Water Level Cascade Control

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Abstract – Liquid level controlling is useful and important phenomena in industrial, domestic and many other applications. The main uses are in chemical and power plants; where a slight deviation can lead to a major accidents and huge losses in revenue. To overcome this issue, it is best to implement cascade control system in the plant. With the cascade control strategy, an improved strategy can be achieved since any change in the liquid level is immediately detected by the level measuring element and level control will takes corrective action. In this paper, comparison between single and double loop control was compared and examined to prove that double loop is far more efficient than single loop. The effect of changing the proportional (P) value in both inner and outer loop was examined to study the effect on the process. Consequently, the most optimum value of proportional (P), integral (I), and derivative (D) in tuning process will also be identified and the effect of detuning the value was observed. The effects of this values is examined and observed on Level Flow Process Control Training System (Model: WLF 922). As the system consists of two different loops, method in which primary and secondary loop are tune simultaneously by using an open-loop test. The PID value from both open loop test is obtained by using Ziegler-Nichols tuning rules. Finally, explanation of the observed behavior based on PID values and general guidelines to assist in the procedure of controller retuning are given.

INTRODUCTION

Many investigations have been done in tuning proportional-integral-derivative (PID) controllers in single-input-single-output (SISO) system, such as Refs [1-3]. However, the single feedback control loop does not sometimes provide a good enough performance for processes with log time delays and strong disturbances. Cascade control loop can be used and are a common feature in the process control industries for the control of level, flow, temperature and pressure loops.

Cascade control that has been introduced many years ago by Franks and Workey [4] is one of the strategies that can be used to improve the system performance, particularly in the presence of disturbance. In conventional single feedback control, the corrective action for disturbances does not begin until controlled variable deviates from the set point. A secondary measurement point, and secondary controller, G_{c2}, in cascade to the main controller, G_{c1}, as shown in Fig.1, can be used to improve the response of the system to load changes.

A typical example is the natural draft furnace temperature control problem [2,3], shown in Fig.1. When there is a change in hot oil temperature, which may occur due to a change in oil flow rate, the conventional single feedback control Fig. 2, will immediately take corrective action. However, if there is any disturbance in fuel gas pressure no correction will be made until its effect reaches the temperature-measuring element. Thus, there is a considerable lag in correcting for a fuel gas pressure change, which subsequently results in sluggish response. With the cascade control strategy shown in Fig. 1, an improved performance can be achieved, since any change in the fuel gas pressure is immediately detected by the pressure-measuring element and the pressure controller takes corrective action.

Recent contribution on tuning PID controllers in cascade loop include [5-8]. In this paper, the performance between single feedback and cascade control is studied. The idea is to prove that cascade control system can provide better performance than single loop control as mentioned in the example of temperature control, as given above.

The next section outlines the effect of different gain, K_c value in cascade control system, how different value of K_c will affect the process response. The process of cascade can often be treated as having two transfer functions with the one in the inner loop, generally having no, or small time-delay while one in outer loop have significant time-delay [5,6]. Thus, studies regarding behavior of the process on change on gain, K_c on both of inner and outer loop also has been done. This is to determine how process response of the system get effected if the value of gain, K_c is manipulated in inner loop and, in both inner and outer loop.

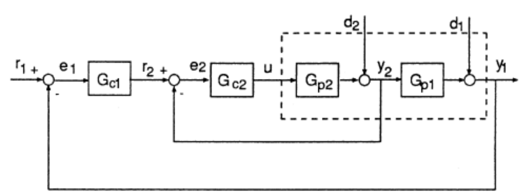

Fig. 1 Block diagram of cascade control system

<u>Description about cascade process control system (Model: WLF 922)</u>

The experiment is conducted by using Level Flow Process Control Training System (Model: WLF 922). This system is controlled by a serial of double loop PID controller by using INVENSYS Foxboro I/A Series DCS which has both analog and digital inputs and outputs respectively. The control unit is supported by a differential pressure transmitter, level transmitter, and flow transmitter. A pneumatic control valve controls the inlet feed and the corresponding flow rate is measured using rota-meter. The level transmitter is used as the primary measuring device and flow transmitter acts as a secondary measuring device.

