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DESIGN AND DEVELOPMENT OF A HIGH-SPEED FULLY AUTOMATIC CABLE WINDING MACHINE FOR SPOOL DIAMETERS RANGING FROM 380 TO 1000 MM

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Abstract

Winding cables at high speeds while maintaining stable performance and accommodating different spool sizes is important for production efficiency and product quality in cable manufacturing lines. In this study, a fully automatic cable winding machine was designed and developed for the high-speed automatic winding of single-core, multi-core, and flat cables, with a mechanical structure designed to operate with spools having outer diameters ranging from 380 to 1000 mm. The developed system consists of automatic empty spool feeding and positioning mechanisms, an accumulator unit, a traverse system, a winding unit, and a stretch film packaging unit. The mechanical, electrical, and pneumatic components of the machine are synchronized through a PLC-based control system, enabling the winding process to be performed with minimal operator intervention. Industrial performance tests were conducted using a 500 m cable length, and the system achieved a line speed of 450 m/min and a production capacity of 40 spools per hour. The developed mechanical structure and control system enable different spool sizes within the 380–1000 mm outer diameter range to be handled on the same machine. The results demonstrate that the developed system provides an effective cable winding solution in terms of high line speed and automation capability.

Keywords: Automatic cable winding machine, cable winding, spool winding, PLC control, industrial automation, high-speed winding.

INTRODUCTION

Cables are among the fundamental components that ensure the reliable transmission of electrical energy and the operation of data and communication systems, and they are widely used in various sectors, including energy, automotive, construction, defense, telecommunications, and industrial automation. The increasing global demand for electrical energy and data communication has led to a continuous increase in cable production volumes, resulting in higher requirements for production capacity, quality, and automation in cable manufacturing lines. Particularly with the widespread adoption of Industry 4.0 applications, reducing human intervention in manufacturing processes, ensuring production continuity, and managing processes through intelligent automation systems have become increasingly important.

Winding and packaging, which are among the final stages of the cable manufacturing process, play a critical role not only in preparing the product for shipment but also in preserving product quality and ensuring safe storage and transportation. Winding cables onto spools or into coils with an appropriate winding

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geometry helps prevent crushing, bending, tangling, and other forms of mechanical damage, while also facilitating safer handling during storage and logistics. In addition, proper packaging enables cables to be easily unwound during installation and use, thereby reducing labor time and improving operational efficiency.

Although automatic winding and packaging systems are widely used in cable production lines, several technical challenges remain, particularly in increasing production speeds and accommodating different spool sizes. Maintaining winding quality across spools with different outer diameters, ensuring proper cable guidance, and sustaining stable winding performance under varying production conditions represent significant engineering challenges in terms of mechanical design and control systems. Therefore, in recent years, various academic and industrial studies have focused on improving the mechanical structures of automatic cable winding systems, enhancing control algorithms, and increasing production efficiency.

Within this context, recent studies have focused not only on automating the winding process itself but also on automating pre- and post-winding operations to improve overall production efficiency. Varal et al. [1] developed a spool transfer system for automatic cable winding machines that integrates the removal of a full spool and the loading of an empty spool within a single mechanism. Experimental results showed that the developed system reduced the processing time by approximately 33% and improved production efficiency. In another study focusing on reducing idle time during production, Avcı et al. [2] developed a high-capacity automatic cable winding machine with three winding heads, capable of packaging cables on perforated spools, slotted spools, and in coil form. By increasing the number of winding heads, a high winding capacity was achieved for different cable lengths. Similarly, in the patent developed by Edstrom [3], an automated system was proposed for the controlled winding of cables and similar flexible materials onto spools, with the aim of reducing operator intervention.

In addition to production capacity, the integration of different winding and packaging methods within the same system has also been investigated in automatic winding systems. In the patent developed by Öztürk and Özbaran [4], a system capable of performing both coil and spool winding on the same machine and securing the cable ends with stretch film after winding was proposed. Taking a different approach to the use of auxiliary materials in the packaging process, Avcı et al. [5] developed a cable packaging system that secures the cable ends without requiring auxiliary packaging materials such as string, stretch film, or strapping. Experimental results showed that the system achieved a winding capacity of 12 coils per minute for short-length cables and 8 coils per minute for long-length cables. These studies demonstrate that, in addition to increasing production capacity, simplifying post-winding operations and automating the packaging process are also important aspects of automatic cable winding systems.

