Pid Auto Tuning Using Relay Feedback

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Abstract-- PID autotuning algorithms based on relay feedback are used to identify different options of the process frequency response before performing the actual tuning procedure.These algorithms require minimal amount of priori information about the controlled process, they are also insensitive to modelling errors and disturbances.In this paper,a PID autotuning procedure implimentation based on Astrom and Hagglund's method(1984) is presented.The procedure is based on the estimation of the ultimate gain ultimate frequency using a relay test signal in closed loop.The PID parameters are calculated using the Ziegler-Nichols tuning rules.In the case where the system is completely unknown,an initial tuning is required before the system can reach the set point,afterwards,a more accurate estimation is made.In case of linear systems,the ultimate gain and the ultimate frequency extracted from the initial tuning are expected to be similar to those extracted from the tuning.In case of nonlinear systems, estimation should be conducted for each change of the set point.Furthermore,the PID parameters extracted in the procedure can be used either for initialisation of other advanced optimization algorithms or for caliberating complicated adaptive regulators. This paper presents a PID autotuning procedure based on Astrom and Hagglund's method. This procedure is able to tune a PID controller without using preliminary experiments, modeling or external tools.

Index Terms – PID, Autotuning, Relay Feedback, Control.

I. INTRODUCTION

In recent years,a number of autotuning techniques for simple and classic regulator structure(eg:PIDs) have been presented in literature[1].The great effort of these researches is motivated by two main reasons: first,a simple regulator is fast, easy to impliment and easy to tune, secondly,a classic structure is well known and accepted in the industrial world.As a result,some of these researches have also found direct industrial application.As far as PIDs are concerned,most methods are based on the identification of one point of the process frequency response,either by a propotional regulator bringing the closed loop system to the stability boundary,or by a relay forcing the controlled process variable to oscillate.This point is suitably moved in the complex plane by opertune choice of the propotional,integral and derivative actions performed by the PID regulator.

Astrom *et.al* [4] is presented to deal with a reduced knowledge about the process dynamics.The main feature of the method is its capability of exploring more than one point of the process frequency response before actually tuning the regulator.In fact,the algorithm looks for various points until some conditions defined by the required control performances(ie.the closed loop phase margin) are fulfilled;only at this step are PID parameters computed[3] .This search is performed by plugging in to the control loop a variable time delay,computed by the algorithm itself at each step of the procedure.In so doing all the tuning formulas can be derived from the same,simple relation and,as a result,almost no a priori information on the process dynamics is required.Moreover, the regulator performance can be forecast easily during the tuning phase,before the PID is connected;this allows a skilled user,in case the required control behaviour cannot be obtained,to reset the tuner and start again with new specifications.Finally,the algoritm ensures conservative PID tuning in most cases,even if its assumptions on the process structure are evidently wrong:this makes it suitable for use as a pretuner for more complex and accurate adaptive PID controllers.

This paper presents a PID autotuning procedure for PLC platforms, based on Åström and Hägglund's method. This procedure is able to tune a PID controller without using preliminary experiments, modeling or external tools. The paper is organized as follows: Åström and Hägglund estimation method will be described in Section I. Simulation results of both the ZN manual method and the relay feedback method will be presented and discussed in Section III.Relay feedback examples are disscussed in sectionIV In Section V, a completely automatic tuning procedure will be presented, implemented using PLC code, which allows real time tuning of the controlled parameters in the field.Last in section VI relay feedback method applied to the complex DTG.

II PROBLEM STATEMENT

Consider the closed loop shown in Fig. 1. The unknown process transfer function is given by G(S) [7] while the PI controller is given by

$$C(s) = K_p\left(1+\frac{1}{T_i s}\right) = K_p\frac{s+\frac{1}{T_i}}{s}. \quad (1)$$

The closed-loop transfer function from reference yr(t) to output y(t) is given by

$$\frac{Y(s)}{Y_r(s)} = \frac{G(s)C(s)}{1+G(s)C(s)} = T(s). \quad (2)$$

For this closed-loop configuration,T(S) is also known as the complementary sensitivity function and L(S)=G(S)C(S) is the loop transfer function. The gain margin (GM)[2] and phase margin (PM) of a closed loop are defined as

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$$GM = \frac{1}{|L(j\omega_u)|} \text{ and } PM = \pi + \angle L(j\omega_g), \quad (3)$$

where ωu and ωg are obtained from

$$\angle L(j\omega_u) = -\pi \text{ and } |L(j\omega_g)| = 1. \quad (4)$$

The problem posed in this paper is to find the PI controllers' parameters using relay tests, such that a closed-loop system with specified gain and phase margins is obtained.

