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CONTROL SYSTEM OF CATENARY CONTINOUS VULCANIZATION LINE FOR RUBBER CABLES

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Abstract. *The paper presents the control system of a continuous vulcanization line for the production of cables and conductors with rubber insulation, where the vulcanization process takes place in water and steam (vapour) atmosphere. The control, monitoring and recording of relevant parameters of the whole technological process was carried out with help of PLC (Programmable Logic Controller) and HMI (Human Machine Interface) and KepwareEx server. The control system is used to generate control signals for the regulation of speed, tension force, extruder temperature, water level and steam pressure in the vulcanization tube according to the technological parameters of the line. The monitoring system enables visualization of all technological units of the line via the HMI screens. The parts and entirety of the line are represented by conveniently drawn symbols that change colour depending on the current state and display the variables relevant to the operation of this object. Through the use of the KepwareEx server and database, the values of the variables important for the operation of the plant are recorded in real time. The developed supervisory and control system allows easy operation and monitoring of all important parameters of the plant.*

Key words: *Production line, Rubber conductors, PLC, HMI, KepwareEx*

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1. INTRODUCTION

Rubber cables are cables with a rubber sheath and a copper conductor. The number of copper conductors ranges from one to several conductors. They are characterized by good electrical conductivity, robustness and flexibility, which make them ideal for supplying portable electrical equipment, devices on ships and in mines. The main characteristics are weather resistance, abrasion resistance, oil resistance, resistance to high mechanical forces and loads, flexibility and softness, resistance to UV radiation, etc. The high quality and performance is mainly due to the use of standard elastomers. According to the complexity of the assemblies and production units, the lines for the production of rubber cables, medium-voltage and high-voltage cables are very sophisticated and complex. The paper presents the control system of the line for continuous vulcanization of rubber conductors and cables with cross-section from 4 mm^2 to 95 mm^2. The line produces cables with insulation and rubber sheath type H05RR-F 300/500V (SRPS EN 50525-2-21 (EN 50525-2-21 / VDE 0285-525-2-21), H07RN-F 450/750V (SRPS EN 50525-2-21 (EN 50525-2-21 / VDE 0285-525-2-21), EpN50 0.6/1KV (SRPS N.C5.350), H01N2-D 100V (SRPS EN 50525- 2-81 (EN 50525-2-81 / VDE 0285-525-2-81) [1].

2. DESCRIPTION OF PRODUCTION PROCESS

The production process of cables with insulation and/or rubber sheathing consists of several production units and stages. They can be basically divided as follows: drawing out the wires of the desired dimensions, stranding them into multi-wire construction which depending on the construction can have one or more copper wires, insulating them on vulcanization lines to obtain a rubber-insulated conductor, stranding conductors into the rope which consists of two or maximum five rubber-insulated conductors and finally insulating the rope by applying a rubber sheath in the vulcanization process (Fig. 1). Vulcanization is a process in which rubber or elastomer materials are passed through a vulcanization tube in a high-pressure water and steam atmosphere. The vulcanization process can be serial or continuous. The rubber used is mostly based on synthetic rubber; ethylene-propylene-diene acid (EPDM), ethylene propylene copolymer (EPR) etc. [2, 3, 4]. In rubber processing, an extruder and a vulcanization tube are used because of undesirable agglomerates and impurities. The process of insulation and sheathing is carried out by melting the rubber obtained by extrusion and applying it to the copper wire or conductor.

Basically, the technological process of continuous vulcanization (CV line) of rubber conductors (cross-linking of rubber) begins in the extruder. Rubber granules or rubber in the form of tapes are inserted into a heated extruder; rubber insulation is prepared in the zones of the extruder, which are heated to a temperature of 80°C to 95°C, depending on the type of rubber. During extrusion, the insulation material is pushed through the extruder barrel at a certain temperature and under certain pressure and under the action of the extruder screw, and after exiting the from extruder barrel, it is applied to the copper conductor passing through the head in which the extruder die is mounted. After that the conductor with the applied insulation enters the vulcanization tube, in which a constant steam pressure (12 bar to 20 bar, corresponding to a temperature of 188°C to 213°C) is maintained [4]. Water vapour in the tube, through which the insulated conductor passes, causes the insulating material to absorb moisture as well as possible, which supports and accelerates the vulcanization process. By regulating the temperature of the extruder, the number of revolutions of the extruder screw, the pressure of steam and water, the speed of the line (passage of the conductor through the pipe) at the exit of the vulcanization pipe, the insulation of the cable hardens. At the part of the pipe called the meeting point (place of contact between water and steam), the steam pressure is balanced by the water pressure with the constant presence of disturbance caused by water leakage at the exit of the cable from the pipe. Changing the parameters of the vulcanization process - pressure and speed (vulcanization time) - affects the mechanical properties of the elastomer and its tensile strength.

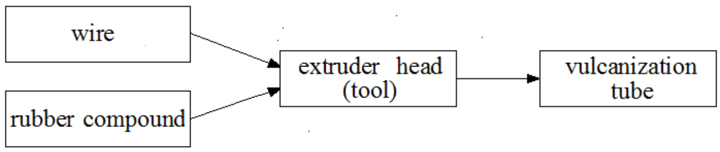

Fig. 1 Simplified block diagram of the technological process of vulcanization

Conventional continuous vulcanization lines are divided according to different spatial settings of the extruder, unwinding system, the vulcanization section (steam section) and winding system.

