Model Predictive Control Of Lime Kiln; A Cost Effective Strategy

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ABSTRACT

The rotary lime re-burning kiln has been the primary method of lime re-burning in the pulp and paper industry for many years. Its popularity has continued unimpaired not only because of the monetary savings that it promotes, but also because of its simplicity of operation, low maintenance costs and reliability. Lime kiln is used in various process industries viz. Paper, sugar, cement, glass and ceramics, leather, etc. The limekiln process is inherently difficult to operate efficiently because of complex dynamics and multi-variable process with non-linear reaction kinetics, and long time delays. It becomes hazardous and explosive in nature if it is operated beyond the set points.

Model predictive controllers can provide more stable operations of the lime kiln, along with lower fuel costs and better capabilities for meeting residual carbonate production goals. The causticizing processe can cause significant issues when upsets occur, and is characterized by long process dead times and interaction between process variables that make control difficult.

In the present paper, a multivariable, non linear, time delayed model of an industrial lime kiln process is simulated and Interaction analysis between the two loops is examined using Relative gain array of the system and Neiderlinski index and analyzed for the input and output constraints handling using Preceding Horizon characteristics of Model Predictive Control strategy.

The lime kiln is an endothermic reactor where calcium carbonate is being continuously converted to calcium oxide by means of the heat produced by a large flame at the front end of the kiln bed. The kiln is one of the most energy intensive processes in a pulp mill.

Therefore, tight control of this process would result not only in quality improvement, but also in significant operating cost savings. The quality of the product is determined by the amount of conversion of $CaCO_3$ to CaO which is a direct function of the exit (or front end) temperature. It, therefore, becomes imperative to maintain the front temperature at such a level that complete, or almost complete, conversion will be ensured. On the other hand, overly high temperature may result in damage to the refractories lining the inner surface of the reactor vessel. Control of the cold end temperature is also important since low values of this variable may result in agglomeration of the feed material in large balls. This will impede uniform exposure of the material to the external heat and consequently lower conversion may result. High inlet temperatures may result in damage to the system of chains located at the inlet, which are installed to increase the overall heat transfer between the hot induced air and the feed.

Model predictive control is a mature technology in the petroleum and chemical industries. However there are very few applications in the pulp and paper industry. It has several advantages over classical control techniques such as dynamic decoupling. The same algorithm can be used for a wide variety of multivariable control problems. Process constraints are handled explicitly. Due to its centralized nature, the controller is easier to tune and maintain than a set of interacting PID controllers. In model predictive control, the controller is not a fixed control law but is an optimization problem that is updated and solved every sampling time. Here, prediction of the future plant behavior is used to compute the appropriate control actions and, therefore, the controller requires a dynamic model of the process. Obtaining models that are applicable over the whole operational range of the process may necessitate a considerable amount of identification work. The fact that the limekiln is inherently a multivariable process with difficult dynamics makes it specifically a good candidate for Model Predictive Control.

Model predictive control (MPC) is a general methodology for solving control problems in the time domain. Models are used for predicting the process output over a prediction horizon. Control actions are calculated over a control horizon in such a way that the predicted process output is as close as possible to a desired reference signal, and the first control action in sequence is applied in each step.

LITERATURE

G N Charos *et al* has shown that the MPC technology has a major advantage that it can function satisfactorily in an uncertain process environment dominated by disturbances and lack of good models.

Heikki Imelainen *et al* emphasized that Lime kiln optimization controls have achieved a stability of operation that has led to more stable and lower residual carbonate levels in the lime .

Daniel B Smith *et al* has shown that the 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.

Mika J.arvensivua *et al* developed a control structure that combines both feed forward (FF) control models and high-level feedback (FB) controllers, strengthened with certain capabilities for adaptation and constraints handling, was developed and tested in a demanding rotary kiln control application. The advantage of combining both FF and FB control approaches over pure FB control is that the FF component does not have to wait for the influence of load disturbance to

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appear in the controlled variables before it can carry out the required control actions.

Rolando Zanovello *et al* implemented a model predictive control algorithm with soft constraints. The technique, finite number of weights model predictive control (FNWMPC), 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 model predictive control techniques.

