Journal of ELECTRICAL ENGINEERING, VOL. 52, NO. 9-10, 2001, 273–277

DESIGN OF ROBUST OUTPUT FEEDBACK CONTROLLER VIA LMI APPROACH

Vojtech Veselý * — **Alena Kozáková** *
Demetrios P. Papadopoulos **

In this paper, the linear matrix inequality (LMI) conditions for output feedback control problems are presented. The underlying theory is based upon the necessary and sufficient conditions for static output feedback quadratic stabilizability of continuous time-invariant polytopic systems. The proposed two computationally simple LMI-based algorithms (the V-K iterative and non-iterative one) are tightly connected with the Lyapunov stability theory and the LQR state feedback design.

K e y w o r d s: LMI conditions, robust output feedback stabilization, polytopic systems, guaranteed cost

1 INTRODUCTION

One of the most frequently mentioned open problems in the control theory is the robust output feedback stabilization problem (ROFSP). Various approaches have been used so far to study the two aspects of the stabilization problem, namely the conditions under which a linear system described in the state-space can be stabilized via output feedback, and the respective procedure to obtain a robust stabilizing controller. The authors of the hitherto results surveyed in [1, 2, 3, 4, 5, 6, 8, 9, 10, 11] and references therein basically conclude that despite the availability of many approaches and numerical algorithms, the ROFSP is still open. The necessary and sufficient conditions for output feedback stabilizability of linear time-invariant continuous-time and discrete-time systems are given in [5] and [12], respectively. However, the results given in these two papers are existential and do not solve the computational aspects of the problem. Recently it has been shown that an extremely wide range of output feedback controller design problems can be reduced to the problem of finding a feasible point under a Biaffine Matrix Inequality (BMI) constraint. However, it is well-known that the BMI problems are NP-hard [13]. The concept of NP completeness is related to the impossibility of finding a polynomial time algorithm for the problem in question. Therefore it is rather unlike that for NP-complete and NP-hard problems there is a polynomial time solution procedure. It has been shown [13] that simultaneous stabilization via static output feedback is a NP-hard problem, namely, given N plants, the problem of checking the existence of a static gain matrix F which stabilizes all the N plants, is NP-hard.

In this paper, the BMI problem of the output feedback controller design has been reduced to a linear matrix inequalities (LMI's) problem. The LMI theory has been used for output feedback controller design in [1, 3, 8]. Most of these works present iterative algorithms. The LMI based V-K iteration algorithm proposed in [4] is based on an alternative solution of two convex LMI optimization problems obtained by fixing the Lyapunov matrix or the gain controller matrix. This algorithm is guaranteed to converge, however not necessarily, to the global optimum.

Two computationally simple LMI-based algorithms for the design of robust static output feedback control of linear continuous-time systems are presented. Both proposed algorithms are LMI-based, the first one applying the V-K iteration and the second one a non-iterative procedure. The paper is organized as follows. In Section 2, problem formulation and some preliminary results are presented. The main results are given in Section 3. In Section 4, they are applied to some examples.

2 PROBLEM FORMULATION

Consider the simultaneous stabilization of a plant G described as follows:

$$
\begin{aligned}
G: \qquad \dot{x} &= \sum_{i=1}^{N} \alpha_i (\mathsf{A}_i \boldsymbol{x} + \mathsf{B}_i \boldsymbol{u}) \quad \boldsymbol{y} = \mathsf{C}_i \boldsymbol{x} \\
\sum_{i=1}^{N} \alpha_i &= 1 \quad \text{for } \alpha_i \in \langle 0, 1 \rangle \text{ and } i = 1, 2, \dots, N
\end{aligned}
\tag{1}
$$

where the state $\mathbf{x} \in R^n$, the input $\boldsymbol{u} \in R^m$, the output $\boldsymbol{y} \in R^l$ and n is the order of G.

