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MODEL PREDICTIVE CONTROLLER DESIGN FOR AN INDUSTRIAL LIME KILN PROCESS

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Summary

Lime is an important material used in various process industries viz. paper, metallurgy, paint, sugar, cement, glass and leather etc. Lime is produced by calcination reaction, which takes place in limekiln at very high temperature. The limekiln process is inherently difficult to operate because of complex dynamics and its multi-variable nature with non-linear kinetics and long transportation lags. It becomes dangerous and fiery in nature if it is operated beyond the set points. The automation of this process is very crucial for optimization of product quality, product rate and economy. MPC is a computer based technique that requires the process model to anticipate the future outputs of that process. In the present analysis, the control of lime kiln process front end temperature and back end temperature has been attempted using MPC technique.

Key words— Model predictive control, lime kiln, control horizon, manipulated variable.

The lime kiln is a chemical reactor designed to regenerate lime from lime mud using hot flue gases. The kiln body is a large rotating, inclined, steel drum lined with refractory bricks. Gravity and kiln rotation assist the lime mud to flow down the kiln from the higher end, normally called the cold end, to the lower or hot end, where a kiln burner is located. This end is also known as the discharge end. The heat transfer mechanism that dominates this section of the kiln is radiation. The hot flue gas and radiation from the flame, flow to the cold end of the kiln while drying, heating, and calcining the counter-flowing 1ime mud. An induced draft fan is responsible for pulling the flue gas through the kiln from to cold end. The flue gas that leaves the kiln is either scrubbed or passes through an electrostatic precipitator to remove particulates. A lime kiln is comprised of a long steel cylinder, 100 meters long with 3 meters of diameter having refractory brick coated inside as shown in fig.1.

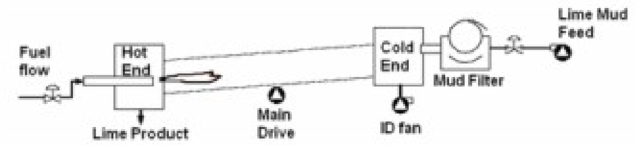

Fig.1 Schematic of lime kiln process

The model predictive control strategy calculates an objective function 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 [1]. The MPC takes control actions at regularly spaced intervals which are called control intervals [2].

Literature

Goran Stojanovski and Mile Stankovski presented a case study of two level control system for tunnel kiln in which MPC and fuzzy control techniques were employed [3].M.Jarrensivu et al. successfully operated an intelligent supervisory level kiln control system at the Wisaforest pulp mill in Finland [4]. The design of knowledge base for an expert system for rotary lime kiln was reported by Lingli Zhu and Tao Zhang [5].

The PLCs were used by Y.Bharadwaja for intelligent control of lime kiln process [6].The improvement of 20-30 % was reported in the quality of clinker by using distributed control system for cement production [7]. Expert systems have been used to identify the plant deficiencies and optimize the lime kiln operation [8].

MPC technology has a major advantage that it can function satisfactorily in an uncertain process environment dominated by disturbances and lack of good models [9].

Lime kiln optimization controls have achieved a stability of operation that has led to more stable and lower residual carbonate levels in the lime [10].

High fidelity dynamic lime kiln model is able to address a host of issues which are beyond the realm of steady state or linear input output models. Testing a control strategy against the non-linear, detailed model, as opposed to traditional transfer function models, would provide additional insight and confidence prior to commissioning [11].

Rolando Zanovello et al implemented a model predictive control algorithm with soft constraints. The technique, finite number of weights model predictive control, is based on the selection of a proper combination of weights when constraints are violated. Robust stability of the FNWMPC technique is studied using m-structured singular value techniques. The algorithm is tested through simulations of a limekiln control problem and is compared to other existing [12].

A multivariable, non linear, time delayed model of industrial lime kiln process is simulated and interaction is examined using RGA analysis and Neiderlinski index.Input, output constraints are also handled using receeding horizon characterstics of model predictive control strategy [13].

A controller has been designed for a multivariable, linearized, and time delayed, constrained model of an industrial lime kiln process using model predictive control strategy. The constraints are further modified to analyze the effect of narrowing the constraints on the setpoint tracking capability of the controllers designed [14].Effect of variation of prediction horizon and control horizon on performance of a model predictive controller designed for lime kiln process was investigated in [15].Robustness analysis of a prediction based controller for lime kiln process has been performed [16]. The model is perturbed by decreasing all the time constants and increasing all the time delays of multivariable transfer function.The responses obtained for actual model and perturbed model have been compared.

Results And Discussions

In the present analysis, *front-end temperature* (Tfe), and the *backend temperature* (Tbe) are controlled with the help of two manipulated variables, the fuel gas flowrate (F), and the percent opening of the induced draft damper (vp). The model of an industrial lime kiln used to design a MPC based control system is selected from literature, given as -

$$\begin{bmatrix} T_{fe} \\ T_{be} \end{bmatrix} = \begin{bmatrix} \dfrac{0.6}{3s+1} & \dfrac{-2.1}{(6s+1)(5s+1)} \\ \dfrac{0.1}{(10s+1)(s+1)} & \dfrac{0.9}{(7s+1)(10s+1)} \end{bmatrix} \begin{bmatrix} F \\ vp \end{bmatrix} \qquad (1)$$

The open loop step response of this plant model is shown in Fig.2.

