Case Study
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A new solution for the control system of the cross cutter in the board factory

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Abstract— **The paper presents a new control system implemented in the phase of reconstruction and modernization of the Valmet 14.5 transverse cutter in the cardboard factory "Umka" near Belgrade, Serbia [1]. The new control system was implemented using a PLC with integrated PROFInet and PROFIBUS communication protocols. Transverse cutters are used for transverse cutting of cardboard or paper tape into pieces of predetermined length, when unrolling it from the roll. The basic requirements that must be met are: reliable operation, work with high tape speeds in the cutting process, high accuracy of the length of the cut pieces, quality cutting, without creasing, tearing, or crushing at the cutting site. In the operation of transverse cutters, the strip being cut reaches the flying shears at the desired speed, which is determined by the speed of rotation of a pair of rollers called the press (press drive). Flying scissors consist of two blades placed perpendicular to the movement of the tape, the length of blades corresponds to the maximum width of the tape being cut (shear drive). The paper also presents the characteristics and technical requirements of the basic functional units of the transverse cardboard tape cutter from the point of view of control. The synchronized operation [2, 3] of the main electric drives powered by frequency converters is described and analyzed, which ensures the adjustment of the peripheral speed of the cutter blades, which is necessary for proper operation. The paper presents the results recorded at the reconstructed transverse cutter plant.**

Keywords; flying shear, control system, PROFInet, PROFIBUS DP, frequency converter

I. INTRODUCTION

Transversal cutters (flying shears) plants are used, among others, in continuous paper or cardboard production processes. In the technological processes of cardboard production, transverse cutters are located at their end, where the material (cardboard) in the form of a long strip is cut into shorter pieces (tabs). Continuity of the process requires that this cutting be done without stopping or slowing down the movement of the strip being cut. The basic technological requirements that should be met by the transverse cutter plant are:

- Cutting the sheet to specified length;
- High accuracy of the length of the cut pieces;
- Quality cutting, without creasing, tearing, or crushing at the point of cutting.

In the operation of transverse cutters, the strip being cut reaches the flying shears at the desired speed, which is determined by the speed of rotation of a pair of rollers called the press (press drive). Flying scissors consist of two blades placed perpendicular to the movement of the tape, the length of blades corresponds to the maximum width of the tape being cut (shear drive). The shears mechanism ensures that the blades are at the same moment opposite each other and cut off part of the web. To ensure proper cutting with high quality of the cut (tab edges) the peripheral speed of the blades must be equal to the speed of the web at the instant of cutting. The principle of operation of the cutter, whose control system will be described in this paper, is based on the variable speed of the motor (flying shears mechanism), which is directly coupled with the shears mechanism. The speed of the blades during one round (cutting cycle) changes, which is why the requirements for speed change dynamics, with the accuracy of speed and position synchronization in the period around the cutting, as well as the speed profile from one cutting to the next, are very demanding. Latest PLC from the Technology series, with integrated PROFInet and PROFIBUS DP communication protocols, was used to implement the control system of the transverse cutter. Press and knife drives are powered by high performance series frequency converters with integrated vector control algorithm for servo drive. PROFInet communication is also used to connect digital and analog input and output signals, via modules grouped into six groups. Frequency converters, whose communication with the PLC is realized by PROFIBUS DP communication, are used to power and control other drives (cart for changing the active un winder - "rowing", decurling, elevator, forks and carts for change of pallets). PROFIBUS DP

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communication is also used for the integration of other "smart" devices (absolute encoders, web tension force measurement, etc.).

II. Functional Components And Description Of The Operation Of The Flying Shears

Plants of transverse cutters (flying shears) are also used in continuous processes of paper or cardboard production. In the technological processes of cardboard production, transverse cutters are located at its end, where the material (cardboard) in the form of a long strip is cut into shorter pieces (tabs). Continuity of the process requires that this cutting be done without stopping or slowing down the movement of the strip being cut.

