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Design of an Automatic Control System for Cane Feeding of the Tandem in the Central "Argeo Martínez"

Magdelen Bazan De Los Santos*, Angela Giralt Sanchez

Department of Automatic Engineering, Faculty of Electrical Engineering, Eastern University, Santiago de Cuba, Cuba

Email address:
magdelen@uo.edu.cu (M. B. De L. Santos), angelagiralt@uo.edu.cu (A. G. Sanchez)
*Corresponding author

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Abstract: In this research, an automatic control system is projected, which guarantees the constant flow of cane to the first mill of the tandem in the Central Argeo Martínez from the province of Guantánamo in Cuba; in such a way that the efficiency of extracting juices during the grinding process is guaranteed. For this it was necessary to characterize the cane feeding systems, as well as the analysis of the current situation of the process in said plant. It also presents the architecture of the proposed control system, the selection of the control strategy, as well as the modeling and calculation of the power of the motors that the process demands. The different instruments used in the process were characterized. The FX3U-32M series Mitsubishi brand PLC was described. The economic impact of the proposal is expressed to the extent that greater efficiency is achieved in the cane juice extraction process, production and maintenance costs decrease, and energy savings are boosted, which represents economic savings for the industry. The proposal for the automatic control system does not present damage to the environment, as it does not cause noise or waste that affects human beings, and it does not depend on the use of polluting energies. This control system does not constitute a source of accidents for the people who operate or manipulate it.

Keywords: Regulator, PSoC Microcontrollers, Hydroelectric Power Plants

1. Introduction

The automation of the different processes for obtaining sugar in Cuban sugar mills has made it possible to improve working conditions, as well as to rationally use resources that are of vital importance and among which are: raw material, fuel, water, steam, electricity, etc.

Industrial automation is the use of computerized and electromechanical systems or elements to control machinery or industrial processes. This has reached a fundamental role in an important number of industries including the sugar industry.

Now, the preparation of the cane in this industry constitutes the first process of a raw sugar factory and consists of passing the canes through equipment that is in charge of untangling the packages, leveling or flattening the mattress and chopping, chopping and defiber it, all with the purpose of producing a stable and continuous flow of homogeneously prepared cane, which guarantees an optimal extraction of the juice in the mills [1, 2]. The adequate preparation of the sugar cane for feeding the first mill is of special importance in any sugar industry, which includes mechanical pre-processing and ensures a stable supply to the mills.

Therefore, maintaining the constant feed to the first mill would generate an increase in efficiency in terms of taking advantage of the steam flow delivered by the boilers, since the fluctuations generated by the poor feeding of cane produce pressure drops or drown the boiler, causing it to lose temperature, destabilizing the energy balance of the company [3].

That is why our objective is to design an automatic control system that allows the constant flow of cane to the first mill of the tandem in the Central "Argeo Martínez" of the Guantánamo province; in such a way as to guarantee the efficiency of extracting juices during the grinding process.

2. Materials and Methods

During the grinding process, it must be taken into account that, in order to obtain satisfactory results in the production of sugar, the quality of the preparation of the cane is paramount, that is, the more chopped it is when it reaches the grinding area, the mills They will do their job more efficiently [4].

This preparation index achieved by the action of the Galician's and the blades, is directly proportional to the stability of the thickness of the cane cushion during the transfer from the tilting of the same until its arrival at the first mill.

However, the transfer of the raw material through the mats is carried out in many mills manually, commanded by the frequency variator that manipulates its motor, with the inconvenience of having to make stops at certain frequencies when the cane feed comes from of railway cars.

That is why, although the purpose of properly preparing the cane for feeding the grinding plant is to extract as much guarapo as possible, sometimes the compression to which the cane is subjected in the mills is not enough for an efficient extraction, therefore, the help of an exhaustive preparation of the cane and the guarantee of a stable supply from the mills [5].

Figure 1 below shows the general process of cane feeding from unloading to arrival at the first extraction mill 2.2.