III ULTIMATE POINT ESTIMATION

Astrom and Hagglund's method determines the ultimate point using a relay test signal as the system input. The test signal is automatically produced as described in Figure1 . The method is based on the fact that system with a phase lag of at least π at high frequencies can oscillate under the ultimate period tu.

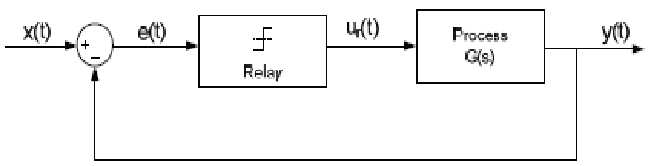


Figure 1: Block diagram for ultimate point estimation

The square signal of the relay output can be represented by a Fourier series:

$$u_r(t) = \frac{4d}{\pi}\sin(\omega t) + \frac{4d}{3\pi}\sin(3\omega t) + \frac{4d}{5\pi}\sin(5\omega t) + \cdots \quad (5)$$

By neglecting higher frequencies:

$$u_r(t) \approx \frac{4d}{\pi}\sin(\omega t) \quad (6)$$

Neglecting higher frequencies is possible since most physical systems act as low pass filters. The transfer function of the relay for a sine wave input with amplitude *a* is:

$$N(a) = \frac{4d}{\pi a} \quad (7)$$

The system will show continuous cycling (marginally stable) when the following condition is satisfied.

$$1 + N(a)G(i\omega_u) = 0 \quad (8)$$

Placing equation [7] into [8] will result in:

$$G(i\omega_u) = -\frac{1}{N(a)} = -\frac{\pi a}{4d} \quad (9)$$

Note that the imaginary part of G(iωu) is zero. So the frequency is the ultimate frequency of the process and the ultimate gain is 1/ G(iωu). Meaning:

$$\omega_u = \frac{2\pi}{T_u} \quad ; \quad k_u = \frac{4d}{\pi a} \quad (10)$$

Comments:

- Other points of the frequency responce can be identified if the relay hysteresis.An integrator or a known time delay can also be inserted in the loop for this purpose.
- The identified point can be used to tune simple regulators,e.g. by using the Ziegler-Nichols method or by introducing phase and amplitude margins specifications.

The test is conducted in closed loop in order to limit the output amplitude deviation from the desired set point. The oscillations amplitude can be controlled by the relay test signal amplitude, where usually a small amount of 2%-10% of the control effort is enough. So, with a relatively simple experiment, a relay test signal can be produced and the system ultimate point can be estimated.

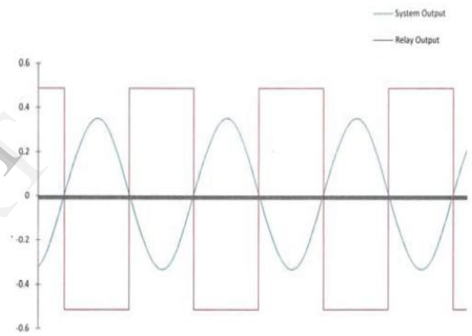


Figure 2: ur(t) and y(t)

Once the ultimate point (ultimate frequency and gain) has been estimated, a PID controller can be tuned using ZN rules. Table 1 provides the tuning parameters for the given ultimate gain and period of the process.

Controller	K_p	T_i	T_d
P	$0.5 \cdot K_u$	-	-
PI	$0.45 \cdot K_u$	$T_u/1.2$	-
PID	$0.6 \cdot K_u$	$T_u/2$	$T_u/8$