On the cross cutter presented in this paper, the cutting process starts from placing the roll with the tape to be cut, on the double unwinder. In the initial cycle, the tape is manually unwound from the roll and passed over a series of non-driven rollers to a pair of traction rollers (the mechanism that pulls the tape) that make up the press drive. The rotation speed of the press rollers determines the speed of the transverse cutter, the maximum value of which for the transverse cutter, described in this paper, is 300 (m/min). The tape that the press pulls and unwinds from the roll must be tensioned by a certain force, which is measured by measuring cells placed on one of the non-driven rollers between the unwinder and the press. The direct measurement of the force in the tape enables the realization of the regulation of the tensioning force of the tape in closed coupling, by controlling the pneumatic brakes installed on the unwinder. On this part of the transverse cutter, between two non-driven rollers, a mechanism for straightening the strip being cut, the so-called lyre. The position of the lyre mechanism is measured by an absolute encoder. The new control solution realized the positioning function [4] of the lyre mechanism as a function of the diameter of the tape roll that is being cut (unrolled). The diameter of the roll being unwound is measured by ultrasonic sensors (one on each unwinder). In this way, operators are freed from the obligation to adjust the position of the lira in order to achieve optimal tape straightening.

For the realization of a continuous cutting process, without stopping, after the initial manual threading of the tape from the roll to the press, a mechanism has been installed that enables the automatic transition of the work of the transverse cutter with the tape from the unwinder 1 to the work with the tape from the unwinder 2, and vice versa, the so-called rowing. This mechanism consists of a series of non-driven rollers placed on the so-called rowing cart. By control the positions of these rollers, conditions are created for replacing the roll from which the tape is unwound. The position of the rowing cart is measured using an absolute encoder, which enables automatic positioning from the control system. A motor drive powered by a frequency converter is used to start the cart. The layout of the above-described units of the transverse cutter is shown in Fig. 1.

In the further technological chain of operation of the cross cutter, the drive of the press delivers the strip to be cut to the flying scissors (mechanism that cuts the strip) that make up the drive of the knife. Flying shears consist of two blades positioned perpendicular to the movement of the belt. This mechanism ensures that the knives are at the same moment opposite each other and cut off part of the tape. To ensure proper cutting with high cut quality, the peripheral speed of the knives must be equal to the speed of the tape at the time of cutting. The cut pieces (tabs) are delivered by means of a conveyor belt to the stacking section where the tabs are stacked and aligned forming the final product of the cross cutter, i.e. a pallet with tabs.

There are two regulated electric motor drives on the stacking section, a drive for vertical movement of a pallet with trays (elevator drive) and a drive for horizontal movement of an empty pallet (in the preparation phase) or a pallet with cut pieces (in the phase of transporting the final product to further processing). Directly in front of the conveyor belt is a mechanism for rejecting defective (damaged or dirty) cut pieces, the so-called. shutter operated manually by an operator or automatically by a quality control system. The basis of the quality control system consists of cameras and real-time image processing software. This system constantly monitors the quality of the tape and, if necessary, generates a signal that is forwarded to the control system of the cross cutter to reject defective pieces.

In order to increase the efficiency of the transverse cutter, two options of its automatic operation were implemented in the control system: 1 - operation according to the desired number of cut pieces, 2 - operation according to the desired height of the pallet with cut pieces.

On the stacking section of the cut pieces, before placing the empty pallet in the required position, there is a mechanism for accepting sheets (called "fork" because of its shape). The process of stacking the cut pieces for the new pallet practically begins on this mechanism. The gripping mechanism is driven by a regulated electric motor powered by a frequency converter.

During the cutting process, in addition to the transverse cutting of the cardboard tape into sheets of the desired length, cutting is also performed in the longitudinal direction in order to cut the edges of the tape and form pieces (sheets) of the required length and width.

The arrangement of the units of the transverse cutter described in the previous part of the text is shown in Fig. 2

