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Model Predictive Control System Analysis for Sugarcane Crushing Mill Process

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Abstract

MPC is a computer based technique that requires the process model to anticipate the future outputs of that process. An optimal control action is taken by MPC based on this prediction. The MPC is so popular since its control performance has been reported to be best among other conventional techniques to control the multivariable dynamical plants with various inputs and outputs constraints. In this paper the performance of an MPC controller on a single stage of milling train of sugar mill is analyzed. A linear model of the plant is taken with flap position and turbine speed set point as manipulated variables and mill torque and buffer chute height as controlled variables. The set point tracking responses are compared for constrained and unconstrained cases. The effect of presence of unmeasured disturbance also is investigated.

Keywords: *Model predictive control, Sugar mill, Buffer chute, Prediction horizon, Multivariable process*

1. Introduction

Sugar production process is a highly complicated process which has a significant multivariable interaction and requires monitoring and control of hundreds of variables [9]. The entire process is comprised of many sub processes out of which the sugar extraction is the key sub process which is attempted to be controlled in this paper.

The controller that has been used for this case study is model predictive controller (MPC) which has shown an excellent set point tracking performance for a multivariable process over conventional controllers. The MPC calculates an objective function [10] based on the prediction of the output samples up to a fixed prediction horizon and then determines the discrete moves of the input manipulated variables in such a way that the objective function is minimized.

In sugar mill, firstly the cane passes through two sets of rotating knives called cane and shredder knives [11] which make its pieces and transform it to shredded 1-2 centimeters fiber called bagasse. These fibers are carried to the chute by cane carrier .Now, from the base of the chute the bagasse is fed to the rollers for juice extraction by altering the chute flap. This flap helps regulate the flow from base as shown in figure 1 [5].

The control of two parameters namely buffer chute height h(t) and mill toque τ(t) is very crucial for maximum juice extraction. The manipulated variables to control these parameters may be the flap position f(t) and the turbine speed set point ω(t).The torque control can be accomplished by chute geometry by flap and the chute height can be maintained by varying the speed of turbine [12]. Thus this process can be viewed as a 2x2 MIMO system with a third input parameter which is an unmeasured disturbance d(t) originates in the variable feed to the buffer .

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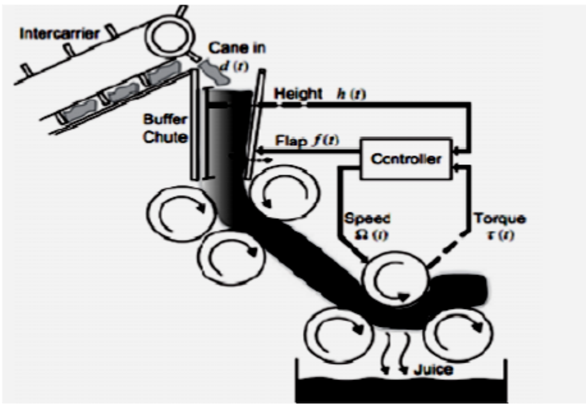

Figure 1. Crushing Process [5]

JN Jones et al. developed a new control system to achieve a constant fiber rate of 98 tonnes/hr and crushing rate of 675 tonnes/hr. Using PID blocks [1].GG Ashe et al. spotted the need to automate the sugar production process to overcome the significant errors made by humans [2]. Silvio Simani proposed a fault diagnosis application for sugar cane crushing process using fuzzy system based on Takagi-Sugeno model [3].

Lewinski J et al. suggested that the mill can be operated with different speed distributions between the rollers which makes the operation of the mill with same peripheral speed possible [8].Control of maceration flow as function of cane fibre levels was attempted at Marian mill during 2009 season which executed a simple programme with fibre signal and crushing rate as the input [7].

