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DESIGN OF A CABLE PACKAGING SYSTEM CAPABLE OF SECURING CABLE ENDS WITHOUT THE USE OF AUXILIARY MATERIALS

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ABSTRACT

Cable packaging machines are devices that automatically wrap long and thin materials, such as wires, cables, and pipes, into organized packages. These machines play a crucial role in cable production by saving time and labor during the manufacturing process. While there are various types and features of cable packaging machines, their common objective is to ensure that materials are wrapped to the correct size, tightly packed, and easily transported.

In this study, the performance of a newly designed and manufactured machine was evaluated. This machine is capable of packaging cables in coil form without the use of auxiliary materials such as twine, stretch film, or straps. The system is composed of seven main sections: the flayer, tension control unit, traverse unit, cable winding heads, clamp group, shrink unit, and the main control panel. A noteworthy feature of the machine is that the cable winding heads can rotate 180°, and the elimination of auxiliary materials in the packaging process reduces costs and minimizes the time lost during cable winding.

Experimental results show that the machine is capable of wrapping 12 coils per minute for short-length cables (5 m, 10 m, 15 m, 20 m, 25 m) and 8 coils per minute for long-length cables (50 m, 100 m).

1. INTRODUCTION

The rapid developments in the construction sector, the increase in the world population, the expansion of industry, and the rapid implementation of new technologies have led to a global increase in demand for renewable energy sources and a growing need to meet individuals' electricity needs in all areas. This situation has significantly increased the demand for installation cables, in particular. Since medium and high-voltage electricity transmission generally occurs over long distances, the production, transportation, and sales of such cables are conducted in large quantities. Today, installation cables are typically sold in 100-meter packages. However, the desire of individual users to purchase only the amount of cable they need has created a necessity for cables to be packaged in shorter lengths, such as 5 meters, 10 meters, or 15 meters.

To meet this demand, cable manufacturers and sellers have begun producing smaller-sized and measured cable coils. Cable winding not only makes the cables more organized and portable but also contributes to their protection. There are two different types of cable winding: coil and spool. To maintain the shape of coil-wound cables, various methods are employed. These methods include tying with twine, wrapping with stretch film, and banding.

After the coil winding process is complete, the end of the cable is secured, and the stretch wrapping process is carried out before the cable is transferred to the shrink unit. The cable, placed inside the shrink film, is then passed through a shrink oven to prevent it from unraveling. Alternatively, in the tying or banding method, depending on customer preference, the end of the coil is secured by tying or banding it, allowing the coil to be transferred to the shrink unit. However, these packaging methods incur costs due to the use of auxiliary materials such as twine, stretch film, and bands, and these materials cannot be recycled.

Various studies have been conducted on automatic packaging and automatic cable packaging machines, which are widely used in everyday life.

In the study conducted by Avcı et al. (2023), the number of cable winding heads in the designed and manufactured machine was increased to three for the first time, significantly minimizing the time lost during the cable winding process. The performance of this machine was tested in the research. As a result of the experiments, it was found that the machine is capable of winding 10-12 coils per minute for cable lengths of 16.5-25 meters and 4.5-5 spools per minute for cable lengths of 100 meters.

Hultman (2022) introduces a new concept for automatic stator cable winding of rotating electrical machines. The

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use of this concept could potentially lead to savings in cycle time and assembly cost compared to manual or lower volume conventional automation. However, in its current form, it is not possible to compete with existing high-volume conventional winding automation for smaller machines. Future experimental work is expected to focus on the use of larger winding cables and special machine designs, providing greater robustness and optimization.

A paper by Ding et al. (2020) introduces this device to meet the specific requirements of space missions, such as a large propulsion output, large cable displacement and high reliability. The cable organizing device enables the cables to be wound layer by layer on a crane. The redundant motor assembly ensures the normal movement of the mechanism when a motor fails and can provide more torque than a single motor. A prototype of the proposed cable winding device has been manufactured and experiments have been conducted to verify the performance of the device.

