Cascade Control System Design and Auto Tuning Using Relay Feedback Technique

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***Abstract*--one of the basic functions of instrumentation engineers is tuning of controllers. In the industries there are no of process loops (SISO and MIMO) necessitate tuning. The auto tuned proportional –integral –derivative controllers are designed for application where load change are expected and need control action fast and accurately. Cascade controllers are designed for fast and accurate response. Cascade system/controller provides good control over single loop controller system. Relay feedback technique is used for tuning of PID controller and this method can be extended to auto tune of cascade controller system. The conventional on –off relay oscillation for a single loop feedback controller is extended to the relay tuning of cascade controllers. In this paper a well established cascade PID controller design using arm controller and relay feedback techniques is presented for cascade controller tuning. In past year the primary and secondary loop both are tuned manually. First secondary tuned and then primary. There are many methods for tune cascade controller like fuzzy logic based self tuning method , and Bi and CAI et al method for inner loop. By using relay feedback method the tuning of the secondary loop to be done without necessarily placing the primary controller in manual mode. The method presented in paper is used for the tuning of cascade controller to obtain its parameter with a minimum computing complexity. Controller parameters KP, KI and KD are calculated using classical Ziegler-Nichols tuning rules or redefined tuning rules. The measurement of relative speed of system is done using limit cycle oscillation.**

***Index Terms*-- Cascade controllers; Auto tuning; SISO; MIMO; PID controller: Relay feedback;**

I. INTRODUCTION

In industrial process control loops, proportional-integral-derivative is extensively used to optimize process desired control action. PID controller is still used widely in presence of fuzzy, adaptive and many more advance control techniques. More than 90% of all control loops are PID [1]. PID controller is like a heart of feedback loop because of simple and effective structure. The PID algorithm is simple and used in many feedback loops. Different forms of PID algorithm like interacting and non-interacting, set-point weighting, standard form, classical form, parallel form are used as per control action demand [2].

The cascade control scheme is an integrated structural design using PID controller for the purpose of accurate, desired control action in presence of load change and variable process dynamics. Cascade control system is designed easily and provides large performance improvement over a single control system. If secondary measurable variable is available then it is advantageous to use cascade control in compare to single element control system. Cascade control system consist two control loops; an inner loop or secondary and outer loop or primary loop and two controller rather than single PID controller. Inner loop controller is called secondary or slave and primary loop controller is called primary or master controller.

The PID relay auto tuner of Astrom and Hagglund is one of the simplest and most robust auto tuning techniques for process controllers. Cascade control system can be tune using fuzzy logic method, c.c. hang et al method [4]. Relay feedback technique is simple and easy; progress in relay feedback techniques is summarized by Yu [5]. The relay feedback test is applied to both inner and outer loop, first inner loop then after outer loop and based on that appropriate choice of relay parameter and with help of Ziegler-Nichols tuning rules two individual controller for inner and outer loop are designed which kept the process close to set point .

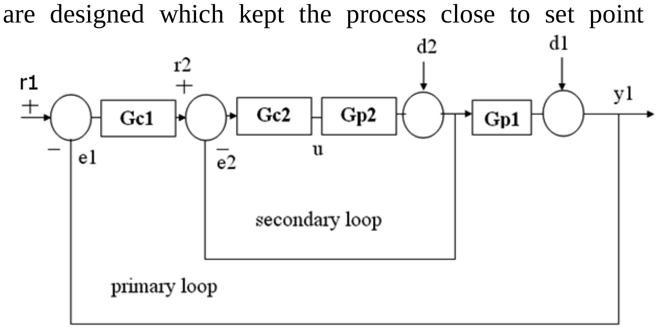

Fig.1. Cascade control system.

II. CASCADE CONTROL SYSTEM

1) Fundamental of cascade system

Cascade control is shown in fig.1 is a multi loop control scheme commonly used in process. Cascade control is built up by nesting the control loops. Where inner loop control the secondary variable and outer loop control the output or control variable. A large part of the disturbance is eliminated by the inner loop. The remaining error is eliminated at a slower rate through the action of the outer loop. Cascade control technique is used to reduce effect of load disturbance. Inner loop is always faster than outer loop to eliminate effect of disturbance before its affect to control variable. Cascade control is reducing both maximum deviations and integral error of disturbance response [5].