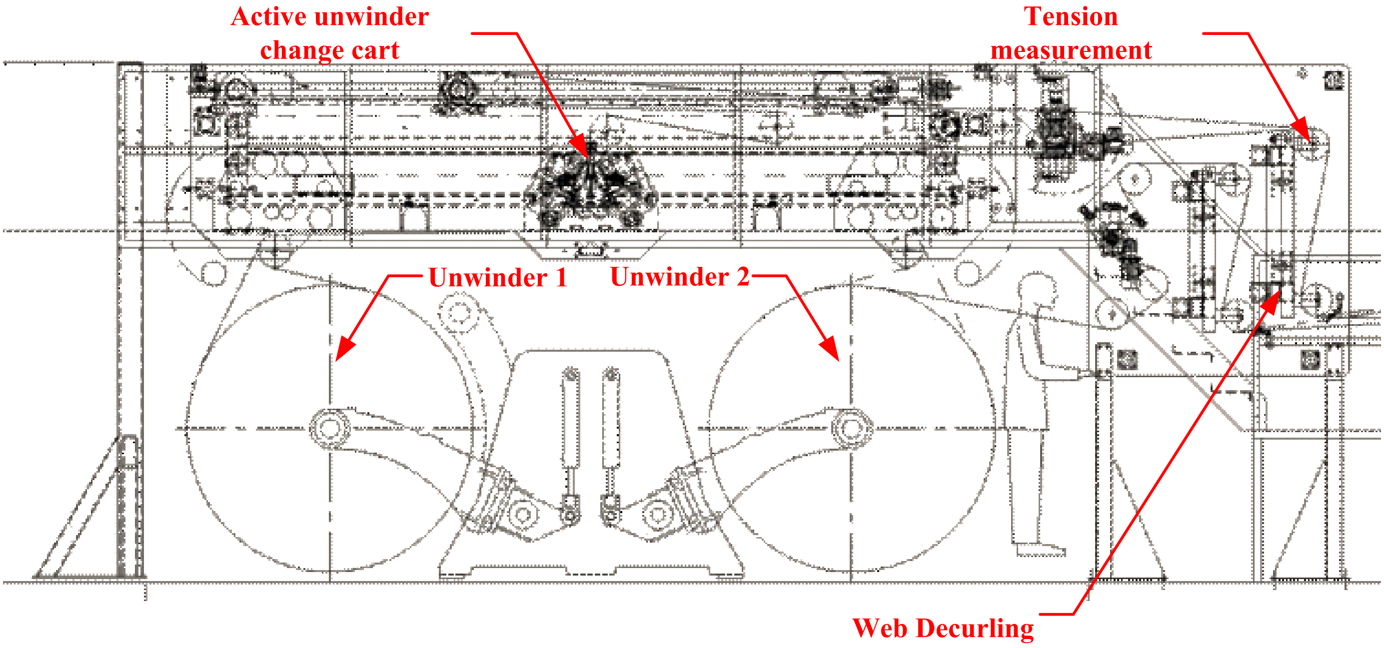

Figure 1. Technological parts of the transverse cutter - tape straightened

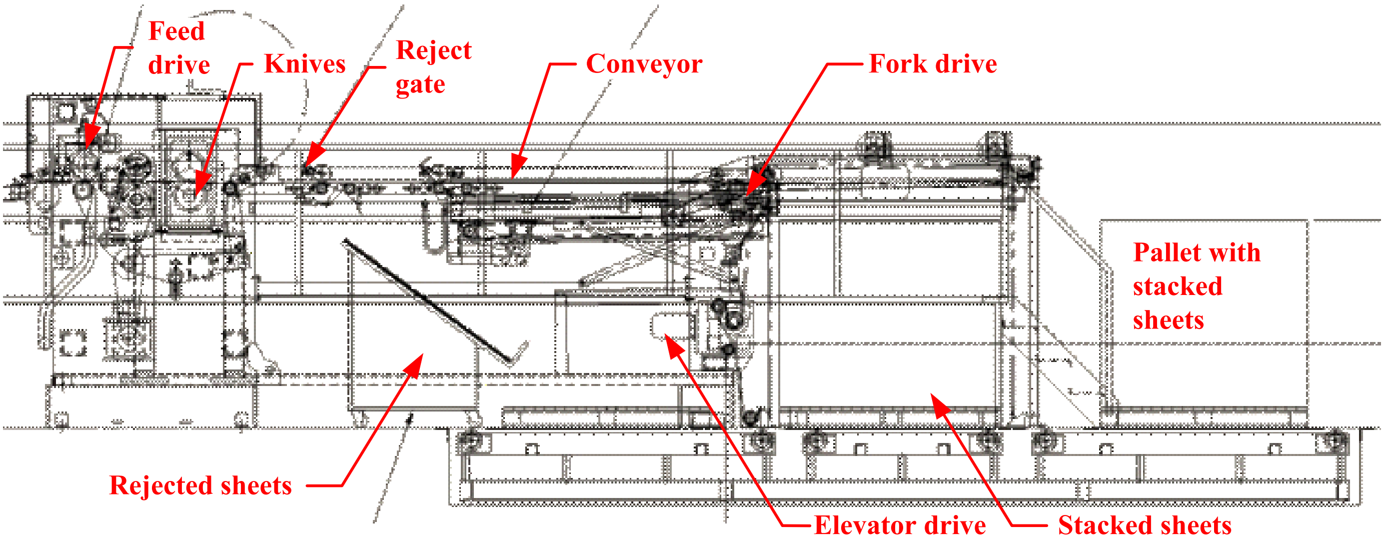

Figure 2. Technological parts of the transverse cutter - tape cutting and stacking of sheets

III. Description Of The Control System

The control system of the transverse cutter must unite all the previously described functional units, which also come from different manufacturers, into one integrated plant that will ensure their maximum utilization.

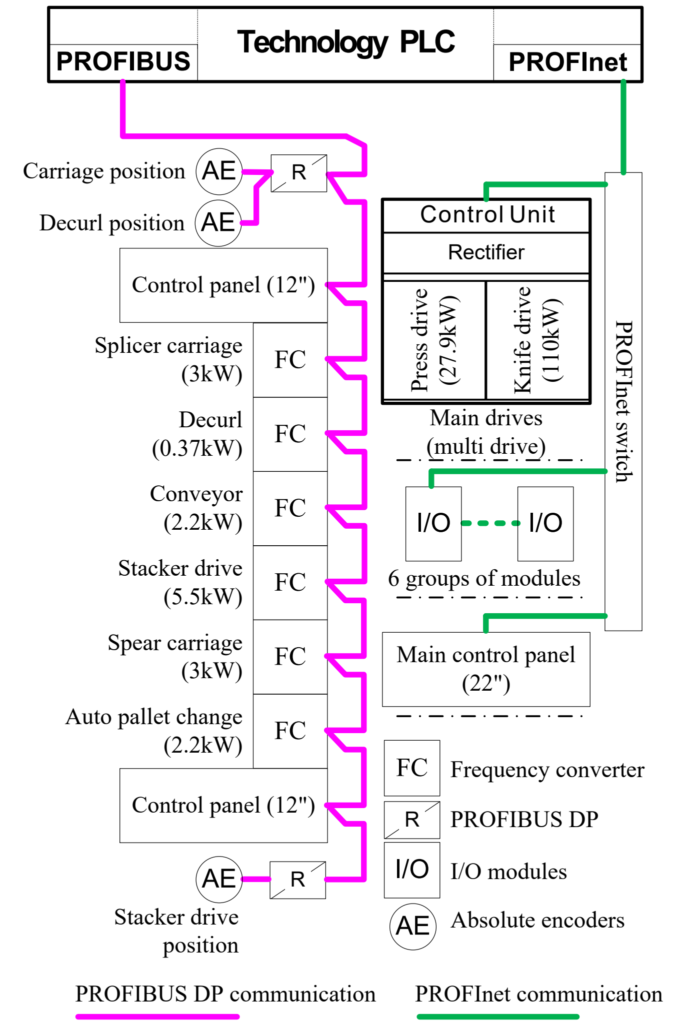

Figure 1. Block diagram of the control system of the cross cutter Valmet 14.5

Fig. 3 shows the basic structure of the implemented control system.

On the Valmet 14.5 transverse cutter in the "Umka" cardboard factory, the control system was implemented using the latest generation Technology PLC with integrated PROFInet and PROFIBUS communication protocols.

The communication between the frequency converters of the main drives (press and knife) and the PLC is performed using the PROFInet protocol, while the communication of the other regulated drives (6 in total) and the PLC is realized using the PROFIBUS protocol. PROFIBUS communication is also used to connect the PLC with absolute encoders, used to obtain information about the positions of:

- The cart for changing the active unwinder,
- The tape straightening mechanism and
- The stacking section.

