SMITH PREDICTOR CONTROL OF INDUSTRIAL PLANT WITH SIGNIFICANT DEAD TIME

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ABSTRACT

Many industrial processes contain significant amounts of dead time due to the transportation of materials from one point in a process to another without any change taking place in the charasteristics of the materials. The engineering problem to be overcome include reduction in stability region and inherent deterioration in transcient behaviour. The paper presents the design of smith Predictor compensator for a two term digital controller as a viable solution. The results show that the compensator accommodates relatively higher gain and a more rapid response from the system for all forms of input disturbance.

KEYWORDS: Smith predictor, digital controller, dead time.

1. INTRODUCTION

Industrial plant with dead time (Δ) caused by the motion of conveyors carrying materials over distances that take several minutes are more difficult to control than those with comparatively shorter time. Most control schemes, especially those with hydraulic, pneumatic or mechanical transmission, are affected by such delays so that the output will not begin to respond to an input change until after a certain interval. The conventional controllers become less effective when the process dead time is significant compared to the dominant process time constant. Proposals to minimise these design difficulties are available in the published literature (2, 3, 4, 7, 14) but they are largely restricted to specific vendor supplied control systems.

One of the earliest recorded work employing prediction principles to minimise the effect of dead time on process dynamic was by O. J. M. Smith (3). The technique became known as the "Smith predictor" which enables the effect of dead time to be removed from the characteristic equation and consequently increases with size of systems stability region (2), making faster responses to set point changes possible. However, the Smith predictor is not used in analogue systems because the generation of dead time required in this method is difficult to realise by hardware. In digital systems this problem is easily solved by storing the signal in memories and retrieving it after the dead time has elapsed. The paper presents a digital Smith predictor controller for the metallurgical process of Sintering Fig. 1, which is typical industrial plant with inherent large amount of dead time.

2. THE CONTROL SYSTEM MODEL

The simplified sinter model (1, 2) shown in Fig. 2 is given by

$$G(s) = \frac{\frac{10}{3}e^{-\Delta s}}{(1+\frac{2}{3}s)(1+\frac{10}{3}s)} \qquad \text{----------(1)}$$

The time unit in Equation 1 is the minute with the dead time Δ estimated as 6min. The equivalent digital version of Equation 1 is given by (1, 2),

$$G(z^{-1}) = \frac{z^{-k}B}{A} \qquad \text{----------(2)}$$
$$k = N+1$$

Where

$N = \Delta / Ts$, Ts is the sampling time.

$B = b_0 + b_1 z^{-1}$

$A = 1 + a_1 z^{-1} + a_2 z^{-2}$

The numerical values of these coefficients (a_i, b_i) are dependent on the sampling, time. The digital controller employed in the proportional plus integral (P + I) controller is given by

$$\frac{U(z^{-1})}{E(z^{-1})} = D(z^{-1}) = \frac{d_0 z + d_1}{z - 1} \qquad \text{----------(3)}$$

where $U(z^{-1})$ is the manipulated variable, $E(z^{-1})$ is the error signal and d_i, are the digital controller parameters dependent on T_s. The structure of this system for the analogue version is shown in Fig. 2.

The closed loop discrete transfer function is given by

$$G_{CL}(z^{-1}) = \frac{D(z^{-1})\,G(z^{-1})}{1 + D(z^{-1})\,G(z^{-1})} \quad \text{----------(4)}$$

and the characteristic equation is given by

$$1 + D(z^{-1})\,G(z^{-1}) = 0 \quad \text{----------(5)}$$

$$z^{N+3} + (a_1\text{-}1)\,z^{N+2} + (a_2\text{-}a_1)\,z^{N+1} - a_2 z^N + b_0 d_0 z^z + (b_0 d_1 + b_1 d_0)\,z + b_1 d_1$$