RESULTS AND DISCUSSION

In the present paper, a multivariable, non linear, time delayed model of an industrial lime kiln process is selected for Interaction analysis between the two loops using Relative gain array of the system and Neiderlinski index and analyzed for the input and output constraints handling using Preceding Horizon characteristics of Model Predictive Control strategy. The step response and Impulse response of the lime kiln process are shown in figure 1 and figure 3 respectively. The corresponding Bode diagram and Nyquist plots are shown in figure 2 and figure 4 respectively.

The lime kiln model is selected and analyzed for interaction analysis using Relative Gain Array and Neiderlinski Index. The RGA analysis suggested that 1-1/ 2-2 pairing is recommended. Stability analysis using Neiderlinski passed the stability test for the recommended pairing.

The model predictive controller is designed with the Prediction horizon as 10, control horizon as 5 and control interval as 2 for the closed loop response determination of the lime kiln process. The following constraints were emphasized on the manipulated and controlled variable---

$-60 \leq Ufuel \leq 190$, $\leq$

$-140 \leq Yfet \leq 160$

$-9.5 \leq Udamper \leq 18$,

$-75 \leq Ybet \leq 55$.

The closed loop response for the process implementing model predictive controller is shown in figure 8. From the figure it can be depicted that the peak amplitude is 1.15 at 28 seconds from the start, with a settling time of 54 seconds for front end temperature. The peak amplitude is 2.41, the peak time is 6 seconds and settling time is 24 seconds for back end temperature. The steady state error in both the cases is zero. These values of dynamic and steady state characteristics of the closed loop responses make them fairly good responses.

CONCLUSIONS

The Model Predictive control strategy gives the satisfactory closed loop performance for the lime kiln process which has a non linear, complex, multivariable, long time delayed dynamics along with interactions in different variables and constraints on manipulated and controlled variables. Constraint handling is easily implemented in this technique, which is of prime importance in process industries and makes it an indispensable tool.

EXPERIMENTAL

1)Determination of RGA (Relative Gain Array)

One of the most important factors, common to all process control applications, is the correct (best) pairing of the manipulated and controlled variables. The original technique is based upon the open loop steady state gains of the process and is relatively simple to interpret. The RGA technique is applied to the transfer function of the Charos and Arkun limekiln process model and obtained as

k = 1.6600 -1.7100

0.3400 1.4000

rga=k.*inv(k')

rga = 0.7999 0.2001

0.2001 0.7999

Interpretations of RGA value

- $\lambda ij = 1$. There is no interaction with other control loops.
- $\lambda ij = 0$. Manipulated input, *i*, has no affect on output, *j*.
- $\lambda ij = 0.5$. There is a high degree of interaction. The other control loops have the same effect on the output, *j*, as the manipulated input, *i*.
- $0.5 < \lambda ij < 1$. There is interaction between the control loops. However, this would be the preferable pairing as it would minimize interactions. Interaction is in such a way that the retaliatory effect from the other loops is in the same direction as the main effect of mJ on yI
- $\lambda ij > 1$. The interaction reduces the effect gain of the control loop. Higher controller gains are required.
- $\lambda ij > 10$. The pairing of variables with large RGA elements is undesirable. It can indicate a system sensitive to small variations in gain and possible problems in applying model based control techniques.
- $\lambda ij < 0$. Negative off-diagonal elements indicate that closing the loop will change the sign of the effective gain.

2) Neiderlinski Index and its interpretation

It can be used to eliminate unworkable pairings of variables at an early stage . The settings of controllers do not have to be known, but it applies only when integral action is used in all loops. It uses only the ss gains of the process transfer function matrix.

N= det G(0) / G11 * G22 ; for a 2X2 system

If N is < 0; under closed loop conditions in all n loops, multiloop system will be unstable for all possible values of controller parameter. This result is n & s condition only for 2X2 systems, for higher dim systems, it provides only suff. Condition, where stability depends on the values taken by controller parameters. Any loop pairing is unacceptable if it leads to a control system configuration for which N is negative.

In present 2X2 system, N= 1.254 (>0)

3) MPC design for the selected lime kiln model

Model Predictive controller is designed with the help of MPC toolbox available in MATLAB software. The tuning parameters selected were prediction horizon as ten, control horizon as five and control interval was selected to be two. The open loop response of controlled variables is shown in figure 7 and the closed loop response is shown in figure 8.