Figure 1. *Transfer, preparation and feeding of the cane from the discharge to the entrance to the first mill.*

As can be seen, the cane preparation process consists of several phases:

1) Unloading of the cane in the supply mat.
2) Orderly unloading of the cane from the supply mat to the elevator, with the help of the package breaker.
3) Leveling the cane on the mats before it reaches the blades.
4) Breaking the resistance of the knots, the bark, and the demolition of the cells of the tissues of the cane with the help of the sets of knives.
5) Unloading of the cane prepared in an orderly fashion from the lifting mat to the driving mat.
6) Discharge of the prepared cane in an orderly manner from the conducting mat to the hopper of the first extraction mill.

2.1. Automation Proposal

In principle, it is proposed to implement a control system where the speed of the elevator and dispensing belts will be manipulated, with the aim of controlling the filling level of the hopper through PID control actions, which are widely accepted in the industry.

These controllers base their operation on the use of a frequency variator to control the speed of the belts, through squirrel cage motors, which makes it possible to vary the speed of these drives in a wide range, which can be from values close to zero (depending on the type of converter) up to values above the rated speed of the motor [6].

The use of converters has a positive impact on increasing energy efficiency by minimizing losses in motors. To measure the level in the dispenser, five capacitive sensors are used whose operating principle is based on varying their capacity depending on the level of the solid (sugar cane) and sending digital signals, which, when received by the converter, are transformed into a signal electricity and these measurements are taken to the automaton.

For the correct operation of the capacitive sensors, they must be placed vertically in the upper part of the hopper. They are waterproof, suitable for harsh environments. To measure the level at the tail of the lifting mat, an ultrasonic level measurement device is installed on it, the signal of which is taken to the automaton [7, 8].

To measure the consumption currents of the blades and leveler, current transformers are used, whose function is to reduce them in such a way that when they are received by the converter, it emits them in a 4 to 20 mA signal that is sent to the automaton. In order to vary the speed of the motors of the dispensing, lifting and conductive mats, frequency variators are used, which in their control circuits have a 4-20 mA analog input connected respectively from the automaton.

In the pyramid-shaped scheme, see figure 2, three levels can be observed. In a first level or field level, there are the motors and sensors, in which the level of the cane bundle in the hopper is measured by means of the sensors, the cane level on the lifting mat through an ultrasonic level sensor and the currents consumed by the blades and leveler. In the second level or control level are the converters, frequency variators and the PLC controller that receives the measurements made in the process, from this level the decisions are made about what the speed of the mats is and if it has to stop. In the third level or level of supervision there is a PC to visualize and command to activate the process.

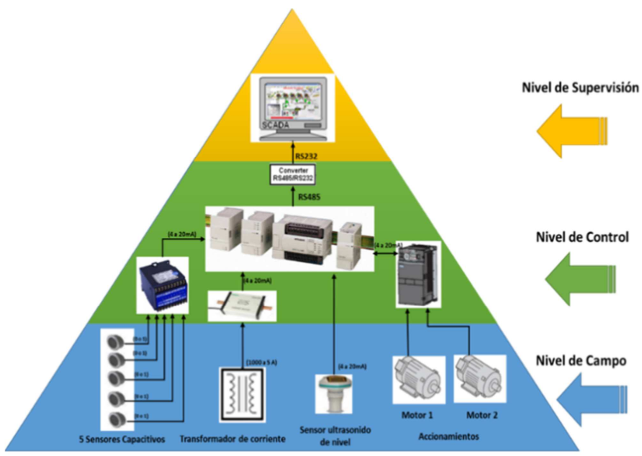

Figure 2. *Pyramidal structure of the Automation Architecture.*

In the preparation index and the flow of prepared cane with which the first windmill. And sometimes it is necessary to stop the Within the process under study, disturbances are understood as all those situations that occur during the feeding of cane to the hopper of the first grinding element and put an end to the malfunction of the area in question.