Table 1: ZN PID parameters according to the ultimate point

IV RELAY FEEDBACK TUNING EXAMPLES AND SIMULATION

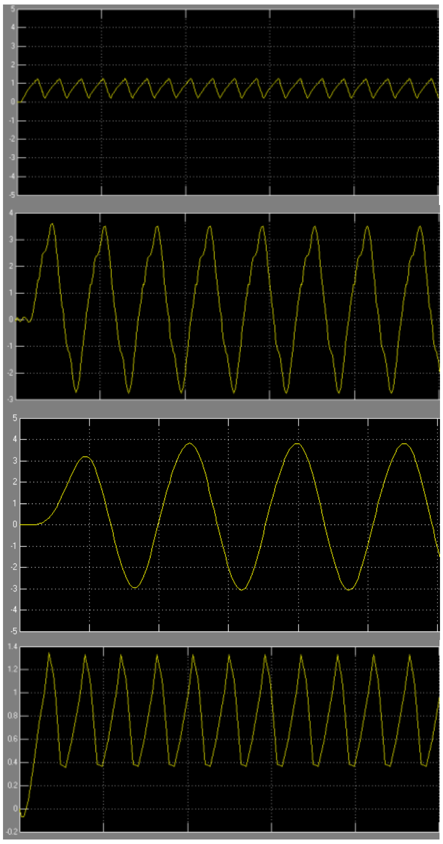
Consider the following different systems,to test the Relay Feedback tuning method,simulations are conducted on them.

$$G_1(s) = \frac{1}{1+20s} e^{-5s}$$
$$G_2(s) = \frac{1}{1+20s} e^{-20s}$$
$$G_3(s) = \frac{1}{(1+10s)^8}$$
$$G_4(s) = \frac{1-5s}{(1+10s)(1+20s)}$$

G1(s) and G2(s) are first order dead time systems (FOPDT) commonly used for describing dynamic industrial processes. G3(s) is a high order system, representing process with extremely high time constants. G4(s) is a non-causal, unphysical system testing the method on a theoretical level.

A.Estimating the ultimate point

In order to estimate the ultimate point for the systems above, simulations were conducted as described in Figure (1). A relay test signal is used to control the system. Relay parameters were configured to guarantee oscillations.



System 1

System 2

System 3

System 4

Figure 3: System 1-4 outputs under relay control

The oscillations presented in Figure 3 are the output signal results of the simulations. These signals were used to find the ultimate point for each of the four systems. The ultimate gain is calculated using equation [11], where *d* – the relay amplitude is known and *a* – the output amplitude is measured.

The ultimate frequency of the output signals was determined from the cycle time of the oscillations.

B.PID parameters tuning

The ultimate point can now be used to tune the parameters of the PID controller. The tuning results were compared to the ZN bode plot method using the MSE criteria.

$$MSE = \frac{1}{T}\int_0^T e^2 dt = \frac{1}{T}\int_0^T (SP - y_{out})^2 dt \quad (11)$$

The results presented in Figure 4 present a step responses for each of the four systems using both relay feedback parameters and bode plot ZN parameters.

SYSTEM	TUNING METHOD	Kp	Ki	Kd	Td	Ti
1	RF	3.3953	0.3395	8.4883	2.5	10.0
	BP	4.1604	0.4543	9.5245	2.28	9.15 72
2	RF	1.1575	0.0386	8.6812	7.5	30.0
	BP	1.3571	0.0438	10.5075	7.7427	30.9 709
3	RF	1.1072	0.01483	21.4513	19.375	77.5
	BP	1.1304	0.0149	21.4335	18.9612	75.8 448
4	RF	3.3953	0.1692	16.9719	5.0	20.0
	BP	3.6005	0.2144	15.1137	4.19	16.7 905

Table2: Comparison Between Controller Parameters

SYSTEM	TUNING METHOD	GAIN MARGIN	PHASE MARGIN	DELAY MARGIN	MS E
1	RF	6.17	48.6	5.13	0.05 91
	BP	4.84	41.5	3.58	0.06 24
2	RF	5.77	66.8	28.3	0.21 89
	BP	4.26	63.6	22.4	0.21 82
3	RF	5.28	76.3	69.4	0.45 89
	BP	5.14	73.7	63.9	0.45 75

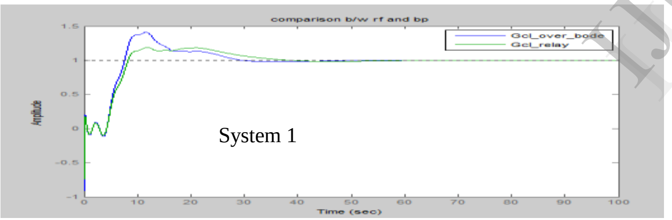
4	RF	7.44	42	6.16	0.1100
	BP	8.45	31.4	4.44	0.1277

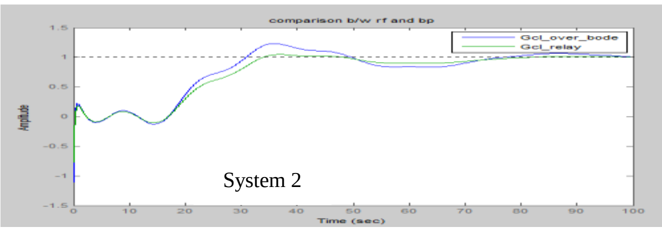
Table3: Comparison Between Margins and MSE

