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A Diagnostic Method of Control-in/out in the Glass Furnace

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The high degree of viscosity and the non-Newtonian fluid dynamics characterizes the process inside a glass furnace. Because the temperature is fluctuating in very short time-intervals, it is hard to determine that the status of its fluctuation is stable or unstable. Usually Shewhart-chart is used to determine the control status. However because of the characteristics of the temperature fluctuations in the glass furnace it does not directly serve the purpose here. Therefore we suggest using ARIMA to diagnose control status and confirm that the method using ARIMA can be a better tool than Shewhart-chart.

Keywords : Control Chart, ARIMA, Diagnostics

1. Introduction

The high degree of viscosity and the non-Newtonian fluid dynamics characterizes the process inside a glass furnace.[1][4] It is not easy to measure certain characteristics like temperature, and to build the statistical models for process analysis. Fortunately the measurement of the temperature at locations such as the crown of glass furnace is possible by employing a direct method using thermo couples. Because the temperature fluctuates in the short time interval and its fluctuation exhibits autocorrelation, it is difficult to determine the status of its fluctuation, and the existence of some statistical relations among the relevant variables.

The characteristics of the melting process in the glass furnace makes it less desirable to apply classical control chart method directly because of the following reasons : [2][4][6]

i) Due to autocorrelation conventional control chart needs relatively long interval data in case of glass furnace.
ii) When out-of-control is checked, we don't usually have an appropriate point of time to act against the point of out-of-control.
iii) Even when we suspect that the process is in-control, we generally have short range of control with small sample size which is not appropriate for statistical analysis.

In a certain unpublished consulting documentation there was a suggestion that the presence of time series component implied through certain complicated procedures expanding control limits. However, we find the need for detailed time series analysis of the furnace temperature process.

Therefore we suggest in place of control chart using ARIMA model for diagnosis of process stability, since ARIMA model is suitable for analysing process stability in short interval data.

In chapter 2, we will discuss using the Shewhart chart and ARIMA for the purpose of diagnostic checking of the stability of glass furnace process. Since detrending is not necessary in the melting temperature process, we can use ARMA model. We suggest that during the white noise sample period the process is in control. In chapter 3 we will apply some models for process analysis, by way of regression analysis, the correlation analysis, and the factor analysis among variables such as temperature, oil, oxygen, pressure, defective rates etc.

2. Control Chart and Autocorrelation

Since control chart was made by W. A. Shewhart in

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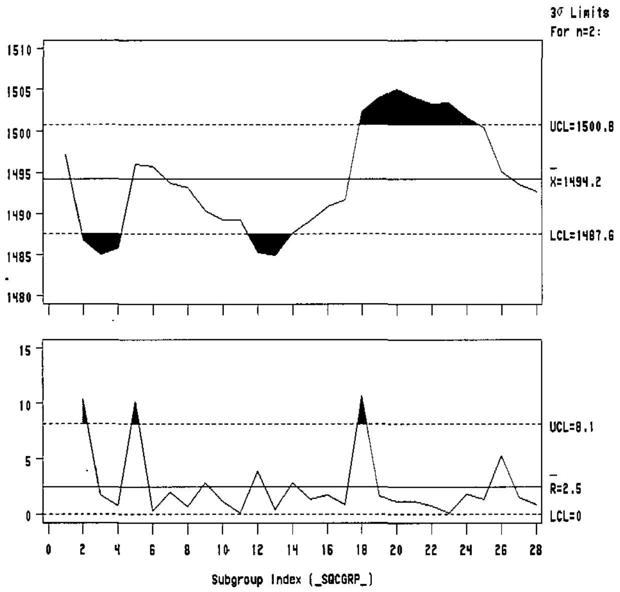
1931, it have been used in the plant environment for process stability. Among them X-R_s chart is used for glass furnace, because the temperature readings, for example, can't be divided by subgroups of output which should be as homogeneous as possible. But data that have an autocorrelation like the variables of glass furnace can not adopt X-R_s chart, because independent and identically distributed error terms (iid henceforth) are assumed to implement the control chart. In order to use X-R_s chart, we must use the data of relatively long observation interval so that we might assume iid errors. Figure 1 is a X-R_s chart of the data of relatively long observation interval (200 min.) in the glass furnace. There are many points which are out of control at both X chart and R_s chart. In such case any point which is out-of-control can't be explained because the process was out of control at that time. Also during 200 min., relative long interval-time, there might be some causes of out-of-control. Therefore we use ARIMA model for diagnosis of process stability.