The line for the production of conductors and cables with rubber insulation consists of the following technical and technological units:

- loading and dosing of rubber granulates or rubber bands,
- unwinding of conductor or wires from the drum,
- tractions (capstans) systems,
- extruders and temperature control systems,
- systems for opening and closing tube, cooling the final product,
- systems for inlet water, inlet steam and meeting point regulation,
- measurement and control of diameter, tension and final cable marking,
- winding of the final product on drums.

A simplified diagram of the process flow is shown in Fig. 2. The production process starts with switching on the main control cabinet and the cabinets distributed along the line, switching on the unwinding drive and loading the drums with non-insulated cable on unwinder, switching on the winding drive and loading the empty drums on the winding device, switching on the system for loading rubber granulate, the extruder and the extruder temperature control system [5, 6, 7]. Unwinding of non-insulated cables or cores is done with an unwinding device. A system of two unwinders and accumulator for the unwound semi-product is used. When changing from one unwinder or rewinder to another, the accumulator receives a certain amount of product so that the production process can continue without interruption. Based on the position of the moving wheel of the wire accumulator, the rotation speed of the unwinder is controlled by the position control method with the PI-controller [8, 9, 10]. After leaving the accumulator system, the uninsulated wire enters the traction system of the line. The traction system consists of three traction devices (capstans). The first traction device is the main traction device, which is located directly behind the accumulator. It operates in the speed mode and its speed is equal to the actual line speed. The second traction device is located directly at the exit of the vulcanization tube. The tube has the shape of a gear wheel; the cable follows the shape of the gear wheel due to its weight. The measurement of the position of the conductor in the pipe is made by a sensor for the position of the cable in the pipe. The output signals of the sensor for the position of the cable in the tube is used for regulate the speed of the second traction device by using part of the signal in the control system of the PID controller with two degrees of freedom. A third traction device is located behind the cooling trough and monitors the speed in relation to the position of the dancer [5, 6, 11] who placed behind the second traction device.

The extruder is tempered with a heated medium, using distilled water [7]. The water system consists of a central tank with a volume of 1000 l, with controlled level and automatic refilling. Water in that system heated to 40°C and fed through a system of pipes to the heat exchanger of each zone of the extruder. The zones are heated according to the technological parameters. The heat exchanger of each zone consists of a heater and a circulation pump. The extruder barrel (cylinder) is made of a metal layer in which there are placed pipes that surround it and is divided into several temperature zones through which heated water is inlet. The extruder operates in the speed mode and is synchronized with the speed of the main traction device of the line. The application of insulation and the process of vulcanization of the conductor begin with the start of the extruder drive, unwinding drive, tractions device s drive and winding drive.

The centre of insulated conductor is determined so that the insulation is applied evenly around the circumference, the vulcanization tube toward the extruder is closed with a telescopic cylinder and the outlet of tube is closed with a water sealing system, the high-pressure pumps are started, which inject water from the tube outlet side through a proportional control valve, and the introduction of steam is started through a proportional control valve on the inlet side of the vulcanization tube. The control and monitoring is done by the main worker of the plant in cooperation with the auxiliary workers, who perform the loading and unloading of the drums and supervise the unwinding and winding. After leaving the vulcanization tube, the rubber-insulated conductor is cooled in cooling tubs. At the exit of the tub, the water is wiped off with compressed air, the cable is marked, the diameter of the conductor and insulation is measured, and it is packed into process or final drums. The whole process is monitored by the HMI panels, and the relevant process parameters are entered into the database [12, 13, 14, 15, 16, 17]. In the event of a high priority fault, the entire line is stopped with an audible alarm. When the line is stopped either by a completed job or by the occurrence of an error, steam automatically is let out from the pipe; the pipe is flooded with water and cooled.

Figure 3 shows parts of the production process. Figure 3a shows the unwinders and part of the vulcanization tube, Figure 3b shows the main traction device, Fig. 3c shows the heat exchanger for temperature control of the extruder zones, Fig. 3d shows a system of pipes and valves for introducing and discharging water vapour into the pipe, Fig. 3e shows a part of the vulcanization tube directly behind the extruder with a telescopic cylinder to close the tube, Fig. 3f shows the system of pipes and the valve to let water into the pipe on the side of the outlet of the vulcanization pipe, and in the background we see the second traction device directly behind the vulcanization tube, water seal system and the water wiping system.

