Model Predictive Control of Pilot Spray Dryer Unit Designed and implemented for an Educational Institute

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Abstract

Model Predictive Control of Pilot Spray Dryer Unit designed and implemented for an educational institute' is an effort to build an experimental set-up for demonstrating the spray dryer technology and the advanced process control strategy for the same to students. During last few decades spray drying has become highly competitive way of drying a wide variety of products. It has gained paramount importance in making powder from the extracts of seasonal fruits, milk, egg etc. in large quantities. The objective of building the Pilot Plant is to provide a platform on which students can perform experiments by operating the plant and observing the effects of variation of different process parameters and load disturbances. It works on the principle of co-current pneumatic nozzle spray dryer. Evaporation of moisture in spray-droplets is accomplished by its direct contact with hot whirling air co-currently under the controlled conditions of temperature and airflow. The plant is built and operated using local instruments and PID controller. The plant model is developed, simulated and tested using software tools. The tested model is then implemented using MPC block in the EMERSON DeltaV DCS. Various trials and experiments are conducted to compare the performance of the control system with PID controller and with Model Predictive Control.

Keywords: Model Predictive Control, Advanced Control for Spray Dryer, Pilot Spray Dryer Control for Educational Institute, Educational set-up of Model Predictive Control

Note: DeltaV is a trademark/brand name of Emerson Process Management, USA.

1. Introduction

Drying is an important industrial and food processing unit operation that is generally present at the end of processing sequence of manufacturing an industrial product. In the food processing industry, drying as a unit operation finds a unique place for food preservation as well as for conversion of an oversupply of perishable foodstuff into products having long life.

Spray drying is a process whereby a liquid droplet is rapidly dried as it comes in contact with a stream of hot air. A major requirement of successful spray drying is the reduction of the moisture content of the liquid droplets to the level that prevents the particles from sticking to a solid surface as the particles impinge on that surface.

India has a vast agricultural & farm produce output. A majority of these 'straight from the farm' products are perishable and seasonal. Food preservation is therefore a 'hot topic' for India as well as many agro-based economies in the world. Considering this importance of spray drying for industrial applications as well as in the drying of foodstuff, a Pilot Spray Dryer Unit has been designed and installed for educational purpose at the instrumentation and control laboratory.

Spray dryer design is based on principles and engineering practices of Chemical Engineering. On the other hand, Process control and Instrumentation engineering principles and practices are essential for implementing the required control strategies. Only a combination of both the engineering technologies can lead to optimum spray drying process control. In view of this, we formed a multidisciplinary team to work on this project.

2. System Description

The system consists of a horizontal drying chamber in which feed, atomized with compressed air in a nozzle, enters at one end of the chamber. Immediately on entering the chamber, the atomized droplets of feed come into vigorous contact with hot whirling air traveling co-currently. During the travel from entrance to the exit of the chamber, heat is transferred from hot air to the droplets, drying them in the process. A major portion of heat is transferred immediately close to the entrance as the rate of heat transfer falls drastically from entrance to the exit of the chamber.

Based on the process design, velocities of both feed and air are arrived at to provide required residence time to the droplet in order to dry it to the desired moisture content.

Some dried particles get deposited at the bottom of the chamber and some remain suspended in the air, which then get separated from the air going out of the chamber in the cyclone separator.

Though temperature in the chamber is high, heat damage to the powder is negligible because of an evaporative cooling effect during critical drying period. As the residence time of the droplets formed by the nozzles throughout the chamber is very short, the particle is exposed to high temperatures for very short time. The dryer is operated under vacuum to keep the drying temperature low as well as to create a draft from the inlet to outlet of the system.

Fig 1 shows a schematic of the system that consists of a feed tank, pneumatic nozzle atomizer, heater, drying chamber, cyclone separator, product collector, and blower.

