect of several geometrical parameters on the performance of a double-sided LSRM [23,24]. A novel stator geometry for LSRMs that improved the force profile was presented in [25]. Moreover, some research was focused on the investigation of new materials and technologies with the ability to directly produce a linear displacement while simultaneously trying to solve new problems directly related to linear actuators, like the cogging force, the attractive force perpendicular to the movement, or the end effects [26].

In the literature, it has been observed in studies that the LSRM was generally designed and applied for special applications. In this study, a graphical interface, not previously seen in other studies, was prepared for an LSRM that was designed to drive an elevator door. The input parameter was set before running and the output parameter was observed with the developed software. The designed system may be applied to all types of linear motor studies, owing to the fact that the input and output parameters are determined by the user. In these studies, digital signal processing and peripheral interface controller microcontrollers are widely used to control the LSRM. The programmable logic controller (PLC), which has been preferred in industrial applications, is used in this study. The motor was controlled, the output parameters were transferred to the computer, and numerical values were recorded using the PLC. Thus, viewing and recording equipment such as oscilloscopes and data acquisition cards were eliminated.

2. Design of the system

The LSRM was controlled with a Siemens brand S7-200 CPU 224 PLC. Linear encoder pulses (A, B, Z) were sensed by the high-speed counter features of the PLC. The velocity of the motor was calculated with an encoder. The currents of the phases were measured by PLC EM-235 analog modules. The forms of system feedback were the phase currents and linear encoder pulses. The overall scheme of the study is given in Figure 1.

The windings of phases were excited depending on the motor position. This energizing scheme provided the inductance profile of the motor. A photographic view of the system with the LSRM is given in Figure 2.

2.1. LSRM and driver

Interest in the rotational switched reluctance motor (SRM) has increased, especially after the development of semiconductor technology. The SRM has a simple structure with salient pole rotor and translator, with windings on the rotor [8,27–29]. Moreover, its speed control range is very large, and unlike classical DC motors, it has no maintenance parts. Owing to these features, these motors have found a widespread area of usage in consumer and industrial applications [30]. They are being used in many practical fields in rotational and linear movement control systems as an alternative to other AC and DC motors. LSRMs are still being developed and put into effect in many applications such as elevators and automatic doors, which require linear movement [11,31,32].

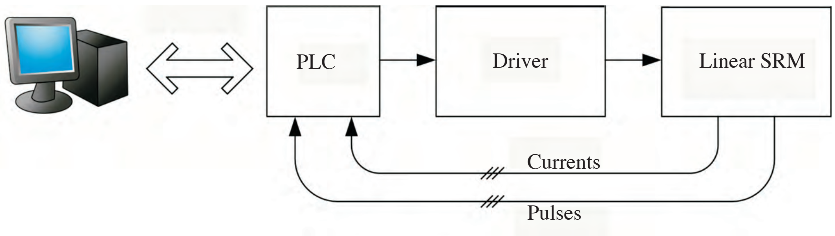

Figure 1. Control and monitor system of the LSRM.

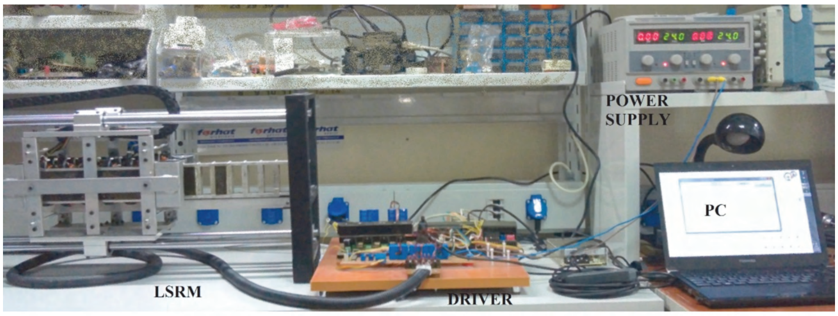

Figure 2. The photographic view of the system with the LSRM.

