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CONTROL SYSTEM OF A PROTOTYPE TECHNOLOGICAL LINE FOR PROCESSING DECORTICATED FLAX FIBRE

Key words: control system, flax, decortication.

Abstract: The technological line for processing decorticated flax fibre is an example of a prototype experimental technological line. In this type of objects, control systems need to be adjusted to the requirements imposed by the necessity to implement technologies with changing parameters whose values are set during experimental research. Moreover, the very structure of the technological line may be modified as a result of the introduction of improvements proposed by process engineers. The article describes a control system that meets the conditions set for the operation of a prototype technological line and presents the modules of the block diagram of the control system. The authors also present behavioural analysis of the control system and the ways to ensure that the requirements of a prototype technological line are met. Moreover, the user interface is described.

System sterowania prototypowej linii technologicznej do przetwarzania dekortykowanego włókna lnu

Słowa kluczowe: system sterowania, len, dekortykacja.

Streszczenie: Linia technologiczna do przetwarzania dekortykowanego włókna lnu jest przykładem prototypowej, eksperymentalnej linii technologicznej. W tego typu obiektach istotne jest dostosowanie systemu sterowania do wymagań wynikających z konieczności realizacji technologii o parametrach, których wartości ustalone są w trakcie badań eksperymentalnych. Również struktura linii może ulegać zmianom wynikającym z ulepszeń wprowadzanych przez technologów. W artykule opisano system sterowania, który spełnia warunki obsługi prototypowej linii technologicznej. Przedstawiono i omówiono moduły schematu blokowego systemu sterowania. Zaprezentowano analizę behawioralną systemu sterowania, sposoby zapewnienia realizacji wymagań prototypowej linii technologicznej oraz opisano interfejs użytkownika.

Introduction

The research on new flax varieties and the modification of traditional flax varieties need to go hand in hand with continuous improvement of the technological process of flax processing. The main research directions for improving the properties of this plant and its application consist in the creation of transgenic flax [1], which is a development of complex composite structures containing flax [2], or the development of new decortication methods for the purpose of obtaining flax with the smallest diameter possible (micro fibril) [3]. The development and new applications of flax fibres entail the development of new innovative technological stands for the processing thereof. Prototypes of such devices should have a structure enabling their easy and quick configuration at the time of their operation, and they should also be modernised and adapted to the changing technological requirements and the state of the art [4]. Characteristic features of a control system of a prototype experimental line include the properties of the main components of the control system, i.e. a central control unit, user interface, measurement elements, actuators, and other components [5, 6]. Properties of a central control unit (as a stand-alone unit or a unit shared by multiple devices) of a technological line control system should be selected in a way to ensure that the unit will meet current technological requirements and be fit for future forecasted tasks [7]. When choosing a central control unit, one needs to do the following:

– Estimate the number and functions of the measurement elements and actuators of the prototype device (number of analogue and digital inputs and outputs);
– Define communication interfaces and local networks (RS232, RS485, Modbus RTU, Modbus Ethernet TCP/IP, CANopen, Profibus, Profinet, etc.) relating to data exchange in the prototype and supervisory control system architectures (e.g., SCADA) [8, 9];
– Choose the type (AC, DC) and level of power supply;
– Assess and choose the required processing speed of the processor and the RAM of the unit being the controller in the prototype control system;
– Choose the programming environment taking into account the manufacturer and the programming language [10];
– Choose the type of the control unit (e.g., compact, modular or other structure), whose selection is determined by the financial costs and the future possibility to expand the hardware of the central control unit; and,
– Establish the market availability of the control unit and of the technical support.

The selection of the properties of the user interface of a technological line control system stems from the need for a graphical visualization of the process and of the implemented technological functions of the prototype. These selections entail the following:

– An estimation of the size of the user interface screen (connected with the complexity and clarity of the visualised prototype);
– The determination of technical and environment conditions of the planned operating environment of the prototype;
– The selection of the type of optimum user interface-user communication (touchscreen, buttons, joystick, keyboard etc.);
– The selection of the power supply type and value;
– The selection of interfaces for data exchange with the central control unit;
– The selection of the programming environment;
– An analysis of the availability of the given user interface in the market; and,
– Financial costs and the availability of technical support.