<Figure 1> X-R_s chart of MC3 (3rd thermo couple in main crown) temperatures in 200 min. intervals

The model we will employ to our problem is a time-series with its mean and variance changing over time. This is called a nonstationary time-series model. A special case of such a model, homogeneous nonstationary process, can be transformed into a stationary process model, by applying algebraic or variance stabilization transform to the variance, and difference calculation to the mean. The process we model is assumed to be a homogeneous nonstationary process. The entire model with accompanying steps of transformation into a stationary process model is the autoregressive integrated moving average(ARIMA) model.[3]

The equation for ARIMA is as follows :

$$\Phi_p(B)(1-B)^d Z_t = \theta_p(B)a_t.$$

where

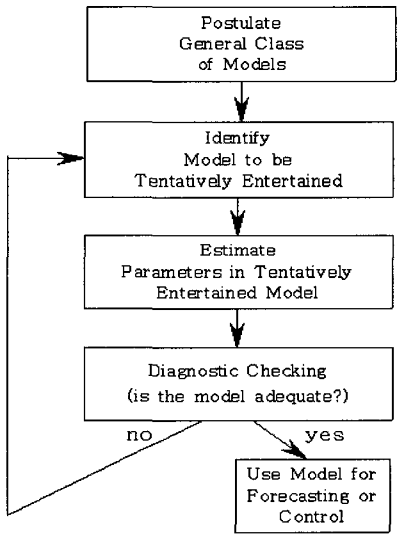
$$\Phi_p(B) = 1-\Phi_1 B-\Phi_2 B^2-\cdots-\Phi_p B^p$$
$$\theta_p(B) = 1-\theta_1 B-\theta_2 B^2-\cdots-\theta_q B^q$$

where B is the backward operator and d is he number of difference operations applied to nonstationary process in order to obtain a stationary process.

As can be seen in the following diagram (Figure 2) we only conduct the first step, model identification, for diagnosis of process stability.

The main tool used in this step is SACF(sample autocorrelation function) which is employed to check process stability. The autocorrelation function(ACF) ρ_k between Z_t and Z_{t-k} is defined as follows :

$$\rho_k = \frac{Cov(Z_t, Z_{t-k})}{\sqrt{Var(Z_t)V(Z_{t-k})}} = \frac{\gamma_k}{\gamma_0}$$



<Figure 2> Stages in the Iterative Approach to Model Building [3]

where $Cov(Z_t, Z_{t-k}) = \gamma_k$ is the autocovariance of Z_t and Z_{t-k}, and γ_0 is its variance.

The stability, so called 'white noise', is defined as the acceptance of $H_0 : \rho = 0$ which means ACF$= 0$. While the process appears to be a white noise process, it has an independently distributed normal random errors, then we conjecture that it is commensurate with the concept of the control-in state by Shewhart. This can be confirmed by repeated empirical case studies. For example we can compare Figure 1 with Figure 3, where we use 20 min. interval time instead of 200 min. in $X - R_s$ control chart.

		100	200
MC3			

<Figure 3> White Noise of MC3

The white noise section of MC3 that is the temperature of main crown in glass furnace is shown in figure 3. It is noted that the broken point in the white noise in figure 3 is similar to the points of out-of-control in figure 1. This fact is not the statistically usual one. Unless the variable is controlled by some automatic control system such as PLC, two results mentioned above are relatively well coincided. The large sample size can be taken for ARIMA in contrast to small sample size for control chart.

Inspecting numerous similar cases of diagnosing physical properties in instrumental processes such as that of glass furnace, we can conclude that a white noise process can be viewed as a process in control. The common section of white noise in each variable can supply sufficient sample size for further statistical analysis. In chapter 3 we apply some statistical models to the white noise section data of a glass furnace.

3. Applying Some Statistical Models

Using short interval data means that we can check different overlapping periods to determine the white noise period, when the process is presumably in control. During that period we can apply some statistical models to critical control factors.

1) Discussion about oil and oxygen

In the case of a glass furnace, there are 7 oil injectors and 5 oxygen injectors. To simplify the process control we implement factor analysis to 7 oil variables and 5 oxygen ones. In case of oil, the cumulative percent of factors that have greater than Eigen value of 1 is 64.12%, and 7 variables are not clearly grouped into new 3 factors that have greater than Eigen value of 1. It indicates that the oil injection is not totally controlled. Therefore grouping into 3 groups from 7 injectors is impossible under present control system. The factor analysis result in the oxygen supply system is similar to that of oil's.

2) Influence of inner pressure of glass furnace to temperature

There are many thermo couples at the glass furnace. The main control position of temperature is generally the upper part of main crown. We build a regression model between a temperature at main crown and inner pressure. Simple regression of temperature on inner pressure resulted in R^2 =0.03, which means very poor fitness. We conclude that because the relationship between pressure and temperature is very weak, we can not use the estimated equation.

3) Selection of variables related to temperature

Selection of variables which affects the temperature of main crown in glass furnace is usually empirical. Such variables can be oil, oxygen, pressure, glass level, and defective rate of products. Even though oil and ambient temperatures should influence the furnace temperature positively, multiple regression results appeared in diametric opposition. We suppose that inappropriate control and maintenance system cause the opposite result in a specific temperature range, which, in this case study, is about 1400 ~ 1500℃. Our interpretation of this result is that the huge glass furnace is controlled segmentally not totally.

4. Conclusion

Classical control chart needs relatively long interval data in presumably autocorrelated processes. Therefore we suggested using instead ARIMA model for diagnosis of process stability. The reasons are as follows :

i) ARIMA model accepts short time interval.
ii) Because of i), we will immediately act against out-of-control.
iii) Because of i), we can get sufficient sample size for statistical analysis.

During the white noise period the process appears to be in control, where we could apply further statistical process analysis.

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