Integration of Statistical Process Control (SPC) and Engineering Process Control (EPC) for quality improvement

Fatin Fazliyana Mohd Latif, Sherif Abdulbari Ali, Nur Amalina Hamzah
Faculty of Chemical Engineering, Universiti Teknologi Mara

Abstract— **SPC and EPC play a different role in manufacturing process quality control. Generally, SPC used to remove assignable causes from the process, while EPC used to keep the process output on the set point by reducing process variability. Both method can identify the effect of process that cause by irregularity and variability in the process that result of errors and poor quality. Previous research was improved the product quality by using EPC independently. They have found that using EPC alone is unable to cope with assignable cause variation. Therefore, using the SPC and EPC integrated control can better ensure the quality of the product. In this research, the methodology used continuous stirred tank reactor model process from past literature was performed by using Simulink Matlab for the simulation and then, continued with Process Capability Six pack in Minitab for further statistical report analysis, where the system was implemented in a chemical process together with existent PID feedback controllers for non-isothermal continuous stirred tank reactor (CSTR). The experimental result clearly shows that process variability was reduced about 76.54%. It is concluded that integrated approach has better way to achieve continuously quality improvement than that using EPC alone.**

Keywords— Quality Improvement, Statistical Process Control (SPC), Engineering Process Control (EPC)

I. INTRODUCTION

In the last 20 years, the importance of product quality has become increasingly apparent. Most people agree that high quality is an important element and potentially the most significant production performance criterion (Ibrahim, 1996). Product quality means the capacity to fulfil consumer needs and satisfaction. Poor product quality will impact the consumer's trust. In this way, it is very important to increase the products quality. In industry, engineers can be improved the product quality by monitoring, regulating and correcting action (Aljebory and Alshebeb, 2014). The popular methods use in product quality improvement which is Statistical Process Control (SPC) and Engineering Process Control (EPC).

SPC is a capable tool to identify assignable cause and eliminate assignable cause. It is a new operation, because of less attention on quality awareness in chemical industries. Generally, SPC use control charts to monitor the process variability and process stability. However, control chart can run successfully when the sample data in normal distribution and independent. A chart is then plot based on these observations against time. Then, three lines were draw on the chart. These line are centre control limit line (CL), the upper control limit line (UCL) and the lower control limit line (LCL). If the point drop inside the control limits, the process is free from any assignable cause. Points outsides the control limits show a process out of control which is present assignable causes in the process. Assignable cause usually contributed toward a large part of overall variability in the process.

EPC has been popular method use in chemical and process industries for process improvement and optimization. It illustrates the input variables can be manipulated to corrected the uncontrollable disturbances to keep the process set point. Generally, EPC focus on manipulated variable to maintain the process output nearest to the desired set point. When the disturbance to the process in outside range, EPC alone is cannot stop the system output altering from the target.

Since SPC and EPC methods came from other backgrounds, but they have same objectives to reduce the variability of process from set point. Therefore, they take different way for achieve the similar objective. The function of SPC to find signals of assignable causes, which may point out an external disturbance that increases variability of process. Otherwise, EPC strongly change the process disturbance effects by making common adjustments to manipulated variables. Nowadays, integration of Statistical Process Control (SPC) and Engineering Process Control (EPC) is an efficient method to improve the product quality by reducing process of variability.

MacGregor (1988) was the first who persuaded the idea of integrating SPC and EPC. The integrated methods use EPC to reduce the process variability, while SPC to monitor the process for assignable cause detection. These studies can be divided in two basic classification based on the part of SPC and EPC together in the integrated action. The first classification usually continuous systems can be controlling using SPC. EPC start to act in the process adjustment at any time SPC detect an out of control signal. The second classification includes adjustment process in continuous process by EPC while SPC focused to control the process for assignable cause. Most researcher's highlighted on this method due to the fact that the processes are naturally not stable and they require continuous adjustment for stability.