The problem dealt with in this paper can be formulated as follows. For a continuous linear time invariant

* Slovak University of Technology, Faculty of Electrical Engineering and Information Technology, Dept. of Automatic Control Systems, Ilkovičova 3, 812 19 Bratislava, Slovakia, E-mail: vesely@kasr.elf.stuba.sk

** Democritos University of Thrace, Department of Electrical Engineering, Xanthi, Greece

ISSN 1335-3632

system described by (1) a robust static output feedback controller is to be designed with the control algorithm in the form

$$\boldsymbol{u} = \mathbf{FC}\boldsymbol{x} \tag{2}$$

such that the closed loop system

$$\dot{\boldsymbol{x}} = \sum_{i=1}^{N} \alpha_i(\mathbf{A}_i\boldsymbol{x} + \mathbf{B}_i\mathbf{FC}_i)\boldsymbol{x} = \sum_{i=1}^{N} \alpha_i \mathbf{A}_{Ci}\boldsymbol{x} \tag{3}$$
$$\mathbf{A}_{Ci} = \mathbf{A}_i + \mathbf{B}_i\mathbf{FC}_i$$

is stable. The cost function associated with the system (1) is

$$\mathbf{J} = \int_0^\infty \big(\boldsymbol{x}^\top\mathbf{Q}\boldsymbol{x} + \boldsymbol{u}^\top\mathbf{R}\boldsymbol{u}\big)\mathrm{d}t \tag{4}$$

where $\mathbf{Q} = \mathbf{Q}^\top \geq 0$ and $\mathbf{R} = \mathbf{R}^\top > 0$ are matrices of compatible dimensions.

Definition. Consider the uncertain system (1). If there exists a control law u^* and a positive scalar J^* such that for all admissible uncertainties the closed-loop system is stable and the cost function (4) satisfies $J \leq J^*$, then J^* is said to be guaranteed cost and u^* is said to be guaranteed cost control law for the uncertain system (1).

The following Lemma is well known.

Lemma 1. *Suppose* $\mathbf{P} > 0$ *to be a solution to the Lyapunov matrix equation*

$$\mathbf{A}^\top\mathbf{P} + \mathbf{PA} + \mathbf{Q} = 0\,. \tag{5}$$

Then $\mathbf{A}$ *is stable if and only if* $\mathbf{Q} > 0$.
If such $\mathbf{P}$ and $\mathbf{Q}$ exist, the matrix $\mathbf{A}$ is said to be quadratically stable.

Corollary 1. *The closed-loop system* (3) *is quadratically stable if and only if there exists a positive definite matrix* $\mathbf{P} > 0$ *such that the following inequalities hold*

$$\mathbf{A}_{ci}^\top\mathbf{P} + \mathbf{PA}_{ci} < 0\,, \quad i = 1, 2, \dots, N\,. \tag{6}$$

The system described by (1) is a polytope of linear systems. With respect to Corollary 1, it can be described by a list of its vertices, *ie*

$$\{(A_1, B_1, C_1), (A_2, B_2, C_1), \dots, (A_N, B_N, C_1)\}\,. \tag{7}$$

3 ROBUST OUTPUT FEEDBACK CONTROLLER DESIGN

The main results are summarized in the following theorem.

Theorem 1. *Consider the linear uncertain system* (1). *Then, the following statements are equivalent:*
- *the system* (1) *is robust static output feedback quadratically stabilizable.*
- *there exist a positive definite matrix* $\mathbf{P} = \mathbf{P}^\top > 0$ *and a matrix* $\mathbf{F}$ *satisfying the following matrix inequality*

$$(\mathbf{A}_i + \mathbf{B}_i\mathbf{FC})^\top\mathbf{P} + \mathbf{P}(\mathbf{A}_i + \mathbf{B}_i\mathbf{FC}) < 0\,, \quad i = 1, 2, \dots, N \tag{8}$$