For $T_s = 3.0$ min, the characteristic equation is

$$z^5 + (a_1\text{-}1)\,z^4 + (a_2\text{-}a_1)\,z^3 + (b_0 d_0\text{-}a_2)\,z^2 + (b_0 d_1 + b_1 d_0)\,z + b_1 d_1 = 0 \quad \text{----------(6)}$$

A block diagram representation of the plant incorporating the Smith predictor is shown in Fig. 3. The transfer function L_c is the controller $D(z^{-1})$ and B^1/A^1 is a model of the actual plant defined in Equation (2). Assuming the equivalence of B^1/A^1 and B/A, the characteristic equation of the Smith predictor control law for the sampling interval $T_s = 3.0$ min,

$$1 + L_c \frac{B}{A} = 0$$

$$z^3 + (a_1 - 1 + b_0 d_0)\,z^2 + (a_2 - a_1 + b_0 d_1 + b_1 d_0)\,z + b_1 d_1 - a_2 = 0 \quad \text{----------(7)}$$

3 SIMULATION STUDIES

Equation 7 shows a reduction in order of the charateristic equation compared with Equation 6. Fiqure 4 and Figure 5 show the system response for $T_s = 1.0$ min and $T_s = 3.0$ min respectively. The smith predictor accommodates a relatively higher controller gain, however, the effect of mis-match between the plant and the plant model in the predictor loop may result to system instability. Measurement noise may exist sinter plants and the performance of control algorithm should be tested to determine the impact on the plant performance of uncontrolled input disturbance. A pseudo-random number generated by a NAG library subroutine GO5DDf and shown in Fig. 6 has been employed in a simulation trial as a measurement noise existing on the surge hopper level signal. The pseudo-random number generator has a normal distribution, mean value equal to zero standard deviation equal to 0.115 and an amplitude factor of 5 is used. The performance of the (P + I) and the Smith predictor in the presence of this noise are shown in Fig. 7 and Fig. 8 respectively.

4. CONCLUSION

The smith predictor controlled system has a remarkable algorithm realisable by direct digital control (DDC). The dead time loops in industrial plant are beyond the capability of the conventional control technique. Unfortunately, dead time loop are associated with important economic factors such as product quality and energy utilization and hence used to be tightly controlled. The smith predictor can be used to overcome these problems of significant amount of dead time which could result in an improvement in product quality and minimum energy consumption. However the effectiveness is very much dependent in the accuracy of process model which form part of the algorithm.