2) Importance of secondary measured variable

Selection of secondary measured variables is important task. Key idea of cascade control is tight feedback control loop around a disturbance. In ideal case the secondary loop is a perfect servo wherein the secondary measured variable responds very quickly to the control signal. There should be a well defined relationship between the primary and secondary measured variables. Essential disturbance should act in the inner loop. It should be possible to have a high gain in inner loop.

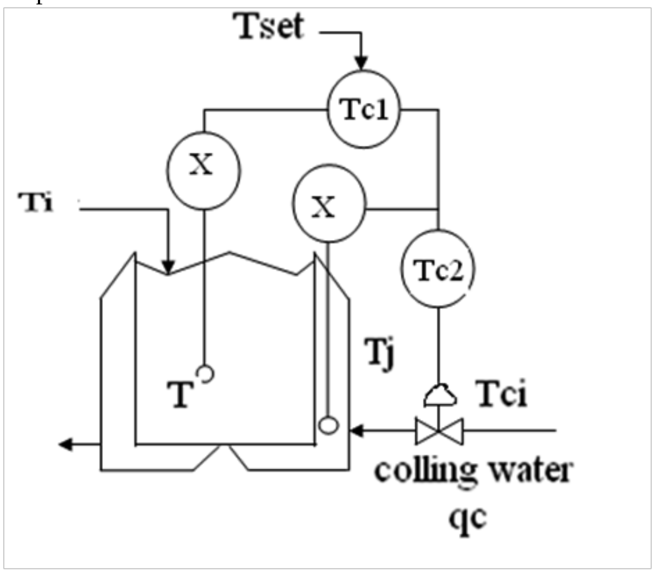

Fig.2.Jacketed kettle cascade system.

3) Jacketed kettle temperature control system

For example consider the Jacketed Kettle system. In this case there is an inner loop which control the jacket temperature Tj and outer loop control the kettle temperature T. Now suppose there is a disturbance variable, temperature of cooling water Tci. Inner loop controller is TC2 and outer loop controller is TC1. In traditional feedback control the output of the temperature control TC1 is direct control the cooling water valve, corrective action is taken whenever the T is changed and there is a heat transfer relation between T and Tj. In cascade control one more additional control loop which measure the temperature of jacket as a secondary variable and control the temperature at desired value by correcting the disturbance Tci. The output of the primary controller is become set-point of secondary controller. There for jacketed kettle system less affected by disturbance and robust control is achieved.

The equivalent transfer function of the secondary loop, given by G2,

$$G2 = \frac{Y2}{R2} = \frac{Gc2Gp2}{1+Gc2Gp2} \tag{1}$$

And close loop transfer function is given by

$$G = \frac{Y1}{R1} = \frac{G2Gc1Gp1}{1+G2Gc1Gp1} = \frac{Gc1Gc2Gp1Gp2}{1+Gc2Gp2+Gc1Gc2Gp1Gp2} \tag{2}$$

For a load disturbance, such as d2 within the inner loop, with d1=0, the transfer function to the output is

$$\frac{Y1}{D2} = \frac{Gp1}{1+Gc2Gp2+Gc1Gc2Gp1Gp2} \tag{3}$$

Without the inner feedback loop and of course no controller Gc2, the transfer function between the same variable is

$$\frac{Y1}{D2} = \frac{Gp1}{1+Gc1Gp1G} \tag{4}$$

In eqns.3 and eqns.4 denominators are different so the response to a disturbance in the cascade control system will be different to that in the single loop system.

III. RELAY FEEDBACK TECHNIQUE

Based on information obtain, the methods for auto tuning can be classified into time domain approaches and frequency domain approaches. A typical example of the frequency domain approach is the Astrom –Hagglund auto tuner based on the approximate estimation of the critical point on the process frequency response from relay oscillation [6]. A continuous cycling of the controlled variable is generated from a relay feedback experiment. This experiment provides information about ultimate gain (Ku) and ultimate frequency (Wu) and based on that a controller can be designed according to Ku and Wu using Ziegler–Nicolas method. However, the sustained oscillation is generated under a controlled situation and it is different from the conventional continuous cycling methods [6].

