Algebraic approach to design and tuning of PI controllers for higher order systems.

Abstract: The contribution deals with control of continuous-time higher order SISO systems via PI controllers designed by technique derived from algebraic approach. The main principle is in approximation of higher order systems with first order systems and in design and tuning of robust enough PI controllers. The PI regulators are tuned by appropriate value of parameter m>0 to obtain fast control response without first overshooting for nominal system. The applicability of the method is illustrated on two simulation examples.

Key words: PI Controllers, Algebraic Approaches, Higher Order Systems, Diophantine Equations, Robust Control.

1. INTRODUCTION

The controllers of PID and especially PI type still play the fundamental role in area of control theory and applications. A large amount of tuning methods with their own specifications has been developed during such a long time of interest. However, simple setting rules are still valuable and desired.

An elegant and effective tool for control design is adopted from algebraic approach (Vidyasagar, 1985; Kucera, 1993; Prokop & Corriou, 1997). This technique is based on general solutions of diophantine equations in the ring of proper and Hurwitz stable rational functions ([R.sub.PS]), Youla-Kucera parameterization and conditions of divisibility. One of advantages of this approach is that behaviour of regulators can be influenced by only one scalar tuning parameter m>0. The important question is how to choose the appropriate m. The possible method is outlined in (Matusu & Prokop, 2005).

This contribution is focused on control of continuous-time higher order SISO systems via PI controllers. Higher order plants are approximated with first order ones, which are supposed as nominal systems and parameters of controllers are computed for them. Subsequently, designed and tuned regulators are used for original plants.

2. ALGEBRAIC CONTROL DESIGN

Suppose the well known general two-degree-of-freedom (2DOF) control configuration shown in Fig. 1. The traditional one-degree-of-freedom (1DOF) system can be obtained simply by putting R=Q.

[FIGURE 1 OMITTED]

The algebraic approach adopted from (Vidyasagar, 1985; Kucera, 1993) requires description of the systems in [R.sub.PS] as a ratio of two rational fractions:

G(s) = b(s)/a(s) = b(s)/[(s + m).sup.n]/a(s)/[(s+m).sup.n] = B(s)/A(s) (1)

where n = max {deg(a), deg(b)} and m > 0.

The fundamental task is to ensure internal stability of the closed-loop system in Fig. 1. All stabilizing feedback controllers are given by all solutions of the linear Diophantine equation:

AP + BQ = 1 (2)

with a general solution P=[P.sub.0]+BT, Q=[Q.sub.0]-AT; where T is free in [R.sub.PS] and [P.sub.0], [Q.sub.0] is a pair of particular solutions (Youla--Kucera parameterization of all stabilizing controllers). Details and proofs can be found in (Vidyasagar, 1985; Kucera, 1993). The analysis of the control error via condition of divisibility leads to the outcome that for asymptotic tracking [F.sub.w] must divide P for 1DOF. One of main advantages of the proposed technique is that controllers can be tuned by only one scalar parameter m>0.

The details, results and references for 2DOF configuration or for other control problems (disturbance rejection, disturbance attenuation, etc.) can be found e. g. in (Prokop & Corriou, 1997; Prokop, et al., 2002).

3. TUNING OF PI CONTROLLERS

From the methodology based on [R.sub.PS] representation follows the fact that controller parameters and control response can be simply tuned by a scalar parameter m>0. The question how to select or reject this parameter from the available set is very topical. The possible choice of m for 1DOF PI controller:

Q(s)/P(s) = [[??].sub.1]s + [[??].sub.0]/s; [[??].sub.1] = 2m - [a.sub.0]/[b.sub.0]; [[??].sub.0] = [m.sup.2]/[b.sub.0] (3)

stepwise reference signal, no disturbances and first order controlled system:

G(s) = [b.sub.0]/s + [a.sub.0] (4)

is proposed and analysed in (Matusu & Prokop, 2005). The result is that output signal with the same first undershoot or overshoot can be obtained if:

m/[a.sub.0] = (5)

where k is a constant.

The "optimal" choice of m seems to be if the response is as fast as possible but still without overshooting. For this case constant k from (5) equals to 1, thus:

m = [a.sub.0] (6)

The value of the parameter [b.sub.0] does not influence the choice of m>0. Putting (6) into (3) gives the "optimal" parameters of PI controller:

[[??].sub.1] = [a.sub.0]/[b.sub.0]; [[??].sub.0] = [a.sub.0.sup.2]/[b.sub.0] (7)

4. SIMULATIONS

Two higher order controlled systems given by transfer functions:

[G.sub.1P](s) = 1/[(s + 1).sup.3] (8)

[G.sub.2P](s) = 1/[(s + 1).sup.7] (9)

are supposed and simply approximated:

[G.sub.1N](s) = 1/3s + 1 = 0,[bar.3]/s + 0,[bar.3] (10)

[G.sub.2N](s) = 1/7s + 1 [??] 0,1429/s+0,1429 (11)

PI controllers tuned according to (7) computed for nominal systems (10) and (11) are described by transfer functions, respectively:

Q(s)/P(s) = s + 0,[bar.3]/s (12)

Q(s)/P(s) = s + 0,1429/s (13)

[FIGURE 2 OMITTED]

[FIGURE 3 OMITTED]

The following simulation conditions were used: reference signal 1 with step to 2 in 1/3 of simulation time and load disturbance 1 n = -in 2/3 of simulation time. The results of closed-loop control both for nominal and perturbed (higher order) systems are shown in Fig. 2 and Fig. 3. As can be seen, output signals seem to be acceptable for most common applications.

5. CONCLUSION

This contribution has been focused on control of continuous-time higher order SISO systems. The main idea is that higher order plants (perturbed, really controlled) are approximated with first order systems (nominal), PI controllers are designed and tuned for nominal systems and subsequently used to control the original ones. Two simulation examples with third and seventh order systems have been shown. The simulations have been done in Matlab + Simulink program environment.

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