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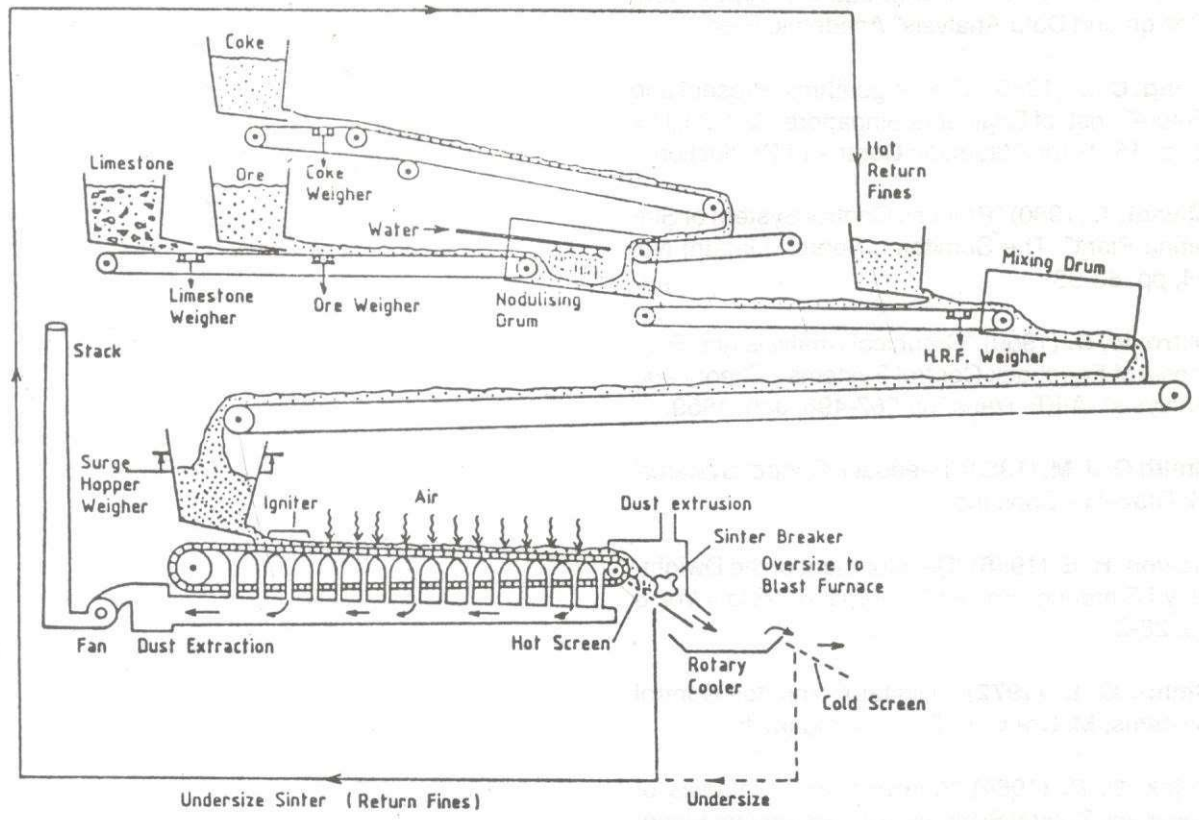