For what is determined during the study that the main disturbances that directly affect the correct preparation of the cane are [9]:

1. Changes or fluctuations in the physical composition of the cane that continually arrives at the mill, that is, variations in the length of the canes, in their hardness, in the level of overlap they have, and if they are burned or not etc.

This situation directly affects the preparation index, resulting in variations in the extraction of the juice in the mill area and therefore losses of sucrose in the bagasse that passes to the boiler.

2. Fluctuations in the times in which the cane feed to the supply mat.

Said disturbance has a marked influence within the technological process of sugar manufacturing, since it affects the flow of cane that must reach the preparation equipment, causing notable variations process in some cases.

The combined factors that determine the quality of the constant feeding process to the hopper are the height of the cane cushion on the elevator belt and the minimum possible speed of the belt [10, 11].

Although theoretically, for a given grind, the height of the cane cushion determines the average speed.

For this reason, they are considered as variables that

The following characterize the process:

1. Level the cane mattress on the Elevator mat.
2. Speed in the motor of the Elevator mat.
3. Speed in the motor of the dispensing mat.
4. Current in the motor of the leveler.
5. Current in blade set motors.
6. Cane preparation rate.
7. Hopper level.

Highlighting as main variables that characterize the process:

1. The degree and % of preparation of the cane (Index cane preparation).
2. The flow of cane supplied to the first team of grinding (hopper level).

(These two are the main technical indicators of the operation of the receiving and preparation process).

3. The height or thickness of the mattress at different points in the system, to guarantee the balance of materials and the efficiency of the preparation machines.
4. The speed of the lifting mat.

2.2. Variables to Manipulate

In the selection process of these variables, it was kept in mind that the grinding plant has limited control, since there are more variables to control than possible to manipulate. For this reason, the variables to be manipulated are:

1. The level in the hopper.
2. The power consumed by the motor of the lifting mat, since it is broadly related to the height or thickness of the mattress at different points in the system, to guarantee the balance of materials and the efficiency of the preparation machines.
3. The speed of the elevator mat, and the conductive mat 4. Overload protections, blade sets and levelers.

2.3. Structure of the Proposed Control System

The proposed control system is shown through the block diagram of figure 3.

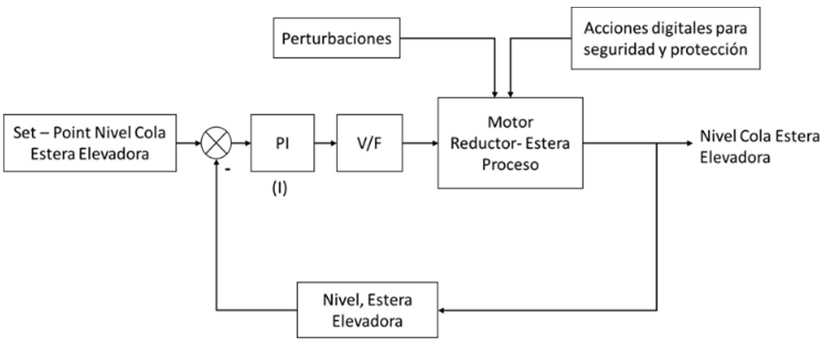

Figure 3. *Block diagram of the proposed control loop for the dispenser mat.*

2.4. Control Loop Operation

The fundamental objective of the speed control loop of the dispenser mat is to achieve a stable supply of cane to the elevator and avoid overloading and triggering of the blades.

This loop aims to achieve these objectives using the cane level at the beginning of the lifting mat as the main variable, but taking into account that it does not have the possibility of acting on the level at the pump under the conditions of the "Argeo Martínez" power plant. On the other hand, as the feeding of the supply mat is discreet and varies depending on the cane shot (disturbance), the parameters that intervene in its flow act on its speed, taking into account the level of cane in the mat that follows.