At the same time, an excellent integration of SPC and EPC was found by Montgomery. He found the integration of SPC and EPC can achieve more an effective effect than single use of SPC or EPC. He also introduced an integration method that used SPC for monitoring and eliminating assignable cause while used EPC for help the process output drive to the value of set point.

II. METHODOLOGY

Firstly, the process was modelled using SIMULINK MATLAB as demonstrated by Fernando (2005) in Figure 1 and Figure 2. The non-isothermal CSTR process reaction as followed:

$$A \xrightarrow{k} B$$

Figure 1 represented by the standard block diagram. In this figure, Y is the controlled variable, U is the manipulated variable, D is the disturbance variable, P is the controller output, E is the error signal, Y_m is the measured value of Y, Y_{sp} is the set point, G_c is the controller transfer function, G_v is the transfer function for final control element, G_p is the process transfer function, G_d is the disturbance transfer function, G_m is the transfer function for measuring element and transmitter and K_m is the steady state gain for G_m.

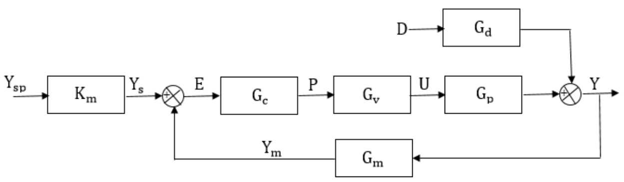

Figure 1: Block diagram of a feedback control system

Figure 2 represented the model develop in Simulink to simulate the feedback controller system by considered a feedback controller system presented in Figure 1 and the following transfer function:

$$G_p = \frac{e^{-2s}}{s^2 + 0.7s + 1} \qquad G_d = G_p \quad G_v = G_m = 1$$

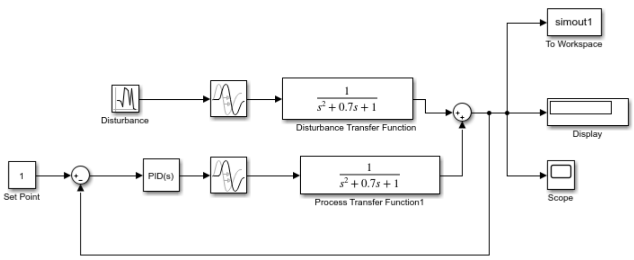

Figure 2: Simulink model of feedback controller system

The controller parameters such as proportional gain (K_c), integral time (τ_I) and derivative time (τ_D) for Ziegler-Nichols method was obtained from (Fernando, 2005) are listed in Table 1.

Tuning Method	K_c	τ_I	τ_D
Ziegler-Nichols	0.39	3.44	0.86

Table 1: Controller Parameter

The value of controller parameter was set-up on PID controller to display the process response. If the response is unstable, the "fine tuning" will applied to obtain a better process response before continue the next step.

Next, 125 samples of process output were collected from Matlab, then transferred into Minitab for further statistical analysis to provide a Process Capability Six pack report. The report is consisting of control charts, histogram, normal probability plot and process capability chart to figure out the existence of assignable cause by observing if any points fall outside of the boundary limit.

III. RESULTS AND DISCUSSION

The process model from (Fernando, 2005) was used to represent the control of product concentration from non-isothermal CSTR. The PID controller is tuned using Ziegler-Nichol criteria of tuning in feedback controller is shown in Figure 2. The value of proportional gain, integral gain and derivative gain of PID controller are 0.39, 3.44 and 0.86 respectively.