The PROFInet protocol is also used to connect input and output digital and analog signals via modules grouped into six units.

High-performance frequency converters with an integrated servo drive control algorithm are used to power the main drives (press and knife). Other regulated drives are powered from frequency converters [5] with integrated PROFIBUS communication.

The significance of the implemented control system is also found in the various options for monitoring the operation of the drive and other equipment, which enables the quick detection of sensor and equipment failures, and thus the efficient elimination of failures in a short period of time.

IV. Main Drives Of Transversal Cutters

In practice, two solutions for starting the main drives can be found at transversal cutters plants - press and knife drives. These solutions are in accordance with the available technology at the time they were developed. Earlier solutions had a mechanism for changing the blade speed within one cycle of the output shaft, while maintaining an approximately constant input speed to the mechanism (constant motor speed). A frequently used name for this eccentric mechanism is "curve mechanism" [6]. With the development of digital techniques for controlling electric motor drives, as well as power electronics, it became possible to change the speed of the motor that drives the knife rollers, with adequate speed change dynamics, without the use of a curve mechanism. This solution was applied to the cross cutter, which is the subject of this paper.

Fig. 4 shows the principle of operation of the main drives of the transversal cutters.

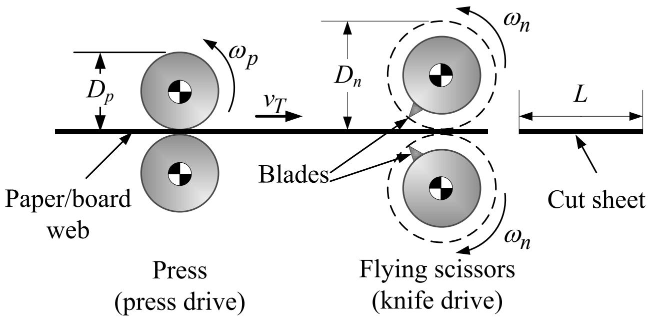

Figure 2. Principle of operation of the main drives of the transversal cutters

The strip to be cut reaches the flying shears at a linear speed (vT), which is determined by the rotation speed of the press drive motors (□p) and the circumference of the traction rollers (□ ·Dp). The mechanism of the flying scissors consists of two knives placed perpendicular to the movement of the tape, the length of the blades of the knives corresponds to the maximum width of the tape being cut.

To ensure proper cutting, the peripheral speed of the knives must be equal to the speed of the tape at the moment of cutting. Good cutting quality can only be achieved if the speed is approximately constant for a short period of time before and after cutting off a piece of cardboard tape. The time profile of the instantaneous value of the peripheral and angular velocity of the knives between two cuts is determined by the ratio of the length of the piece (L) being cut to the circumference of the knife (□ ·Dn), which is its design characteristic.

V. Description Of The Flying Shear Control System On The Valmet 14.5 Transversal Cutters

The mechanism of flying shears on the cross cutter, which is the subject of this paper, belongs to the category of mechanisms with variable speed of the drive motor. Such a drive requires more complex control, but also appropriate drive characteristics.

On the one hand, the converter must enable precise control of the motor torque with a high response speed, on the other hand, the construction of the mechanism itself must be with the smallest possible total inertia. That is why the design of the flying shears is such that cutting is done at every pass, and the used drums on which the knives are mounted have a minimum moment of inertia. Also, due to the large values of the dynamic moments of the motor, a solution was applied with a direct coupling of the motor with drums with knives, without using a reducer.

Fig. 5 shows the layout of the mechanical part of the flying shears mechanism with a variable speed drive motor and direct start of the scissors, without a reducer.

It is interesting to note the deviation of the shape of the knives from a straight line. This is a consequence of the necessity of adapting the shape of the knives to the cutting process, which has a finite duration, during which the strip being cut crosses a certain path.