In the action of the loop, the level of the lifting mat is used as the main parameter, so that if this level increases, the output of a PI regulator with reverse action will decrease the speed of the dispensing mat, establishing a link between the cane flow and the permissible range of the level in the elevator, for which a stable mattress is guaranteed without the risk of overloading or tripping the blades.

Digital actions for the safety and protection of the process in the supply mat.

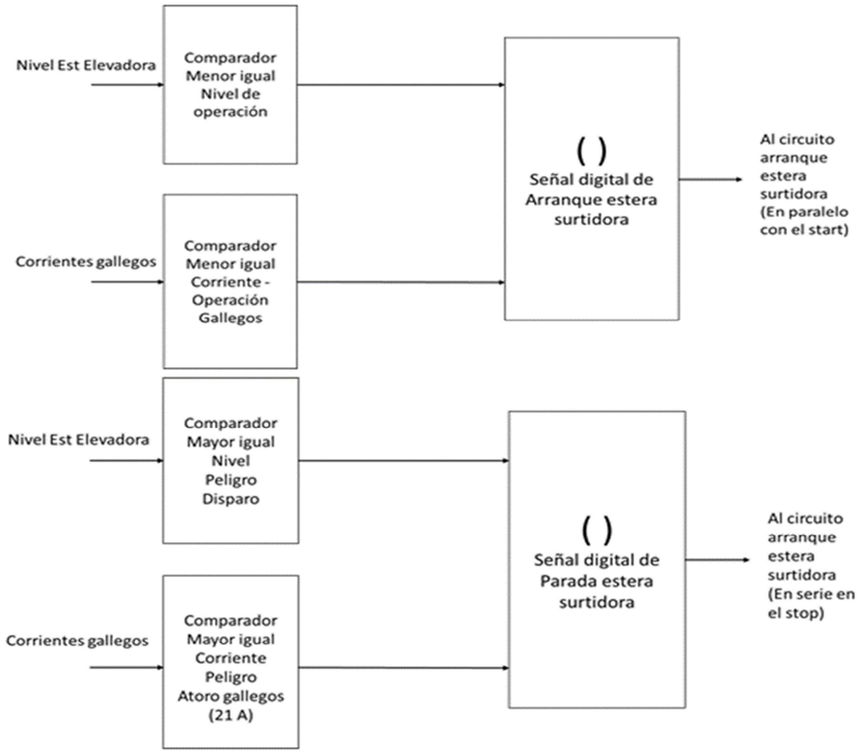

Figure 4. *Block diagram for the safety and protection of the process in the dispenser mat.*

To guarantee the operation of the cane supply from the dispenser to the elevator, avoiding the danger of overloading or firing of the blades, the action of four comparators is proposed, (Figure 4) that will act from the dangerous level that would cause said outcome and taking also take into account the dangerous current detected in the consumption of Galician's who are located before the first blade.

So, with two comparators that are activated with a value greater than or equal to the established level and current of the Galician's, a digital one is reflected at its output and in turn acts on the variator control circuit to stop the motor of the dispenser mat and with the use of two comparators less than or equal to the level and current of Galician's, they are activated by starting up the dispenser mat again.

Of course this will be done by setting a range between stop condition and start condition.

The control system applied for the elevator and intermediate mats is shown through the block diagram of figure 5.