In the study by Wu et al. (2019), developed an automatic cable winding system to address the issue of low mechanical automation. The system uses machine vision to automate the manual processes of cable placement and arrangement, with a PC controlling the mechanical arm's rotation based on target coordinates obtained from video images. A target recognition algorithm, based on Hu invariant moment and a multi-degree of freedom neural network (MDOFNN), was designed to identify target contours and determine their coordinates. Experimental comparisons with a support vector machine (SVM) showed that the algorithm had a higher recognition rate, making it well-suited for industrial applications. This innovative approach significantly enhances the automation of cable winding systems.

The study by Hultman and Leijon (2018), together with the detailed presentation of fully automated stator cable winding assembly equipment, represents an important step forward that could provide potential cost savings in future manufacturing processes and requires further reliability studies.

The aim of the study by Hultman and Leijon (2017) is to present and validate further developments in the presented method for robotized cable winding of the Uppsala University Wave Energy Converter generator stator. In the study, the cable preparation consists of three parts: feeding the cable from the drum, forming the cable end and cutting the cable. Previously, these operations were performed manually and only used with small cable drums, so the robot cell had to be stopped frequently. The new equipment is reported to have been tested on an experimental robot stator cable winding assembly. Through the experiments, it was confirmed that the equipment can realize a fully automatic and robust cable preparation.

The invention made by Öztürk and Özbaran (2014) relates to an automatic machine consisting of a winding head on which the cable is wound in sequence at the desired length, a knife mechanism that performs cutting, holding and dragging operations, a hold-turn mechanism that enables the cable package to be held and centered, a strap throwing machine that enables the cable package to be fixed by throwing a strap, a pressing mechanism that ensures that the cable end remaining outside the package is kept to a minimum and an automatic machine that enables the production to be faster, higher quality and to produce package length in accordance with the standards.

The invention made by Öztürk and Özbaran (2010), is a cable winding machine that performs coil and spool type winding operations in the same machine, and it is characterized in that it consists of a winding station that performs both coil and spool winding with at least two winding heads symmetrical to each other in order to perform the winding process, channeled spools for use in the spool form winding process and head fasteners for use in coil winding mode and coil heads that can shrink and expand. stretch film made of polyethylene, PVC, etc. to fix the end of the wrapped material outside the spool or coil and at least two stretch wrapping mechanisms and at least two rotational gripper pliers that enable the stretch film to be fixed by wrapping it around the spool or coil and at the same time holding the last end of the material cut in the spool or coil during this process.

The invention of Öztürk and Özbaran (2007) is a cable packaging machine in which both coil type and spool type packaging can be performed by means of the same mechanism. Coil type and spool type wrapping operations are carried out by means of coil head and spool wrapping heads, which are intertwined with each other in a single wrapping head and which perform wrapping operations according to the selected mode.

A paper by Wen and Stapleton (2008) presents the work on tension control and introduces the design and testing of a prototype system that reduces tension variations through the use of fluidized muscle. The results show that the proposed system provides better performance by increasing the winding speed.

Literature research has shown that most of academic studies focus on winding machines, and in the machines examined, auxiliary materials are used to prevent the final form of the wound cables from being compromised. In this study, however, a machine equipped with an auxiliary station designed to prevent cable unraveling without the use of binding materials was designed and manufactured.

2. MATERIAL AND METHOD

In this study, a cable packaging machine capable of securing the cable end without the need for any auxiliary materials has been designed. The general flowchart of the cable packaging process is presented in Figure 1. The developed machine, which eliminates the need for auxiliary materials, is designed so that different operations occur at each of the winding heads, ensuring that none of the heads remains idle. The machine has the capacity to wind 12 coils per minute for short cables (5 m, 10 m, 15 m, 20 m, 25 m) and 8 coils per minute for long cables (50 m, 100 m).

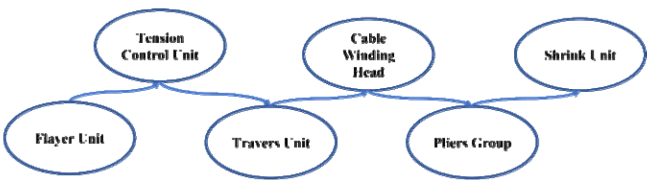

Fig. 1. General flow chart of cable packing process

Cable Packing Machine Components

The position and general components of the cable packaging machine, designed and manufactured in the study to secure the cable end without the need for any auxiliary materials, are presented in Figure 2.