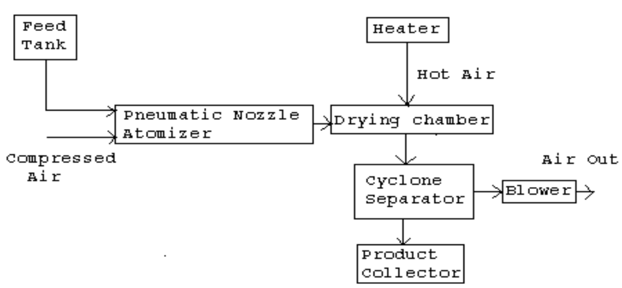

Figure 1:System schematic

3. Process Monitoring, Instrumentation and Control

The process control development involved identifying process variables and deciding the manipulated and controlled variable(s). For a spray dryer, the variables of interest from a process control perspective are already known. These are:

- Temperature at spray-air contact
- Outlet temperature
- Droplet size distribution
- Feed flow
- Hot-air flow
- Outlet relative Humidity
- Vacuum in the chamber

As a first step of implementation, a Single Input Single Output (SISO) scheme was implemented using conventional instruments. This implementation covered providing following instrumentation and controls on the field and a local control panel:

- Chamber Temperature is **controlled** by **manipulating** power input to the electrical air heater using conventional PID controller. This is the single input, single output system referred before.
- High and low chamber temperature alarms are provided on a window annunciator that includes a feed tank low-level alarm.
- Temperature and relative humidity at the outlet of the chamber are indicated and monitored.
- A Safety interlock that permits the feed entry only when the inlet air temperature crosses a preset value is provided.
- Vacuum in the chamber is monitored with draft gauge.

Advanced Process Control (APC) techniques are being taught to graduate students at our institute. However the students were not getting exposure to practical implementation of these techniques. Since a DCS with in-built advanced control facilities was available at the laboratory, as the next step, for the same SISO system, it was decided to design and implement Model Predictive Control (MPC) on this spray dryer.

4. Model Predictive Control

MPC is an Advanced Process Control technique which is gaining importance and preference over PID control due its inherent advantages of constraints handling, effective control of multivariable processes and difficult to control processes having high time constants.
Several excellent expositions of the technique of MPC are available in the literature. Interested readers may refer any of them for familiarization with the theoretical basis of MPC [1].

5. MPC Implementation

5.1 Process Model Identification

The first step of MPC implementation involved identification of the process model for the SISO system mentioned earlier.

Determining the Settling Time
Step tests were conducted on the system by changing the output in manual mode. For this purpose, the system was brought to a steady state by giving a fixed 50% output. Next, the output was raised to 75% as a step change. The step response of the process variable (chamber temp.) was recorded to arrive at the settling time of the system. Similar step tests were performed also on the lower side of the steady state manual output. Based on the tests, the settling time of the system was found to be four min.

MPC Module Creation in DCS
Next, MPC block and Analog I/O blocks available within the DCS were configured for the SISO system. This included Tag Nos., Analog input/output assignments, soft-wiring the blocks and setting the parameters. Control module so formed was downloaded to the CPU. When downloading is over, the DCS automatically enables historical data recording for the manipulated, controlled and constrained variables. The chamber temperature, which is a controlled variable was itself used as a constrained variable by assigning high and low value constraints.

Model Generation
For the purpose of model generation, the parameters required are settling time and step size. Settling time of four minutes, determined before, was used. The step size selected was 5%.
With these inputs, the step test of the prediction utility within the DCS was started. This utility generates a model of the process based on the step test and calculates the model parameters. The step test is based on Pseudo Random Binary Signal (PRBS). After completing the test, the utility also provides for validation of the generated model. Fig. 2&3 present the step tests.