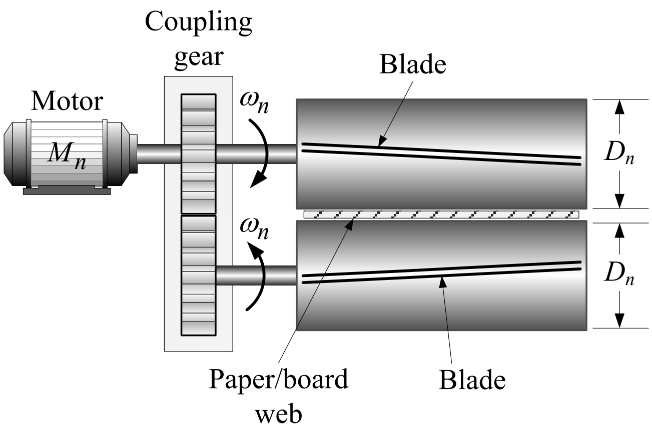

Figure 3. Disposition of the mechanical components of the cross-cutter flying shears with variable drive speed

The control structure of the implemented flying scissors drive has a position regulator as a superior regulator, as well as a speed and torque regulator [7]. To generate the reference value of the position of the knives, a dedicated application developed for this type of work, which is executed in the applied Technology PLC, was used. The structure of the control part of the scissor drive is shown in Fig. 6. The torque command is processed in the control part of the inverter and scaled into the q-component of the current of the vector-controlled asynchronous motor.

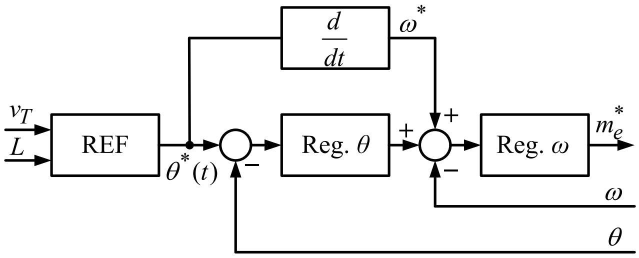

Figure 4. The structure of the control part of the flying shears drive

Based on the explanations given about the operation of the flying scissors, it is clear that the time dependence of the reference position (θ*(t)) changes cyclically, with a period equal to the time between two cuts (T). The time between cuts is calculated according to the set length of the sheets and the belt speed, which is variable during operation. The time between cuts is the same time it takes for the drums on which the knives are placed to describe a full circle. In Fig. 6, the block "REF" represents the block for generating the reference position.

Fig. 7 shows the geometry of the knife with variable drive speed, and the method of generating the reference position of the knife is described below.

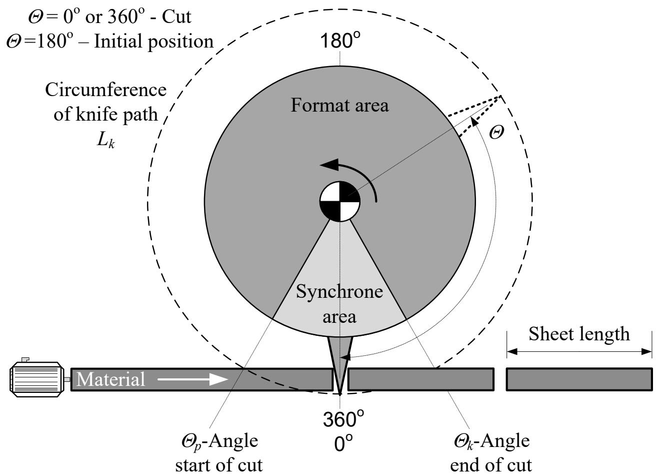

Figure 5. Blade geometry with variable motor speed

From the geometry shown in Fig. 7, two areas of the trajectory of the tip of the knife can be observed, that is, two parts of the period between two cuts. The first is the synchronization region where the peripheral speed of the knife is equal to the speed of the belt. The second is the area of the format in which the speed of rotation of the motor is variable and depends on the ratio of the length of the pieces and the circumference of the knife [8].

Fig. 8 shows the graphic dependence of the reference position of the knife (angle of the knife) in the period between two cuts for three different cases determined by the ratio of the length of the pieces to be cut and the circumference of the knife.

The above diagram shows the dependence for the operation of the cross cutter when the required length of the pieces (format) to be cut (L_2) is greater than the so-called mole length (L_k) which is equal to the circumference of the knife, ($L_2 > L_k$).