In addition to the automation of winding and packaging operations, the controlled feeding of cables and the achievement of stable winding performance are other important topics addressed in the literature. Zhe et al. [6] proposed a method for controlling cable tension in bidirectional cable winding systems and demonstrated that the developed control system maintained cable tension within safe limits, thereby ensuring stable winding performance. Kevac and Filipovic [7] investigated the effects of varying physical parameters during winding and developed a general mathematical model for different cable winding and unwinding systems. The model considered the effects of winding radius and cable length on the dynamic behavior of the system, and the obtained results were validated through experimental studies. Focusing on the controlled delivery of the cable to the winding zone, Hultman and Leijon [8] developed a cable feeding system for robot-assisted automatic cable winding. The system was shown to reduce

cycle time compared with manual winding by providing cable feeding, guidance, and slip control. Taken together, these studies indicate that winding performance depends not only on the mechanical configuration of the winding system but also on cable feeding, guidance, tension control, and the management of varying winding radii.

EXPOSITION

When the studies in the literature are evaluated as a whole, it is observed that they mainly focus on the automation of spool transfer [1], increasing production capacity [2], reducing operator intervention through automatic winding [3], improvement of packaging processes [4,5], cable tension control [6], modeling of winding dynamics [7], and development of cable feeding and guidance systems [8]. However, these studies generally address different sub-problems individually, while integrated solutions capable of operating over a wide range of spool outer diameters and winding long-length cables at high line speeds remain limited.

In this study, an automatic cable winding system capable of operating with spools having outer diameters ranging from 380 to 1000 mm and winding 500 m long single-core, multi-core, and flat cables at high speeds was designed and developed in accordance with the specified requirements. In addition, PLC-based control software was developed to enable the synchronized operation of the mechanical and automation components of the system for different spool sizes and production conditions.

MATERIAL AND METHOD

In this study, an innovative cable winding machine was designed and developed for the high-speed automatic winding of single-core, multi-core, and flat cables onto spools with outer diameters ranging from 380 to 1000 mm. The general process flowchart of the developed system is presented in Figure 1. The system is capable of winding 500 m long cables, operating at a line speed of 450 m/min, and achieving a production capacity of 40 spools per hour. In addition, the developed PLC-based control software enables a stable, flexible, and high-performance winding process for different cable types and spool diameters.

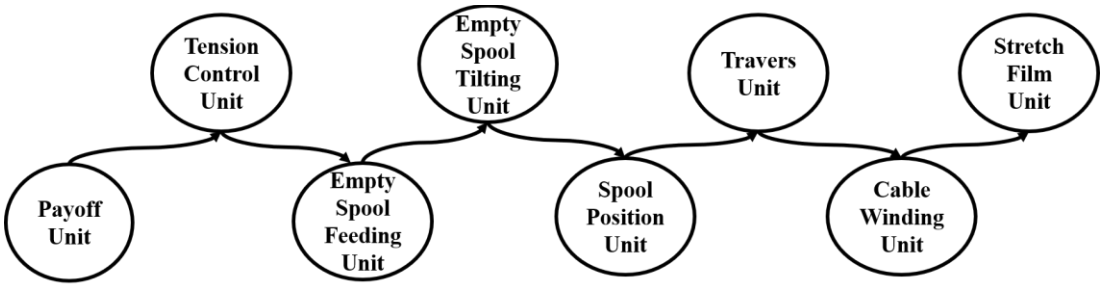


Fig. 1. *General flow chart of cable packing process*

Cable Packaging Machine Components

The general layout of the automatic cable winding machine developed in this study and its main components are presented in Figure 2. The machine was designed to enable the automatic winding of different cable types at high speeds and over a wide range of spool diameters.

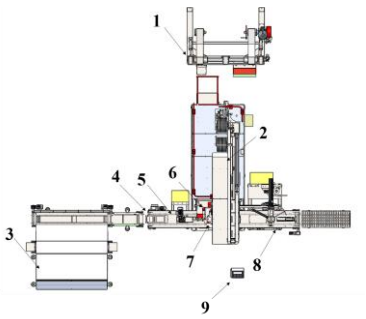


Fig. 2. *Machine General View 1. Pay-off Unit 2. Accumulator Unit 3. Empty Spool Feeding Unit 4. Horizontal-to-Vertical Empty Spool Tilting Unit 5. Spool Positioning Unit 6. Traverse Unit 7. Winding Unit 8. Stretch Film Unit 9. Main Control Panel*

Pay-off Unit

To operate the system, the required settings of all mechanical, electrical, and pneumatic components of the machine are first completed. The cable is then fed into the system through the pay-off unit, initiating the winding process. The operating parameters of the pay-off unit are adjusted via the control panel, and the cable is transferred to the accumulator unit in a controlled manner according to the required cable length and production conditions.