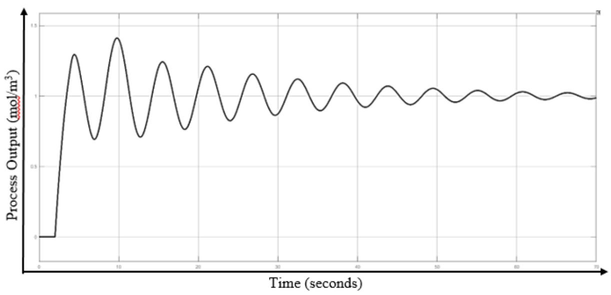

Figure 3: Process response before tune

This experiment was conducted with the desired product concentration which is set point was assumed at 1 mol/m^3. Based on Figure 3, the process performance shows many oscillations due to assignable cause. The process unable to reach the desired set point. The higher peak only has achieved 0.5184 mol/m^3. From these observation, it is clear that control system required to obtain a desirable and satisfactory process response.

A common method that is practiced in EPC in order to achieve better process response is by performing fine tuning to the controller variable. This is done by direct adjusting the controller parameter such as K_c, τ_I and τ_D. In this case, after the fine tuning was done, the process performance still not satisfactory, so the controller parameter need to be adjusted through trial and error until a satisfactory response is produced. The new controller variables are presented in Table 2 meanwhile Figure 4 presents the process response after tuning was performed.

Tuning Method	K_c	τ_I	τ_D
Ziegler-Nichols	0.16	0.24	0.14

Table 2: Controller parameter after fine tuning

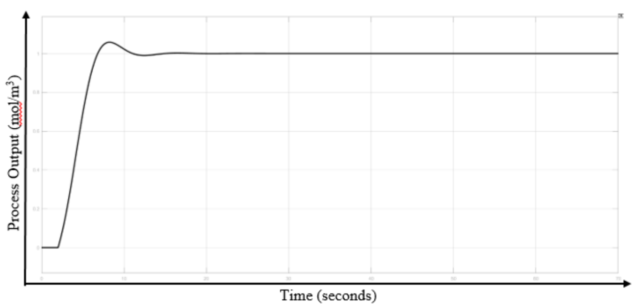

Figure 4: Process response after fine tuning

Based on Figure 4, it can be observed that the process response had improved significantly. The process performance stable and nearest to the set point which is 1 mol/m^3. The most noticeable difference is that the oscillation was reduced, it indicates that the process variability within the process also reduced.

Table 3 presented the result summary for before and after tuning.

Criteria	Before tune	After tune
Rise time (s)	13.99	3.4
Settling time (s)	201	10.2
Overshoot (%)	48.3	6.42

Table 3: Summary of tuning

From table 3, its shows that rise time and settling times after tune is smaller than before tune which mean the process will take a shorter time to stabilize the process at the desired set point. The percentage of overshoot show that differences between before and after tune is about 76.54 %. It means the process variability was reduced about 76.54%.

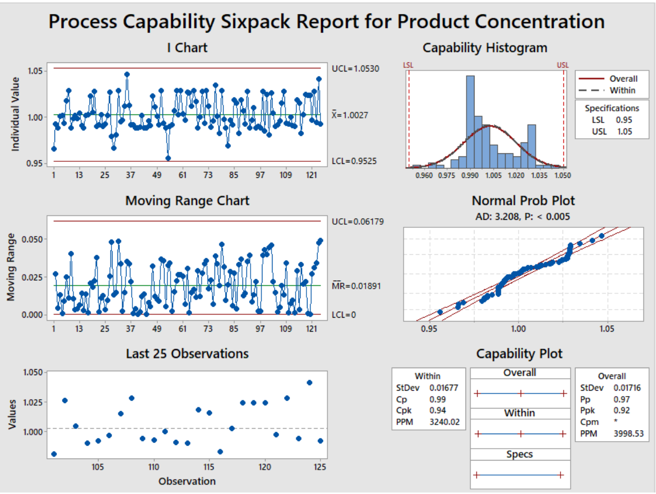

Figure 5: Process Capability Sixpack

The control charts for individual (I-Chart) are used the moving range to monitor the existence of assignable cause. It can be found from the chart that when all of the point are in the control limit. The process data output display in Figure 5 is within the Upper Control Limit (UCL) and Lower Control Limit (LCL), indicating that the process is stable and in-control.