The selection of the properties of measurement elements used in the control system of the experimental technological line requires the definition of all physical values (velocity, acceleration, shift, altitude, pressure, temperature, load, etc.) that will be monitored in a prototype device on an on-going basis, and it also factors in the future expansion of the measurement elements. When selecting measurement elements, one should also choose the following:

– The interface of data exchange with the central unit (apart from standard analogue or binary signal transmission),
– Signal processing elements,
– The ranges and accuracy of measurement elements, and,
– The types and levels of the required power supply of the elements.

The selection of quantitative and qualitative measurement elements should always be subject to cost optimisation, and the selection of architecture, terminals, and additional equipment should be conditional on the standardisation of measurement elements assumed for the prototype. The selection of the properties of actuators used in a technological line control system is connected with the following:

– The selection of the actuator type depending on the implemented functions and movements;
– The determination of the power supply of the actuator (electric, pneumatic, hydraulic, etc.);
– The determination of the major physical value and inputs (force, velocity, acceleration, shift, pressure, temperature, load, etc.);
– The selection of the ranges and accuracy of the inputs implemented; the selection of the type of the actuator's direct control systems;
– The determination of the interfaces for communication and data exchange with the central control unit; and,
– The selection of the actuator based on its energy consumption, availability in the market, purchase price, and costs of operation.

The article presents the methods used to comply with the requirements regarding a technological line control system, based on the example of the technological line for processing decorticated flax fibre implemented at the Institute for Sustainable Technologies – National Research Institute.

1. System architecture

The development of a control system of a prototype technological line required initial determination of the assumptions of the solution and definition of the implemented functions, and their further analysis and experimental verification. The developed solution of the prototype experimental technological line (Fig. 1) is intended for degumming of a decorticated flax fibre [11]. This process is carried out in water with set thermal parameters, with the participation of other factors (ultrasound or mechanical inputs, to name a few). The prototype configurable technological line developed is modular in structure (Fig. 2), and arrows point to the direction in which the band of the flax fibre is transported after unrolling. Process water is circulated in a closed cycle between the MWT, MRPL, MKW1, and MKW2 modules. The MWT module is responsible for initial preparation of the operating fluid and its on-going treatment during the forced process in the water's closed cycle in the installation [12].

Fig. 1. View of the prototype technological line

This module is a novel solution that can be freely configured with new types of filters and elements used for the treatment of an operating fluid. The solution in question is equipped with the following: an electric two-column water softening system (DTR) [13], three working tanks with electric level sensors; electric shut-off valves, electric water pumps, mechanical spin-on filters with electric pressure sensors, an electric UV sterilisation system series V [14], an electric single-column carbon filter series CRB [13], and an electric reverse osmosis system series RO MAXI [13].

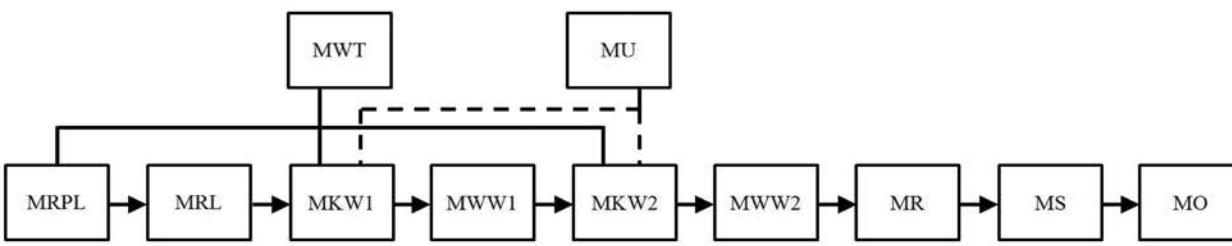

Fig. 2. Block diagram of the technological line: MRPL – flax rinsing reactor module MRL – flax unrolling module MKW 1/2 – bath module 1/2 MWW1/2 – pressing and wringing module 1/2 MR – loosening module MS – drying module MO – receiving module MWT – process water module MU – ultrasound module