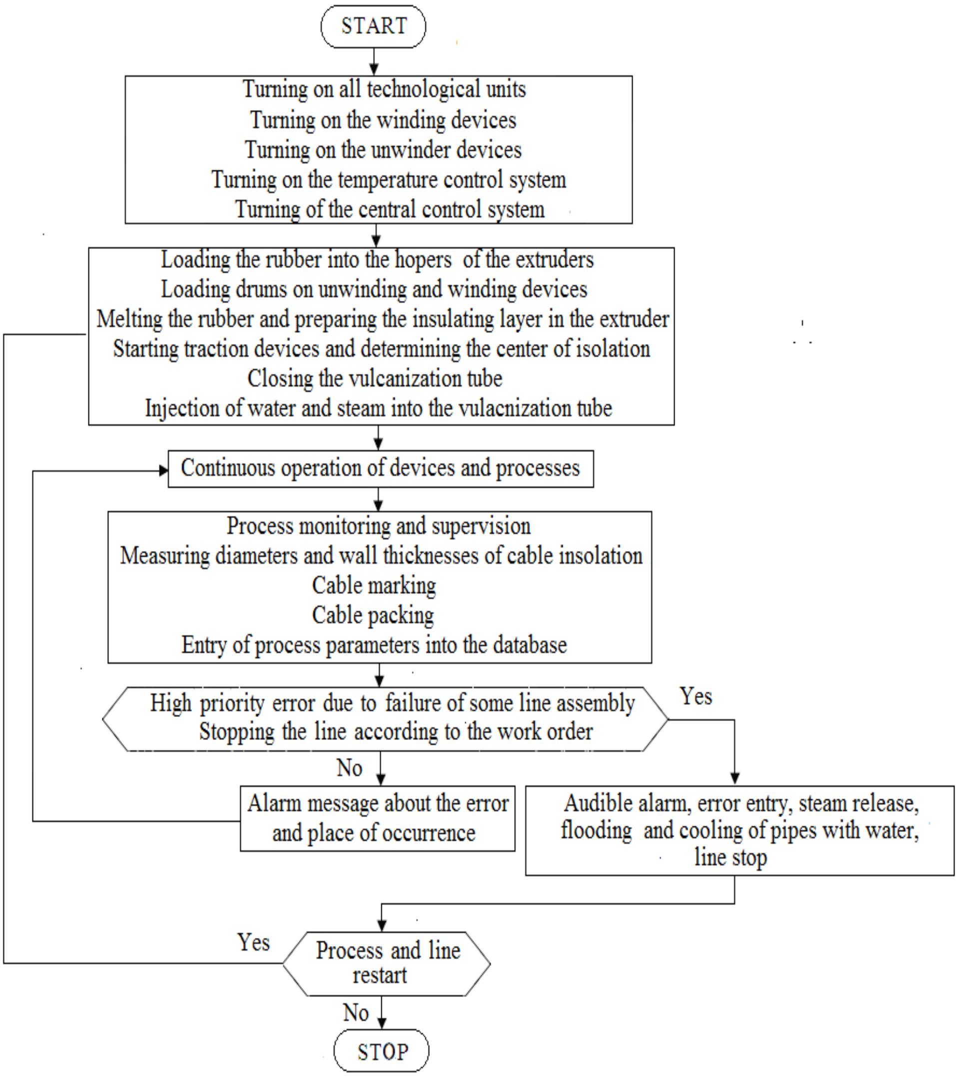

Fig. 2 A simplified block diagram of the rubber cable manufacturing process

Fig. 3 a) Rope unwinding, part of the tube for vulcanization and winding, b) main traction (capstan) device, c) extruder with tempering system, d) steam injection, e) tube closing system, f) water inlet and traction (capstan) device at the exit from the tube

3. CONTROL SYSTEM AND CONTROLLERS

All parts and units of the production process are fully automated; the operation of all drives and units is synchronized with the speed of the main traction device. The designing of the monitoring and control system is a very complex task. The central system for monitoring and control of the plant requires the connection of all parts of the production process into a single functional unit, i.e., the connection of all control and measurement devices into a single unit, taking into account all technical and technological requirements. The control system consists of several PLCs and data acquisition systems, systems for controlling DC and AC motors, on-off valves, proportional valves, heaters, where control is done by position, speed, temperature, pressure, level, etc. One or more different controllers are used for each technological unit. The aim of the implementation is to provide the management of the continuous vulcanization line (CV line) using a PLC and an HMI panel to control the speed of the line, the temperature of the extruder zones, the temperature of the vulcanization tube, the water level in the tube, the steam pressure in the tube, and to allow easy monitoring of all process parameters and their recording in the corresponding database tables in real time [18, 19]. When designing such a control system, it is first necessary to know the production process well and have an accurate overview of all discrete and analogue inputs and outputs, as well as to choose the method and type of control. Then select suitable PLCs and controllers for direct current (DC) and three-phase (AC) drives, as shown in the block diagram in Fig. 4.

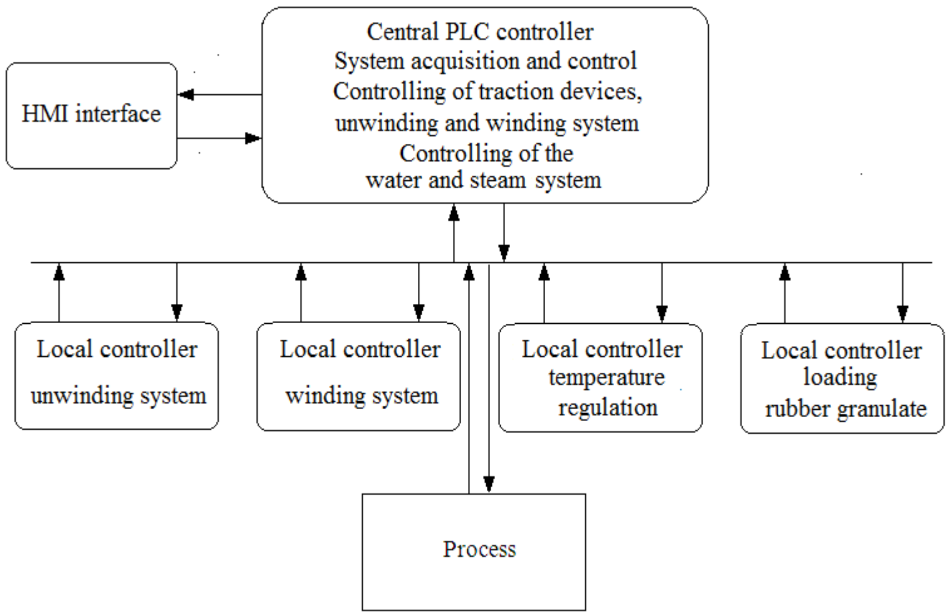

Fig. 4 Control system of the line for continuous vulcanization in the atmosphere of water vapour