The stator of the LSRM is the movable part of the machine and the fixed part of the magnetic core is equivalent to the rotor, as shown in Figure 3. The controlled LSRM is designed as double-sided and mutual windings are connected in parallel. Same-phase windings on the same side are connected in series. The rated power of the LSRM is 250 W and the current of the motor is 5 A.

The driver for the efficient operation of the motor was designed in consideration of the windings. A classical bridge converter was chosen for exciting the phases of the motor. The circuit of the driver is given in Figure 4. The gate signals of the power switches were generated by the PLC. The current sensors were used for monitoring the currents of the phases. After the exciting of the phases, they were switched off, as it was important that waste energy be removed as quickly as possible. The time was decreased by using free-wheeling diodes. The waste energy of the phases was returned to the power supply's capacitor.

2.2. Programmable logic controller

A Siemens brand S7-200 CPU 224 PLC was chosen as the controller of the system. It is a highly effective and economical solution for automated control in the compact performance range. An EM-235 coded analog module with 12-bit resolution was connected to the PLC as an extension module for sensing the current of the phases. The connection diagram of the controller is given in Figure 5. The output pulses of the linear encoder were sensed by the high-speed counter features of the PLC. The position of the motor was determined with encoder pulses and the speed was also calculated. The gate signals of the power switches of the driver were generated

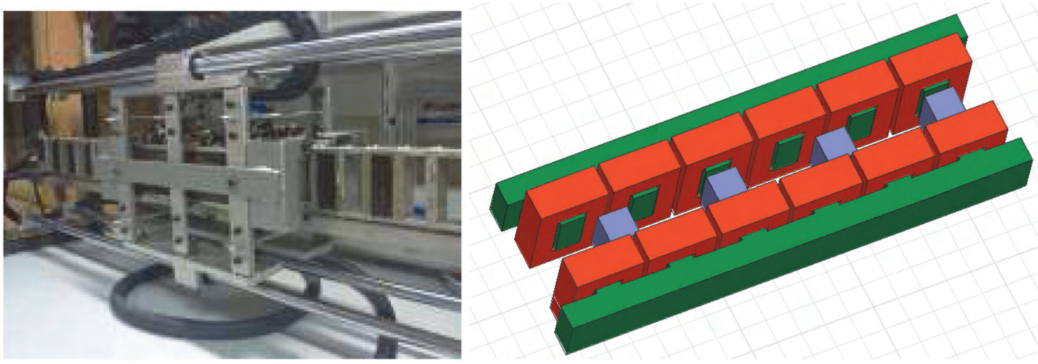

Figure 3. Photographic (a) and 3D views (b) of the LSRM.

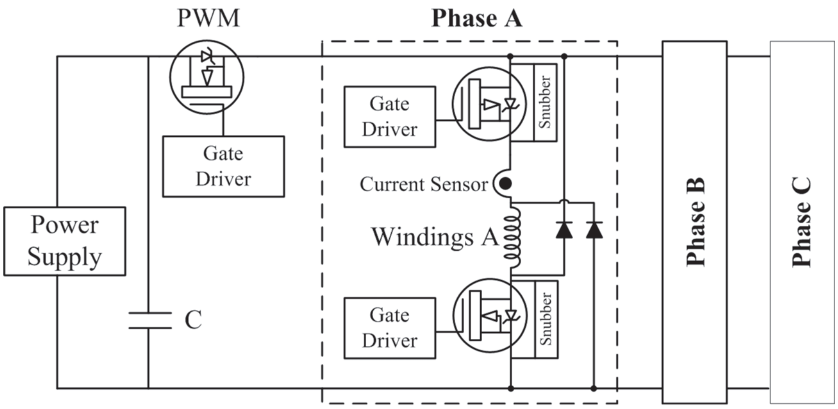

Figure 4. The circuit of the LSRM's driver.

by the output of the PLC. The special PC/PPI cable of the PLC was used for communication between the PC and PLC. Its connection type is RS-485 on PLC point and USB on PC point.