Fig. 1 Schematic Layout of a Sinter Plant

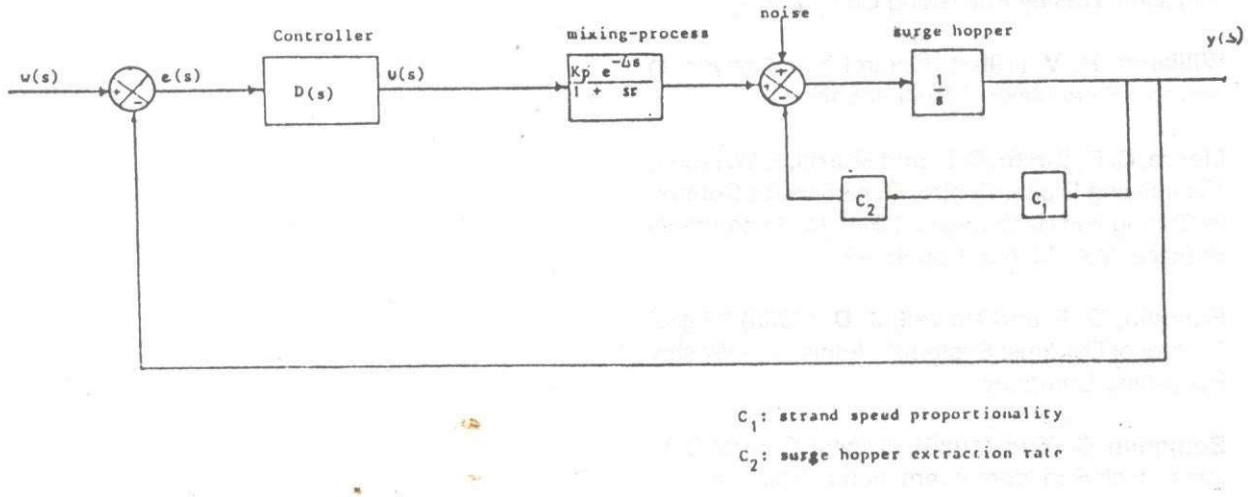


Fig. 2 Simplified Block Diagram for the Raw Feed Circuit

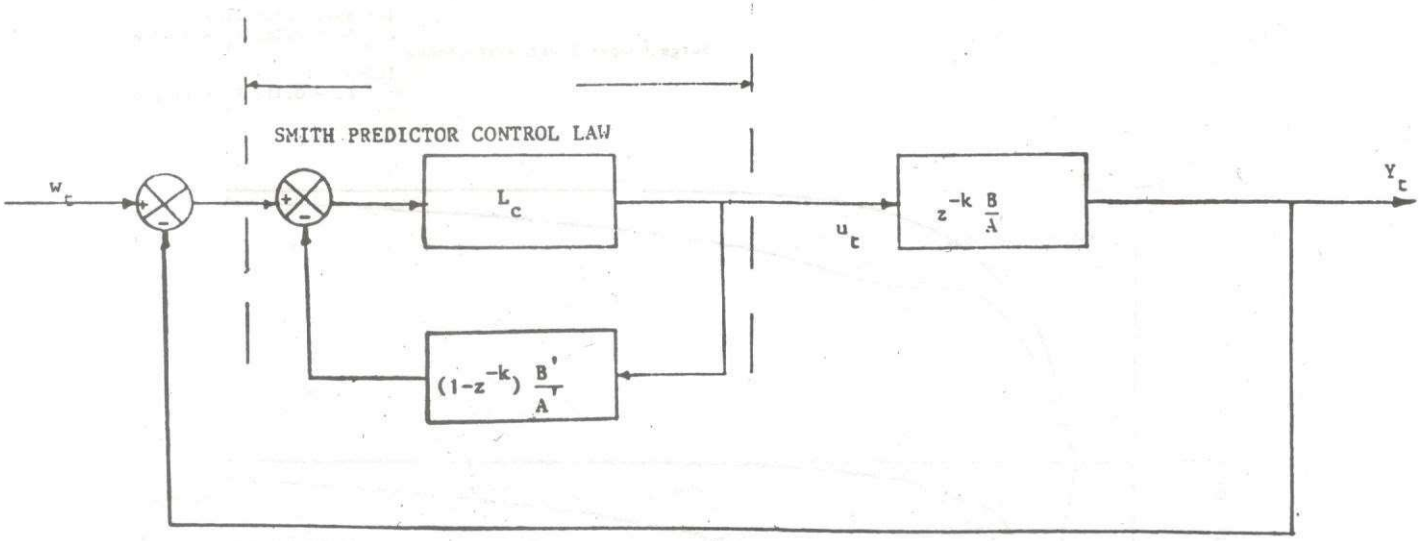


