Modeling and Control of a Sugar Cane Process

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Abstract. It is presented the design, modeling and simulation of an automatic control system in sugar cane preparation degree, which makes use of artificial vision techniques for the continuous mensuration of this parameter.This control system comes upon a scientific and technique innovation, rending possible automatic control of the optimum preparation degree, according to differents models of available preparation machines, to later employment of bagasse and others possible changeable interest in the sugar mill.

Key words: modeling, control, robust, vision, automation.

1 Introduction

The preparation station is the first one in a cane sugar factory, and its main objective is to receive the discreet lots of canes coming from the field and to produce a continuous flow of prepared cane and with a optimum preparation degree, in order to feed a mill train or a diffuser, where it is carried out extraction of sugar cane juice.

The main variable to control in the preparation station is therefore the preparation degree, the parameter determining quality of the elaborated product, that is to say the prepared sugar cane.

Modeling and automatic control of preparation degree [1], [2] is a scientific, technological and economic problem, taking into account that in all over the world doesn't exists an automatic control of this parameter and that manual control is extremely inefficient. This can be verified by simple observation of this station operation in different sugar mills. So we can appreciate different preparation degrees in these stations as son as frequently it takes place stops of preparation machines caused by overloads and obstructions.

The preparation degree is a measure in per cent of open cells, and its juice can be extracted by compression in the mills or by diffusion in a diffuser. It can also be a measure of type and size of the particles (also called fineness) that are produced in dividing into pieces and breaking up sugar cane stalks in preparation machines.

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Two basic objectives are attended in the preparation station:
To increase juice extraction in mills train or in diffusers when sugar cane stalks fibrous structure are broken and juice cells are free. To increase tandem processing capacity increasing volumetric density of feed sugar cane mattress is the objective.
According to [4] "The entire sugar canes more or less entangled have a low volumetric density because of the great proportion of air space between sugar canes stalks. But when they have been cut in the preparatory plant, we have smaller pieces rather uniforms, and consequently with smaller empty volume. In such a case, the pressed sugar canes in the mills are bigger in proportion

Hugot [3] mentions the following figures about volumetric density: 8-10 lb./cu.ft. for entire sugar canes more or less tangled and 15-20 lb./cu.ft. For those grounded in the mills.

Depending on several factors we can have an optimum preparation. A very fine preparation (greatly small sugar cane particles) causes a degradation in mills process and rend more difficult burnt of the bagasse in the furnaces. According to this some experts recommend that the preparation were as fine as possible.

Jenkins [4] recommends that the preparation should be fixed in a average value, so that optimum results weren't obtained with not one sugar cane types. In such cases another easy means for to vary preparation degree in relation to sugar cane would be very attractive.

There are two generic types of preparation, one with long and narrow pieces and another with particles more or less uniforms.

Different laboratory analytic techniques have been used in measuring the preparation degree, among those we have: sieving, volumetric density, energy consumption, expert visual judgement and others. In commercial practice, visual observation is the one commonly used. Although different observers are generally congenial with comparative evaluation of fineness for a certain number of samples; this method can be applied only if we dispose of samples series as a reference point.

The preparation area is basically conformed by cane conveyors and preparation machines, such as levellers, sugar cane knives and shredders.
Usually, sugar cane bundles are directly discharged from railroad boxcars or trucks to a sugar cane conveyor or to a lateral table, which feeds to a second sugar cane conveyor where are located the preparation machines. As a study case has been selected a plant with two sugar cane knives situated in the second conveyor. Fig 1.shows a scheme of this plant and the designed control system.

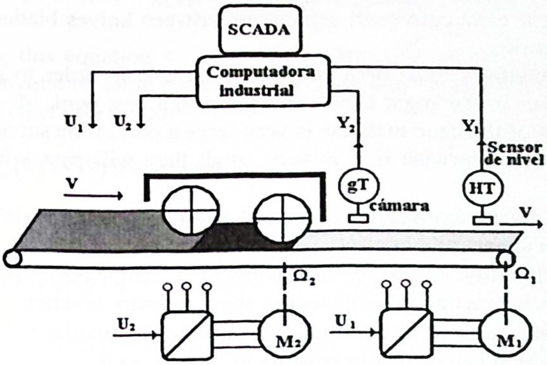

Fig. 1: Lateral view of a cane conveyor with two cane knives.

The knife blades are removable, so that they can be easily taken off for resharpening or for replacing.