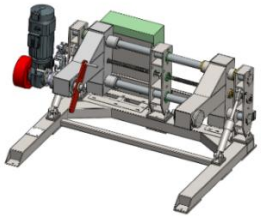


Fig. 3. *Payoff Unit*

Accumulator Unit

The accumulator unit serves as a temporary cable storage system to ensure continuous and stable cable feeding during the winding process. The system consists of two groups of pulleys arranged parallel to each other. The first pulley group is stationary, and the cable enters the system through this section. The second pulley group is movable and performs linear motion according to the required cable feed.

By moving forward and backward according to the cable demand of the winding unit, the movable pulley group maintains cable tension and ensures continuous feeding. Its motion is provided by a pneumatic cylinder and belt mechanism, while the movable pulley group is guided along linear guides to ensure controlled linear movement.

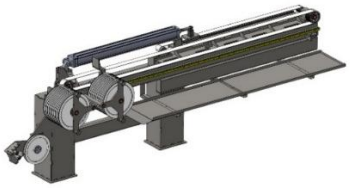


Fig. 4. *Accumulator Unit*

Empty Spool Feeding Unit

The empty spool magazine was designed to automatically feed spools with different outer diameters into the production line without operator intervention. The magazine unit has a storage area of 2400 x 1600 mm, allowing multiple empty spools to be stored simultaneously. The spools are transported to the feeding point by a robust chain conveyor system and transferred to the winding station in a controlled manner.



Fig. 5. *Empty Spool Feeding Unit*

Horizontal-to-Vertical Empty Spool Tilting Unit

The empty spool tilting unit was designed to rotate the empty spool received from the spool feeding mechanism from a horizontal to a vertical position in a controlled manner. After the tilting operation, the spool is transferred to the positioning unit, where it is brought to the required reference position for the winding unit.

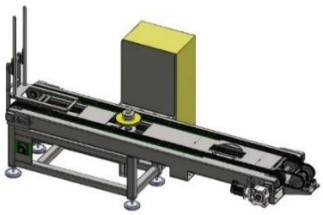


Fig. 6. *Horizontal-to-Vertical Empty Spool Tilting Unit*

Spool Positioning Unit

The spool positioning unit was designed to bring the empty spool to the correct position before it is transferred to the winding unit. In this unit, the spool is precisely positioned to ensure that the traverse mechanism is properly aligned with the central hole of the spool. This prevents potential alignment errors during transfer to the winding unit and improves the reliability of the winding process.



Fig. 7. *Spool Position Unit*

Traverse Unit

The traverse unit was designed to ensure that the cable is wound onto the spool with the desired winding geometry and arranged in uniform layers during the winding process. The unit moves laterally through a servo motor-driven linear motion mechanism, precisely guiding the cable across the width of the spool. The cable is delivered to the winding zone in a controlled manner through a guide tube located on the traverse mechanism and is maintained at the required position throughout the winding process. The motion parameters are automatically adjusted by the developed PLC-based control software according to the spool dimensions and winding parameters, thereby ensuring uniform winding performance for different spool diameters and cable types.

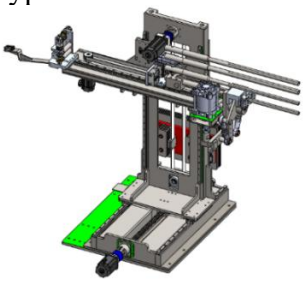


Fig. 8. *Traverse Unit*

Cable Winding Unit

The winding unit is the main station where the cable is wound onto the spool to the desired length in accordance with the specified winding parameters. In this unit, the cable is guided in a controlled manner across the width of the spool by the traverse mechanism, ensuring that it is wound in uniform layers. During the winding process, cable tension is balanced by the accumulator unit, while the developed PLC-based control system synchronizes the spool rotational speed with the traverse movement to achieve a uniform winding geometry.