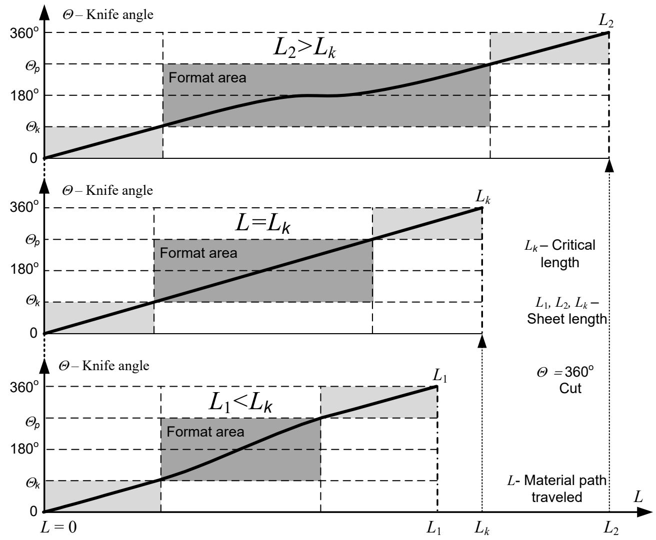

Figure 6. Graphic representation of the growth of the reference position in the period between two cuts

It can be seen from the diagram that the angle does not change in the middle of the format (the knife is stationary), around 180°. The middle diagram represents the dependence of the change of the reference angle for formats equal to the circumference of the knife, (L = L_k), when the change of angle is constant, which means that the speed of the knife is constant.

The diagram below shows the dependence of the reference angle of the knife for the operation of the cross cutter with formats (L1) smaller than the so-called mole length (Lk), (L1 < Lk). Then the angle change is greater in the format area, that is, the knife accelerates in relation to the tape. In all three cases, in the area of synchronization, the angle change is constant, that is, the speed of the knives is synchronized with the constant speed of the belt.

In the range of desired cutting formats smaller than the critical one, the speed change should be achieved in a shorter cycle time, which leads to large values of the moments required for such a speed change. In order to keep the torque values below the maximum permissible motor torque value (double the nominal value), the cutting cycle is extended, and that is, on formats smaller than the critical one, the speed of movement of the material (tape) is limited as a function of the given cutting format.

VI. Achieved Results

During parameter setting, testing and commissioning of electric drives with new frequency converters, synchronization of the speed and position of the knife and press drives was implemented in the "Technology" PLC, with fast execution and exchange of information with the converters [9]. An algorithm operation period of 1 (ms) was achieved, which meets the needs of the plant for the required cutting accuracy at a maximum speed of 300 (m/min), i.e. the shortest cutting cycle of only 200 (ms).

Fig. 9 shows the operation of the cross cutter knife drive at the given format L=1400(mm). The two curves in the timing diagram above are the line speeds of the belt and the knife. The matching of line speeds at the moment of cutting, as well as the stopping of the knife drive in the upper position are visible in Fig. 9.

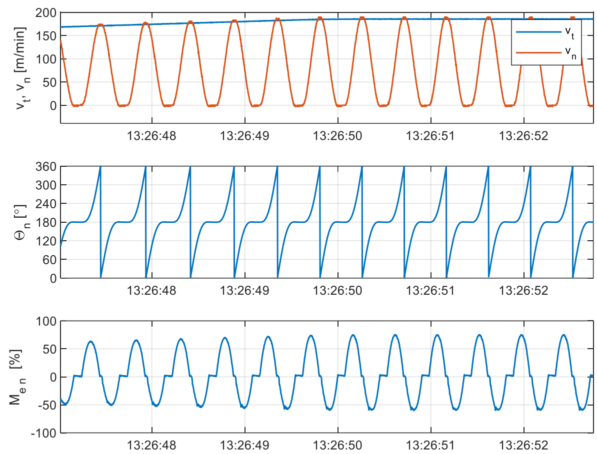

Figure 7. Recorded timing diagrams of the knife drive at the given format L=1400 (mm)

The timing diagram in the middle shows the change in blade drive angle for a given format. A high degree of similarity of the waveform with the curve shown in the upper part of Fig. 8 is noticeable. The lower time diagram shows the torque of the blade motor, with a pronounced dynamic component in the format area, but also two characteristic periods of constant torque, when the blade motor is in the upper position, and when the motor runs at a constant speed in the synchronization area.