2. Plant Model

The transfer function model of the considered milling plant is shown in Figure 2 [5]

$$\begin{bmatrix} \tau \\ h \end{bmatrix} = \begin{bmatrix} \tau \\ h \end{bmatrix} \begin{bmatrix} \frac{-5}{25s+1} & \frac{s^2-0.05\,s-0.005}{0.1s^3+1.1s^2+s} \\ \frac{1}{25\,s+1} & \frac{-0.0023}{s} \end{bmatrix} \begin{bmatrix} f \\ \omega \end{bmatrix} + \begin{bmatrix} \frac{-0.005}{s} \\ \frac{0.0023}{s} \end{bmatrix} [d]$$

Figure 2. Transfer function of crushing mill [5]

Where the controlled variables τ and h are the mill torque and buffer chute height respectively and the manipulated variables f and ω are flap position and turbine speed set point respectively, d being the disturbance. The following constraints will be considered on manipulated variables for multivariable sugar mill process:

$0 \le f \le 1$, $6 \le \omega \le 10$(rpm)

The tuning parameters for the controllers are specified in table 1 as follows [4]:

Table 1. Tuning parameters of MPC [4]

Tuning Parameter	Value
Control interval(sec)	1.0
Prediction horizon	10
Control horizon	2
Rate weight for f	0.1
Rate weight for ω	0.1
Weight for τ	1
Weight for h	0
Duration(seconds)	30
Robustness	0.8

The weight of the controlled variable buffer chute height h(t) is set at value zero since the regulation of h(t) is less important than that of turbine speed ω(t). This will result in an excellent setpoint tracking response for ω(t). The controller can not show an outstanding setpoint tracking responses for all controlled variables simultaneously.

3. Results and Analysis

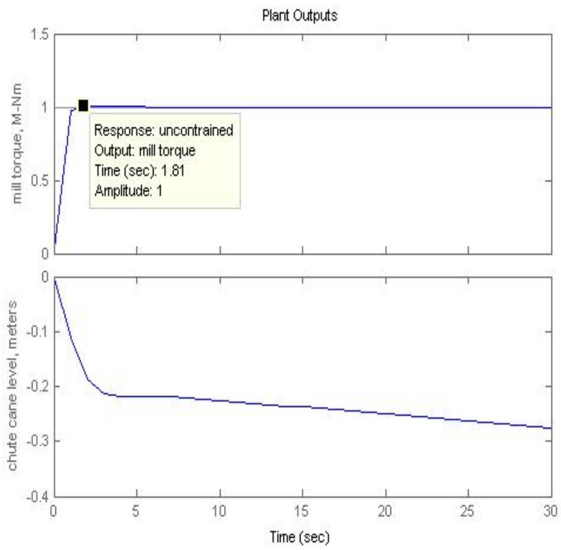

Figure 3. Set-point response for step change in mill torque for unconstrained variables

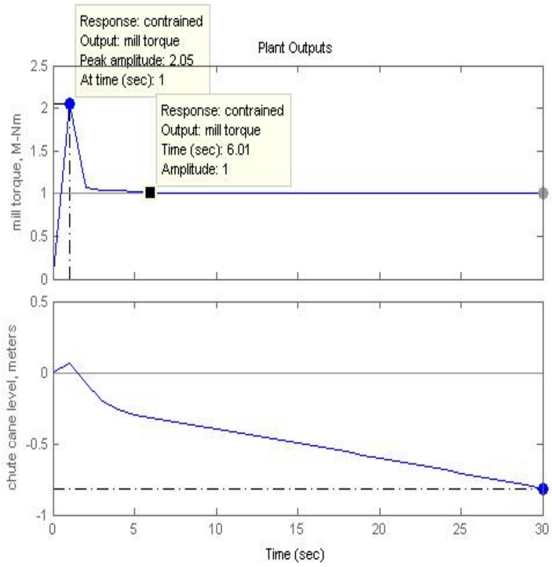

Figure 4. Set-point response for step change in mill torque with constrained variables

The figure 3 and figure 4 show the setpoint tracking responses with and without constraints respectively assuming the unmeasured disturbance d(t) equal to zero and setpoint for the mill torque is 1M-Nm. With no constraints the response is better with no overshoot and smaller settling time as compared to one with constraints on manipulated variables imposed. This can be clearly observed in figure 5 which presents a comparison between cases depicted in figure 3 and figure 4.