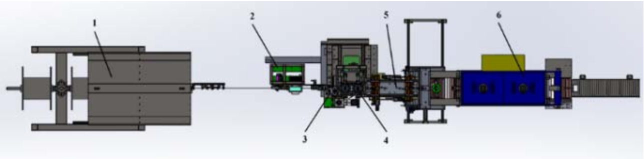

Fig. 2. Machine General View 1. Flayer Unit 2. Tension Control Unit 3. Travers Unit 4. Cable Winding Section 5. Pliers Group 6. Shrink Unit

Flayer Unit

Once all components of the cable winding line, along with the electrical and air supplies, have been set up, the machine becomes ready for cable winding. After an appropriate reel is connected to the flayer unit, the cable end from the reel is passed through the flayer cabin. For safety reasons, the movable cabin is then closed, and the system is prepared for the cable feeding process (Fig. 3).

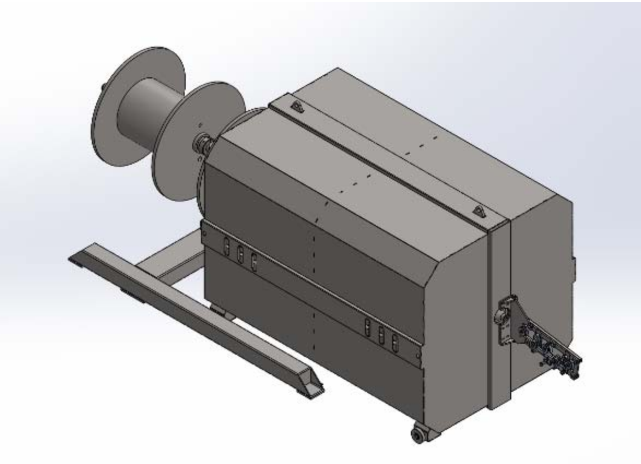

Fig. 3. Flayer Unit

Tension Control Unit

A unit has been developed to maintain the tension of the cable being transferred from the flayer unit to the cable feeding unit. At high winding speeds, as the coiled cable approaches the final meters, the desired length and form cannot be achieved due to the cable’s inertia. To address this issue, a magnetic brake and piston mechanism have been integrated into the pulley. This system is activated when there are 5 meters remaining to complete the coil, ensuring that the desired form is maintained (Fig. 4).

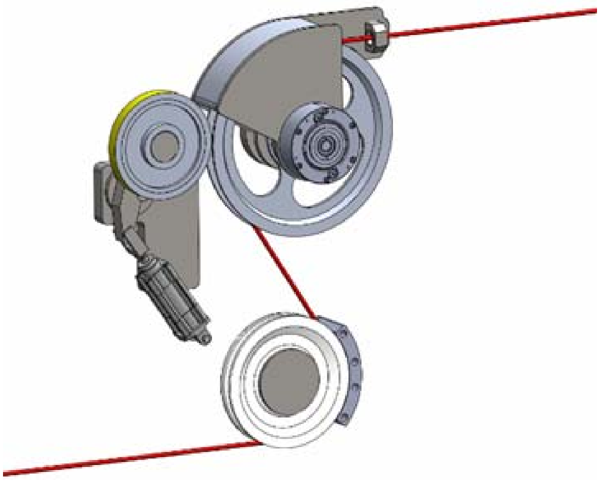

Fig. 4. Tension Control Unit

Travers Unit

The traverse unit is used to ensure the correct positioning of the cable during the winding process. This mechanism moves up and down, as well as left and right, to ensure the cable is wound evenly. The machine software automatically adjusts the speed of these movements, requiring the operator to input only the coil diameters and the winding speed per minute (Fig. 5).

