Proceedings of the
American Control Conference
Baltimore, Maryland • June 1994

REAL-TIME EVALUATION OF AN ITERATIVE SCHEME FOR CLOSED LOOP IDENTIFICATION AND CONTROL DESIGN

A. Voda[1], I. D. Landau
Laboratoire d'Automatique de Grenoble and GR "Automatique"
ENSIEG, B.P. 46, 38402 Saint Martin d'Heres, FRANCE
alina@lag.grenet.fr

Abstract

This paper considers two real-time applications of an existing iterative identification / control design procedure in which the model estimation is coupled to the controller by an appropriate prefilter of the closed-loop dataset. The plant models identified here were used to develop an auto-tuning scheme for the feed tank pression of the Heating Company of Grenoble.

1. Introduction

Recently it has been motivated that the problem of designing a high performance control system for a plant with unknown dynamics through separate cycles of indentification and model based control design requires iterative schemes to solve the problem,([1], [2], [3]). The key ingredient for the successful application of control design methods to identified models is to let the global control performance criterion dictate what identification criterion should be, and to design the controller in a way that takes account of data-based information about the plant/model mismatch ([4], [5], [6]). The present paper gives results of the applications of an iterative procedure of closed loop identification / control design. The first step consists in the auto-calibration of a simple controller (PID), in order to get a primary feedback ([7], [8]). During the next iterations, prefilters are built, for control-relevant prediction identification from the closed loop dataset. For more details on the approach presented, the reader is referred to [9].
This paper considers the iterative procedure as applied to a servo and disturbance rejection control problem, with measured signals collected whilst the plant is operating under closed loop control. Throughout this paper, all the results are derived from an identification of an $ARMAX$ model of the plant by a filtered prediction errror method, and a pole placement control design.
The paper is organized as follows: Section 2 briefly recalls the iterative design procedure of [9]. The application of this technique on a school case plant (an air heater) is presented in Section 3. An industrial experiment on a pression loop from the Heating Company of Grenoble is given in Section 4. Section 5 concludes.

[1]Author to whom all correspondence should be addressed.

2. Description of the multi-step procedure

The plant is considered to be modeled by:

$$y = \frac{B}{A}u + v \tag{1}$$

where u is the control signal, y the measured variable, and v a disturbance signal. All signals are assumed to be discrete time signals where the sampling interval is the time unit. Furthermore A and B are polynomials in the backward shift operator. Let the transfer function of the plant be G_0. This transfer function is not known, but a nominal model in the form of a rational transfer function $G = \frac{B}{A}$ is obtained by parameter estimation. Let the input and the output of the true plant be u_0 and y_0, respectively, and let the same variables for the nominal plant be u and y. The disturbance v in (1) is given by:

$$v = \frac{C}{A}e \tag{2}$$

where e is white noise. Polynomials A, B, and C are estimated by a filtered prediction error (e_{fp}) method, which minimizes the mean square value of:

$$e_{fp} = F(\frac{A}{C}y - \frac{B}{C}u) \tag{3}$$

Let the controller be:

$$Tr = Su + Ry \tag{4}$$

where r is the set point and R, S, T are polynomials. The controller is designed based on the nominal model of the plant $G = \frac{B}{A}$. The closed loop characteristic polynomial is :

$$P = AS + BR \tag{5}$$

To obtain the regulator polynomials R, S and T the pole placement method is used, the polynomial P being given given by the specifications.

$$P = A_m P_F \tag{6}$$

where A_m the desired closed loop model polynomial and P_F the auxiliary closed loop polynomial. Combining (1),(4), it was find that the control performance error is :

$$e_{cp} = \frac{S}{P}(Ay_0 - Bu_0) \tag{7}$$

From this form, different possibilities can be regarded to make compatible identification and control criteria ((3) and (7)).