One or more different controllers are used for each technological unit. The main controller is Allen Bradley Compact Logix L35E [12, 13]. It monitors and controls the entire process and is located in the main control cabinet. In the technological units for unwinding, winding and temperature control of extruder smaller Allen Bradley PLCs of the MicroLogix 1400 type [20] are used, located in control cabinets along the line. Rubber granulate loading is controlled by a Siemens LOGO 7 PLC. Monitoring and setting of process parameters is performed by a central 15" HMI (touch screen) Magelis XBTGT 7430, a panel located on the main control panel of the line. Unwinding and winding parameters are monitored and set via local 5.7" Magelis HMI panels HMI GTO. All PLCs except the rubber loading and dosing controller, which are connected to the central PLC via an analogue connection, are connected via Modbus or Ethernet IP protocol. In the cabinets along the line there are also controllers for AC drives ABB type ACS 880 [16, 17] and controllers for DC drives Siemens type Sinamics DCM 6RA80 series [14, 15]. Software on the main PLC is written in the ladder diagram and FBD diagram. The control software on PLC consists of the main routine, the indication routine, OP panel routine, routine for inserting, discharging water and steam and control the meeting point of steam and water, temperature control routine, line speed control routine, analogue signal and signal scaling routine and communication routine. The program for PLCs was written in the software packages RSLogix 5000 V20, RSLogix 500 V8.2 and Siemens LOGO! Soft, and the software for HMI panels was developed in the Vijeo Designer V6.0 and V6.2 software packages. Setting of AC and DC controllers was done with the HMI panel for ABB controllers and the Starter tool for Siemens Sinamics controllers.

Maintenance managers can monitor the process using the Kepwarex server and process monitoring application [21, 22]. Different access levels have been defined and permissions have been created at the level of: operator I: worker, operator II: worker, technologist and engineer. The HMI panel consists of several screens corresponding to individual process units. They display the values of process parameters with flows based on the actual appearance of the process. The main screen of the HMI panel also represents the scheme of the entire plant and can be seen in Fig. 6; all technological units from unwinding to winding are clearly visible. Clicking on individual elements opens the screens of the individual parts of the process with the corresponding values and fields for setting the process parameters. The states of the parts of the process are colour-coded and signalled, *yellow* - ready, *red* - malfunction and *green* - operation. Process and status visualization, display and measurement of parameters relevant to process operation, monitoring of alarm signals, selection of manual and automatic operation of the line, monitoring of trend graphs, etc. are easily enabled. The speed of the line is set by the HMI panel or the line speed potentiometer, the speed of the extruder and the main puller is set only by the potentiometers on the main control panel. All default values are set according to the type of the product being manufactured. All devices in the line are synchronized with the main drive unit (main capstan) and accelerate and decelerate the line according to the set ramp times, increasing or decreasing the speed of the line, the number of revolutions of the extruder screw, ensuring a constant thickness of the applied insulation.

In the old control system of line, the meeting point regulation was done by on-off control of the water and steam inlet valves depending on the temperature value at the selected meeting point, so the temperature of the meeting point varied up to ±15°C. In the new solution, the control of the meeting point of water and steam is done by a PID control implemented with the PIDE instruction of the CompactLogix PLC [13] with two degrees of freedom, where the control signal is routed to the proportional valve for the water inlet, while the steam pressure is kept at a constant value. Both valves, for the inlet of

Fig. 5 a) Main control cabinet with CopmactLogix L35E PLC, b) main control desk with HMI panel, c) unwinder cabinet with ABB controllers and MicroLogix 1400 PLC, d) main traction device cabinet with Sinamics DCM converter, e) winder cabinet, f) cable position device cabinet Solz

