Study of the Performance of a Urea Manufacturing Plant in a Fertilizer Industry Making use of a Feedback Control System to Monitor the Quality of the Product

N. K. Mandal¹, Rishab Sarbadhikary², Chaitali Sikder³, Evan Chowdhury⁴, Debrup Sarkar⁵

¹, ², ³, ⁴, ⁵Department of Electrical Engineering, University of Engineering and Management, Kolkata, India

Abstract - A theoretical study has been carried out to find the performance of a feedback control system in which a PID Controller can be used to control the quality of product in urea manufacturing plant of a Fertilizer industry. This has been done by finding the overall transfer function of the system and hence the frequency response at different frequencies using MATLAB. Studies has also been carried out to find steady state error due to the application of different types of input signals, such as unit step, unit ramp and unit parabolic. Some numerical calculations have been done. Results have been tabulated, shown graphically and discussed.

Keywords - PID controller; Mixing Chamber; Urea Manufacture Plant; Frequency response; Steady state error.

I. INTRODUCTION

Application of various types of control system, have been given due importance in chemical industries as well as other industries such as cement manufacturing industry, etc. [1, 2] due to the following facts:

i. They help in conserving material, manpower and electrical energy.

ii. They help in saving the time of operation.

iii. They also contribute in increasing the reliability and the stability of the system.

With the development of new technology of control systems, computing equipment and modelling, the automation in the fertilizer industry have made remarkable progress in the recent years. [3, 4]

In this investigation, an attempt has been made to study the performance in the fertilizer industry making use of a feedback control system with PID Controller to monitor the quality of urea in the plant.

II. INSTRUMENTATION AND METHODS

A. Automatic control system for monitor the quality of urea in a Urea Manufacturing Plant in a Fertilizer Industry:

Figure-1 shows the schematic diagram of a urea manufacturing unit in a Fertilizer Plant making a feedback control system to monitor the quality of the product.

Urea is a stable, organic fertilizer that can improve the quality of the soil. It provides nitrogen to the plants and increases the yield of the crops. But giving excessive amount of urea causes harm for the plant. Nowadays some low quality urea is also given in the soil which reduces the soil fertility and destroys the plants and the crops as well. [5] In fertilizer industry the low quality of urea is sensed by the sensing unit and can be measured by the controller. In this system if output signal is equal to the desired input signal, then the system automatically stops sending signal to the sensing unit, when desired quality of urea is produced.

B. Analysis:

The analysis of the system has been done to find-

i.) The overall transfer function,

ii.) Overall gain of the system, and

iii.) Development of MATLAB program to find the frequency response and

iv.) The steady state error of the system.

I. Determination of overall transfer function:

To determine the transfer function of the whole system, let us consider block diagram model of the system as shown in Fig.2.
Using Block Diagram model as shown in Fig.2, we get closed loop transfer function for PID control action, as

\[
Y_p(s) = (K_p + K_i s + K_d / s) K_m K_p s(\zeta s + 1)
\]

\[
X(s) = (K_p s^2 + K_i s + K_d / s) K_m K_p / s(\zeta s + 1)
\]

\[
(2 K_p s^2 + K_i s + K_d) K_m K_p s(\zeta s + 1) \quad \ldots \ldots (1)
\]

Where,

\(X_i\) = Desired input signal.

\(Y_o\) = Actual output signal.

\(K = (K_p + K_i s + K_d / s)\) = PID Control Factor.

\(K_m\) = Signal of Mixing chamber.

\(K_p\) = Signal at plant.

\(K_i\) = Sensing unit signal.

\(\zeta\) = Time constant.

\(E_s\) = Error Signal.