The time diagram of the same sizes from the press and knife drive recorded on the transverse cutter when working with the given formats L=550(mm) is shown in Fig. 10. The change of angle in time for a format smaller than the basic format (L_k) shows a high similarity with the curve shown in the lower part of Fig. 8.

On this format there is no stoppage of the knife drive, moreover, the knife drive in the upper position has the highest speed, but a period of operation with constant speed in the area of synchronization can be observed, before and after the moment cutting (when the blade angle suddenly drops from 360° to 0°). This sudden change is visible only on the time diagram of the angle, in the physical sense it represents only the continuation of circular motion.

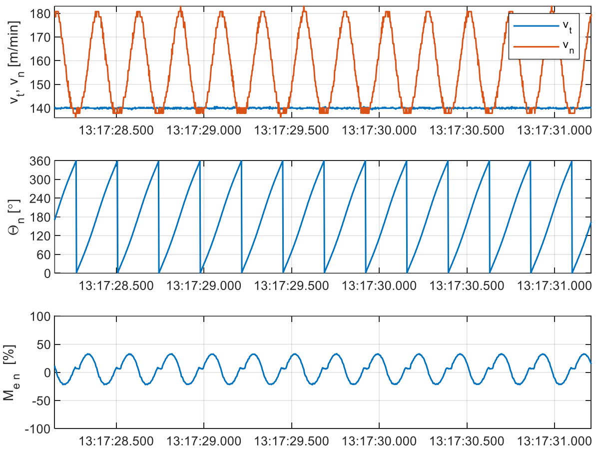

Figure 8. Recorded timing diagrams of the knife drive at the given format L=550 (mm)

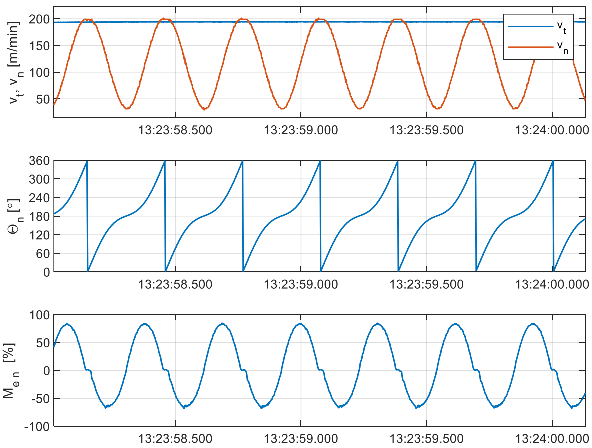

Figure 9. Recorded timing diagrams of the knife drive at the given format L=1000(mm)

The time diagram shown in Fig. 11 shows the operation of the knife drive at the given format L=1000 (mm). With this given format, there is also no stopping of the knife during the cycle, but the slowdown of the motor and directly coupled drums is noticeable.

VII. CONCLUSION

The designed and implemented control system of the transverse cutter showed complete adequacy in relation to the high degree of complexity of the process. Its functional and structural solutions fully correspond with modern trends and technological achievements in this field at the global level, thus confirming compliance with current international practices and standards.

The results obtained after the application of the new control system solution on the cross cutter showed that the system successfully combined all the necessary functions with the use of hardware and software products that are currently available and during the future lifetime of the cross cutter. In the period after installation, the cross cutter worked practically without any breakdowns and downtime.

It has been proven that the required high accuracy of the cutting length can be achieved by using regulated drives with asynchronous motors, which are powered by frequency converters, which means without the need to use specialized regulators and separate control units.

With the implementation of the new control system, certain technological functions of the transverse cutter have been improved, such as the function of regulating the cardboard tension force, the function of automatic control of the belt straightening system (lira), the function of automatic operation of the transverse cutter according to the desired number of sheets and the desired height of the pallet. These features made it easier for operators to work, reduced the possibility of human error and thus increased plant uptime.

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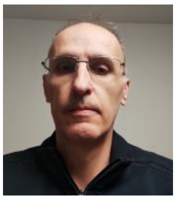

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