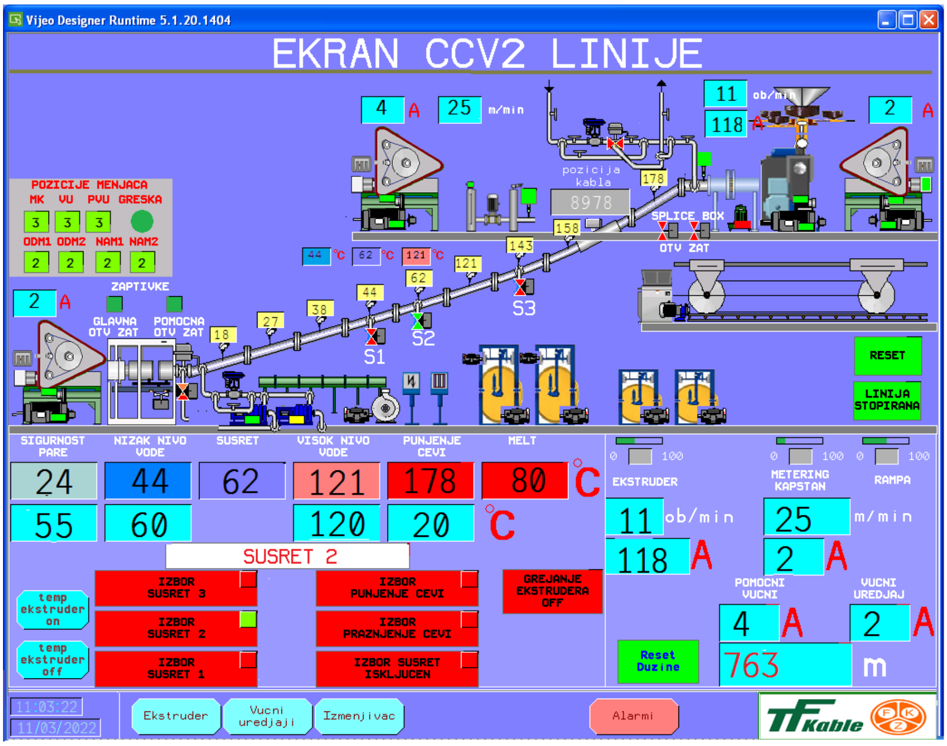

Fig. 6 Technological scheme of the whole line (The main screen)

water and steam, are proportional controlled with current signal. The working pressures in the pipe range from 12 bar to 20 bar. The temperatures at all points of the tube and at the joints are measured by J-type thermocouples, housed in special casings and placed along the vulcanization tube. The signals from the thermocouples are fed into the PLC via temperature cards. Based on the temperature of the meeting point and the temperatures at other points along the pipe, as well as the routine written to control the meeting point, the control signals for the water and steam inlet valves are generated in the range of 4-20 mA. Figure 7 shows the trends of the meeting point temperature corresponding to the set water level and steam pressure (Fig. 7a)) and the trend of the steam pressure when steam is introduced into the vulcanization tube (Fig. 7b)), where the abscissa is the time and the ordinate is temperature of water (Fig. 7a) and the steam pressure in the range from 0 to 20 bar (Fig. 7b). The resulting oscillation of the meeting point steam and water temperature is in a range of less than ± 5 °C.

A block diagram of the vulcanization pipe showing the choice of meeting point is shown in Fig. 8. A total of nine thermocouples, labelled Tc1 to Tc9, are installed to the vulcanization tube. Thermocouples Tc1, Tc2 and Tc9 serve as indicators of the presence of steam at the end of the tube and the presence of water at the entrance to the tube, respectively. In the event that the steam at the end of the pipe drops to the position of thermocouple Tc2, the software automatically turns on both high pressure pumps and tries to push the steam towards the meeting. If this action is unsuccessful, as indicated by the presence of steam at the position of thermocouple Tc1 (steam safety), the valve for discharging steam is turned on to automatically release the steam from the pipe. When the water reaches the inlet of the pipe Tc9, the pump, which is working at that moment, is switched off. Such situations are accompanied by sound and light alarms. Before starting the vulcanization process, you can select one to three fixed meeting points by simply pressing one of the three buttons on the HMI panel. When the vulcanization process starts, the software automatically prohibits the selection of any other type of meeting point.

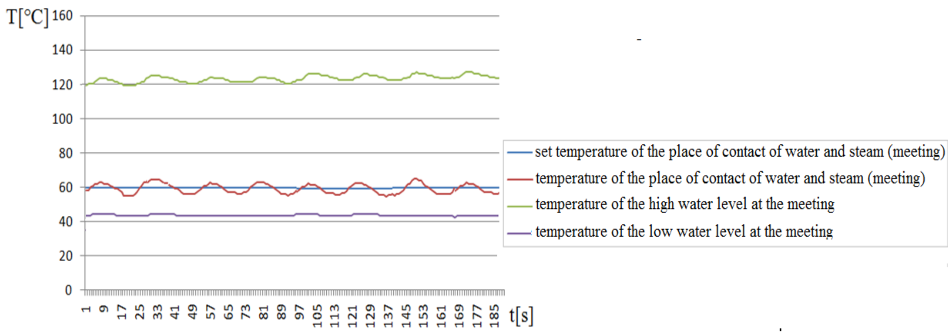

Fig. 7a Dependence of meeting point water and steam temperature, high and low water levels on meeting point, obtained from data from the database

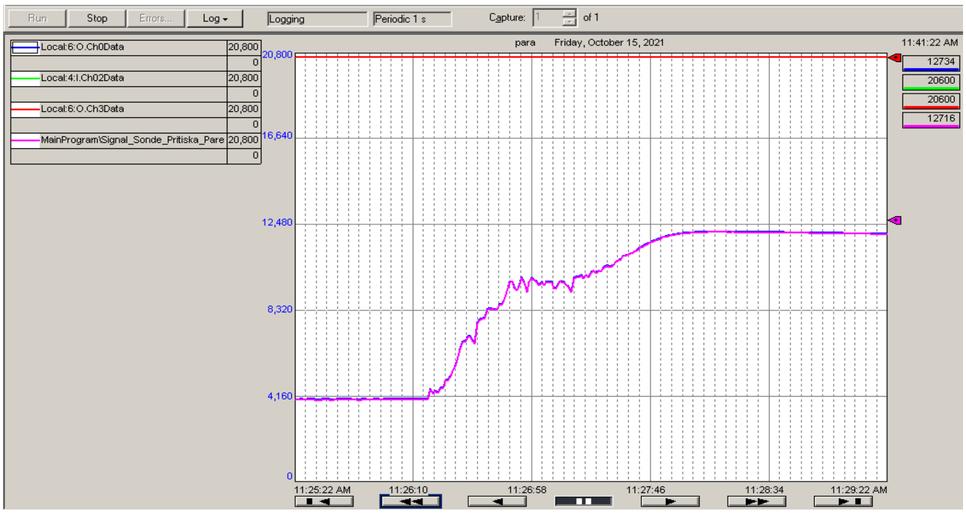

Fig. 7b Steam pressure trend when steam is admitted into the pipe obtained directly on the OP panel (HMI screen)