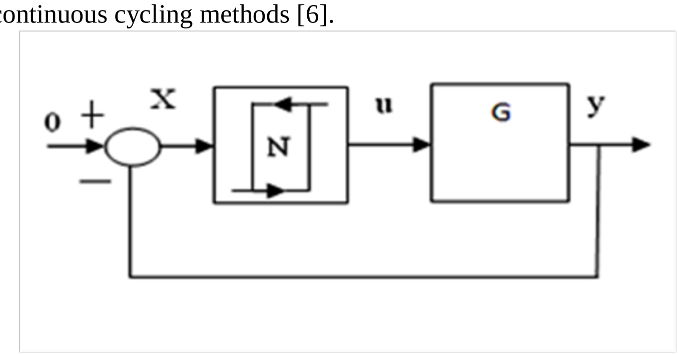

Fig.3.Relay feedback techniques block diagram for SISO.

The relay feedback method involves replacing the PI/PID controller by relay. In relay feedback experiment we can use normal ideal on-off relay and relay with hysteresis also. When relay is replaced then continuous sustain oscillation is generated and the period of the oscillation is ultimate period Tu and the frequency of oscillation is ultimate frequency Wu. The fig.3 shows the relay feedback system.

Where nonlinear part *N(a)* and the plant transfer function G. The condition for oscillation is given by $N(a)G(a) = -1$, where the control signal is a square wave and the process output is sine wave. Describing function approach is used to calculate the ultimate gain for the relay. Describing function of ideal relay is given by

$$N(a) = \frac{4d}{\pi a} \tag{5}$$

TABLE I
ZIGLER-NICHOLAS TUNING RULES FOR P/PI/PID CONTROLLER

Ku; ultimate gain, tu; ultimate period			
Types of controller	kp	ki	kd
P	0.5ku		
PI	0.45ku	0.85tu	
PID	0.6ku	0.5tu	0.125tu

Relay with hysteresis is used to reduce the effect of noise from the propagated sine wave. Describing function of the relay with hysteresis is given by

$$-\frac{1}{N(a)} = -\frac{\pi}{4d}\left(a^2 - e^2\right) - i\frac{\pi\varepsilon}{4d} \qquad (6)$$

Where a is the amplitude of the oscillation at the input of the relay, d is the relay amplitude and e is the hysteresis width ε. The ultimate gain ku is given by

$$K(u) = \frac{4a}{\pi M} \qquad (7)$$

Where a is the amplitude of the limit cycle oscillation and M is the value of the relay output magnitude.

Example 1;

Design a PID controller for third order system given below using a relay feedback system.

Use a non linear block of relay with plant transfer function in close loop as shown in fig.4.a

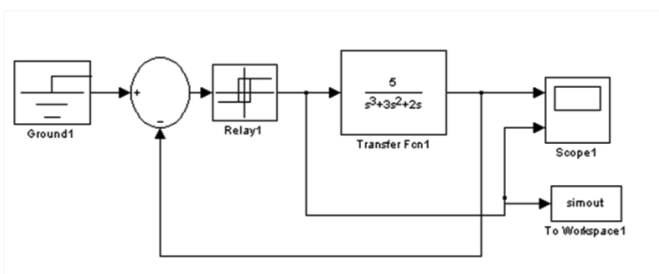

Fig.4.a. Relay feedback method for auto tuning of PID.