The sugar cane knives rotate with angular velocities between 400 and 800 RPM. This machine breaks the sugar canes in small pieces, forming a more condensed sugar cane mattress to make more easy juice extraction in the mills or in the diffuser. When two sets of sugar cane knives are used, the first one (leveller knives) works with a wide separation adjustment (high clearance) allowing to pass a high proportion of uncut sugar canes. The second knife set (cutting knives) completes this work and is used as a very low clearance.

The authors are developing a project of advanced control for the sugar cane preparation plant ,at the time being it has been demonstrated the necessity and convenience in designing and setting up an automatic control of the preparation degree. Therefore it is necessary to obtain a model of the process

2. Modeling in Preparation Process

The preparation degree (g) is the output of the second preparation machine and it depends on the following factors:

· Machine angular velocity.

· Hardness or resistance of sugar canes to be cut, which at once depends of their variety, maturity and freshness.

· Sugar cane flow (F) to be processed.

· Separation between knives blades and sugar cane conveyor level work. Edge of sugar cane knives, which decreases progressively.

· preparation degree apported by the first machine.

In order to control the preparation degree it can be used as manipulated variables:

angular velocity of machine, height of sugar cane mattress (H), the power of machine, velocity of sugar cane conveyor, separation between knives blades and sugar cane conveyor level work .

The height of the mattress must be a controlled variable in order to guarantee a mass automatic balance in the sugar cane conveyor and a best work of preparation machines. If the height of the cane mattress is very large a part of the sugar canes will pass besides the knives; otherwise if it is very small they will pass without being processed.

The velocity of sugar cane conveyor (V) is used as a manipulated variable in order to control the height of sugar cane mattress (H) in this one.

Manipulation of separation can be realized when the machine possesses an adjustable bar-anvil, and this is practically inexistent in sugar industry practice.

Therefore it has been selected as manipulated variable the angular velocity of the preparation machine which is technically feasible in several ways.

Considering a fixed separation, constant height of sugar cane mattress (H) for an automatic regulation loop, sugar cane knives replaced with a certain periodicity and using incremental variables, the following expressions can be obtained for calculation of variation in preparation degree.

$$g(t) = \lambda_1 * \Omega(t) - \lambda_2 * V(t) - \lambda_3 * D(t) - \lambda_4 * \rho(t), \quad \lambda_i > 0 \tag{1}$$

As it is observed, perturbations that affect the preparation degree are sugar cane conveyor velocity

(V), sugar cane hardness (D) and volumetric density of sugar cane mattress. An increment of anyone of them causes a reduction of the preparation degree and vice versa.

The preparation machines can be moved by electric motors, hydraulic motors and steam motors. Whichever it is the type that is used, the following equation can settle down:

$$M_m(t) = M_a(t) \tag{2}$$

Where Mm(t) y Ma(t) are respectively the motor and the antagonistic moments. At once the antagonistic moment is calculated by equation (3)

$$M_a(t) = J \times d\Omega/dt + B \times \Omega(t) + M_c(t) \tag{3}$$

Where J= Jmotor + Jmachine, B is the coefficient of viscous damping and Mc(t) is the load moment opposed by the sugar canes mattress while they are cut and broken in pieces.

In non linear form the load moment depends of sugar cane hardness, height of the mattress, velocity in crossing the machine, knives edge and angular velocity.

Under previous assumptions, considering small variations around the nominal operating point, and using deviation variables we can write:

$$M_c(t) = \alpha_1 \times \Omega(t) + \alpha_2 \times V(t) + \alpha_3 \times D(t) \tag{4}$$

Applying this equation we can obtain variations in load moment opposed by the knives. If anyone of these variables increases very little over nominal value the load moment will increase proportionally.

Substituting (4) in (3) it is obtained

$$M_a(t) = J \times d\Omega/dt + B \times \Omega(t) + \alpha_1 \times \Omega(t) + \alpha_2 \times V(t) + \alpha_3 \times D(t) \tag{5}$$

Substituting (5) in (2) it is obtained

$$M_m(t) = J \times d\Omega/dt + B \times \Omega(t) + \alpha_1 \times \Omega(t) + \alpha_2 \times V(t) + \alpha_3 \times D(t) \tag{6}$$

Taking the Laplace transform on both sides of equation (6) with initial conditions assumed to be zero we have:

$$\Omega(S) = \frac{1}{JS + B + \alpha_1} \times \left(M_m(S) - \alpha_2 \times V(S) - \alpha_3 \times D(S)\right) \tag{7}$$

Equations (1) and (7) represent a linear model of the process, in the environment of nominal operating point. The coefficients of the model depend on the specific plant and some of them are difficult to obtain.