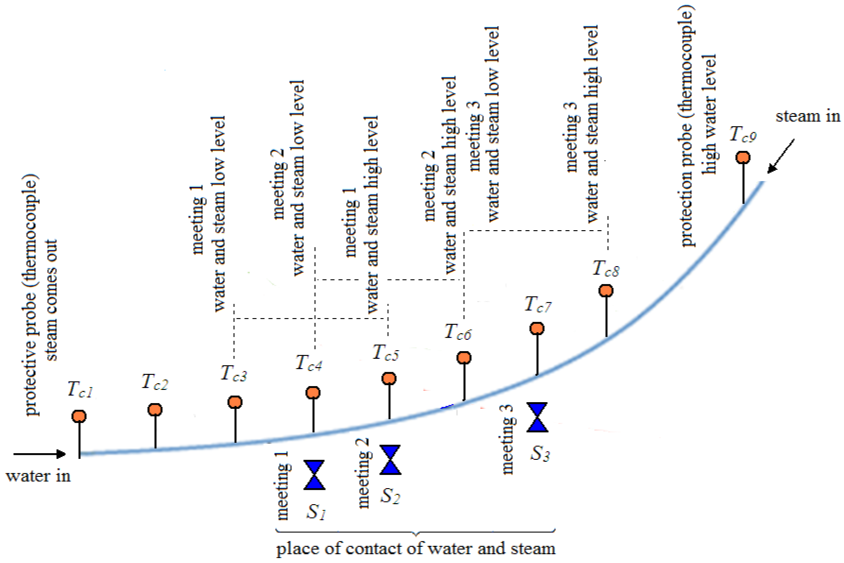

Fig. 8 Control of the meeting point of water and steam

The management system for vulcanization control consists essentially of a system for regulating the speed of the line (passage time of the cable through the vulcanization section) and regulating the pressure of steam and water in the pipe. In addition to the selection of the meeting point, it is possible to select the water injection operations, i.e. the flooding (cooling) of the pipes and the emptying of the pipes. These operations are allowed only when the line is not started. The filling action with water is also used for tube cooling.

The meeting point regulation routine realizes the control of the meeting point, the inlet of water and steam, the flooding and draining of water and steam. The length of the steam section is chosen by selecting the meeting point. The regulation of the water level is based on the set temperature of the meeting point, the temperature of the meeting point and the temperature of the high and low level of the meeting, while the regulation of the steam pressure is based on the measurement of the current steam pressure in the tube and the set desired value of the steam pressure. The temperature values on the thermocouples for the high and low water level at the junction also enter in the regulation process. The worker selects one of three encounters. The condition for letting steam in means that the vulcanization pipe is closed, i.e., connected to the extruder head at the inlet and closed with a seal at the outlet. By selecting the meeting point when the pipe is closed, the high pressure pumps are started in automatic mode and the water and steam injection starts. Before the pipe is closed, the worker adjusts the thickness of the insulation. Two PIDE instructions from the PLC [13] control the water steam meeting point depending on the temperature at the selected meeting point.

A screen monitoring part of the process of tempering the extruder with a heated liquid (distilled water) is shown in Fig. 9. The values of the desired temperatures of the extruder zones are entered in the blue boxes, and the red boxes indicate the current (reached) temperature. The blue and red bar graphs show the current and the (desired) set temperature trends, respectively.

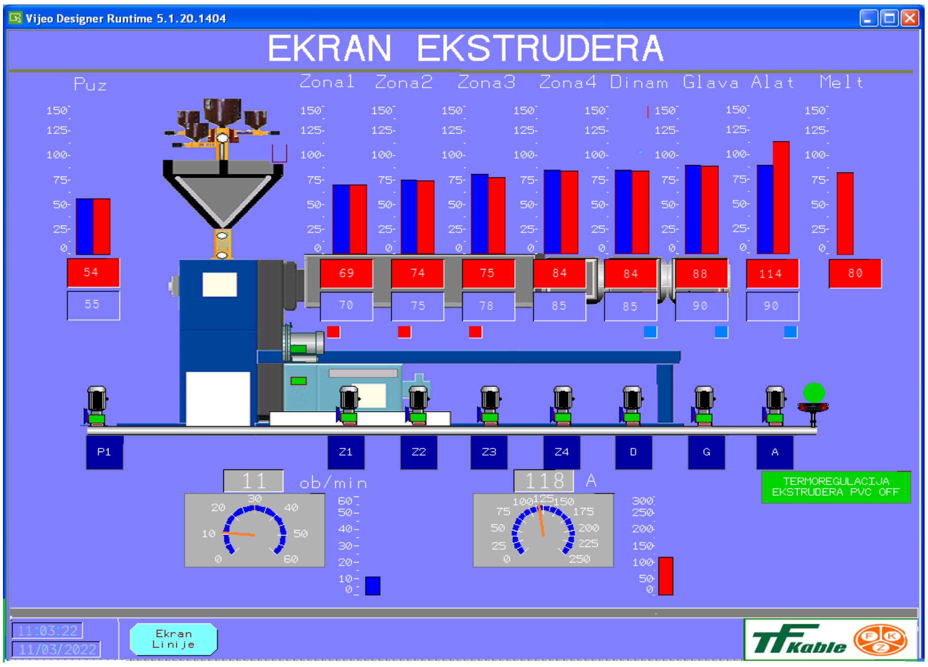

Fig. 9 Technological diagram of all parts of the system for driving and tempering the extruder (HMI screen)