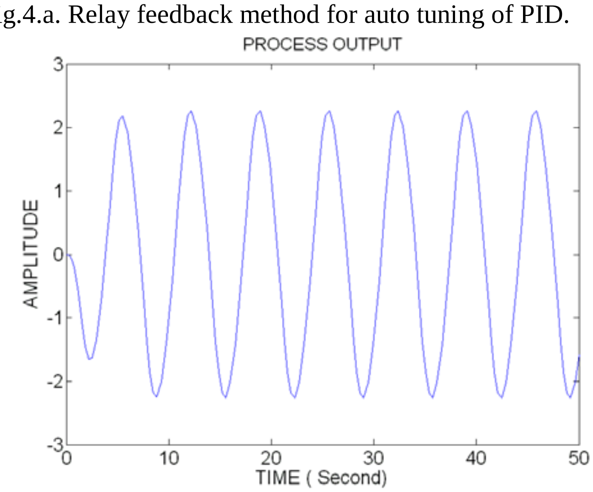

Fig4.b Sustain oscillation of process.

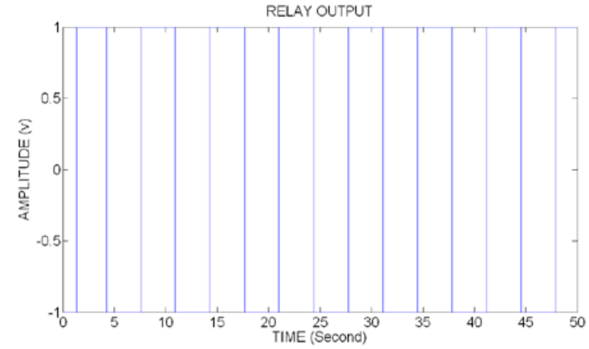

Fig.4.c Relay output.

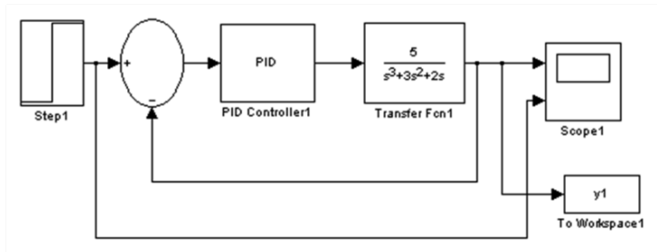

Fig.4.d.Implementation of PID controller using relay method.

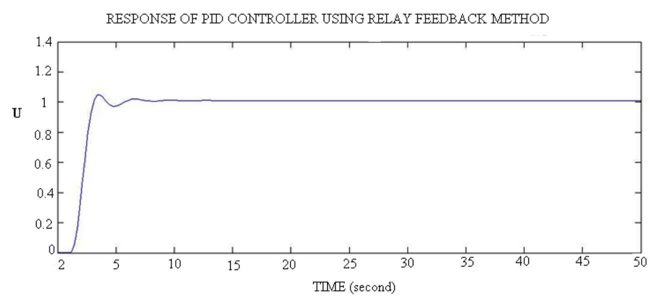

Fig.4.e. Output of plant with PID using relay technique.

IV. RELAY FEEDBACK TECHNIQUE FOR CASCADE CONTROL SYSTEM.

The proposed relay feedback test for auto tuning for SISO discussed in above section is applied for cascade controller tuning as shown in fig.3. The tuning of the cascade controllers, at commissioning, should be performed with the secondary loop first and then the primary loop around it. Re tuning of the secondary loop, if necessary, can be done with the primary loop still closed. The systematic approach towards auto tuning is discussed below.

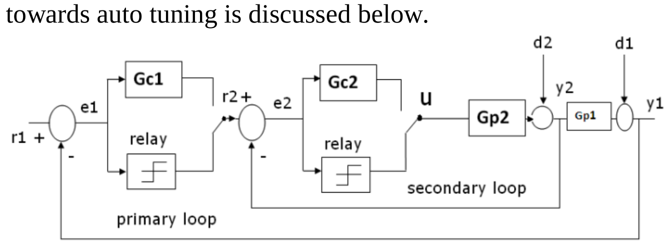

Fig.5. Relay feedback technique for cascade control system.

When the system is set to the tuning mode, two relay are used to replace the two controllers as shown in Fig.5. The switching amplitude of the relay in the outer loop is set to zero or set in manual mode. Measurements on the limit cycle oscillation in the inner loop enable the ultimate frequency and ultimate gain of that loop to be determined.