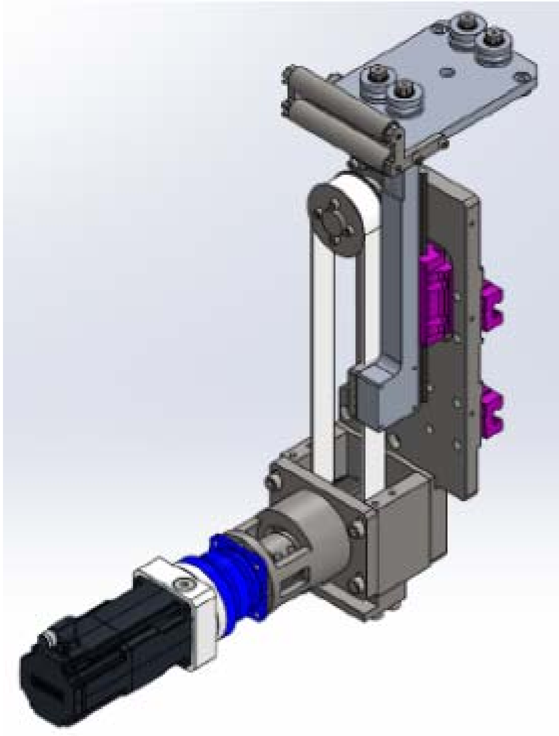

Fig. 5. Travers Unit

Cable Winding Section

The section where the coil winding process is carried out determines the coil lengths using the mechanism shown in Figure 6. This mechanism facilitates the process through the vertical movement of the frame. After the cable is fed from the traverse to the first winding head by the operator, the upper cylinder attached to the winding head descends with the help of a piston to grip the cable.

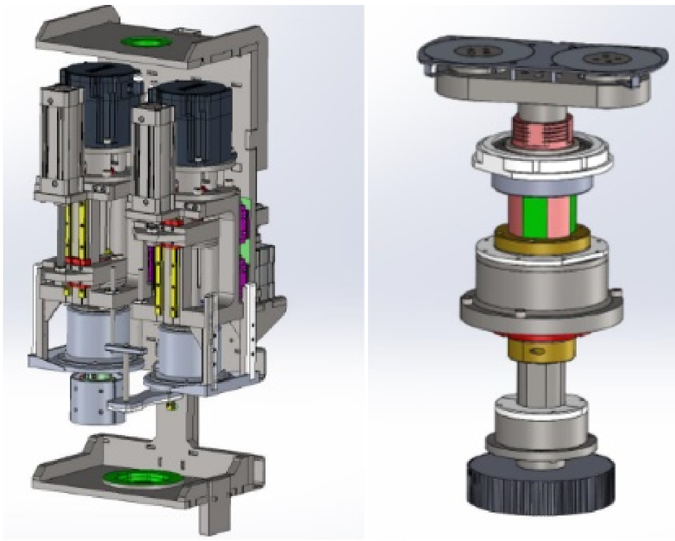

Fig. 6. Cable Winding Section

The winding process begins upon confirmation from the operator's control panel. When the first winding head reaches the final length of the coil, the winding group rotates 180 degrees using the mechanism depicted in Figure 6, and the winding process continues with the second winding head.

Pliers Unit

It is used to take the completed spool and coil from the winding head and to leave them to the packaging unit or ready product section by rotating (Fig 7).

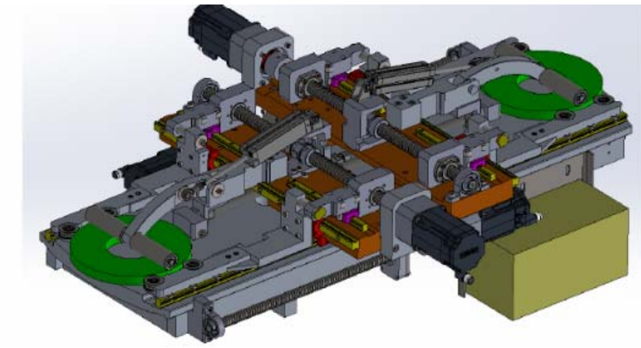

Fig. 7. Pliers Group

Shrink Unit

The coil-wound cable, after the winding process is completed, is transferred to the cable shrink unit using clamps without the use of stretch film, bands, or twine. The cable is then placed inside the shrink film, and the packaging process is completed (Fig 8.).