### 2. Determination of overall gain of the system:

At \(s = j\omega\), the equation (1) can be expressed as

\[
A(j\omega) = K_m K_p [(K_p s^2 + K_i) + j(K_p s)] \quad \ldots \ldots (2)
\]

\[
+j\omega^3 + 1 + K_m K_p K_i (-K_p s^2 + j K_i s + K_i)
\]

\[
A(j\omega) = K_m K_p \sqrt{(K_p s^2 + K_i)^2 + (\omega K_i)^2} \quad \ldots \ldots (3)
\]

\[
\sqrt{(K_m K_p K_i s^2 + K_i s^2 + 1)^2 + (\omega s^2 + K_i)^2}
\]

The overall gain in dB can be given as,

\[A \text{ (in dB)} = 20 \log |A(j\omega)|\]

Using equation (3), the frequency response of the system can be obtained at different values of \(\omega\) \([10^1 \text{ rad/sec to } 10^4 \text{ rad/sec.}].\)

### 3. MATLAB programme to find frequency response of the system:

\[\text{>> n=[145];}\]
\[\text{>> d=[30 1 0 145];}\]
\[\text{>> g=tf(n,d);}\]
\[\text{145}\]

\[g = \frac{1}{30s^3 + s^2 + 145}\]

Continuous-time transfer function.

\[\text{>> bode(g)}\]

### 4. Determination of steady state error:

The error signal is,

\[
E_s(s) = \frac{X_i(s)}{1+ G(s) H(s)}
\]

\[= \frac{X_i(s) s^2 (s\zeta + 1)}{\zeta^3 s^3 + s^2 (1+K_i) + K_i s + K_i s K_m K_j}\]

\[= \frac{\zeta s^3 (s\zeta + 1) X_j}{\zeta^3 s^3 + (1+K_i) s^2 + K_i s + K_i K_p K_m}\]

The steady state error of the system can be expressed as

\[e_{ss} = \text{Lt} \frac{s^2 (\zeta s + 1) X_j}{s^2 (s\zeta + 1) X_j} \ldots \ldots (6)\]

\[s \rightarrow 0 \quad \zeta s^3 + (1+K_i) s^2 + K_i K_p K_m K_j\]

The test signals that can be used for calculations of steady state error are:

i. Unit step input, \(X_i(s) = 1/s \ldots \ldots (7)\)

ii. Unit ramp input, \(X_i(s) = 1/s^2 \ldots \ldots (8)\)

iii. Unit parabolic input, \(X_i(s) = 1/s^3 \ldots \ldots (9)\)

### III. RESULTS AND DISCUSSION

The data obtained after the analysis of the automatic control of a Urea manufacture in a fertilizer plant for monitor the quality of urea, can be used to study the performance of the same by calculating steady state error and frequency response by assuming some standard values of the parameters.
TABLE 1 shows the steady error obtained when different types of signal applied with PID control action.

<table>
<thead>
<tr>
<th>Type of Controller</th>
<th>Type of Signal Used</th>
<th>Steady State Error (es)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PID</td>
<td>a) Unit Step</td>
<td>a) 0</td>
</tr>
<tr>
<td></td>
<td>b) Unit Ramp</td>
<td>b) 0</td>
</tr>
<tr>
<td></td>
<td>c) Unit Parabolic</td>
<td>1/K1K2K3K4K5</td>
</tr>
</tbody>
</table>

It can be observed that from the above TABLE 1, that for both unit step unit step and unit ramp input the steady state error is zero; it is possible for ideal cases only. But for practical systems there with a small error for each case. Again, for unit parabolic input, the steady state error depends on the values k1, k3, k1, k2, k3, so in this case, steady state errors can be adjusted by considering the suitable values of these constants.

It can be seen from Fig 3, that frequency response magnitude is constant up to 5 rad/sec, then it decrease with slope of -20dB/decade.

IV. CONCLUSION

In this investigation, we have studied the performance of a typical automatic controlled system to monitor the quality of product in a urea manufacturing unit of a fertilizer industry with PID controller control action. But the actual performance can be obtained by designing or arranging such type of system in practice and conducting some experiments.

In this study, we have considered PID controller control action only. The results will also vary if we consider other controllers, such as proportion, derivative, proportion and derivative, or proportional and integral and other values of K1, K2, K3 and K4.

REFERENCES