Theorem 2. *Consider the system* (7). *The following statements are equivalent:*
- *The system* (7) *is static output feedback simultaneously stabilizable with a guaranteed cost*

$$\int_0^\infty \big(\boldsymbol{x}^\top\mathbf{Q}\boldsymbol{x} + \boldsymbol{u}^\top\mathbf{R}\boldsymbol{u}\big)dt \leq \boldsymbol{x}_0^\top\mathbf{P}\boldsymbol{x}_0 = \mathbf{J}^* \tag{9}$$

  and $\mathbf{P} > 0$.
- *There exist matrices* $\mathbf{P} > 0$, $\mathbf{Q} > 0$, $\mathbf{R} > 0$ *and a matrix* $\mathbf{F}$ *such that the following inequalities hold*

$$(\mathbf{A}_i + \mathbf{B}_i\mathbf{FC})^\top\mathbf{P} + \mathbf{P}(\mathbf{A}_i + \mathbf{B}_i\mathbf{FC}) + \mathbf{Q} + \mathbf{C}^\top\mathbf{F}^\top\mathbf{RFC} \leq 0\,, \quad i = 1, \dots, N\,. \tag{10}$$

- *There exist matrices* $\mathbf{P} > 0$, $\mathbf{Q} > 0$, $\mathbf{R} > 0$ *and a matrix* $\mathbf{F}$ *such that the following inequalities hold*

$$\mathbf{A}_i^\top\mathbf{P} + \mathbf{PA}_i - \mathbf{PB}_i\mathbf{R}^{-1}\mathbf{B}_i\mathbf{P} + \mathbf{Q} \leq 0 \tag{11}$$
$$(\mathbf{B}_i^\top\mathbf{P} + \mathbf{RFC})\Phi_{u_i}^{-1}(\mathbf{B}_i^\top\mathbf{P} + \mathbf{RFC})^\top - \mathbf{R} \leq 0 \tag{12}$$

  where

$$\Phi_{u_i} = -(\mathbf{A}_i^\top\mathbf{P} + \mathbf{PA}_i - \mathbf{PB}_i\mathbf{R}^{-1}\mathbf{B}_i^\top\mathbf{P} + \mathbf{Q})\,, \quad i = 1, \dots, N\,.$$

For system (7) theorems 1 and 2 yield the following two design procedures (A, B) for a simultaneous static output feedback stabilization with a guaranteed cost of the system (7).

Procedure A (iterative algorithm)

1. $j = 1$, $\mathbf{F}_0 = 0$.
2. Compute $\mathbf{P}_j = \mathbf{P}_j^\top > 0$ from the following inequality using the LMI-based algorithm

$$(\mathbf{A}_i + \mathbf{B}_i\mathbf{FC})^\top\mathbf{P}_j + \mathbf{P}_j(\mathbf{A}_i + \mathbf{B}_i\mathbf{FC}) + \mathbf{Q} + \mathbf{C}^\top\mathbf{F}_{j-1}^\top\mathbf{RF}_{j-1}\mathbf{C} \leq 0\,,\ i = 1, \dots, N\,, \quad \mathbf{P}_j > 0\,, \quad \mathbf{P}_j \leq \rho\mathbf{I}$$

   where ρ is some positive constant and $\mathbf{I}$ is the identity matrix.
3. Compute the matrix $\mathbf{F}_j$ using the LMI-based algorithm from the following inequality

$$\begin{bmatrix} (\mathbf{A}_i + \mathbf{B}_i\mathbf{F}_j\mathbf{C})^\top\mathbf{P}_j + \mathbf{P}_j(\mathbf{A}_i + \mathbf{B}_i\mathbf{F}_j\mathbf{C}) + \mathbf{Q} & \mathbf{C}^\top\mathbf{F}_j^\top\mathbf{R} \\ \mathbf{RF}_j\mathbf{C} & -\mathbf{R} \end{bmatrix} \leq 0\,. \tag{13}$$