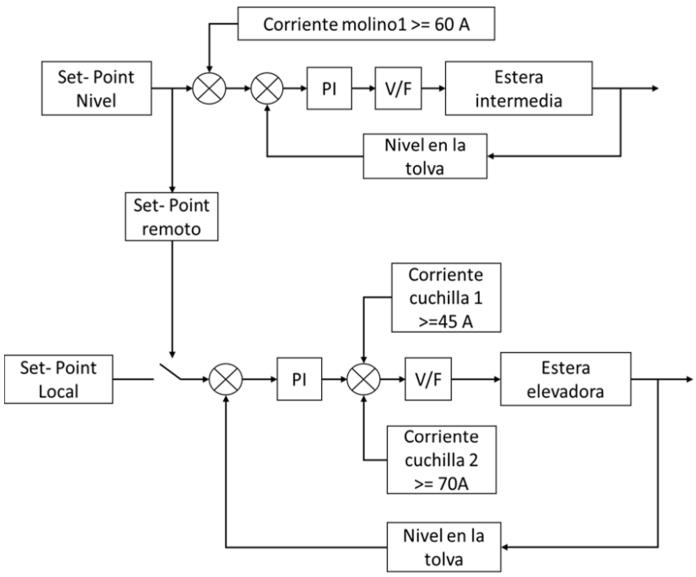

Figure 5. *Block diagram of the control loop proposed for the elevator and intermediate mat.*

2.5. Loop Performance

In the action of the loop, the level in the hopper is used as the main variable, so that if this level increases, the output of the PI regulator with reverse action will decrease the speed of the intermediate belt, and in turn the speed of the elevator; In this loop, the current of mill 1 in the intermediate mat acts as protection, that is, if the current of mill 1 is greater than 60 A, the set point decreases and with this the speed of the intermediate mat decreases, decreasing the level in the hopper and with it the load to said motor.

In the case of the lifting mat, the current of blades 1 and 2 acts as protection, that is, from 45 and 70 A respectively, these blades are subtracted, with a certain weight, from the output of the regulator that acts on the lifting mat, reducing its speed and thus its load, avoiding tripping due to overload and lost time.

In this loop the local or remote set point can be selected. Remotely, the lifting mat works with the adjustment point selected in the intermediate mat and locally, each mat is worked independently with the aim of operating the mats separately in case of repair or test.

3. Models Involved in the Feeding Process

Due to the above, the modeling of the sensors is reduced to considering them as linear elements with a determined gain without delay [12].

Drive modeling: The final action element in the control loop is the electrical drive, in this case formed by the frequency converter-induction motor system, for which a first-order linear element is chosen as a model, given the small electromagnetic time constants of the drive and motor with respect to the mechanical inertia of the motor and gear [12].

The parameters of the blocks have been determined from the knowledge of the data of the motors and of the frequency converters recommended for the installation in the case of the sugar mill "Argeo Martínez", being in this way the drive represented by the following transfer function [13].

$$M(s) = \frac{0.124}{0.014s+1} \quad (1)$$

The modeling of the mats or conveyors [2],

It allows to obtain the output flow of the mat depending on its speed and the input mass flow.

Conveyor mats with side walls for solids, have a certain volumetric capacity, to model the flow and thickness of the cane mattress, the following were taken into account restrictions: the transported solid has a uniform height or level in the cross section of the mat, the density of the transported solid is constant, the degree of inclination of the inclined section of the mat is not so great as to cause a slippage of the reed mattress in the opposite direction to the movement of the mat and the effect of the preparation mechanisms on the flow dynamics is negligible [13].

The belt conveyor can be seen as a system of distributed parameters with two input variables (flow of solids at its entrance and velocity of the belt) and two output variables (flow of solids and level or height at its exit), as shown can be seen in Figure 6.

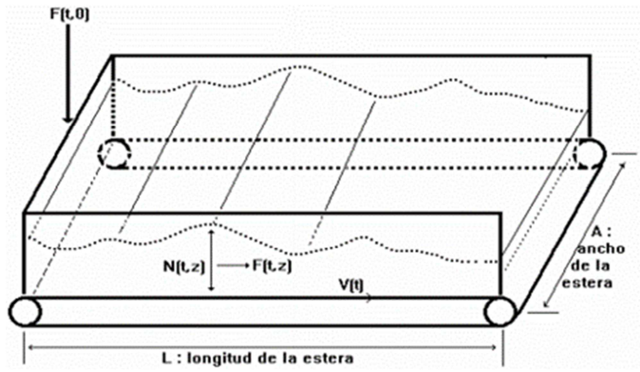

Figure 6. *Parameters of a cane conveyor belt.*

The discharge or flow at any point in the mat is calculated by:

$$F(t,z) = A_e * N_e(t,z) * V_e(t) * \rho_e \quad (2)$$

Where: A_e: Width of mat (m)