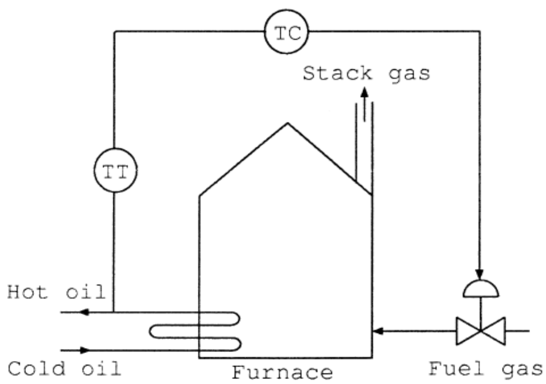

Fig. 2 The natural draft furnace temperature control with single feedback loop

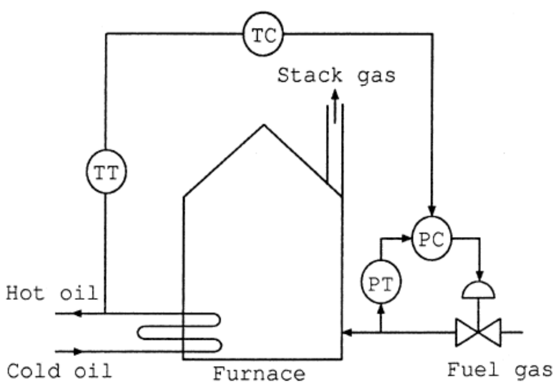

Fig. 3 The natural draft furnace temperature control with cascade control

The operation is summarized as the level transmitter measures the level in the tank and gives it to the controller based on the error value. The controller produces controller output in the range of 4-20 mA and the same is given to I/P converter which produces equivalent pressure in the range of 3-15 psi. The pressure actuates the pneumatic control valve which opens or closes and eventually error value is brought to zero. The model is connected to a personal system through Foxboro system. The process automation is performed through SCADA programming and the same is operated in both run-time and development modes. Generally, the experiment are conducted in run-time mode and visualization. The cascade control system is interconnected with DCS and eventually the process variables are made available in remote stations through internet architecture which illustrated in Fig. 4.

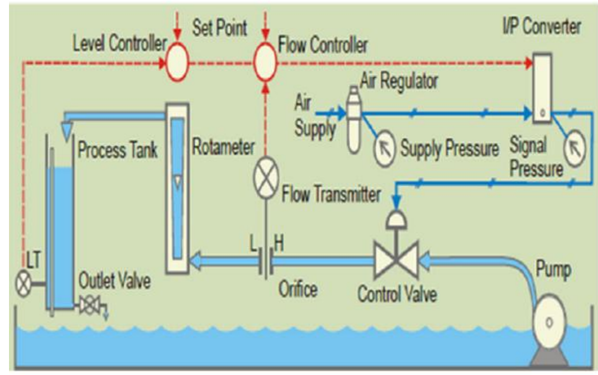

Fig.4 Scheme representation on Level Flow Process Control Training System (Model: WLF 922)

Fundamentals of Cascade Control System

The configuration of cascade control system is shown is Fig 1, where an inner loop is embedded within an outer loop and outer loop output variable is to be controlled. The control system consists of two process and two controllers with an outer loop function G_{p1}, inner loop transmitter function G_{p2}, outer controller, G_{c1}, and inner loop controller, G_{c2}, respectively.

The two controller cascade control systems are standards feedback controllers. Usually, a proportional controller is used for the inner loop, integral action is needed when the inner loop process contains essential time delays, and the outer process is such that the loop gain in the inner loop must be limited.

To serve the purpose of reducing or eliminating the inner loop disturbance d_2 before it effects can spill over to the outer loop, it is essential that the inner loop exhibit a faster dynamic response than that of the outer loop. Consequently, the phase lag of the closed inner loop will be much less than that of the outer loop. This feature leads to the rationale behind the use of cascade control. The crossover frequency for the inner loop is higher than that for the outer loop, which allows higher gains in the inner loop controller in order to regulate more effectively the effect of a disturbance occurring in the inner loop without endangering the stability of the process.

A cascade control structure has the following advantages over a single feedback control loop system [7]:

1. The secondary controller is used to correct disturbance arising within the inner loop before they can affect they control variable.
2. The effect of parameter variations in the process G_{p2} are corrected in the inner loop by secondary controller.
3. The effect of any phase lag existing in G_{p2} may be reduced by the secondary loop, thus allowing the speed of response of the primary loop to be improved.

METHODOLOGY

In this study, there are two single loops of level, LIC 31 and flow, FIC 31 being manipulated. These controlled variables are experimented by using open loop test to analyzed the open loop process response which are response rate (RR), dead time (T_d) and time constant (T_c). Fig. 5 shows the example of data extraction for graphical method. From the graph, process characteristics of both loop are determined by reformulated tangent method, a method where analysis are done in trigonometric functions.

$$RR = \frac{\tan\theta}{\Delta MV}\frac{a}{b} \quad (1)$$

$$T_d = T_d(length)x\ b \quad (2)$$

$$T_c = T_c(length)\ x\ b \quad (3)$$

Once process characteristics have been found, the mode of control must be selected. Mode of control is important as it will results in an off-set process response. For this process, P+I mode of control is used as the process is fast and noisy [8].