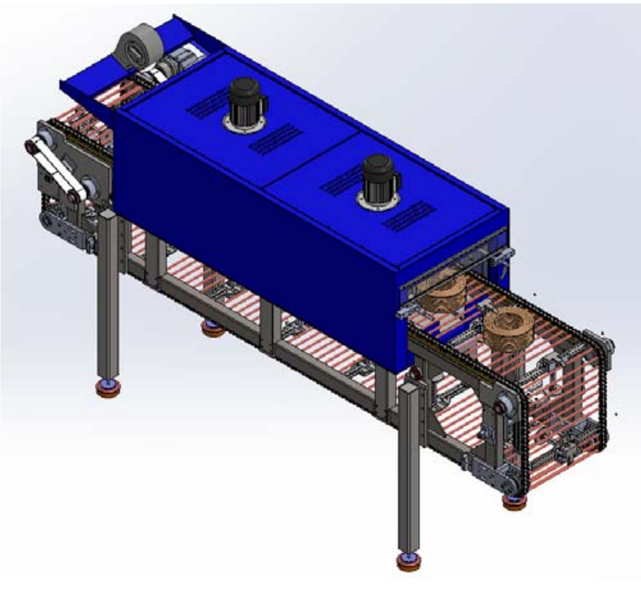

Fig. 8. Shrink Unit

Main Control Panel

The developed cable packaging machine, capable of securing the cable end without the need for any auxiliary materials, is controlled by a PLC through a touch operator panel (HMI) (Fig 9.).

Errors that occur during the operation of the line are displayed on this screen. The machine's control unit uses a SIEMENS brand PLC, and the PLC program has been created using TIA PORTAL.

Fig. 9. Main Control Panel

3. RESULT AND DISCUSSION

The winding heads of the designed machine are capable of 180° rotation, ensuring that none of the winding heads remain idle. The cable to be wound into coils is initially fed to the winding head with the assistance of the traverse and is secured by the cylinder on the winding head lowering. After the cable winding is completed, the winding head rotates 180° without cutting the cable from the completed coil. The cable is cut when the cylinder on the second head, positioned in front of the traverse, lowers.

The coiled cable, once winding is completed, is held by tongs at the winding head. The winding head holding the coil, with the aid of the tongs, rotates to wind the remaining portion of the cut cable. After the excess cable is collected, the completed coil is removed using the tongs. Without the use of any auxiliary materials, the coil is transferred to the shrink unit with the help of the tongs. In the shrink unit, the designed apparatus ensures that the coil form remains intact while it is transferred to the shrink film and progresses through the shrink tunnel. Upon exiting the shrink tunnel, the coiled cable is ready for delivery to the customer. These processes continue seamlessly for each winding head.

The PLC configuration necessary for the machine, including drivers, input and output modules, and analog modules, is selected and configured as shown in Figure 10. The required communication network is then established. The system topology is physically constructed, and all drivers and modules are activated. Each driver and module is individually tested to ensure proper system operation.

Fig 10. PLC plan of the system

The motor resistance powers for the machine components that have been designed and manufactured are provided in Table 1.

***Table 1** System Motor Resistance Powers*

Machine Components	*Motor Powers*
Winding Head Adjustment	*0,75 kW*
Winding Head Rotation	*6,4 kW*
Winding Head 1-2	*3x5.5 kW*
Clamp Open-Close	*2x0.75 kW*
Clamp Forward-Backward	*2x0,75 kW*
Clamp Rotation	*6,4 kW*
Travers Left-Right	*0,75 kW*
Travers Up-Down	*0,75 kW*

The components of the cable packaging machine, which is designed and manufactured to secure the cable end without the need for any auxiliary materials, are shown in Figures 11 and 12.