The MRPL reactor module is equipped with the following: an electric drive activating the reactor's rotating movement controlled by the frequency converter series ATV32 [15], an electric water pump, electric shut-off valves, a 4.5 kW electric instantaneous water heater, and electric pressure and temperature sensors. The MKW1 and MKW 2 modules are equipped with fluid level, temperature and position electric sensors, pneumatic and ultrasound actuators controlled electrically, and 9 kW instantaneous water heaters (also electrically controlled). The MU module generating 25 and 35 kHz impacts and directly controls ultrasound actuators placed in technological baths. Another module of which the technological line is composed is the MRL module on which the roll of input material is placed. This module is equipped with an electric drive for flax fibre unrolling that is controlled by the frequency converter series ATV32, and pneumatic elements supporting the operation of material unrolling. After the bath, the material is transported to the pressing and wringing modules. The MWW1 and MWW2 modules are equipped with electric drives controlled by frequency converters series ATV32 and by the electrically controlled pneumatic actuators, whose position is controlled electrically. Once bathed and wringed, the input material is transported to the loosening module. The MR module carries out its functions through its own electric drive controlled by the frequency converter series ATV32 and an electrically controlled pneumatic actuator whose position is identified electrically. The MS module is yet another module of the technological line, and it is responsible for the drying of the input material with hot air generated by three 15 kW duct heaters series VK [16]. The drying module is equipped with an electric drive controlled by the frequency converter series ATV32 and a temperature sensor. And last, but not least, the MO module of the device is equipped with induction sensors indicating whether the end product is present and whether it has been rolled.

2. Control system

A Modicon PLC (N_PLC) [17] is the main control unit playing the role of a controller and a master unit at the same time (Fig. 3). This controller communicates with the Magelis user panel [15] over the Modbus Ethernet TCP/IP protocol [18], exchanging information with the user. The master controller is responsible for controlling measurement elements and actuators located in the modules of the technological line. Data exchange between individual measurement elements and actuators of the control system consists in the communication with individual system sections, and it employs the following communication interfaces and local networks: Modbus Ethernet TCP/IP, Modbus RTU, I/O (analogue and digital) [18,19]. Regarding the developed control system, the Modbus RTU communication interface is used for data exchange in the ME6 section. In this section, the measurement data collected from the original turbidity measurement system are initially fed to the local PLC (L_PLC) and then, after their analysis in that PLC, to the master PLC via the Modbus RTU interface.