The auxiliary poles polynomial P_F considered as 1: Consider the polynomial closed loop characteristic:

$$P = A_m$$

The identification and control criteria are compatible ((3) and (7)) if the control performance error which is minimized is:

$$e_{cp} = \frac{SC}{P}(\frac{A}{C}y_0 - \frac{B}{C}u_0) = \frac{SC}{A_m}(\frac{A}{C}y_0 - \frac{B}{C}u_0) \tag{8}$$

The filtered prediction error e_{fp} is equal to the control performance error if the identification is performed in closed loop and the transfer function of the data filter is chosen as:

$$F = F_{pe} = \frac{SC}{A_m} \tag{9}$$

Remark: This statement assumes that the polynomial C in the data filter is equal to the identified one. In an iterative scheme, from a step to another, it is supposed that C doesn't change significatively.

2.1. General iterative procedure

It is thus shown that criteria for control and identification can be reconciled simply by performing identification in closed loop and by using a proper data filter in the estimation. For other types of filter following the same main idea see [9]. A multi-step closed loop identification and control design procedure can be derived from these results, and it consists on the principal steps shown in the Fig. 1. For the first step, of the auto-calibration of a simple PID controller see [10].

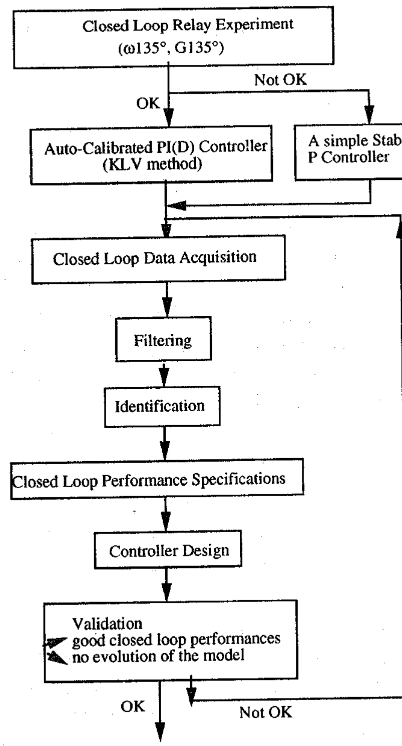

Figure 1: Multi-step closed loop identification and control design procedure

3. Control of the Air Heater Process

We are illustrating on a real system (air heater) the implementation of the proposed multi-step procedure.The functional diagram is shown in Fig. 2. The air is heated at the pipe input by means of an electrical resistor supplied by a power amplifier. The temperature of the air at the output is measured by a thermocouple. The objective is to control the air temperature at the output of the heater,and for this purpose, the model of the transfer between the temperature and the voltage applied to he resistor has to be identified.
The relay experiment and the identification/control scheme are implemented on a PC equiped with an I/O board. The programs that we use are the real-time ver-

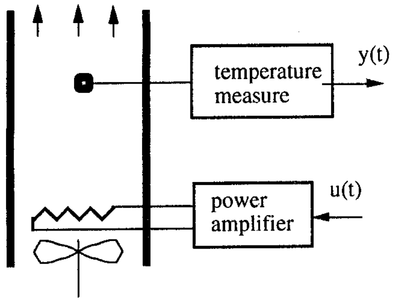

Figure 2: Functional diagram of the air heater

sion of SIMNON, PIM and PC-REG software. The closed loop relay experiment gives the frequency and the gain for a phase lag of $\angle\phi \approx -135°$: $G_{(135)} = 0.055$, $\omega_{135} = 0.647\frac{r}{s}$ and the KLV auto-calibration method can be then applied to find a primary PI controller ($K_p = 5.17$, $T_i = 7.10s$). A sampling period (for the next phase, of data acquisition and identification/control design) can also be chosen based on the bandwidth of this primary auto-calibrated closed loop ($0.076Hz$).
During the iterative procedure, at every step the closed loop specifications are maintained constant (the model bandwidth is fixed). The closed loop model is in the form of a continuous second order with a natural frequency ω_0, and a damping factor ξ. The values depend on the first identified model bandwidth.