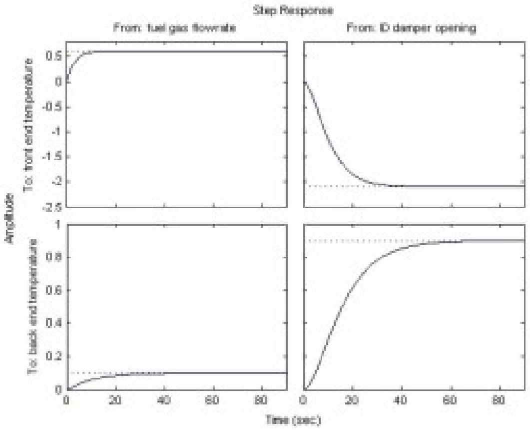

Fig. 2 Open loop step response

It clearly indicates that the pairing of ID damper opening and front end temperature exhibits an inverse response which makes the controlling process difficult.

Now this plant is to be controlled by an MPC controller with set points for controlled variables front end temperature of eight one five and one one zero degree celcius respectively. The consequences of varying MPC controller settings will be investigated.

The responses shown in figure 3 and figure 4 depict the set point tracking response of MPC with control horizon (CH) equal to 1, 2 and 5 respectively keeping prediction horizon fixed at 10 [2]. It is clearly observed that settling time of responses is very large with control horizon equal to 1 hence set point tracking is worst in this case .The responses are almost similar with control horizon value of 2 and 5.

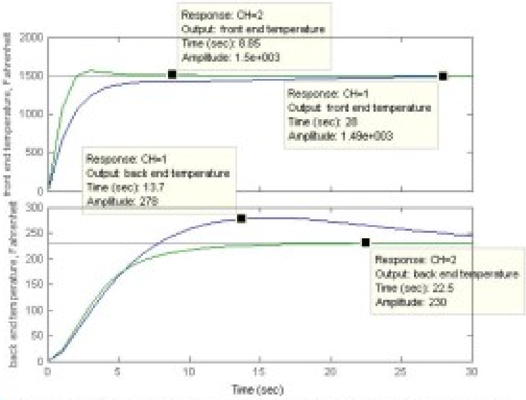

Fig. 3 Set point responses with control horizon (CH) value of 1 and 2

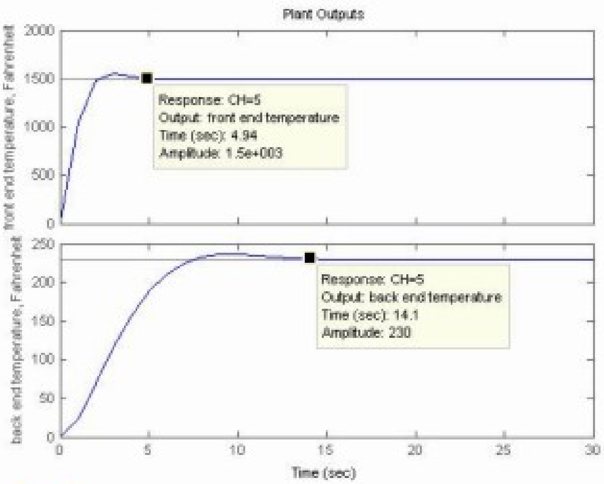

Fig. 4 Set point responses with control horizon (CH) value of 5

The Fig.5 shows the controller response with control horizon value of 2 and prediction horizon value of 4 i.e control horizon (CH) to prediction horizon(PH) ratio, (M/P) =0.5

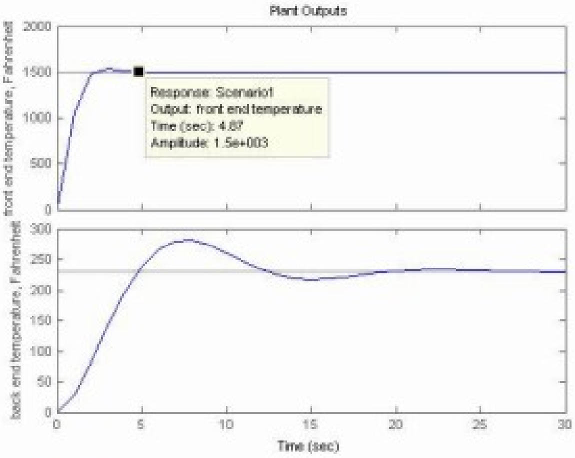

Fig .5 Set point responses with control horizon value of 2 and prediction horizon of value 4 (M/P=0.5).

The comparison of Fig.4 and Fig.5 reveals that the same value of M/P ratio results in identical set point tracking response.

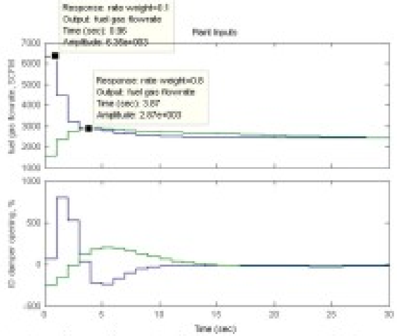

Fig. 6 Manipulated variable moves with input rate weight of value 0.1 and 0.8

Fig.6 compares the calculated moves in the two manipulated variables for respective rate weights of 0.1 and 0.8. It is clearly observed that the increase in the value of input rate weight results in decrease in the required value of discrete moves in manipulated variable i.e decrease in the amount of control effort required for set point tracking.

Conclusion

It has been observed that the response of MPC controller is very fast with very small settling time and very good set point tracking performance. Further it has been found that the same control horizon to prediction horizon ratio results in same controller performance and the increase in the value of input rate weight results in decrease in control moves in manipulated variables.

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