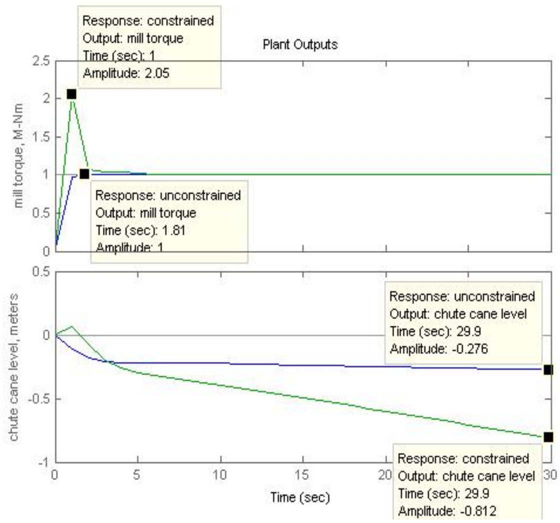

Figure 5. Comparison of the cases presented in figure 3 and figure 4

Now let us investigate the effect of unmeasured disturbance on the set point tracking responses.The figure 6 compares the degradation in set point tracking responses with step and ramp type unmeasured disturbances added at t=25 seconds.

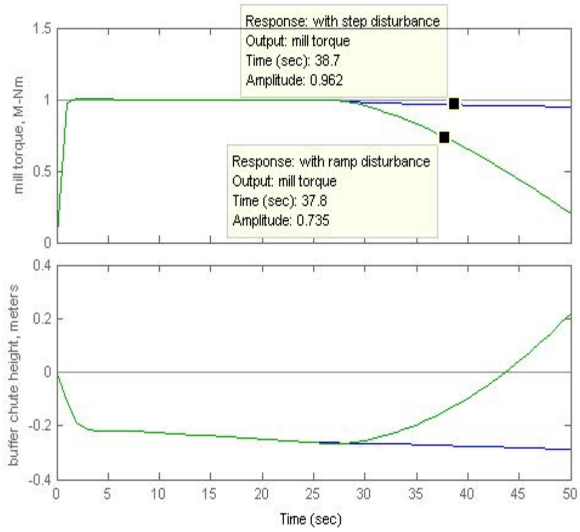

Figure 6. Set-point response degradation with step and ramp type unmeasured disturbance added at t=25 seconds

Hence the degradation in the set point tracking response is negligible in case of unit step disturbance which shows the good noise rejection capability of MPC. But the effect of ramp type disturbance is very adverse as output is forced towards zero. Hence the degradation in the set point tracking response is negligible in case of unit step disturbance which shows the good noise rejection capability of MPC. But the effect of ramp type disturbance is very adverse as the mill torque is forced towards zero.

Figure 7 compares the set point tracking performance with control horizon (CH) of value at 1 and 2. It clearly shows that control horizon of value 2 results in no overshoot and faster set point tracking as compared to control horizon of value 1.

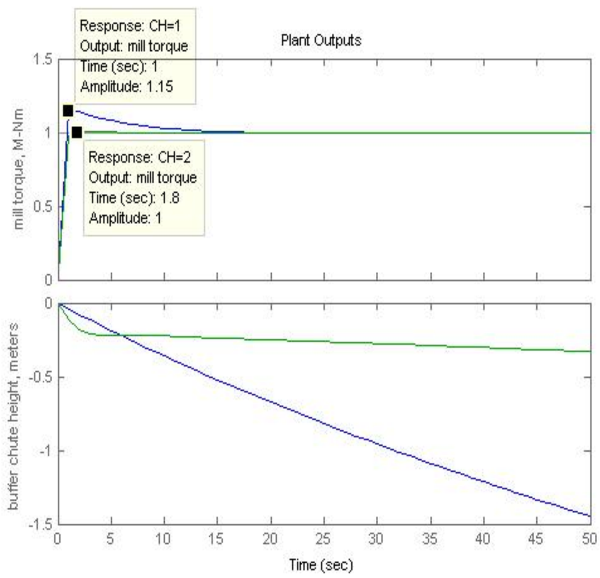

Figure 7. Set point responses with control horizon value of 1 and 2

4. Conclusion

It been observed that the MPC technique gives an excellent performance in control of complex non linear multivariable industrial process with faster response as compared to other conventional methods. The response for unconstrained process model has been observed to be better than one with constraints imposed on input variables. The effect of unmeasured disturbance on set point response is more adverse if it is of ramp type.

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