4. Compute er $= \|\mathbf{F}_j - \mathbf{F}_{j-1}\|$. If er<error then stop, otherwise go to Step 2

In Step 2, ρ can be minimized and in Step 3, also a bound can be imposed on the norm of the controller matrix requiring

$$\mathbf{F}^\top \mathbf{F} < \mathbf{F}_{\max} .$$

Table 1. Computation results obtained using Procedures A and B

No	r	q	ρ	γ	MaxEig	
					Procedure A	Procedure B
1	1	1	$1/\gamma$	0.01	−0.0256	0.1984
2	1	5	$1/\gamma$	0.001	−0.0518	0.7266
3	1	5	$1/\gamma$	0.01	0.285	−0.1349
4	1	10	$1/\gamma$	0.001	−0.0496	1.2416
5	1	10^{-7}	$1/\gamma$	0.001	−0.0029	-3.614×10^{-4}
6	1	1	10^6	0.03	−0.0207	−0.0484
7	1	1	10^6	0.03	−0.2543	−0.1689
8	1	0.01	10^6	0.03	−0.0198	−0.0152
9	1	0.0001	10^6	0.03	−0.0205	−0.0132
10	2	1	10^6	0.03	−0.0209	−0.047
11	5	1	10^6	0.03	−0.0207	−0.0162
12	10	1	10^6	0.03	−0.0247	−0.055
13	10	1	10^3	0.03	−0.0331	−0.055
14	1	1	10^4	0.03	−0.0231	−0.0484

Procedure B (non-iterative algorithm):

1. Compute $\mathbf{S} = \mathbf{S}^\top > 0$ from the following inequality using the LMI based algorithm

$$\begin{bmatrix} \mathbf{S}\mathbf{A}_i^\top + \mathbf{A}_i\mathbf{S} - \mathbf{B}_i\mathbf{R}^{-1}\mathbf{B}_i^\top & \mathbf{S}\mathbf{Q} \\ \mathbf{Q}\mathbf{S} & -\mathbf{Q} \end{bmatrix} < 0 \qquad \gamma < \mathbf{S}, \quad i = 1, \dots, N \tag{14}$$

where $\gamma \geq 0$ is some non-negative constant and $\mathbf{S} = \mathbf{P}^{-1}$.

2. Compute $\mathbf{F}$ from the following inequality using the LMI based algorithm

$$\begin{bmatrix} -\mathbf{R} & \mathbf{B}_i^\top \mathbf{P} + \mathbf{R}\mathbf{F}\mathbf{C} \\ (\mathbf{B}_i^\top \mathbf{P} + \mathbf{R}\mathbf{F}\mathbf{C})^\top & -\Phi_{u_i} \end{bmatrix} < 0 \qquad i = 1, \dots, N . \tag{15}$$

In the Step 1, γ can be maximized and in the Step 2, a norm bound can be imposed on the static output feedback $\mathbf{F}$. If the solution results (12)–(15) are not feasible, either the system (7) is not stabilizable with a prescribed guaranteed cost, or it is necessary to change $\mathbf{Q}$, $\mathbf{R}$, ρ and γ in order to find a feasible solution. If the solution (12)–(15) is feasible then $\boldsymbol{u} = \mathbf{F}\boldsymbol{y}$ is the guaranteed cost control law and

$$\mathbf{J}^* = \mathbf{x}_0^\top \mathbf{P} \mathbf{x}_0 \geq \int_0^t (\boldsymbol{x}^\top \mathbf{Q} \boldsymbol{x} + \boldsymbol{u}^\top \mathbf{R} \boldsymbol{u}) \mathrm{d}t$$

is said to be a guaranteed cost.

4 EXAMPLES

EXAMPLE 1.

To illustrate the two proposed approaches, consider the design of a PI controller to control the speed of a small DC motor. A continuous-time model of the DC motor is as follows:

$$\begin{aligned} \mathbf{A}_i &= \mathbf{A}_0 + \varepsilon_1 \mathbf{A}_{V1} + \varepsilon_2 \mathbf{A}_{V2} \\ \mathbf{B}_i &= \mathbf{B}_0 + \varepsilon_1 \mathbf{B}_{V1} + \varepsilon_2 \mathbf{B}_{V2} \end{aligned} \qquad i = 1, \dots, 4 \tag{16}$$