This previous analysis shows that a plant conformed by a frequency converter, motor, machine and the conveyor can be represented by a first order system with a pure retard whose equation is:

$$\frac{g(S)}{U(S)} = \frac{K \cdot e^{-LS}}{1+TS} \tag{8}$$

The plant gain (K) is uncertain due to the gradual loss of knives edge, between a substitution of the blades and the following one.

Using experimental methods the following values were calculated:
K_{max} = 5,0 (recently sharp knives)
K_{min} = 1.5, (blades with a week of use)
K_{nom} = 2.5 (nominal value)

The total delay of model L is the addition of real delay in the plant and apparent delay due to considerate a high order system as a first order one. As we will show later, the former is greater than the apparent one.

The real or pure delay is the time delay (L) introduced by the sugar cane conveyor. It depends of distance " d " between video camera and the preparation machine output, linear velocity (v) of sugar cane conveyor which is the manipulated variable in the regulation loop of the sugar cane mattress height (D)

According to this it will be advisable to place video camera near the preparation machine in order to reduce time delay.

In this case, we have estimated in 3 meters the minimum distance for to place video camera and the maximum range of sugar cane conveyor velocity from 1 to 6 m/min. So we will have that time delay will vary between 30 and 180 seconds.

Finally, using experimental techniques we have estimated apparent time constant of the model, T = 40 seconds, this parameter is associated to dynamic of frequency converter and motor.

Conclusively, it is a process with a dominant delay and as an aggravating circustance, it is variable in a wide range because of its difficult dynamics.

3. Analysis of Different Control Algorithms.

The control system components are an industrial computer, an artificial vision kit and a frequency converter varying velocity of squirrel-cage motor

It was decided to evaluate different control configurations, considering at the beginning the simplest and common, that is to say, a PID standard controller syntonized by Ziegler-Nichols classic method.

Delay (Lm) introduced by processing images techniques of prosecution of images for measurement of preparation degree is supposed constant and equal to 5 seconds.

Using simulation techniques the system was carry to the limit of stability, with integral and derivative actions disabled; the following values were obtained for critical gain and critical period: Kpcrít = 0. 55 y Pcrít = 250 s.

Using closed loop Ziegler-Nichols formulas; it was determined the controller's parameters: Kp=0.33, Ti=175 y Td =31.25.

After Tuning of the controller, the system was simulated for plant nominal values and it was obtained the following indicators: 5 % overshoot, time response equal to 800s approximately and ITAE= 215 for 1500 s in simulation.

Later on, parameters of the plant were varied in correspondence to their nominal values in order to evaluate robustness of the system. It was observed that for nominal delay of 100s with a gain of 3.8 (smaller than the maximum gain) the system is already in the limit of stability.

Therefore, we can conclude that this alternative of control is not adequate in this process of difficult dynamics, with dominant delay and also variable.

As a second alternative, it was used the method proposed in [1] to adjust conventional controllers PID in robust form. Supposing d=0.5 the controller's parameters are fixed in the following way:

$$K_p = \frac{1}{K} \bullet \frac{T + \frac{L}{2}}{L(D+1)} = 0.24 \quad T_i = T + \frac{L}{2} = 90 \quad T_d = \frac{T \bullet L}{2T + L} = 22.22 \quad (9)$$

Like in the previous case, the system was simulated for plant nominal values, and it was obtained the following indicators: 3 % maximum overshoot, time response of 500 s approximately, and ITAE= 160 for 1500 s in simulation.

Later on, varying parameters of the plant as in the other case in order to evaluate robustness of the system, it was observed an improvement in the system behavior but with an insufficient value of robustness for controlling the plant. For example, with a process gain k= 5 and a time delay L = 125 seconds the system is already in the stability limit.

The design of a robust controller for the regulation of the sugar cane mattress level is presented in [5].

4. Conclusions

The hardware components of the system are a computer vision kit, a data acquisition card, an industrial control computer and a frequency converter. The PID controller is in the industrial control computer.

The control system uses artificial vision and processing patterns in order to measure preparation degree on line and continually.

The video camera will be placed as near as possible to the preparation machine to reduce to a minimum time delay introduced by the sugar cane conveyor.

This automatic regulation loop guarantees optimum preparation degree required by the sugar mill and it also prevents overload stops in preparation machines. The control system can be easily extendrd to others preparation plants different from that analyzed in this paper.

The dynamics of the preparation process is characterized by its great uncertainty, reason why the controller PID syntonized by classic methods cannot guarantee the demanded benefits.

Consequently it is necessary to use advanced algorithms for synthesis of a controller with sufficient robustness.

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