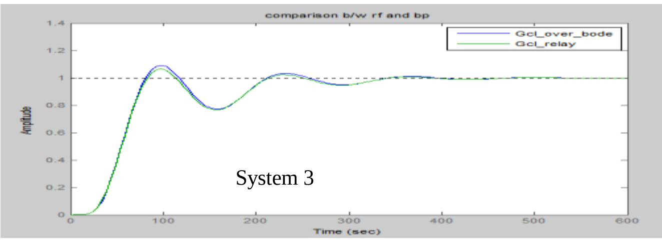
SYSTEM	TUNING METHOD	SETLING TIME	PEAK RESPONSE	RISE TIME	%OVERSHOOT
1	RF	33.2	1.19	7.51	18.8
	BP	27.1	1.41	6.88	41
2	RF	74.6	1.05	30.4	4.65
	BP	92.8	1.23	27.4	23
3	RF	327	1.07	41.2	6.59
	BP	328	1.09	40.3	9.05
4	RF	41.9	1.22	10.2	21.6
	BP	61.2	1.4	9.91	39.6

Table4: Comparison Between Step Response Parameters

The simulation results shows that relay feedback method gives better performance than ZN bode plot method. Because the method uses only the ultimate data of the process, it shows poor performance for large time-delay processes, as does the classic ZN method.







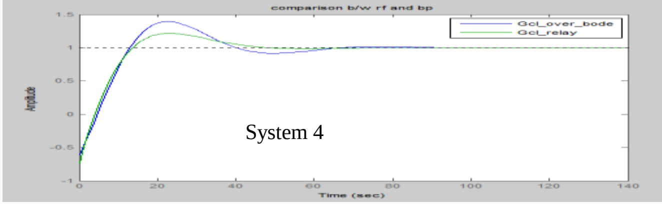


Figure 4: Step response for both tuning methods

II. V.CLOSED LOOP PI CONTROLLER TUNING

The closed loop PI controller autotuning procedure is based on two consecutive phases that ate exicuted automatically.

$$G(s) = \frac{0.2}{(1+5s)(1+10s)} e^{-2s}$$

During the first phase the relay test signal is used to control the system.In this case the amplitude of the test signai is rather large:0-75% of the controller output range,as described n the first phase in figure 6.The intial estimation of the ultimate point found from the half-set-point from a single oscilation and PI parameters are determined according to ZN tuning rules.Further the controller is activated in closed loop as described in figure 5 so the system will reach the desired set point.

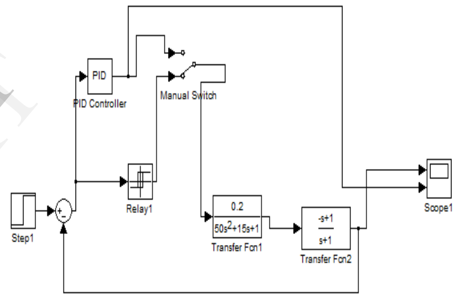


Figure 5: Block diagram for the autotuning procedure

The amplitude of the relay test signal in this case can be rather small(2-10% of the control effort).Tests conducted during this work show that three oscilations are usalyy enough to complete the fine estimation of the ultimate point.The table below shows the parametrs for each phase.

Phase	Kp	Ti
1	12.73	16.66
2	14.32	20.83

Table 5: Autotuning results, phases 1&2

The simulation results of the two phases are shown in figure

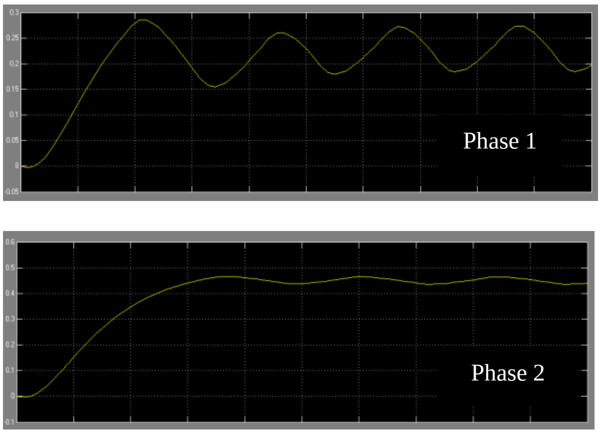


Figure 6: PI controller autotuning procedure

VI RELAY FEEDBACK METHOD APPLIED TO mDTG

mDTG is used as a strap down inertial sensor and its rotor is held at its null position by force balancing through the permenant magnet toquer assembly.mDTG loop electronics is used to process the pick off output by sensing the rotor angular deflection from null position and then torque back the rotor to the null position.The general transfer function of mDTG is given below.