Based on the capability histogram, the Upper Specification Limit (USL) and Lower Specification Limit (LSL) are assumed to be $\pm 0.05\ \mathrm{mol/m^3}$, which considered into 1.05 and 0.95, respectively. It is observed that all of the data fall within the specification limits, representing that the process is capable.

The process capability also can have evaluated using the process capability plot. Here, only the value of C_{PK} will be used to measure of the potential process capability. At the same time, the value of P_P and P_{PK} is only applicable when the process is out of control (Montgomery, 2009). Generally, higher C_{PK} values indicate a more capable process. Lower C_{PK} values indicate the process may need improvement. According to Wooluru *et. al* (2014), the general acceptable value of C_{PK} is 1.33 and any lower than that means the variation is either to wide compared to the specification or that the process is off-centred. Based on the capability plot, the C_{PK} obtained is 0.94, which is lower than acceptable value, the potential capability of the process dos not meet requirements, it considered ways to improve the process such as reducing the process variability. Lower C_{PK} value means the process is too close to the LSL because the process is not centered.

To test whether our data from the CSTR process comply with this assumption, normal probability plots are created to determine whether the data is normally distributed or not. If most of data point lie on this line, the data may be considered to be normally distributed. Conversely, if the point appears to be an S shape, then the indication is that the data are not normally distributed. For this process, the majority of the data are close to the line except for a few data at end of the line. Thus, it can conclude that all data approximately follows the normal distribution that the respectively sampling intervals have been appropriately chosen.

The other ways to determine the normality of the process whether the data is normally distributed or otherwise by using parameter of significance value, p-value and null hypothesis. Before conducting the analysis, need to be clearly understood about the parameter used. As a brief summary, the null hypothesis is either to be accepted or rejected depending if the p-value is greater or lesser than significance level, respectively. For this study, the significance level is assumed to be 0.01. However, the p-value obtained from the graph is less than 0.005 which is lesser than 0.01. This means that the null hypothesis is rejected and the data is normally distributed.

IV. Conclusion

In this paper, it can be concluded that disturbance and assignable cause in manufacturing process can result in the deviation of output quality from the desired set point. So, the combination of SPC and EPC methodology can keep the process under control no matter that the system is stimulated by an assignable cause or random disturbance. The result clearly shows that using the integration of SPC and EPC is a way to achieve continuous quality improvement than the use of EPC alone. For recommendations for future researchers to improve the product quality by applying different tuning such as Cohen-Coon, Takahashi, Direct Synthesis, Internal Model Control and others. Also, applying different SPC tools such as EWMA, CUSUM and other to further analyse the process performance.

Acknowledgment

First of all, I would like to thank and express my gratitude to Allah S. W. T for His countless blessing and favors. Besides, a great appreciation also goes to my supervisor, Dr Sherif Abdulbari Ali for his constant guidance, patience and advice which really helpful in order for me to complete my project. Without his I believe that I cannot give my best to finish the research project.

References

[1] Aljebory K.M and Alshabeb M. (2014). *Journal of Mechanical and Industrial Engineering*, 8: 243-256

[2] Fernando G.M. (2005). Tuning PID Controllers Using the ITAE Criterion. *International Journal of Engineering Education*, 21(3):1-7

[3] Ibrahim K.A. (1996). Active Statistical Process Control. *Department of Chemical and Process Engineering*, University of Newcastle.

[4] MacGregor J.F. (1988). Online Statistical Process Control, *Chemical Engineering Process*, 84(10)

[5] Montgomery D.C. (2009). *Statistical Quality Control (6th Edition).* New Jersey, USA :John Wiley & Sons, Inc

[6] Wooluru Y, Swammy D.R and Nagesh P. (2014). *International Journal for Quality Research*. 399-416.