Figure 6 shows the linear encoder pulses and the connection of the controller. The number of pulses was countered with the PLC, and the direction of the movement of the motor was also determined by the pulse sequence. When the direction changed, an interrupt occurred and this information was monitored. The linear encoder has 62.5 μm resolutions with quadrate sensing. It was coupled to the stator of the LSRM. Output signals A and B have 90° electrical differences. Every 5 mm, an index signal was generated. It was used to reset the incidental counting fault.

Figure 7 shows the photographic views of the motor driver and the PLC. It also includes the current sensors, power supply of the PLC, and the PC/PPI cable for connection between the PC and PLC.

The velocity of the motor was maintained at the desired value with the proportional-integral (PI) controller. The parameters of the PI controller were defined and improved with the experimental results. The acquired output value of the PI was applied as the pulse-width modulation (PWM) signal of the PLC.

2.3. PC and PLC software

A flowchart of the software is given in Figure 8. The C# and PLC algorithms are given together because they communicate simultaneously. Figure 9 shows the user interface of the software. On the C# section, first the COM Port was opened for communication with the baud rate speed and com port number. When the connection was successfully set up, other parts of the software were activated; otherwise, the software would

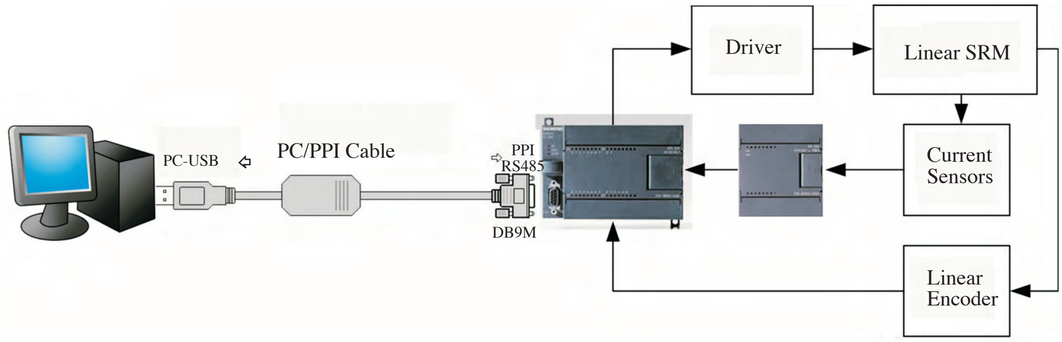

Figure 5. Connection diagram of the controller.

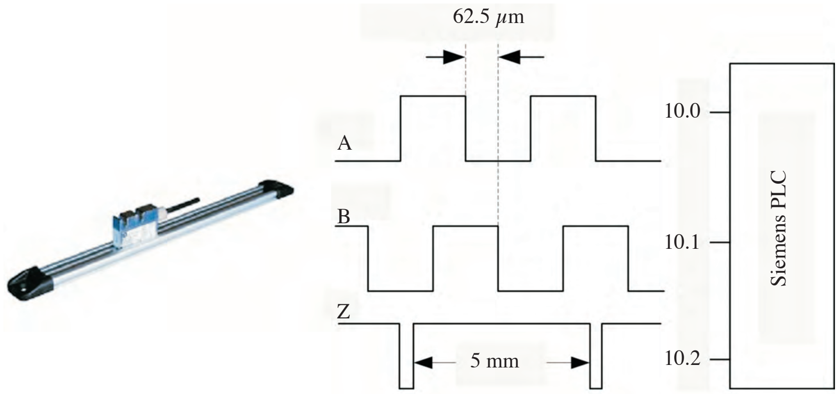

Figure 6. Linear encoder pulses and connection with the controller.