The process characteristics found in both loop is substituted into tuning rules by Ziegler Nichols. The selection of tuning rules is based on closed loop's settling criteria and type of performance test [8] The tuning rules of Ziegler Nichols can be obtained in Table 1 that the rules only two parameters which are RR and T_d.

Table 1 Tuning Rules by Ziegler Nichols

Mode	P	I	D
P	100 RR T_d		
P I	111.1 RR T_d	3.33 T_d	
P I D	83.3 RR T_d	2 T_d	

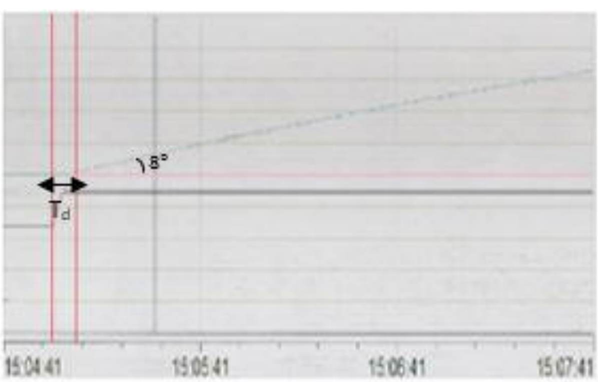

Fig. 5 Data extraction by graphical method

As first, the value of P and I obtained was examined on single loop feedback control system and double loop cascade control system, this to ensure which system are more efficient. Secondly, we examine the effect of changing the value of gain, K_c on the cascade control system. The value of K_c were change on inner loop and on both inner and outer loop. Then, the value of K_c was increased for the factor of two and decreased for the factor of two. The effect and behavior of the process was studied and discussed below.

RESULTS AND DISCUSSION

<u>1. Comparison Study on Feedback and Cascade Control</u>

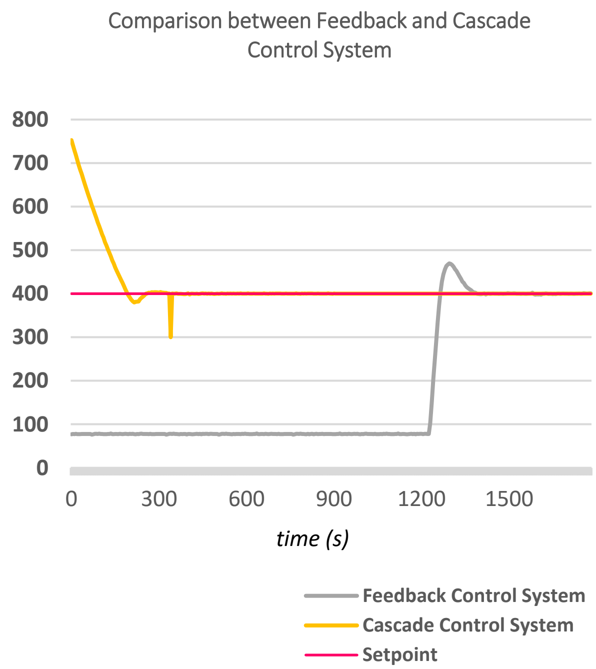

Fig. 6 Comparison between Feedback and Cascade Control

Two examples are presented here to illustrate the value of effectiveness of cascade control system. The performance of the double closed loop system is evaluated by comparing with single loop feedback system by introducing the same value of P and I value to the system.

Closed loop cascade control system achieved set point and stabilized faster compared to closed loop feedback control system. The cascade control applies the technique of nesting one control loop inside another. This allows the workload to be shared between the two loops [5]. By sharing the workload between two controllers, the closed loop control are increased. Accuracy, speed of response, settling time, and any other control errors are all improved. This is different to feedback as feedback only consists of one loop only.

In terms of the system, the outer loop of cascade which are flow control act as level measuring element will immediately detect any change in liquid level and level control will takes corrective action, thus resulting in fast process response unlike feedback that only consists of one loop and no actions can be done if flow of the system being disturbed until the effect reaches level-measuring element.

In terms of quantitative comparison, double loop system took about 20 minutes faster to stabilize compared to single loop. It is evident that double loop control is more efficient and able to reduced time delay compared to single loop control.