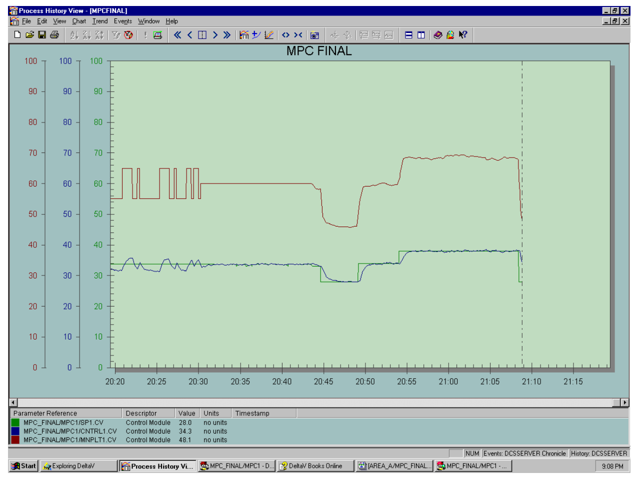

Figure 2:PRBS test for model identification

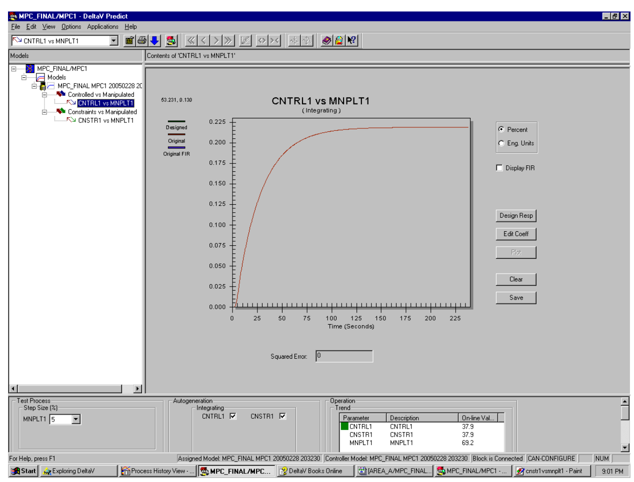

Figure 3:Response curve of PRBS test

5.2 Model Validation

The validation essentially involves comparison of the ARX model with FIR model. The steps for validation are:

Inspection of validation errors for process output: This involved observing error between calculated output and actual output for a selected data set. A high squared error above 3% indicates poor model.
Fig.4 &5 present model verification.

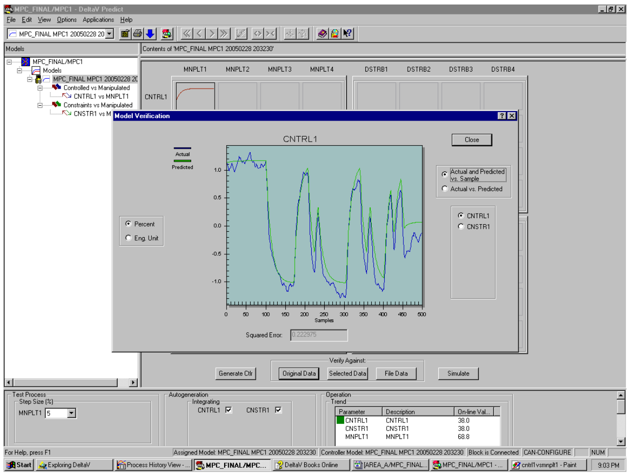

Figure 4:Model verification

The squared error in our case was 0.229 indicating a good fit.

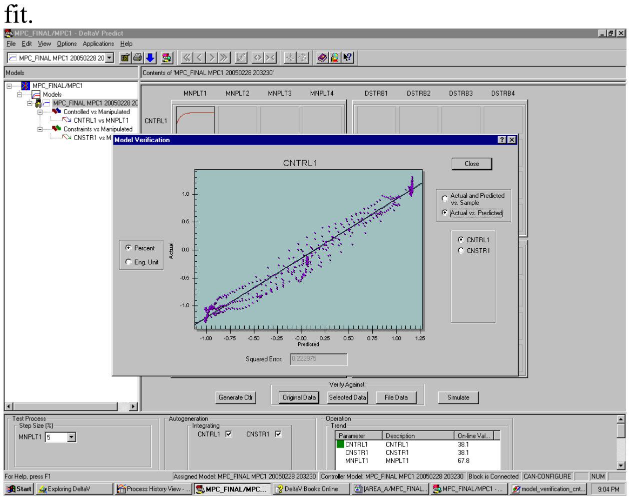

Figure 5:Model performance

Inspection of step response: In this, the sign of the gain is checked. The value of the gain is verified based on the knowledge of the actual process gain. The ARX and FIR models are compared over the initial part of the curve. Good match between the ARX and FIR model indicates good accuracy of the model.