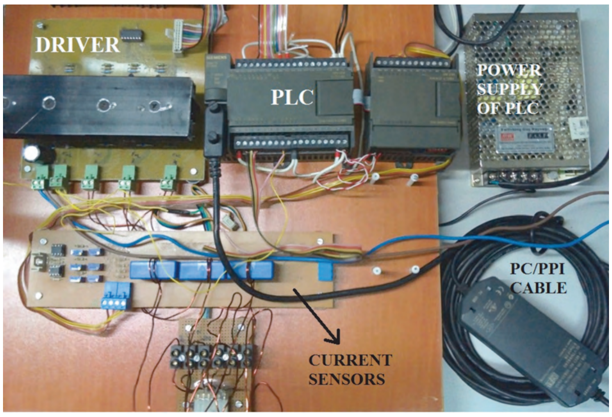

Figure 7. Photographic views of the driver and controller.

wait until the connection was set. The firing angles of the phases must be entered into the "phase energizing length"-related text box. The reference velocity as m/s and sensor resolution as mm must also be entered into the text box. The working method must be selected optionally as one-way or multiway (continuously). When the first and second destination points are entered in mm, all of the data of the initialization are ready to be sent to the PLC. When the "Set Value" button is clicked, the data package containing the firing length of the phases, reference velocity, sensor resolution, and destinations is sent through the PLC. The C# software waits until the confirmation of the data package transmission is received. In the PLC section, after some configurations are set up, the PLC waits for the data package. After confirmation that the data package has been successfully received,