where

$$\mathbf{A}_0 = \begin{bmatrix} -0.9235 & 1 & 0 \\ -0.2363 & 0 & 0 \\ 1 & 0 & 0 \end{bmatrix}, \quad \mathbf{B}_0 = \begin{bmatrix} 0 \\ 0.4221 \\ 0 \end{bmatrix}, \quad \mathbf{C} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

$$\mathbf{A}_{V1} = \begin{bmatrix} 0.11 & 0 & 0 \\ -0.0172 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \qquad \mathbf{B}_{V1} = \begin{bmatrix} 0 \\ -0.0529 \\ 0 \end{bmatrix},$$

$$\mathbf{A}_{V2} = \begin{bmatrix} -0.4065 & 0 & 0 \\ -0.06433 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}, \qquad \mathbf{B}_{V2} = \begin{bmatrix} 0 \\ 0.2522 \\ 0 \end{bmatrix}.$$

$$\varepsilon_i \in \langle \underline{\varepsilon}_i, \overline{\varepsilon}_i \rangle, \quad i = 1, 2, \quad |\varepsilon_i| = 1 .$$

According to (7), there are 4 polytope systems which vertices are computed for different permutations of the two variables ε_i, $i = 1, 2$ considered alternatively at their maximum and minimum, *ie*

$$\begin{aligned} \mathbf{A}_1 &= \mathbf{A}_0 + \underline{\varepsilon}_1 \mathbf{A}_{V1} + \underline{\varepsilon}_2 \mathbf{A}_{V2} , \\ \mathbf{A}_2 &= \mathbf{A}_0 + \underline{\varepsilon}_1 \mathbf{A}_{V1} + \overline{\varepsilon}_2 \mathbf{A}_{V2} , \\ \mathbf{A}_3 &= \mathbf{A}_0 + \overline{\varepsilon}_1 \mathbf{A}_{V1} + \underline{\varepsilon}_2 \mathbf{A}_{V2} , \\ \mathbf{A}_4 &= \mathbf{A}_0 + \overline{\varepsilon}_1 \mathbf{A}_{V1} + \overline{\varepsilon}_2 \mathbf{A}_{V2} . \end{aligned} \tag{17}$$

Expressions for $\mathbf{B}_1$ through $\mathbf{B}_2$ have been obtained by analogy. The computation results are given in Tab. 1 where $\mathbf{Q} = \mathbf{I}q$, $\mathbf{R} = \mathbf{I}r$, $\varepsilon_1 = \varepsilon_2 = 1$. MaxEig denotes the maximum real part of closed loop eigenvalues considering all 4 polytopic systems.

According to Tab. 1, for the results in the row 3 obtained using the algorithm B (*ie* 3/B), (similarly 7/A and 7/B), the computed gain matrices $\mathbf{F}$ are as follows

$$\begin{aligned} &3/\mathrm{B}: \ \mathbf{F} = [-4.8696 \ \ -0.8469] \\ &7/\mathrm{A}: \ \mathbf{F} = [-2.2403 \ \ -0.6094] \\ &7/\mathrm{B}: \ \mathbf{F} = [-0.0544 \ \ -0.0852] \end{aligned}$$

In addition, Tab. 1 implies that:

1. the robust static output feedback controller design is NP-hard,
2. choice of ρ and γ in general changes the design results (see items 1, 2, 3, 6, 12, 13),
3. there are local solutions to the LMI optimization (see items 10, 11, 12).

The transfer function pertinent to the polytopic system (16) is

$$G(s) = \big(0.4229 + \varepsilon_1(-0.0529) + \varepsilon_2(0.2522)\big) \big/ \big(s^2 + 0.9235s + 0.2363 + \varepsilon_1(0.11s - 0.0172) + \varepsilon_2(-0.4065s - 0.0643)\big)\,.$$

Results of the frequency domain PI controller design are

$$F_{R1}(s) = \frac{2.5s + .5}{s} \qquad \text{with MaxEig} = -0.111 \text{ or}$$
$$F_{R2}(s) = \frac{4.87s + 0.85}{s} \qquad \text{with MaxEig} = -0.12\,.$$

Bode plots of the uncertain system without and with the PI controller F_{R2} are given in Fig. 1.