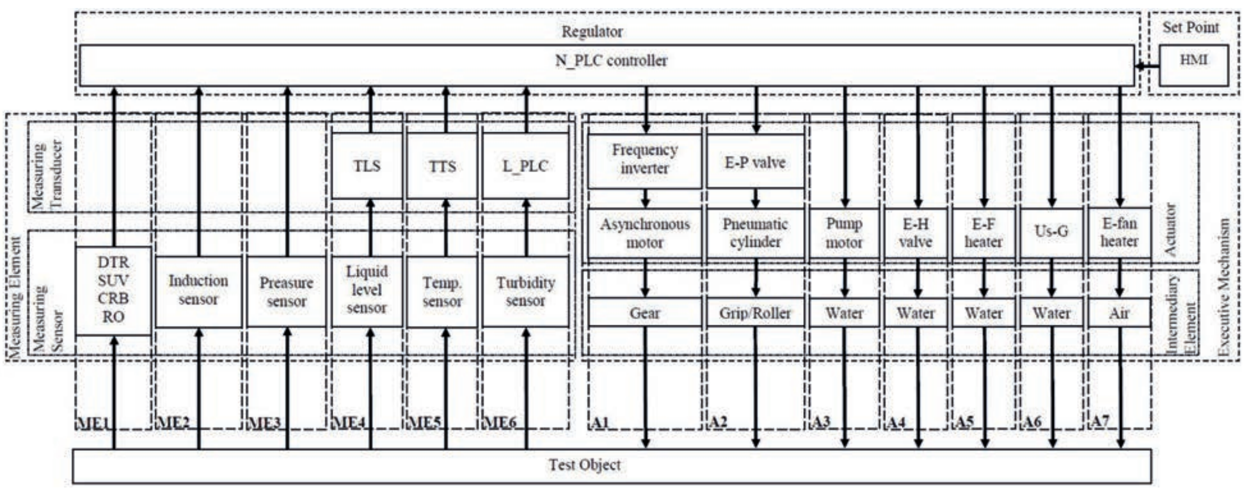

Fig. 3. Draft of the technological line control system

The Modbus Ethernet TCP/IP interface is used in two networks. In one of them, it is used for the exchange of data between the master PLC and the Magelis user panel, while, in the other, it is used for the exchange of data between the local PLC and the PC that archives measurement data of the turbidity measurement system. Data exchange in the developed control system is mainly carried out using analogue and digital I/O networks. Each of the two networks is divided into various sub-networks designed for the operations of individual sections of measurement elements and actuators. Within the analogue I/O network, an exchange of data between sections of the measurement elements listed below takes place: ME3, ME4, and ME5. The digital I/O network includes the data exchange between the sections of elements (both measurement elements and actuators): ME1, ME2, ME4, ME5, A1, A2, A3, A4, A5, A6, and A7. The ME4 and ME5 sections use the analogue and digital I/O communications. This results from the application of numerous different liquid and temperature measurement systems that enable direct measurement by delivering the analogue signal directly to the master PLC, as well as indirect measurement using additional processing systems. Due to the complexity of the operations performed in the technological line, many different types of actuators have been used, which indirectly impacts the research object. The object's rotation and movement along the technological line is performed through the operation of the A1 section composed of six asynchronous drives controlled directly by their frequency converters (Fig. 4a). The A6 section, which is composed of forty eight 25 and 35 kHz ultrasound generation sub-circuits (Us-G), is controlled digitally by

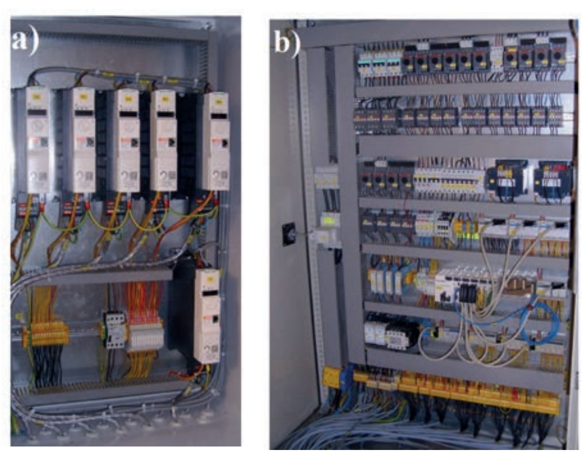

Fig. 4. View of the electrical enclosure of the technological line; a) operation of electric drives; b) master PLC

the master PLC, and its aim is to effect high frequency hydraulic impacts on the research object. All of the other actuators are controlled directly or indirectly by the master PLC from the electrical enclosure presented in Fig. 4b.

3. Algorithm for the control of the technological line operation

Figure 5 presents the algorithm of the processing of decorticated flax fibre in the developed technological line, as carried out by the control system. The algorithm shows the individual phases in which the master control unit carries out the processes of input material processing and the management of its transportation to each module of the technological line. The algorithm contains information about key parameters for the given technological operation. In the first IP phase of the algorithm, the system is activated and the availability of all required media is checked, the operating fluid is prepared and then its preparation is confirmed by the MWT, MRPL, MKW1 and MKW2 measurement modules and the MS operational condition is verified, and the actuators are set in the starting position. In the PPR phase, the control system performs the operation of the initial preparation of the product roll in the reactor during which the batch of flax is centrifuged at the set parameters of velocity (v_r) and centrifuging time (t_r), and centrifuging takes place in an aqueous environment with the set parameters of the temperature (T_r) and pressure (p_r) of the operating fluid. Once (t_r) reaches its set value, another phase of the algorithm starts. In the RL phase, the roll of the flax fibre is unrolled at a set velocity (v_{rl1}), while maintaining relevant tension of the unrolled material [21]. At the same time (in the same phase), the control system monitors the size of the roll and its presence. In the next phase (the KLW1 phase), the band of flax fibre is put in Bath 1, where flax degumming takes place with the controlled participation of certain frequency ultrasounds (f_{w1}). In this phase, the master PLC monitors and maintains the set level of fluid (h_{w1}) and its temperature (T_{w1}) and also controls the time (t_{w1}) and velocity (v_{w1}) of the flax band flow in Bath 1.