From the considerations given in Section 2, the closed loop characteristic polynomial is $P = A_m$ and the data filter is $\frac{S}{A_m}$. After six iterations the retained model of the plant is a discrete second order:

$$G_p(q^{-1}) = \frac{q^{-1}(0.031 + 0.029q^{-1})}{(1 - 1.144q^{-1} + 0.283q^{-2})}$$

which has two real poles $p_1 = 0.36$ and $p_2 = 0.78$, and a steady state gain $G_0 = 0.4$. In fact, the identified model doesn't evoluate significatively after the second iteration, as it can be seen from Fig. 3 and 4. At every step, the controller is designed by the pole placement method, to meet the specifications given in the form of an equivalent continuous closed loop model of second order with a natural frequency of $\omega_0 = 0.4\frac{r}{s}$ and a damping factor $\xi = 0.9$. The step response is shown in Fig. 5.

For comparison purposes, the above technique was compared with a simple prefilter, that is, just to prefilter the data with a bandpass filter with passband covering the intended crossover frequency of the closed loop system. A 4th order Butterworth filter is used.The models obtained at the first iteration give oscillatory poles, which is far

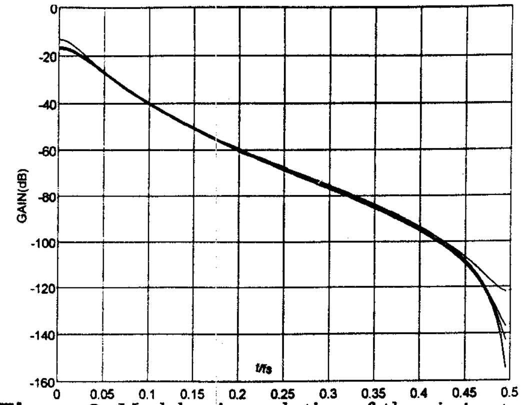

Figure 3: Model gain evolution of the air heater

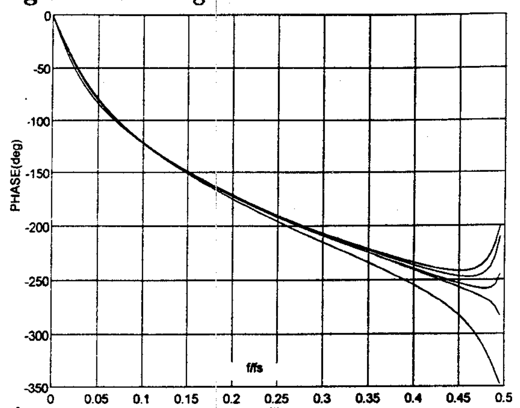

Figure 4: Model phase evolution of rthe air heater

from the reality, and a low steady state gain G_0. An open loop model of the plant is available in the form:

$$G_p(q^{-1}) = \frac{q^{-1}(0.067 + 0.076q^{-1})}{(1 - 1.057q^{-1} + 0.223q^{-2})}$$

which has two real poles $p_1 = 0.29$ and $p_2 = 0.76$, and a steady state gain $G_0 = 0.8$.

4. Control of the Feed Tank Pression

The multi-step closed loop identification and control design procedure is implemented on a loop from the Heating Company of Grenoble, precisely: the control of the feed tank pressure. The functional diagram of the process is shown in Fig. 6. The feed tank contains the water that is fed into the boilers, by means of 4 pumps. The pression in the tank has to be constant, at the reference value $p_r = 3.2psi$ (to maintain the thermodynamic equilibrum of the water, at a temperature suitable to eliminate the O_2). This pressure p is disturbed by the characteristics of every arrival component (turbine condensate, softened water, high pressure exchanger condensate). To regulate the pressure of the tank, a PID controller is used, which acts on

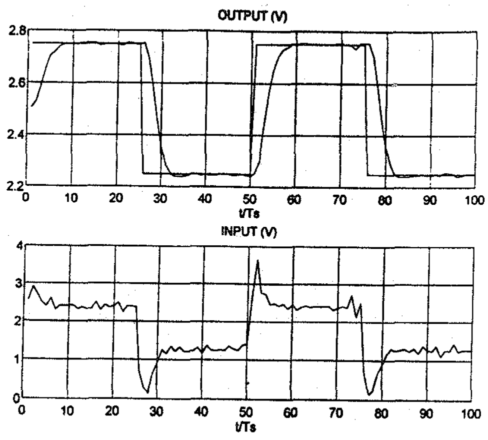

Figure 5: Step response of the air heater

the opening valve of the saturated steam (the control action u).