EXAMPLE 2.

The second example deals with the robust controller design for a linearized power system. Numerical parameter values of the linearized model of a synchronous generator with exciter and the operating point (per units on generator rating) have been taken from [14]. The polytopic system has been obtained according to (16) where

$$\mathbf{A}_0 = 10^3 \times \begin{bmatrix} 0.0403 & -0.04 & -0.0093 & 0.0377 & -0.0001 & 0.0163 & -0.0409 & -0.0061 \\ 0.0602 & -0.0797 & -0.0215 & 0.0746 & -0.0001 & 2.8733 & -0.06 & -0.0147 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 1.2085 & -1.0788 & -0.1958 & 0.961 & -0.0014 & 0.0112 & -1.0795 & -0.1646 \\ -0.3021 & 0.2895 & -0.0226 & -0.3533 & 0.0007 & 0.0043 & 0.2892 & 0.0106 \\ 0 & 0 & 0 & 0 & 0 & -0.0021 & 0 & 0 \\ 0.9688 & -1.1518 & -0.3461 & 1.201 & -0.0014 & -2.8454 & -1.1733 & -0.2366 \\ 0.6006 & 0.063 & 0.2872 & -0.3979 & -0.0002 & -0.0085 & 0.0635 & 0.1268 \end{bmatrix}$$

$$\mathbf{B}_0^\top = \begin{bmatrix} 0 & 0 & 0 & 0 & 1.9896 & 0 & 0 & 0 \\ 0.2 & 669 & 0 & 0 & 110 & 0 & 0 & 0 \end{bmatrix}$$

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix}$$

$$\boldsymbol{x}^\top = [v_t \; i_{fd} \; \delta \; i_t \; \omega \; v_{fd} \; i_{kd} \; i_{kq}]$$
$$\boldsymbol{y}^\top = [v_t \; i_{fd} \; \delta \; i_t] \qquad \boldsymbol{u}^\top = [\Delta v_i \;\; \Delta P_m]$$

$$\mathbf{A}_1 = 0.1\mathbf{A}_0 \mathbf{B}_1 = 0.1\mathbf{B}_0 \qquad \varepsilon_1 = 1,\ \varepsilon_2 = 0$$
$$\mathbf{Q} = 10^{-5}\mathbf{I} \qquad \mathbf{R} = \mathbf{I}$$