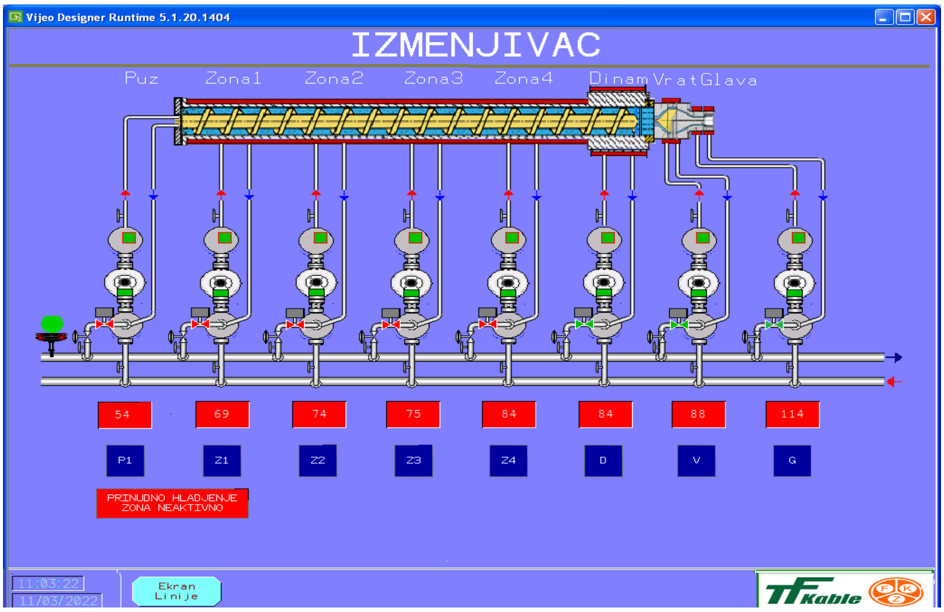

Fig. 10 Technological diagram of all parts of the system for driving and tempering the extruder (HMI screen)

All operating states of the extruder drive and the zone circulation pumps are signalled by colour, *yellow* - ready for operation, *red* -failure and *green* -in operation. The current drive motor current and the speed (screw revolutions) of the extruder are displayed with bar graphs and pointer gadgets. Pressing any circulation pump opens the screen for the exchanger, which is part of the extruder temperature control system (see Fig. 9).

5. Conclusion

A monitoring and control system based on HMI, PLC and KepwareEx server with all decentralized peripherals was developed to control the technological units that are an integral part of the production of rubber cables through the process of vulcanization in a water vapour atmosphere. The control of rubber granulate into extruder hoper loading, regulation of extruder temperature, speed, pressure and water level in the vulcanization tube, etc. was carried out taking into account all possible situations during the operation of the machine and all devices, with warning alarms and alarms that stop the operation of the line. All units from loading to the final product are controlled relatively easily through the graphic evaluation of all parts and units of the process.

The control system ensures proper operation of the line. In addition to regulating the operation, it also takes into account the quality of the insulation in terms of cable parameters and its thickness. With the help of the Kepware server and database, it is possible to create and print reports. Special attention is paid to the control and regulation of steam and water supply with a view to safe operation. Protections have been made to close the tube and automatically release the steam if the pressure is exceeded occurs or steam escapes from the tube of the end of tube. Alarm signals are displayed on the panels with text and flashing signals, accompanied by audible signals. Alarms are also stored in the panel's log and in the database. Lower priority alarms are displayed on the panel and are active as long as a fault is present, indicating the times of occurrence and fault. In addition, the current values of temperature, pressure, size of insulation thickness, etc. are recorded. The process has been completely automated which reduces waste and increases the reliability of the plant. Designing was carried out, new electrical cabinets were made, equipment was selected for operation and management of all parts and units of line, software for PLC and panels was developed, a cable position sensor was installed in the vulcanization tube. The proof of this is that the line in the cable factory has been in operation for five years; cables for the European and USA markets are produced on the line. A new technical solution was introduced to regulate the meeting point of water and steam in relation to the length of the vulcanization section, with regulation of the water level in the pipe based on the meeting temperature. A similar system was introduced in the insulation application line with a one traction device.

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REFERENCES

[1] Novi katalog proizvoda Fabrike kablova Zaječar, 2022, [Online]. Available: http://www.fkz.rs/katalozi/FKZSPDF.pdf

[2] B. E. Roberts, S. Verne, "Industrial applications of different methods of cross-linking polyethylene", *Plast. Rubber Process Appl.*, vol. 4, no. 2, pp. 135–139, 1984. [Online]. Available: https://www.osti.gov/etdeweb/biblio/6510656

[3] K. Schwarr, C. H. Chien, Ethylene-propylene co and ter polymer rubber, Report 4b, Menlo Park, CA: Stanford Research Institute.