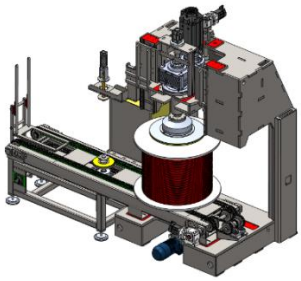


Fig. 9. *Cable Winding Unit*

Stretch Film Unit

The stretch wrapping unit was designed to package the spool after the winding process and securely fasten the cable end. Following the winding process, the spool is transferred to the stretch wrapping unit while the cable end is held in position, and the spool is automatically wrapped with stretch film at this station. The stretch wrapping process prevents the cable end from unwinding, maintains the integrity of the wound cable, and prepares the product for storage and shipment. After the stretch wrapping process is completed, the packaging process is finalized and the spool is transferred to the next station.

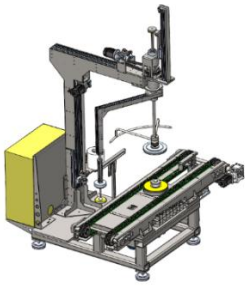


Fig. 10. *Stretch Film Unit*

Main Control Panel

All operations of the developed automatic cable winding machine are managed through a touchscreen Human-Machine Interface (HMI) and controlled by a PLC-based control system. Machine operating parameters, including spool diameter, cable type, winding length, and production speed, can be defined through the operator panel, while the production process can be monitored in real time. Errors, warnings, and system status information that may occur during operation are displayed to the operator on the HMI screen, ensuring safe and uninterrupted operation of the production process. A Siemens S7-1500 PLC was used in the developed control

system, and the PLC software was developed using the TIA Portal engineering environment. Real-time communication between the operator interface and the PLC enables the synchronized operation of all mechanical and pneumatic units.

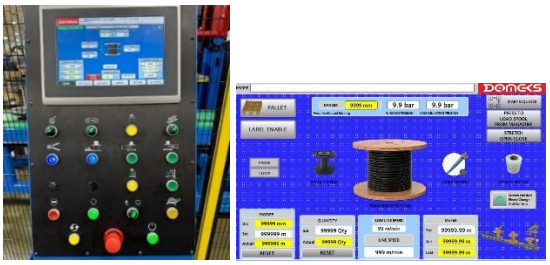


Fig. 11. *Main Control Panel*

RESULT AND DISCUSSION

The automatic cable winding machine developed within the scope of this study was designed to perform empty spool feeding, spool positioning, winding, and packaging operations fully automatically and was tested under industrial production conditions. Empty spools are automatically fed from the magazine unit by means of a chain conveyor and precisely aligned in the positioning unit. Through this positioning process, the traverse mechanism is aligned with the central hole of the spool along the correct axis, enabling the winding process to start reliably.

During the winding process, the cable is fed under controlled tension by the accumulator unit and guided across the width of the spool by the traverse mechanism. The PLC-based control system continuously synchronizes the spool rotational speed with the traverse movement, ensuring a uniform winding geometry for different spool diameters. The developed system is capable of winding single-core, multi-core, and flat cables onto spools with outer diameters ranging from 380 to 1000 mm without requiring any mechanical adjustments.

Performance tests conducted under industrial production conditions demonstrated that the system successfully wound 500 m long cables, operated at a line speed of 450 m/min, and achieved a production capacity of 40 spools per hour. Throughout the tests, the winding geometry was maintained, spool changes were performed automatically, and the system exhibited stable operating performance under different production conditions.

The machine control system consists of a Siemens PLC, servo drives, an HMI operator panel, remote input/output modules, and a communication infrastructure. The PLC program was developed using the TIA Portal engineering environment. The system topology, hardware configuration, and communication network were established, and all input/output modules and drives were individually tested. The developed PLC software enables synchronized control of all mechanical, pneumatic, and electrical components of the machine, while allowing the production process to be monitored in real time through the operator panel. The PLC hardware configuration and system topology are presented in Figure 12.



Fig. 12. *PLC plan of the system*

The motor power ratings of the components of the machine designed and manufactured in this study are presented in Table 1.

Table 1. *System Motor Powers*

Machine Components	Motor Powers
Payoff Unit	11 kW
Payoff On-Off	0,75 kW
Spool Feeding Unit	2 x 0,55 kW
Winding Head	1,5 kW
Stretch Up-Down	1,5 kW
Stretch Rotation	0,75 kW
Horizontal-to-Vertical Empty Spool Tilting Unit	0,37 kW
Spool Position	0,75 kW

The general view and main components of the automatic cable winding machine developed within the scope of this study are presented in Figure 13.