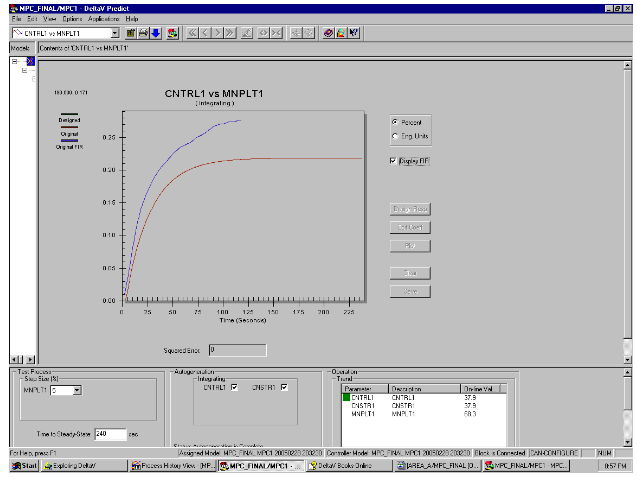

Figure 6:ARX and FIR model comparison

It can be seen from the fig. 6 that in our case there is a good match between the two models.

Making minor corrections to the process dynamics: Due to noise, the process response curves may not be smooth. For such situations, the DCS provides step response design tools to smoothen out the response, thereby introducing minor corrections in the process dynamics.
As can be seen from fig.3, the response curves were smooth during our experiment. Therefore corrections to the process dynamics were not required.

5.3 Development of the MPC Operator Interface

Tools provided within the DCS were used for developing a suitable operator interface.

5.4 Tuning MPC Controller using the simulation facility

The DCS provides a *Simulate* feature to test and tune the MPC Controller. In *Simulate*, the MPC controller connects to the process model rather than the actual process. All inputs are as generated within the model, all outputs of the MPC controller affect the relevant outputs in the process model. Therefore this facility offers a good opportunity to tune the controller performance.

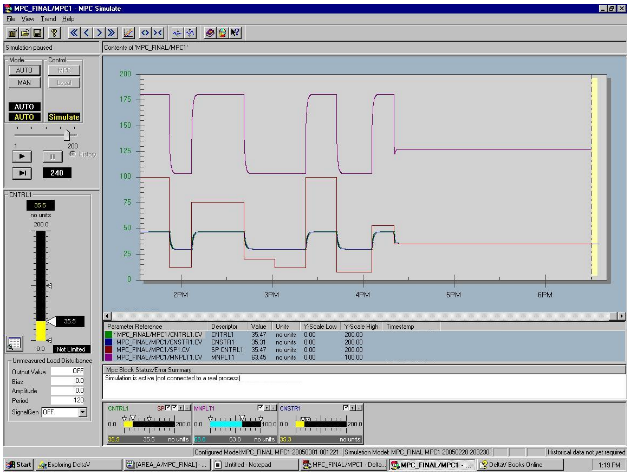

Figure 7:Simulation for PM and PE adjustments

Testing the Response Using Simulation

We used the *Simulate* feature to observe the control response for set-point changes, measured and unmeasured disturbances and constraints handling.

Control robustness:

Control robustness is the sensitivity of control to changes in process dynamics. *Penalty on Move* (PM) is a parameter provided within the DCS that affects robustness. PM controls how much the MPC controller is penalized for making a change in the manipulated output. Accordingly, large PM values result in a slow controller with a wide stability margin. Small PM value results in a fast controller with a narrow stability margin. When the model is accurate, changing the PM value does not affect the controller performance significantly. However a substantial difference in the controller performance might occur if the model does not match with the process.

The DCS calculates default values for the PM using the model parameters. However, the user may change these values to improve desired performance as mentioned above.

In our experiment, even when PM values were changed, the performance of the controller remained more or less unaffected. This therefore served as another confirmation of the accuracy of our model.