[4] V. Seymour, Z. Gomzi, "Modeling of the power cable production line", *Thermochimica Acta*, vol. 457, no. 1-2, pp. 70–82, 2007. doi: 10.1016/j.tca.2007.02.020

[5] I. Kocić, D. Mitić, S. S. Nikolić, N. Danković, P. Đekić, "Upravljanje multimotornim sistemom kontinualne linije upotrebom konvencionalnih regulatora", *Zbornik radova međunarodnog simpozijuma INFOTEH-JAHORINA,* Jahorina, Bosnia and Herzegovina, March 15.-17., 2023., pp. 158–163.

[6] S. S. Nikolić, I. Kocić, D. Antić, D. Mitić, N. Danković A. Milovanović, P. Đekić, "The winder dancer position control model using different PID control structures and micrologix PLC", *FACTA UNIVERSITATIS Series: Automatic Control and Robotics*, vol. 21, no. 2, pp. 77–93, 2022. doi: 10.22190/FUACR220409007N

[7] I. Kocić, Uputstvo za rad i održavanje linije za kontinualnu vulkanizaciju gumenih provodnika i kablova CCV2, "TFKable Fabrika kablova Zaječar" u Zaječaru, 2019.

[8] I. Kocić, S. S. Nikolić, D. Mitić, P. Đekić, N. Danković, N. Jotović, "Data collection tool for process identification using PLC and Kepware Tools", *FACTA UNIVERSITATIS Series: Automatic Control and Robotics*, vol. 21, no. 3, pp. 177–186, 2022. doi: 10.22190/FUACR221118014K

[9] I. Kocić, S. S. Nikolić, D. Mitić, A. Milovanović, N. Danković, P. Đekić, "Simulation analysis of feedforward-feedback control of winding device using 2-DOF control structure and control structure in state space", *Proceedings of the 20th International Conference on Thermal Science and Engineering of Serbia - SIMTERM 2022,* Niš, Serbia, October 18.-21., 2022., pp. 573–581.

[10] S. S. Nikolić, I. Kocić, D. Antić, D. Mitić, A. Milovanović, P. Đekić, N. Danković, "Torque regulation of the output pulling device of the cable line for insulation", *Proceedings of the 20th International Conference on Thermal Science and Engineering of Serbia - SIMTERM 2022,* Niš, Serbia, October 18.-21., 2022., pp. 558–572.

[11] S. S. Nikolić, I. B. Kocić, D. S. Antić, D. B. Mitić, N. B. Danković, M. B. Milovanović, P. S. Djekić, "Speed and tensile force control of the pulling devices of the continuous line", *Thermal Sciences*, vol. 27, no. 6A, pp. 4447–4460, 2023. doi: 10.2298/TSCI230418138N

[12] Allen-Bradley-Controllogix-Ethernet-Manual, [Online]. Available: https://www.kepware.com/getattachment/c7cd42b2-e3a8-403e-ac5b-ddff9cb03985/allen-bradley-controllogix-ethernet-manual.pdf

[13] Logix 5000 Controllers General Instructions, [Online]. Available: https://literature.rockwellautomation.com/idc/groups/literature/documents/rm/1756-rm003_-en-p.pdf

[14] SINAMICS DCM DC Converter Operating Instructions, 02/2015, A5E34763375/RS-AA/001, [Online]. Available: https://cache.industry.siemens.com/dl/files/240/109478240/att_851818/v1/manual-DC-Converter_en.pdf

[15] SINAMICS DCM List Manual (LH8), 02/2015, 6RX1800-0ED76, [Online]. Available: https://cache.industry.siemens.com/dl/files/243/109478243/att_851774/v1/Listenhandbuch_eng.pdf

[16] ACS880 primary control program, [Online]. Available: https://library.e.abb.com/public/6b0e2b9eba86e68bc1257b0c0053dab2/EN_ACS880_FW_Man_C.pdf

[17] ACS880-01 drives, Hardware manual, [Online]. Available: https://search.abb.com/Library/Download.aspx?DocumentID=3AUA0000078093&LanguageCode=en&DocumentPartId=1&Action=Launch&

[18] I. Kocić, P. Đekić, A. Milovanović, D. Antić, S. S. Nikolić, N. Danković, "Application of KEPServerEX applications for acquisition and supervision of production processes", *Proceedings of the XV International Conference on Systems, Automatic Control and Measurements, SAUM 2021,* Niš, Serbia, September 09.–10., 2021., pp. 17–20.

[19] I. Kocić, S. S. Nikolić, A. Milovanović, D. Mitić, P. Đekić, N. Danković, "Single screw extruder temperature control using PLC and HMI in cable production process", *Proceedings of the 9th International Conference on Electrical, Electronic and Computing Engineering-IcETRAN 2022,* Novi Pazar, Serbia, June 06.–09., 2022., pp. 137–142.

[20] MicroLogix™ 1200 and MicroLogix 1500 Programmable Controllers, [Online]. Available: https://literature.rockwellautomation.com/idc/groups/literature/documents/rm/1762-rm001_-en-p.pdf

[21] KEPServerEx manual, [Online]. Available: https://www.kepware.com/getattachment/2745a0a9-079a-4630-b15c-8081aba1a91d/kepserverex-manual.pdf

[22] XAMPP FOR MYSQL Amey Laxman Gawde, [Online]. Available: https://cs.nyu.edu/courses/Fall12/CSCIGA.2433001/XAMPP.pdf