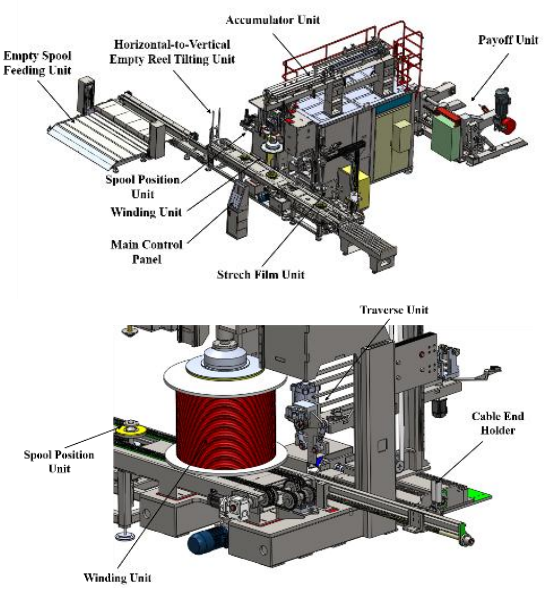


Fig. 13. *Cable packing machine parts*

The performance of the automatic cable winding machine designed and developed in this study was experimentally evaluated under industrial production conditions. During the performance tests, the operating capability of the system was investigated under different spool outer diameters and production parameters. The production capacity, maximum line speed, and supported spool outer diameter range of the developed machine were compared with those of the existing systems, referred to as Machine 1 and Machine 2. A single-core cable with a cross-sectional area of 4 mm² and an outer diameter of 4.2 mm was used in the performance tests. The experiments were conducted with a winding length of 500 m at a line speed of 450 m/min. Under the specified test conditions, the production performance and supported spool outer diameter ranges of the machines were evaluated, and the comparative results are presented in Table 2.

In Table 2, the technical performance of the developed automatic cable winding machine is compared with that of the existing systems. The comparison considers the maximum line speed, cable winding length, supported spool outer diameter range, and production capacity.

Table 2. *Performance Comparison of the Developed Cable Winding Machine with Existing Systems*

Machine Name	Winding Speed (m/min)	Cable Length (m)	Spool Outer Diameter Range (mm)	Production Capacity (spools/hour)
Cable Winding Machine for Spool Diameters Ranging From 380 to 1000 mm	450	500	380-1000	40
Machine 1	450	500	300-800	38
Machine 2	450	500	360-560	39

Note: Data for Machine 1 and Machine 2 are based on internal benchmarking against comparable commercial cable winding systems. All three machines were evaluated under the same fixed test winding speed (450 m/min) to enable a direct comparison of spool diameter range and production capacity.

According to the comparison results, the developed system offers a wider spool size range than the existing systems, as it is designed to operate with spools having outer diameters ranging from 380 to 1000 mm. In addition, the system is capable of automatically winding 500 m of single-core, multi-core, and flat cables at a line speed of 450 m/min.

Existing systems are designed to operate within specific spool diameter ranges and may require additional mechanical adjustments to accommodate a wider range of spool sizes. In contrast, the developed system is designed to accommodate different spool sizes without requiring additional mechanical adjustments, owing to its adaptable mechanical structure and PLC-based control system. The results demonstrate that the developed machine provides significant advantages over the

existing systems in terms of production flexibility and operational efficiency.

CONCLUSION

In this study, a high-speed automatic cable winding machine was developed to address these requirements. The machine was designed to operate with spools having outer diameters ranging from 380 to 1000 mm and to automatically wind single-core, multi-core, and flat cables. The integrated operation of the automatic spool feeding and positioning mechanisms, accumulator unit, traverse system, and PLC-based control infrastructure enables the winding process to be performed fully automatically.

Experimental studies were conducted using a single-core cable with a cross-sectional area of 4 mm² and an outer diameter of 4.2 mm, with a winding length of 500 m. The test results showed that the developed machine could operate at a maximum line speed of 450 m/min and achieve a production capacity of 40 spools per hour. The mechanical structure of the machine was designed to accommodate different spool sizes within the 380–1000 mm outer diameter range without requiring additional mechanical adjustments. Furthermore, the PLC-based control system was developed to accommodate different cable types and production parameters. The results demonstrate that the developed machine provides an effective solution for automatic cable winding applications through its high line speed, production capacity, and ability to accommodate different spool sizes.

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