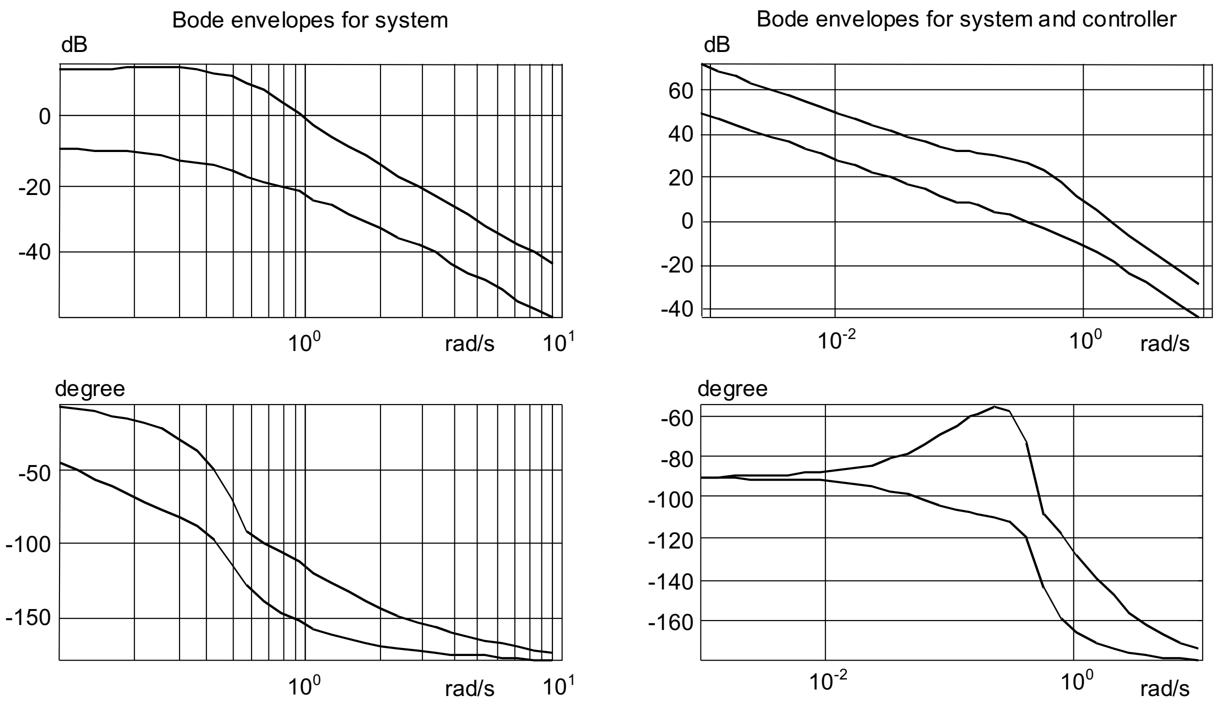

Fig. 1. Bode plot of the uncertain system and of the uncertain system under the PI controller F_{R2}.

Computation results obtained via Procedure A:

$$\mathbf{F} = \begin{bmatrix} -15.9037 & -2.6736 & -25.3321 & 0.7755 \\ -1.2949 & 0.1602 & 0.8665 & 1.6986 \end{bmatrix}$$

$\mathrm{MaxEig} = -1.6952$

Guaranteed cost:

$$\mathbf{J}^* = \int_0^\infty \left[\mathbf{x}^\top(\mathbf{Q} + \mathbf{C}^\top \mathbf{F}^\top \mathbf{RFC})\mathbf{x}\right] \mathrm{d}t \le 9.1069 \times 10^3 \|x_0\|^2$$

Computation results obtained via Procedure B

$$\mathbf{F} = \begin{bmatrix} -0.0087 & -0.0196 & -0.0414 & -0.0106 \\ -0.068 & 0.0089 & -0.1028 & -0.0057 \end{bmatrix}$$

$\mathrm{MaxEig} = -0.8669$

Guaranteed cost:

$$\mathbf{J}^* = \int_0^\infty \left[\mathbf{x}^\top(\mathbf{Q} + \mathbf{C}^\top \mathbf{F}^\top \mathbf{RFC})\mathbf{x}\right] \mathrm{d}t \le 624.9463 \|x_0\|^2$$

5 CONCLUSION

In this paper, new procedures for the robust control design via static output feedback for linear continuous-time system have been proposed. The first procedure (Algorithm A) applies the LMI-based V-K iteration whilst the second procedure (Algorithm B) uses a non-iterative LMI approach.

Both proposed algorithms are computationally simple.

References

[1] BENTON, R.E.—SMITH, D. : A Non-Iterative LMI-Based Algorithm for Robust Static Output Feedback Stabilization, International Journal of Control **72** No. 14 (1999), 1322–1330.

[2] GOH, K.C.—SAFONOV, M.G.—LY, J.H. : Robust Synthesis via Bilinear Matrix Inequalities., Int. Journal of Robust and Nonlinear Control **6** (1996), 1079–1095.

[3] CRUSINS, A.R.—TROFINO, A. : Sufficient LMI Conditions for Output Feedback Control Problems, IEEE Trans. on AC **44** (1999), 1053–1057.

[4] EL GHAOUI, L.—BALAKRISHNEN, V. : Synthesis of Fixed Structure Controller via Numerical Optimization, In Proc. of the 33rd Conf. on Decision and Control, Lake Buena Vista, FL — December 1994, pp. 2678-2683.