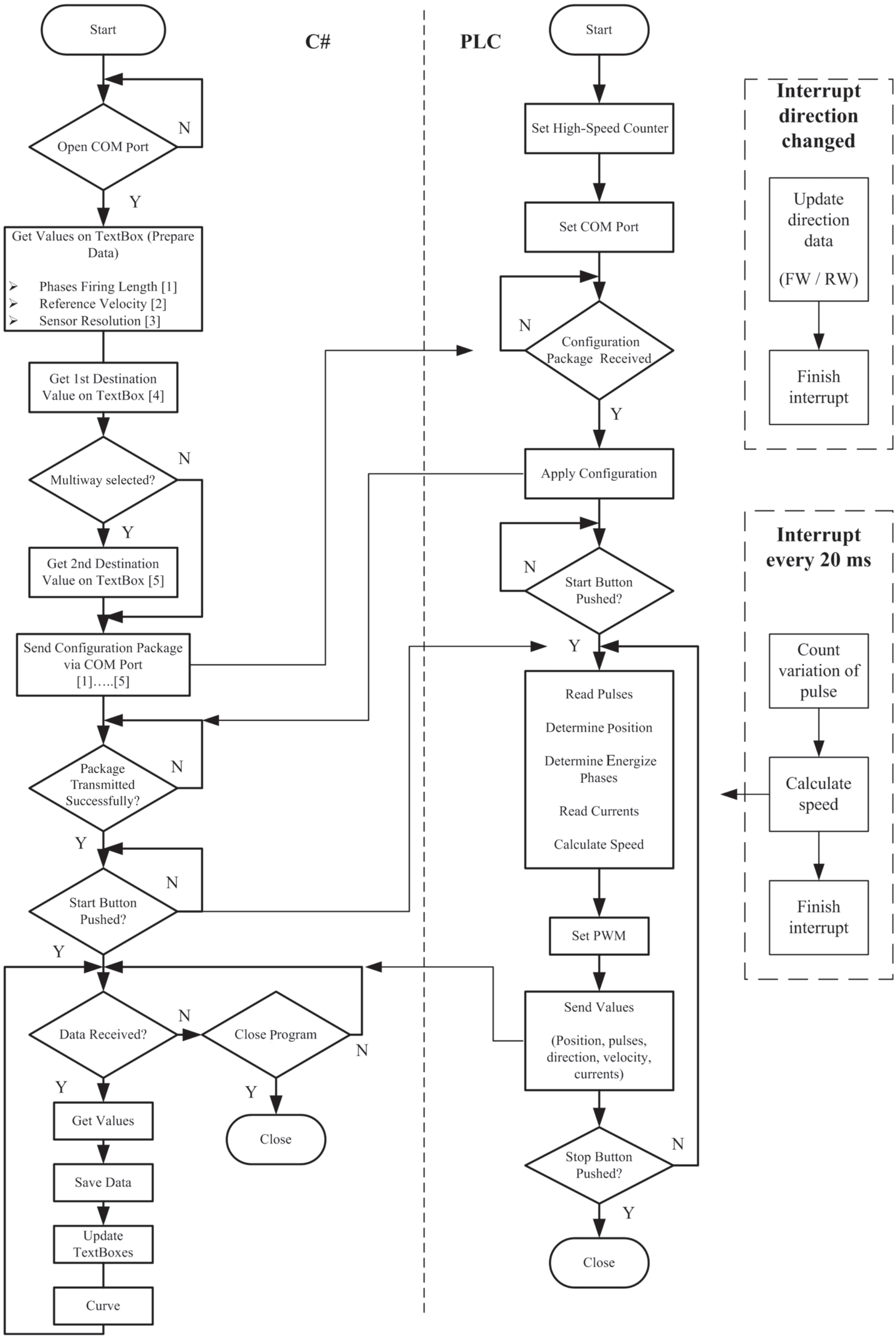

Figure 8. Flowcharts of the software.