Fig. 3 Structure of Smith Predictor

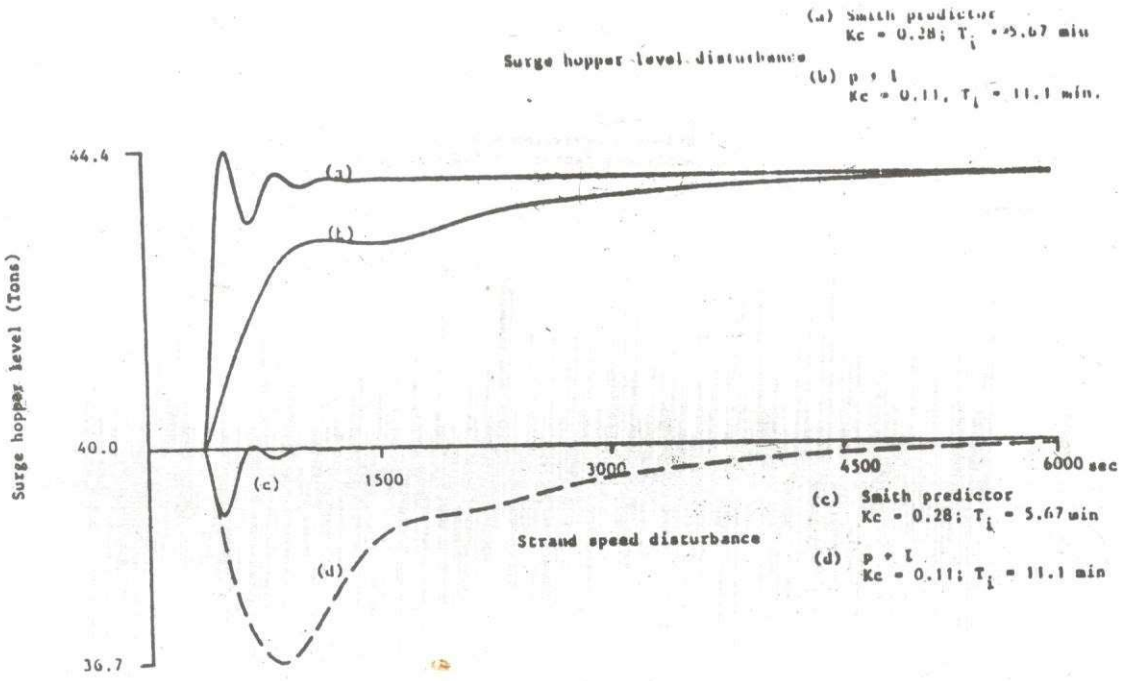


Fig. 4 10% disturbance in hopper level and strand speed for controller design for T_s = 1.0 min