[5] KUČERA, V.—DE SOUZA, C.E. : A necessary and Sufficient Condition for Output Feedback Stabilizability, Automatica **31** No. 9 (1995), 1357–1359.

[6] MEHDI, D.—AL HAMID, M.—PERRIN, F. : Robustness and Optimality of Linear Quadratic Controller for Uncertain Systems, Automatica **32** No. 7 (1996), 1081–1083.

[7] PROKOP, R.—CORRIOU, J.P. : Design and Analysis of Simple Robust Controllers, Int. Journal of Control **66** No. 6 (1987), 905–921.

[8] CAO, Y.Y.—SUN, Y.X. : Static Output Feedback Simultaneous Stabilization via LMI Approach, Int. Journal of Control **70** No. 5 (1998), 803–814.

[9] KROKAVEC, D.—FILASOVÁ, A. : Unmatched Uncertainties in Robust LQ Control, In 3rd IFAC Conference ROCOND, Prague, June 21–28, 2000, PNo.65.

[10] KACHAŇÁK, A.—KRBAŤA, R.—BELANSÝ, J. : Design of μ Optimal Robust Controller for a Thermoplastic Process, In 3rd IFAC Conference ROCOND, Prague, June 21–28, 2000, PNo54.

[11] VESELÝ, V. : Output Robust Controller Design for Linear Parametric Uncertain Systems, In 3rd IFAC Conference ROCOND, Prague, June 21–28, 2000, EUR-22.

[12] ROSINOVÁ, D.—VESELÝ, V.—KUČERA, V. : A Necessary and Sufficient Condition for Output Feedback Stabilizability of Linear Discrete-Time Systems, In IFAC Conf. Control Systems Design, Bratislava, Slovak Republic, 2000, pp. 164–167.

[13] TOKER, O.—ŐZBAY, H : On the NP-Hardness of Solving Bilinear Matrix Inequalities and Simultaneous Stabilization with Static Output Feedback, In Proc. of the American Control Conference, Seattle, Washington, June 1995, pp. 2525–2526.

[14] PAPADOPOULOS, D.P.—BANDEKAS, D.V. : Enhancement of Synchronous Generator Dynamic Stability Characteristics with Output Feedback, Acta Techn. SAV, **40** (1995), 103–117.

Received 9 May 2001

Vojtech Veselý (Prof, Ing, DrSc) was born in 1940. Since 1964 he has been working at the Department of Automatic Control Systems at the Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, where he has supervised up today 13 CSc (PhD) students. Since 1986 he has been Full Professor. His research intersets include the areas of power control, decentralized control of large-scale systems, process control and optimization. Prof Vesel spent several study and research visits in England, Russia, Bulgaria. He is author of more than 130 scientific papers.

Alena Kozáková (Ing, PhD) graduated from the Faculty of Electrical Engineering and Information Technology, Slovak University of Technology (FEI STU) in 1985 and received her PhD in Technical Cybernetics in 1998. Since 1985 she has been with the Department of Automatic Control Systems, FEI STU. Within her research and teaching activities she focuses on robust and optimal control.

Demetrios P. Papadopoulos (1942) received the degrees BSEF (1965), MS (1968) and PhD (1970) in Electrical Engineering from Marquette University, Milwaukee-Wisconsin/USA. During 1970 to 1972 he was an Assistant Professor at the Department of Electrical Engineering of Gonzaga University Spokane-Washington/USA. From 1972 and up to this time he is with the Public Power Corporation of Greece, working on special projects of power systems. Since 1981 he is a Professor and Director of the Electrical Machines Laboratory of the Department of Electrical Engineering at Democritos University of Thrace (DUT). From 1987–1988 he served as a Vice-Rector at DUT and from 1989–1991 as a General Secretary of the Eastern Macedonia and Thrace Region of Greece. He is a Senior Member of IEEE, Member of the Technical Chamber of Greece, and also of the societies ΠΜΕ, ΤΒΠ, HKN and ΣΧ. His research interests are in electrical machines and power systems area.