The task is to identify the transfer function between the pressure p of the tank and the opening valve, and then to regulate the pressure at the reference value $p_r = 3.2psi$. This value has to be maintained continuously, so the closed loop approach is necessary.

When applying the first step of the iterative procedure, the closed loop relay experiment, it doesn't succeed because of the too low gain of the process at ω_{135}, ($G_{(135)} = 0.048$), combined with the very low value of the nominal control signal (¡ 10controller is tuned (gain = 20) for the closed loop. The next step is the iterative scheme of identification and control design. The choice of the sampling period ($T_s = 2s$) is done considering closed loop performances (rise time of $20s$, no overshoot). The $PRBS$ signal is applied at the controller reference. It cannot be applied at the controller output because the operation conditions would make the total control signal u to reach its lowest saturation limit.

After the first iteration, a pole placement regulator is designed, and for the next iterations, the filter $\frac{SC}{A_m}$ is used for the acquisition data. The closed loop polynomial P is fixed (closed loop performance specifications).

The models obtained during the iterations are all of first order. After the second iteration it can be

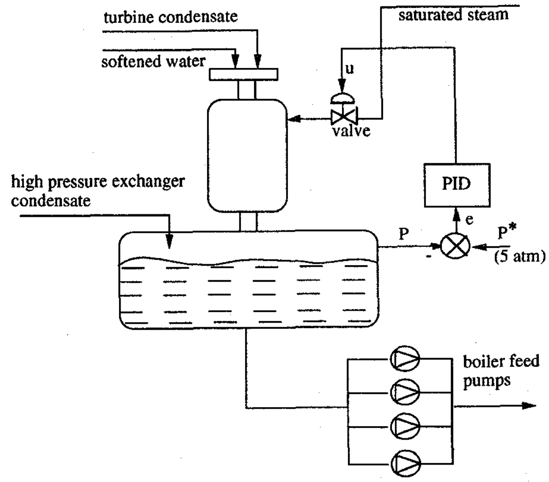

Figure 6: Functional diagram of the feed tank

considered that the identified pole of the model doesn't evoluate anymore. After the fourth iteration the frequency response of the model doesn't evoluate anymore (as it can be seen from Fig. 7 and 8, and the closed loop performances are very satisfactory at the sixth iteration. The final model of the plant is :

$$G_p(q^{-1}) = \frac{q^{-1}(0.002 + 0.003q^{-1})}{(1 - 0.903q^{-1})}$$

At every step, the controller is designed by the

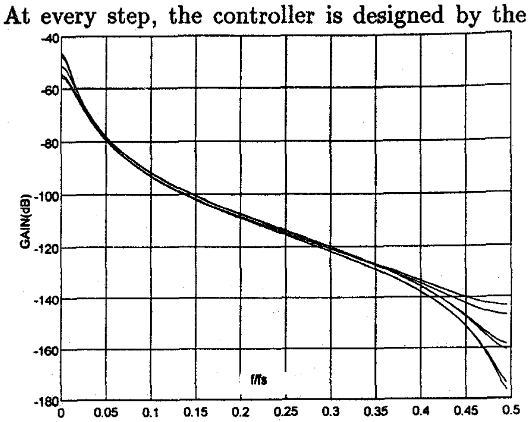

Figure 7: Model gain evolution of the feed tank pression

pole placement method, to meet the specifications given in the form of an equivalent continuous closed loop model of second order with a natural frequency of $\omega_0 = 0.4\frac{r}{s}$ and a damping factor $\xi = 0.9$. Finally, for the last identified model, a RST controller is applied, with performance specifications that are less pretentious ($\omega_0 = 0.1\frac{r}{s}$ so as