$N_e(t,z)$:: Height or thickness of the mattress (m)

$V_e(t)$: Belt speed (m/min)

ρ_e: Density of the cane mattress in the mat lift (kg/m^3)

In particular, we will be interested in the output flow of the riser mat F_s^e as it coincides with the inlet flow to the hoppe F_e

$$F_s^e = F(t,z) = F_e, \quad (3)$$

With which the sensor should be located in the final section of the supply mat in order to measure the level of the mattress $N_e(t,z)$

Hopper modeling: The dispenser model depends on the shape and dimensions [14]. A hopper of constant rectangular section with height R, width A and depth P is considered. The mass balance equation in the hopper is as follows:

$$dm/dt = F_e - F_s = F_N \quad (4)$$

The cane flow absorbed by the first grinding equipment can be calculated by:

$$F_s = A * H * \gamma(t) * w_m \quad (5)$$

The tangential speed of the masses of the constant w_m is mill, because they are operated at constant speed. The width of the masses (A), obviously, is also constant and equal to the width of the hopper. On the contrary, neither the thickness of the cane mattress between the masses H (the separation between the upper mass and the cane mass) nor the density of the mattress at that point (γ) are Both depend non-linearly on the height or level of the mattress in the hopper and on the pressure applied to the mills.

However, if the level of the cane cushion in the hopper remains between 40 and 80% of the maximum height of the hopper and the pressure applied to the mills is constant, then both the buoyancy H and the density can be considered practically constant in that interval.

Since the height of the mattress in the hopper is controlled at a constant value, then it can be considered without great error that the cane flow absorbed by the first grinding equipment is proportional to the speed of the mills constant for the entire possible operating space.

The mass of cane in the hopper is calculated by:

$$m(t) = A * P * N_T(t) * \rho_0 \quad (6)$$

Where:

A: Width of the hopper (m).

P: Hopper depth (m)

N_T: Height of the cane mattress (m).

ρ_0: Average density of the cane mattress in the hopper (kg/m^3)

Finally, the hopper model is determined in the time domain by:

$$N_T = 1/(A * P * \rho_0)\,(F_e\,(t) - A * H * \gamma(t) * w_m) \quad (7)$$

The dispenser or feed hopper is modeled as an integrator, whose output variable (cane level in the hopper) depends on the integration of the input flow. In the case of the “Argeo Martínez” sugar mill, the integration constant is 0.000185.

Modeling of the squirrel cage electric motor For the modeling of the squirrel cage motor, the recalculation was first carried out, by two different methods, of the motors, present in the main drives (mats) of the area of preparation in order to obtain the necessary data from it, such as power, speed (m/s), etc., considering the most severe regime as the operating condition, that is, at full load.

Frequency regulation: Range of higher performance and simplicity of use, especially applied in torque, speed and position controls:

General Specifications FR-A700

1) Large Power Range: 0.4 to 630 kW (divided into 29 references).
2) Speed output regulation range: 0 to 400Hz.
3) Adjustable PWM carrier frequency from 0.7 to 14.5 kHz (without power reduction).
4) 4 selectable maximum overload levels.

Perfectly adjustable to the needs demanded by each type of application, being able to supply up to 250% of the nominal value for 3 seconds.

5) Incorporation of an integrated braking unit up to 22kW thus allowing direct connection to the DC bus of braking resistors. Built with highly reliable components 5 years superior to the average of any other variator.