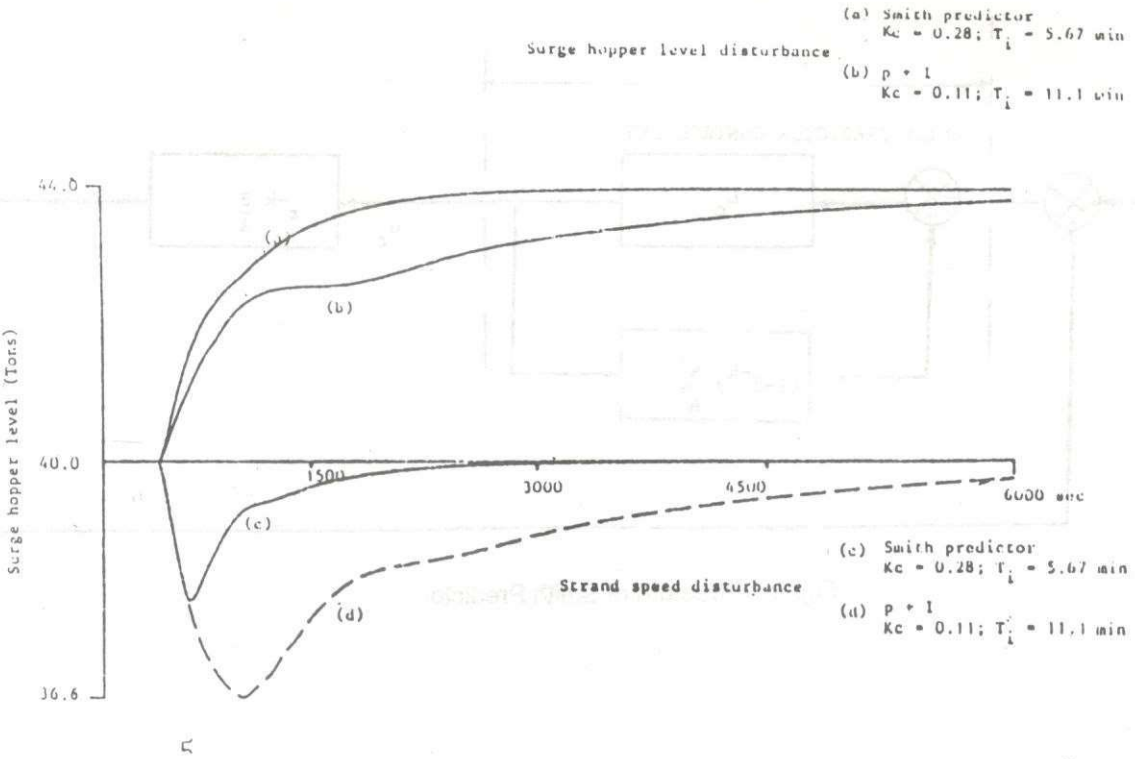


Fig. 5 10% disturbance in hopper level and strand speed for controller design for T_s = 3.0 min