Having been bathed in Bath 1, the flax fibre band is pre-dried by pressing and wringing that take place in the WWL1 phase. The pressing and wringing operations carried out by the control system in this phase are performed at the set pressure force parameters (F_{ww1}) and at a controlled velocity (v_{ww1}). The next two phases – KLW2 and WWL2 – are carried out by the control system analogically to the preceding phases, and all the process parameters are maintained at the set levels. Once the flax fibre band has been bathed in the two baths and wringed, the master control unit subjects the fibre to loosening at a set velocity (v_{rm1}), thus activating the RLM phase. After loosening, the flax fibre band is dried – the SL phase during which the master control unit carries out the drying operation in the thermally controlled atmosphere (T_{s1}) and at a set velocity (v_{s1}) of the band flow. In the final phase of the process carried out by the control system, the flax fibre band is rolled and the size of the end roll is monitored (the ZL phase). The developed algorithm implemented by the control system enables one to end the process at this stage or to automatically start the process for another input material being a flax fibre roll for the purpose of another test or small batch production [22].

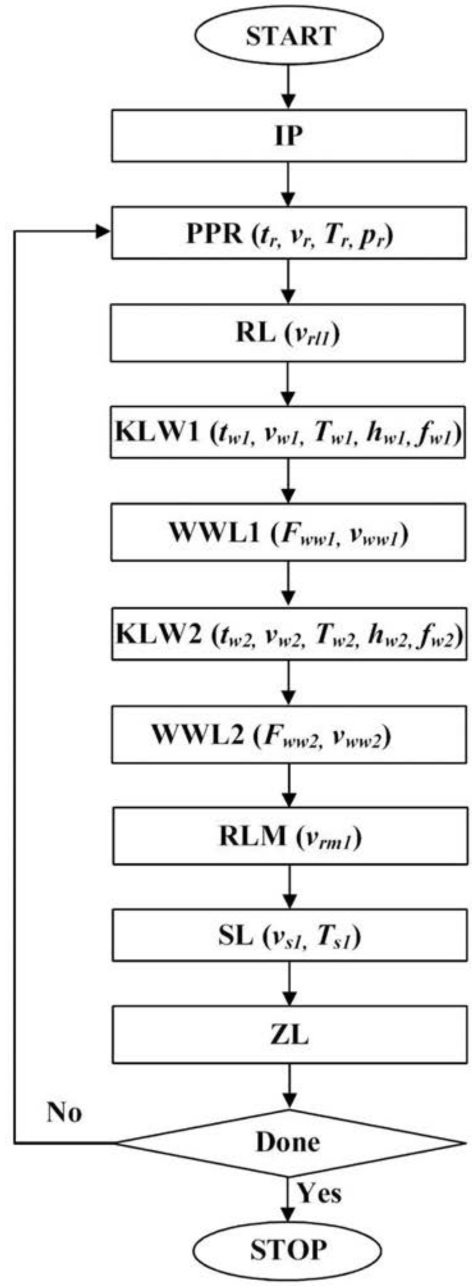

Fig. 5. Work algorithm of the technological line control system for individual input material feed cycle

4. User interface

The master control unit exchanges information with the user via the Magelis user panel (Fig. 6) containing the original user interface developed (Fig. 7).