$$\frac{WN^2}{S^2 + WN^2} \qquad (12)$$

Where WN^2 =Nutation Frequency

The basic plant is constituted with mDTG dynamic mix and its scale factors,preamplifier,demodulator,2Nnotch filter,power amplifier,and readout resistor.The preamplifier is configured as two stages for implementing the offset correction.Phase sensitive rectification is used to convert the pickoff output to DC signal.

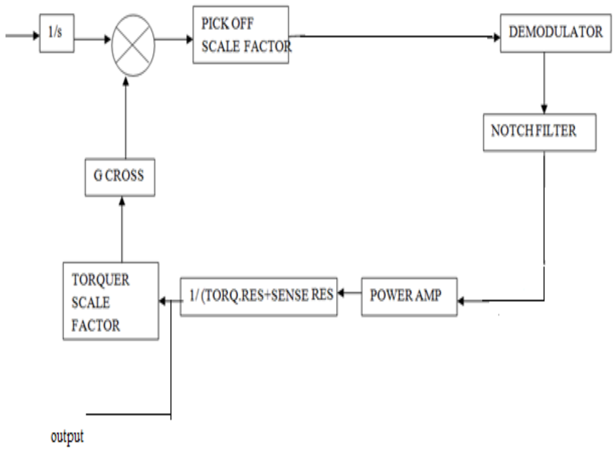


Figure 7:Block schematic of mDTG basic loop electronics

The simulation results are plotted below and here also relay feedback autotuning gives better perforance

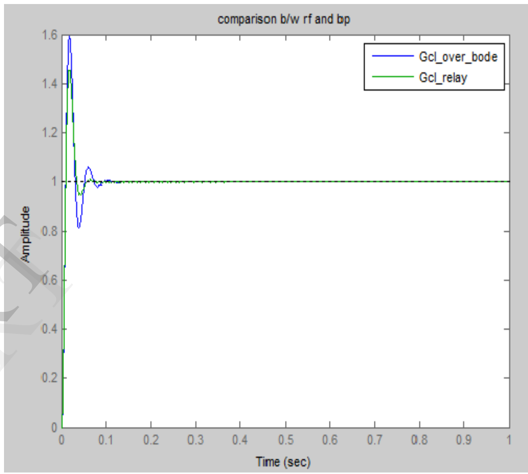


Figure 8:Step response comparison

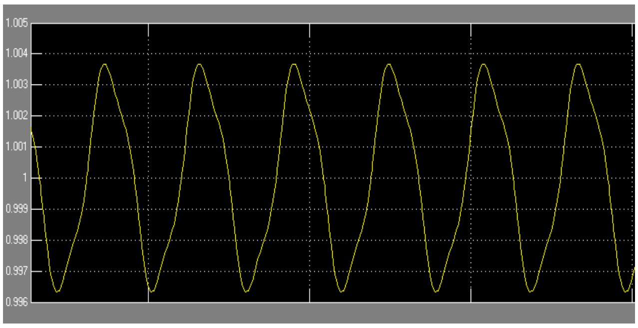


Figure 9:Output under relay control

TUNING METHOD	GAIN MARGIN	PHASE MARGIN	SETTLING TIME	MSE
RF	8.48	39.6	61.5	0.0071
BP	7.93	38.6	62	0.0088

Tabl 6:Performance comparison

VI CONCLUSION

Auto tuning procedure based on Astrom and Hagglund's method was presented.This method is useful to determine the ultimate point in closed loop.Here in this procedure there is no need of any prior knowledge about the system.The only design parameter to be set is the relay signal amplitude,which in inherently small.While limiting the amplitude for stability reasons,this method automatically gives oscilation in the ultimate frequency.

Practically, when no prior knowledge exists, initial tuning must be conducted until reaching the set point, where fine tuning will take place. In linear systems the parameters from the initial and fine tuning are expected to be similar. In nonlinear systems, retuning should be made for every change in the set point. For time-variant systems, retuning can be made every specific time frame in which system parameter change.

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