2. The Effect of K_c Change in Outer Loop

In cascade control system, there are two loop, inner and outer. The inner loop is the master which control the system while the outer loop is the slave. Thus, the system being controlled mainly by the inner loop. In this section, studies on effect of changing the value of gain, K_c on outer loop is conducted and how significant would the change be to process where the value of K_c being manipulated on inner loop only.

$$Gain, K_c = \frac{100}{PB} \quad (4)$$

Gain expressed as the sensitivity of an element to changes in its input, and a device with high gain is very sensitive to input changes resulting in a fast response process. Thus, the value of K_c gained from open loop test previously was increased by factor of F=2. The value of K_c first being increased in inner loop only and in both inner and outer loop. The significance of slave loop is illustrated in Fig. 7.

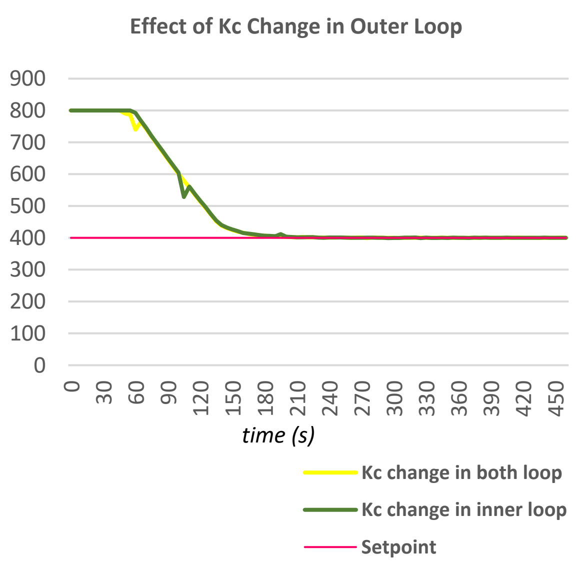

Fig. 7 Effect of Kc change in outer loop

The increase in K_c in outer loop does not contribute much different as compared to increase in K_c in inner loop only as can be observed from the graph. However in analyzing analogue data from both process, process with high K_c in both loop are more stable and does not fluctuate much as high K_c results in fast response thus better performance of the process. The significant is too small as the loop only act as the slave and corrective action is decided by the master.

3. Effect of Gain, K_c Change

In previous section, we have determined that process with high K_c value in both loop is performed better than in inner loop only. In this section, change of K_c with respect to nominal tuning of a factor of F=4 for increase and also of a factor of F=0.5 decreased on both loop was examined. Results are reported in Figure 8 where the process variable, PV is plotted versus time, s.

By analyzing trends in Figure 8 it is evident that effect of incorrect tuning of the master and slave loop causes a decrease of process efficiency where longer time needed for the process to stable and reach set point. The process with low K_c oscillate took longer time to respond and oscillate first before stable compared to process with high K_c value. This is because when the K_c is too low, the control action may be too small when responding to system disturbance [5].

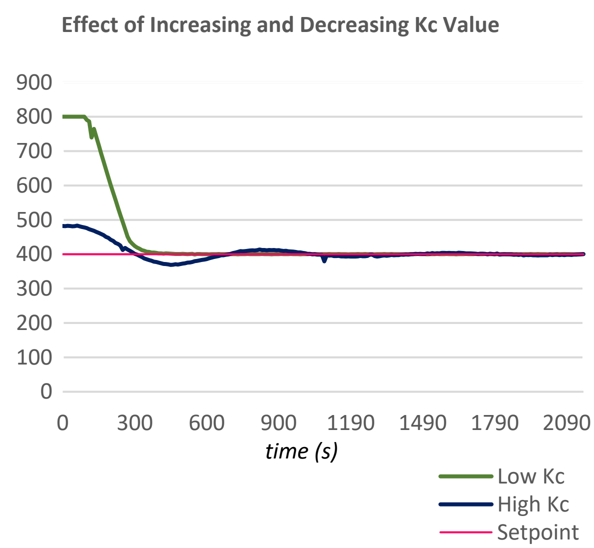

Fig. 8 Effect of Proportional Band Value

A high K_c results a small change in the output when a change in the error occurred. However if the K_c is too high the system can be unstable. Thus, current K_c is already at optimum.

CONCLUSION

The double loop cascade control is far more efficient than single loop has been proved by providing time taken for the process to reach set point and stable. The effect of P, I and D value that control the process optimally towards the desired set point are also studied and analyzed in order to find the most optimum P, I and D values. The comparative analysis shows that increasing value of gain, K_c will fasten the process thus improved closed loop performance.

The analysis illustrated above allows a full understanding of effects of cascade controllers tuning on loop performance and to find explanation to operator retuning of master loop while monitoring system suggested on the slave loop.

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