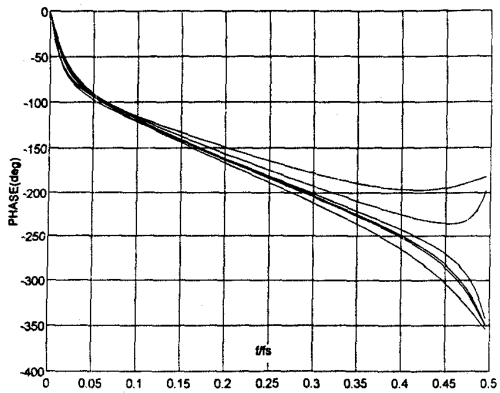

Figure 8: Model phase evolution of the tank pression

not to sollicitate too much the electro-valve). The step response of the closed loop with the RST is shown in Fig. 9. Notice that the specified performances are achieved: a rise time of $38s$, a specified one of $40s$.

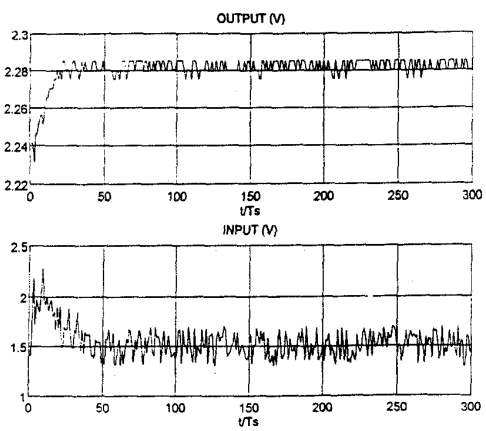

Figure 9: Step response of the feed tank pression

5. Conclusions

An iterative procedure for the combined design of the identification and control is tested. Each identification step uses the previously designed controller to obtain new data from the plant and to filter these dataand minimizes a filtered prediction error. The control performance error is expressed in the same terms as the prediction error, so as to make compatible the two criterions. Two examples give evidence of the utility of the multi-step procedure. The model of the plant doesn't evoluate in a significative fashion and good closed loop performances are obtained after the second iteration. A topic for future investigations is the use of other data filters and/or other control design methods.

References

[1] R. Schrama, "Accurate identification for control: the necessity of an iterative scheme", *IEEE Transactions on Automatic Control*, vol. 37, pp. 991–994, 1992.

[2] R.R. Bitmead Z. Zang and M. Gevers, "H_2 iterative model refinement and control robustness enhacement", *in 30th Conference on Decision and Control*, pp. 279–284, Brighton, U.K., Dec. 1991.

[3] R.L. Kosut W.S. Lee, B.D. Anderson and I.M.Y. Mareeels, "On adaptive robust control and control-relevant system identification", *in American Control Conf. (ACC)*, pp. 2834–2841, Chicago, USA, June 1992.

[4] K.J. Åström, "Matching criteria for control and identification", *in 2nd European Control Conference (ECC 93)*, Groningen, Netherlands, July 1993.

[5] M. Gevers, "Towards a joint design of identification and control", *in 2nd European Control Conference (ECC 93)*, Groningen, Netherlands, July 1993.

[6] B. Bitmead, "Iterative control design approaches", *in 12th IFAC World Congress*, Sydney, Australia, July 1993.

[7] I. D. Landau and A. A. Voda, "The 'Symmetrische Optimum' and the Auto-Calibration of PID controllers", *in IFAC Sympos. Adaptive Control Signal Processing (ACASP)*, pp. 287 – 292, Grenoble, France, July 1992.

[8] A. Voda and I. Landau, "A method for the auto-calibration of PID controllers", *Automatica*, vol. to appear.

[9] A. A. Voda and I. D. Landau, "Multi-step closed loop identification and control design procedure - applications", *in 10th IFAC Sympos. on System Identification (SYSID 94)*, Copenhagen, Denmark, July 1994.

[10] A. A. Voda and I. D. Landau, "Applications of the KLV method for the Auto-Calibration of PID controllers", *in 2nd IEEE Conference on Control Applications (CCA)*, pp. 829 – 834, Vancouver, British Columbia, Sep. 1993.