Control Sensitivity

Sometimes it may be necessary (to meet the application requirements) to give higher priority to one controlled variable (CV). *Penalty on Error* (PE) is a parameter available within the DCS that allows placing more importance on a specific CV. The default value for the PE is one for all CVs. One could change the PE from this default value to prioritize control action. When it is necessary make a specific CV more sensitive, the associated PE could be set to a value greater than one. On the other hand, setting the PE associated with a CV to a value less than one reduces its sensitivity.

In our case, since the system was SISO, the value of PE was chosen to be one.

Fig. 7 presents effect of the PM and PE adjustments.

5.5 Process Control using MPC

After testing the MPC block in the DCS simulation environment, the controller was used to control the process. The results on live process are presented in the fig. 8&9.

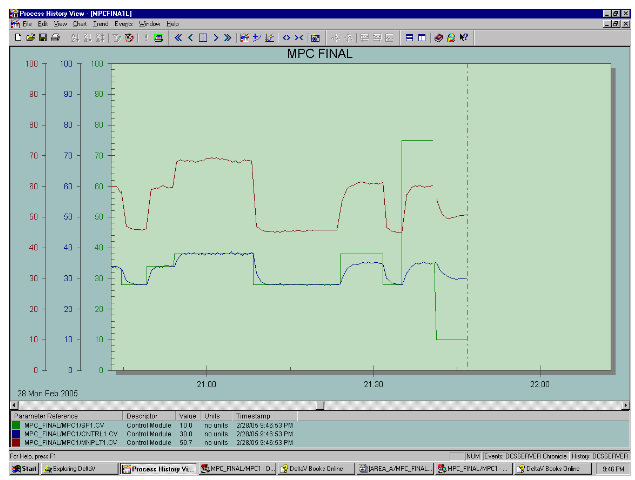

Figure 8:MPC control and constraints test

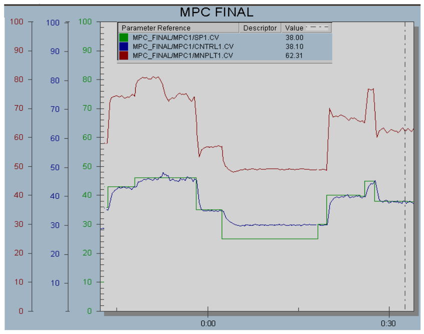

Figure 9:MPC control and constraints test

6. Conclusion

PID comparison

Since the system was a relatively straight forward SISO system, there was no substantial difference between the performance of the system with conventional single loop PID control and MPC control.

Constraints Handling

As can be seen from the figure number, MPC was able to handle the constraints very effectively. The dryer chamber temperature was constrained between a low limit and a high limit around the setpoint. No excursion of the temperature took place beyond the constraints set in the MPC.

Model Accuracy

The model generated within the MPC was of very high accuracy as confirmed during the tests using PM and PE parameters.

7. Directions for Future Work

Future developments envisaged in this unit include development of MIMO control scheme. MPC is best suited for situations that involve multiple inputs and multiple outputs with strong process interactions. A spray dryer in reality being a MIMO system, this is the next logical step for future work.
Considering the utility of the MPC technology for superior control of process variables with constraint handling and thereby for product quality improvement, we also intend to spread its awareness among local small and medium industries.

8. Achievements & Learning Values

We believe we have been able to achieve the following as a result of design and implementation of this pilot dryer unit along with MPC strategy development:

a) Bring together to collaborate faculty and students of two engineering institutes, which are participants of the Technical Education Quality Improvement Programme (TEQUIP) of the Govt. of India, assisted by the World Bank.

b) Build an experimental set-up for undergraduate and graduate students in the Chemical and Instrumentation engineering disciplines for learning spray drying process.

c) Develop good understanding of the process, plant & equipment design, control system design and process performance monitoring.

d) Build confidence in the students to work on real life processes and provide them exposure to automatic plant operation.

e) Develop MPC application and thereby deploy a specialised higher end automation tool available within the DCS, to serve as a practical learning tool for the students.

f) Demonstrate MPC advantages over conventional PID control.

9. Acknowledgement

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