LITERATURE CITED

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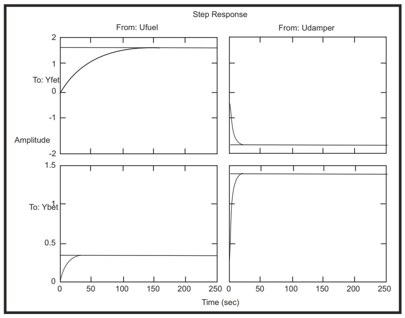

Figure 1. Step Response

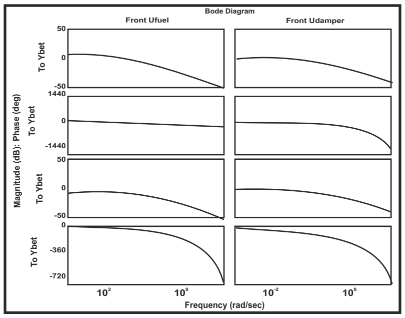

Figure 2. Magnitude and Phase plots

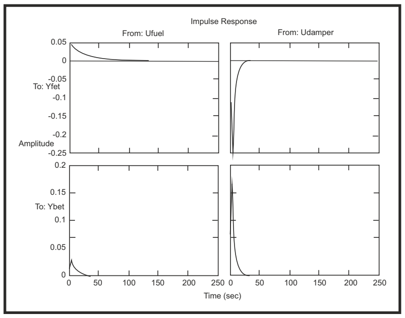

Figure 3. Impulse Response

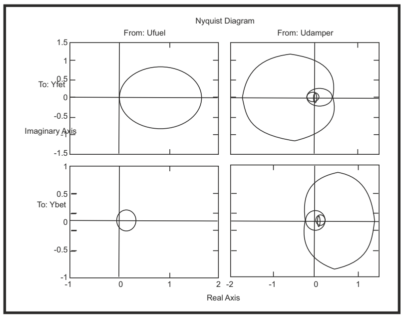

Figure 4. Nyquist Diagram

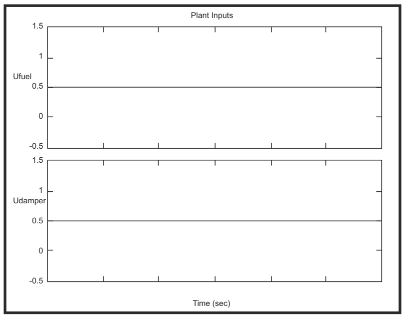

Figure 5. Open loop response for Plant Inputs

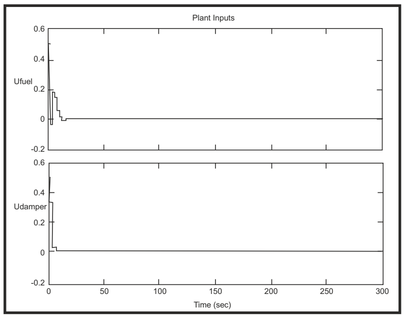

Figure 6. Closed loop response for Plant Inputs

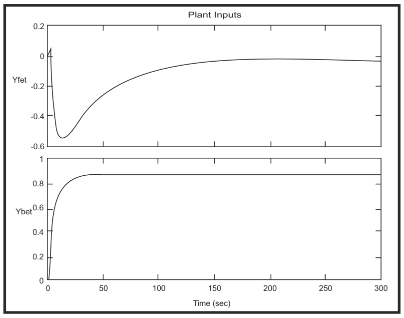

Figure 7. Open loop response of Plant Outputs

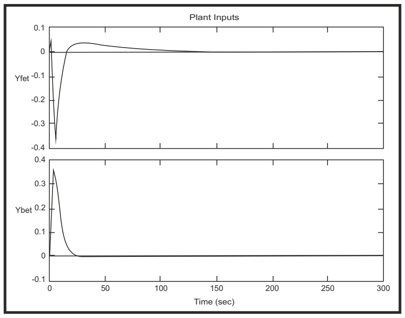

Figure 8. Closed loop response with p= 10, m=5, control interval =2.