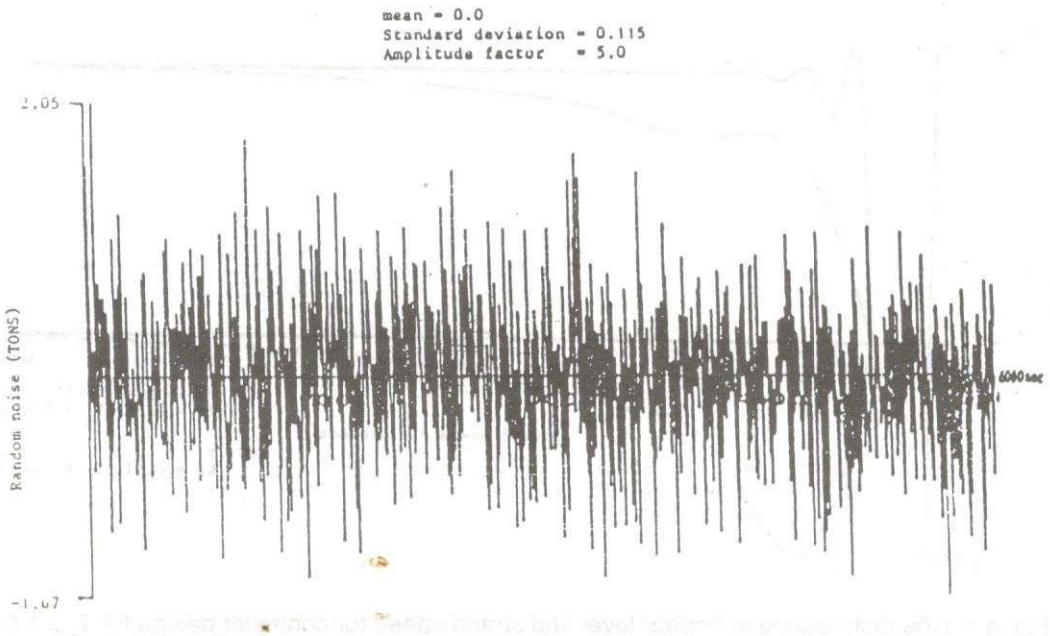


Fig. 6 A pseudo-random number representing measurement noise in a sinter plant

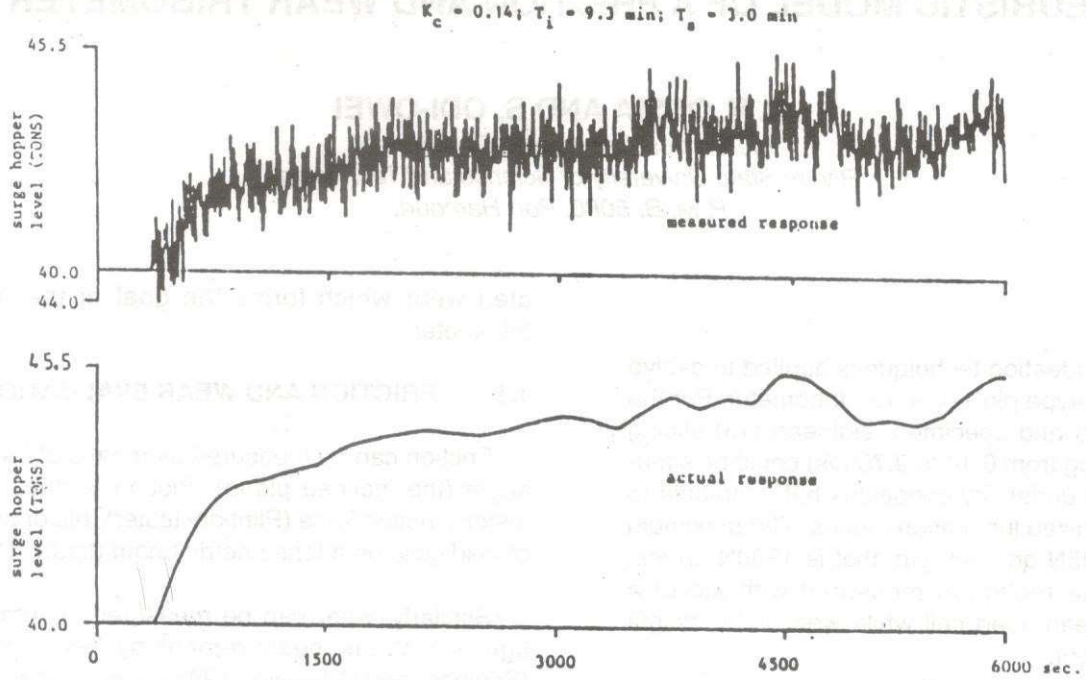


Fig. 7 Performance of p + I in a noisy system

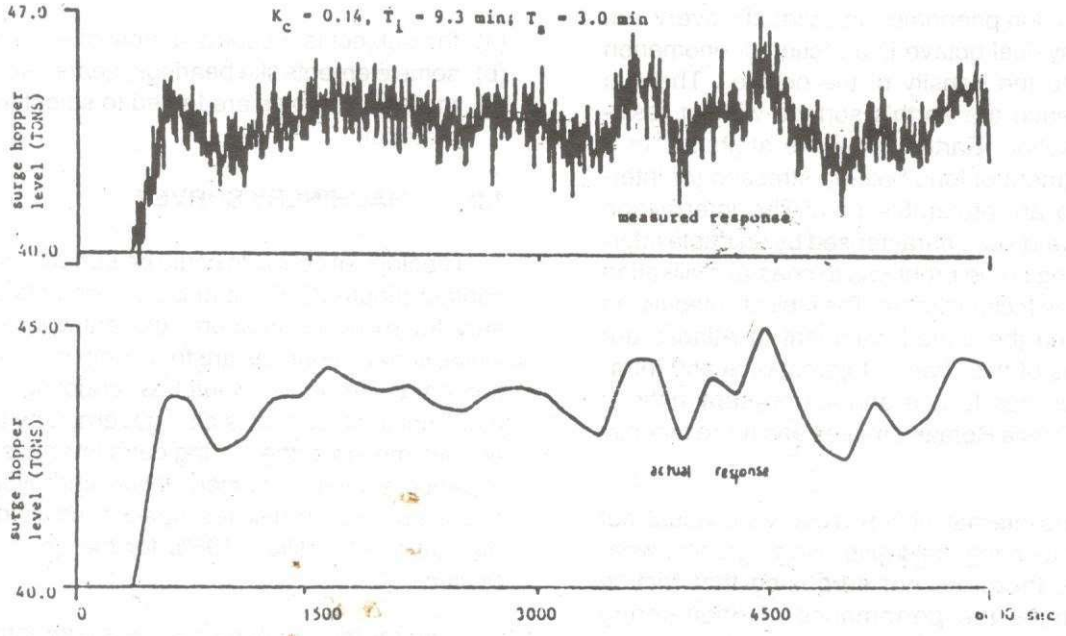


Fig. 8 Performance of Smith predictor in a noisy system