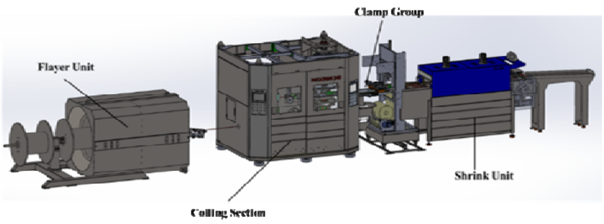

Fig. 11. Cable Packaging Machine Sections Capable of Securing the Cable End Without Requiring Any Auxiliary Materials

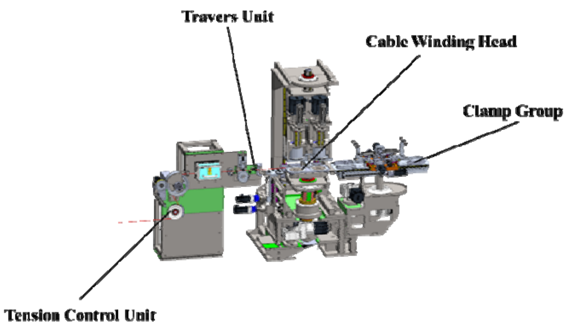

Fig. 12. Cable Packaging Machine Sections Capable of Securing the Cable End Without Requiring Any Auxiliary Materials

The performance of the machine designed and manufactured in this study has been tested. Experiments were conducted to evaluate coil winding at various lengths, including short lengths such as 5, 10, 15, 20, and 25 meters, as well as longer lengths up to 100 meters. The results, compared with existing machines, are presented in Table 2.

***Table 2** Winding Speeds and Number of Coils Wound by the Machines*

Machine Name	*Winding Speed (m/min)*	*Cable Length (m)*	*Number of Coils (pcs)*
Cable Packaging Machine Capable of Securing the Cable End Without Requiring Any Auxiliary Materials	*800*	*100*	*8*
	200-250	*5-10-15-20-25*	*12*
Machine 1	*700*	*100*	*7*
	100-125	*5-10-15-20-25*	*4-5*
Machine 2	*400-500*	*100*	*4-4.5*
	-	*5-10-15-20-25*	*-*

Some of the existing machines designed and manufactured by the company include the Machine 2 and Machine. The Machine 2 features dual winding heads and performs both reel and coil winding. The Machine 1 has two winding heads and is designed for coil winding of cables. Existing machines use auxiliary materials (such as string, stretch film, and strapping) for packaging the wound cable. In contrast, the newly designed cable packaging machine does not require any auxiliary materials to secure the cable end and is equipped with two 180° rotating winding heads, performing coil winding without the need for additional materials. The newly designed machine was compared with the existing machines in terms of the number of coils wound for both short and long cable lengths.

The results of the tests are as follows:

- The newly designed machine achieved higher winding speeds, enabling it to wind nearly three times the amount of cable into coils compared to existing machines for short cable lengths.
- It was observed that the new cable packaging machine, which does not require any auxiliary materials, wound 8 coils of 100-meter-long cables at a speed of 800 meters per minute.
- The new machine does not use any auxiliary materials for packaging the completed coil, thereby minimizing the use of additional materials.

4. CONCLUSION EXPOSITION

In manual machines, short-length cables are packaged at a rate of 2 coils per minute by an operator. However, the automated machine developed in this study has increased this rate to 6-7 coils per minute. Despite this improvement, previous machines still could not fully eliminate idle time. Additionally, automatic cable packaging machines typically use auxiliary materials (such as string, stretch film, and strapping) to package cables without disturbing their final form.

In this study, a cable packaging machine was designed to minimize idle time in the cable feeding, winding, and collecting processes while eliminating the need for auxiliary materials to secure the cable end. The newly designed machine features a movable winding station that reduces idle time during the winding process, thus increasing capacity. The elimination of auxiliary materials also helps minimize costs. At the end of the design, the number of coils wound by the machine was measured and compared with existing machines. It was observed that, compared to existing machines, the newly designed machine achieved approximately three times the number of coils for short-length winding (5-10-15-20-25 meters).

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