Most important features

1) Energy Saving.
2) By updating the vector control rial used in the predecessor series (FR-F500), greater savings have been achieved in permanent regime and especially in accelerations/decelerations.
3) The current FR-A500 and FR-F700 range allow up to 5 V/F points to be programmed. In the case of the FR-F700 and together with the optimal torque excitation control, you can achieve great energy savings: • Anti-mill function • Soft start of the motor that rotates in the opposite direction due to the mill effect.
4) Automatic reset and frequency search in front of micro voltage outages.
5) Wear prevention functions.
6) Allows predicting the longevity of the drive (eg capacitors 10 years) through digital inputs and outputs.

CD-420

The CD-420 converter is intended for applications in the level measurement of solids and liquids where it is not continuous measurement possible for process reasons. The CD 420 works together with capacitive proximity sensors mod. STF-2500C, or any similar, including electromechanical, that supply open collector or dry contact outputs. The converter output is adjustable from 0 to 100% of span, and accepts up to six sensors. In cases where active sensors are used, such as the STF-2500C, the CD 420 provides the supply voltage for them, simplifying application projects, to dispensers of auxiliary external sources of continuous power [15].

Technical specifications

1) Power: 110/220Vac 60Hz;
2) Inputs: 1 to 6 digital inputs (opto-isolated);
3) Outputs: 1 analog signal output 4-20mA;
4) 1 -12Vdc/450mA output (for powering up to 6 70mA sensors);
5) Operating temperature: 0-50°C;
6) Mounting: 35mm DIN rail or screws;
7) Degree of protection: IP-00;
8) Consumption: 9.6VA;
9) Weight: 705g; and
10) Dimension: 75×100×123mm (WxLxD).

Capacitive Sensor STF-2500C

STF-2500C is a precision electronic device designed to detect various types of solid or liquid materials in aggressive media or in applications where conductor sensors do not show up due to the presence of moisture, corrosion, etc. [15].

Technical specifications

1) STF-2500C together with the CD420 converter for monitoring and level control;
2) Power supply: 12 -30 Vdc (24 VDC nominal);
3) Display: LED “triggered”;
4) Sensitivity: 0 - 50 mm (adjustable);
5) Outputs: high and low mode (maximum current 100mA mode).
6) Operating temperature: 0-50°C;
7) Installation: fixing and screws;
8) Degree of protection: IP-65;
9) Consumption: 0.7VA;
10) Dimensions: 42 mm x Ø127mm (height x depth daddy).

PLC Mitsubishi FX3U

Thanks to the design of the FX3U, the PLC can be even better adapted to your requirements. As with the rest of the members of the FX family, a large number of diverse modules can be connected to the right of an FX3U base unit. If the new FX3U series communication extension modules are used, the FX3U automatically switches its communication bus to high-speed mode. Even so, full compatibility with the FX0N and FX2N series extension modules is guaranteed. If modules from these series are connected, the FX3U then also automatically reduces the baud rate on the bus [16].

The FX3U is equipped with six high-speed counters, each of which can process signals up to 100 kHz simultaneously per channel. In combination with three pulse train outputs with max. 100 kHz, a simple 3-axis positioning system results that does not require additional modules [16].

1) Input/output range 16 to 384 (max. 256 in base/ extension unit).
2) Program memory 64 k steps (standard).
3) Processing of basic instructions 0.065 µs/logical instruction.
4) Analog signal processing Up to 80 analog inputs, 48 analog outputs.
5) Analog extensions available 14 different modules with analog inputs and outputs and for temperature recording.

4. Conclusion

A proposal was made to modify the control of the cane feeding process into the hopper of the first grinding element at the “Argeo Martínez” sugar mill. In particular, the substitution of manual control for an automatic one.

From the detailed description of each drive involved in the cane preparation process and its control schemes, as well as their technical requirements, the possible disturbances that can affect the process are defined.

The instruments that were selected for the automatic control system are described, which allows the constant flow of cane to the first Tandem mill in the "Ageo Martínez" power plant in the Guantánamo province.

Acknowledgements

To the group of workers of the Argeo Martinez power plant.

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