Fig. 6. View of the user panel in the electrical enclosure of the master PLC

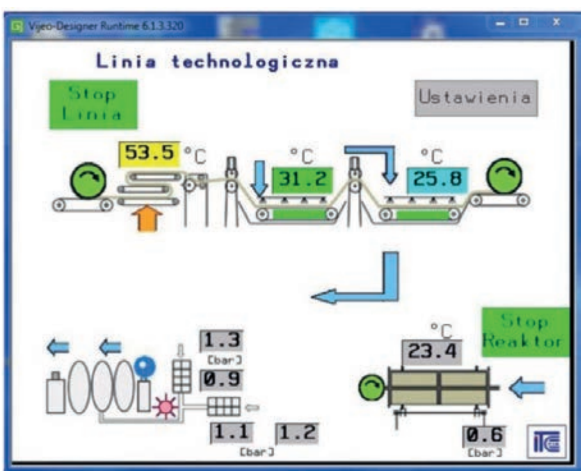

Fig. 7. View of the main screen of the user panel

The user interface developed consists of the following working screens: the main screen, settings screen, and alerts screen. The main screen is used for controlling the technological process and the visualisation of the current operations of the device. The visualisation of the operating order of individual elements and modules of the stand – as seen on the main screen – is divided into three areas. In the top part of the main screen, the main technological line is visualised, while the bottom right corner of the screen shows the control and signalisation of the reactor's work. In the bottom left corner, on the other hand, the process water module is visualised. Using the rectangular buttons displayed on the main screen, the user can switch on or off the technological line or reactor or go to the settings screen. The settings screen allows the modification of the basic operating parameters of the device, e.g., the speed at which the band of the flax fibre is moved along the line, or the time and temperatures or activation and deactivation of individual modules at a given phase of the process. Any device errors are communicated by alerts that signal irregularities that are displayed on the main screen along with the alert button. When such a button is displayed on the screen, the user is informed of irregularities found in the operation of the device that prevent continuation of the technological process. By pressing this button, the user is transmitted to another screen that notifies them of the type of irregularity/failure and provides them with additional information about its location.

Conclusions

The experimental tests carried out on the prototype technological line for the processing of decorticated flax fibre helped the authors select all the components of the control system that are compliant with the requirements of the process engineers. The control system developed enables the user to control and monitor the operation of the prototype experimental technological line. The system is modular, which enables easy and convenient and quick reconfiguration of the device and its adjustment to new technological requirements and conditions of another device. This is particularly important in the case of an experimental device, because it allows one to carry out different technological tests, small batch production, or quick adjustment to semi-industrial and industrial production. The modular PLC is the central control unit that enables further development and expansion of the prototype control system, which is due to its modularity allowing easy and convenient replacement of individual modules of the controller or addition of new ones. In its current structure, the PLC can operate six different measurement elements and seven sections of different actuators. The original control algorithm implemented in the master PLC and the original user interface software were created in their commercial programming environments. The control algorithm's main functions include the performance of the technological process and the detection of failures and events that are elements of the technological process diagnostics [23]. Other elements of the control system presented that facilitate activation of the prototype technological line and proper performance of the process include the following:

– Elements relating to process efficiency, achieved through the use of efficient hardware units (high reliability and resistance to unfavourable working conditions) and software that allows independent implementation of individual process phases and operations;

- Elements relating to the costs of development and manufacture – uniform programming environment, the use of commercial elements, abandonment of SCADA-type elements, which are not necessary in this type of a process;
- Elements relating to scalability – possibility to implement devices with different efficiency adjusted to changing market demand or devices used for different types of production (other substrates and other product quality) resulting from the outcomes of technological trials; and,
- Elements relating to safety, i.e. implemented hardware and software safeguards preventing the user from exceeding the nominal values of actuator parameters, which is quite a frequent occurrence as far as prototypes are concerned, and which poses a threat to users, the environment, and the device.

The developed control system enabled the authors to effectively activate and test the prototype technological line for the processing of decorticated flax fibres obtained from traditional fibrous plants and new types of flax, and also to select its process parameters [24].

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