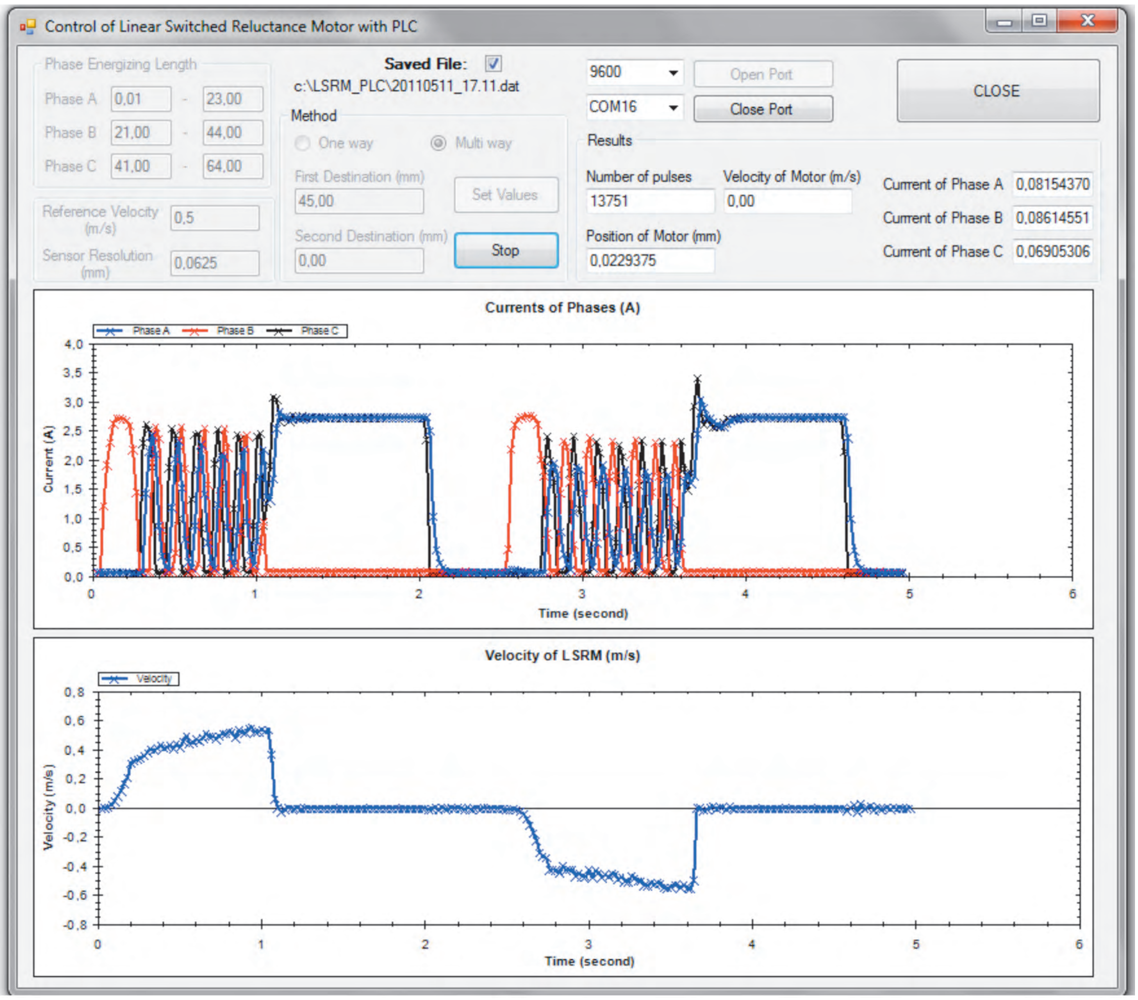

Figure 9. A screenshot of the user interface of the developed software.

the PLC sends the data back for confirmation and waits for the start data. When the data for confirmation is received in C#, the "start" button is activated. After the start button is pushed, this software sends the data for starting to the PLC and starts to wait for the information about the number of pulses, position of the motor, and velocity for monitoring and plotting data until the stop button is clicked. When the data package is received from the PLC, the configuration and calculation values are set up and the system starts counting the pulses. The position of the motor is calculated by multiplying the sensor resolution and the number of pulses. Depending on the position, the software determines which phase must energize. Every 20 ms, an interruption is generated to calculate the speed using a variation of pulses. The PWM value is determined to maintain the desired speed of the motor. The data package for the monitoring system is prepared and sent to the COM port. It includes the position, direction, and speed of the motor and the number of pulses and currents of the phases. This loop continues until the stop button is pushed. For every data package received by the PC, an interruption has occurred. The data package is encoded for updating texts, curving, and saving.

3. Conclusions

The design of a control and monitoring system for a LSRM was the aim of this study. The parameters of the LSRM were 250 W, 6/4 poles, 3 phases, 24 V, and 5 A. It was controlled with a Siemens brand S7-200 CPU 224

PLC, depending on the input parameters set by the user. Some output parameters of the LSRM were sensed and calculated by the PLC and sent through the PC via the COM Port. The software was developed with Visual C#.Net 2008 for the monitoring and setting of some parameters. Saving data to file as an option, COM port settings, phase energizing length, reference velocity, sensor resolution, and first and second destination must be set by the user. The number of pulses, velocity and position of the motor, and the currents of the phases were monitored instantly for all data received by the serial port. The velocity of the translator and currents of motor phases were plotted, which leads to determination of the accurate energizing length. For determining the motor position, a linear incremental encoder was used. The linear encoder generates pulses (A, B, Z) that are sensed by the high-speed counter features of the PLC. It has 62.5 μm resolutions with quadrate sensing. Moreover, the velocity of the motor was calculated with the encoder. The current of the phases was measured by PLC EM-235 analog modules. This PLC-controlled LSRM study leads industrial practices and the educational sector to highlight the importance of linear motion, which is used in many implementations.

In this study, the designed system, which was prepared for all types of linear motor applications, was provided to run a motor depending on the options selected by the user. The motor was designed for an elevator door application, but the system may be used for powerful applications (linear rail systems, large doors) with development. The output parameters of the system as the position, currents, and speed of the motor were visualized. The currents and velocity may be observed in the graphics. The designed system provides easy usage, especially in applications for different distance requirements. The phase energizing length, which is the most important parameter affecting the output power of the motor, may change, and thus unbalanced currents can easily be identified. The numerical data of the motor (currents, position, and velocity) was recorded and curved. Thus, additional recording or visualization equipment was eliminated.

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