The parameters of the PI controller in the inner loop are then determined, using the formulae presented in section III. The PI controller is then switched into the inner loop, and the ultimate frequency and ultimate gain of the system are obtained from the limit cycle of the loop with the relay output levels set at appropriate values.

The parameters of the main PID controller can then be derived using the same tuning law of Ziegler – Nicholas as the SISO.

1) Auto-tuning of the secondary loop

As per fig.4 relay feedback around the secondary loop and primary loop in manual, the sustain oscillation is presented at frequency of Gp2(s). The describing function of the loop is given by

$$N2(a) = \frac{4d2}{\pi a2} \qquad (8)$$

Where a2 is amplitude of oscillation and d2 is the relay amplitude. And based on formulae discussed in section this is the ultimate for tuning the secondary loop. And a p or pi controller is tuned using Ziegler -Nicholas rule (table I).The describing function from e2 to u2 at the frequency of oscillation given by

$$\frac{4d2}{\pi a2} = \left| - \frac{1}{Gp2(jw)\left(1 + Gc1(jw)Gp1(jw)\right)} \right|_{w = w'u2} \qquad (9)$$

Comparing with the closed loop transfer function of the system, where both Gc1(s) and Gc2(s) are in place,

$$G1 = \frac{Gp1(s)\,Gp2(s)Gc1(s)Gc2(s)}{1 + Gc1(s)\,Gp2(s)(1 + Gc1(s)Gp1(s))} \qquad (10)$$

It can be seen the describing function of the relay is approximately the magnitude of Gc2 at the cross over frequency and hence find the ultimate gain and period required for tuning the controller. And controller is tuned using Z-N rules.

2) Auto tuning of primary loop

Once the secondary loop is designed the primary loop is closed with a relay feedback. The limit cycle oscillation is observed at the similar manner in above section. The describing function of the relay at frequency wu1 is given by

$$\frac{4d1}{\pi a1} = \left| \frac{1}{\left(\frac{Gp2(jw)Gc2(jw)}{1 + Gp2(jw)Gc2(jw)}\right) Gp1(jw)} \right| \quad W=wu1 \qquad (11)$$

And it's give the value of the ultimate gain, and ultimate period Gc1(s) required for tuning the PI/PID controller. And based on the ZN rules (table I) the controller is designed.

Subsequent re-tuning of either controller, if required, can be done entirely in close loop no need to put in manual. It is easy to implements cascade controllers using the arm controller. Arm controllers work as the heart of the system LPC2103 or family IC can be used. Communication of the system is through modbus protocol, and GUI using labview tool.

V. CONCLUSION

In this paper, well established method of auto tuning of cascade controller is discussed. Fine tuning of cascade inner loop P/PI controller and outer loop PID controller is done using relay feedback technique. It involves the on –off relays to obtain the ultimate gain and ultimate frequencies/period. The secondary loop is tuned first using relay feedback and proposed P/PI controller for inner loop is designed using ZN rules. The primary loop is tuned by closed secondary loop and ultimate gain and frequency/period is obtain using proposed method, PI/PID controller tuned for loop. In any case if need re-tuning of secondary loop then it is done with both loop closed.

VI. REFERENCES

[1] K.J. Astrom and T. haglund , "Auto Tuning of PID controllers," 1st ed. Reserch and triangle park, NC:instrum. Soc. Amer.,1988.

[2] K.J. Astrom and T. haglund , "PID controllers, 2nd edition,"

[3] Sihai Soong,Lihua Xie and WEn-Jain Cai,"Auto Tning of Cascade Control System".

[4] C.C.Hang ,A.P.Loh, V.U.Vasani, "relay feedback Auto Tning of Cascade Control System".IEEE tran. Vol.2.no.1.march 1994

[5] Minxia Zhuang , Derk P. Atherton ,"Optimum cascade Pid Controller Design For SISO systems," university of Sussex, U.K.

[6] Shih-Haur Shen and Cheng-Ching Yu.,"Use Of Relay-Feedbck Test For Automatic Tuning of Multivariable Systems," dept. of. Chem.. national Taiwan inst. Of .tech.,Taipei.