# **ROBUST QUADRATIC STABILITY AND STABILIZATION WITH INTEGRITY FOR UNCERTAIN DISCRETE SINGULAR SYSTEMS**\*

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## Yao Bo, Zhang Qing-Ling, Chen Yue-Peng

College of Science, Northeastern University Shenyang, Liaoning 110004, P.R.of China

**Abstract**. In this paper, the problems of robust quadratic stability and stabilization with integrity are explored for uncertain discrete singular systems using algebraic Riccati inequalities. Sufficient conditions for the quadratic stability and stabilization by state feedback are given. The state feedback control law is so designed that it keeps the resultant closed loop system be quadratically stable when system actuators are at fault, i.e. the system possesses integrity. A numerical example is presented to illustrate the results.

Key Words: Integrity, Quadratic Stabilization, Uncertain Discrete Singular System, Actuator

### 1. INTRODUCTION

Singular systems are dynamical in the sense of being governed by a mixture of algebraic and differential equations. In that sense, the algebraic equations represent the constraints to the solution of the differential part.

These systems are also known as descriptor, semi-state and generalized systems. In the recent years, there has been a great interest in the study of singular systems due to their large application in many fields such as electrical networks, economic systems, and biochemical engineering systems [1, 2]. The complex nature of such systems causes many difficulties in analytical and numerical treatments of the singular system, particularly when there is a need for their control. Therefore, the question of their stability deserves great attention. Many results for example Bajic, Campbell, Lewis, Owens, Debeljkovic, Takaba, Zhang et al. concerning the stability of a particular class of these systems, operating in free as well in forced regimes, in the sense of Lyapunov, are presented as the ba-

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sis for their high quality dynamical investigation [1-11], especially the topics related to robust control. In these results some kinds of uncertainties are assumed and characterized by norms and structures. Sometimes, the systems may be of unsatisfactory performance or even unstable when the control component fails. This type of failure is unavoidable in controlling a physical model since the component will be out of order at some stage of its life. It is necessary to take it as a kind of uncertainty and study how to control the systems efficiently when the failure really happens. This kind of control is called fault tolerant control, which is well understood in normal systems [12, 13].

Few articles have appeared so far that discuss the problem of fault tolerant control for singular systems [14-18]. It is more complicated since singular systems may possess impulsive (causality) behaviors. Chen et al. studied the fault tolerant control for continuous singular systems and gave some results for integrity property of continuous singular systems [15, 16, and 18]. Zhang et al. also studied design of circular pole assignment controller with integrity for singular systems.

Integrity property is one of fault-tolerant properties of either normal or singular systems [17]. The systems are said to have integrity if the systems preserve the stability in the presence of system component failures.

In this paper, we discuss the fault tolerant control problem of uncertain discrete singular systems in the case of system actuator failure. First we investigate the quadratic stability and stabilizability of uncertain discrete singular systems by Lyapunov method. The stability is related to norm, which can be characterized via Riccati equations or inequalities. This provides a convenient way of solving the problems by LMI toolbox. Then after describing the system actuator failures mathematically, we give the key result in this paper about fault tolerant control of uncertain discrete singular systems. We design an integrity controller by solving Riccati inequalities. An example is presented to illustrate the results obtained in this paper.

The outline of this paper is as follows: In section 2 the system and the problem are formulated. Then the quadratic stability and stabilizability are investigated by means of Riccati inequalities in section 3. The fault tolerant control problem is discussed in section 4 and in section 5 an example is presented to illustrate the results.

### SYSTEM DESCRIPTION AND PROBLEM FORMULATION

Consider an uncertain discrete time singular system given by

$$Ex(k+1) = (A + \Delta A)x(k) \tag{1}$$

where  $x(k) \in \mathbb{R}^n$  is the state variable. E and A are constant matrices of appropriate dimensions, respectively. Usually *rank*  $[E] \le n$ . The time-varying parameter uncertainty  $\Delta A \in \mathbb{R}^{n \times n}$  is a real matrix function of the form:

$$\Delta A = DF(k)G\tag{2}$$

where *D* and *G* are constant matrices of appropriate dimensions, and F(k) is an uncertain matrix satisfying  $F^{T}(k)F(k) \leq I$ . Without loss of generality, we assume that matrix D is of full column rank.

In this paper, we will first discuss the quadratic stability and stabilizability of discrete singular systems and then investigate the fault tolerant control problem.

To begin the work we define Lyapunov function as

$$v(Ex(t)) = x^{T}(t)E^{T}VEx(t)$$
(3)

where  $V \in \mathbb{R}^{v \times n}$ ; v > 0, if  $Ex(t) \neq 0$ . The difference between the two states is

$$\Delta(v) = x^{T}(k)((A + \Delta A)^{T}V(A + \Delta A) - E^{T}VE)x(k)$$

For quadratic stability of singular systems, we have the following definition.

**Definition 1:** An uncertain discrete singular system (1) is said to be quadratically stable if there exists a nonsingular symmetric matrix V and a constant  $\alpha > 0$  so as that the following inequalities hold:

$$\Delta(v) = x^T(k)((A + \Delta A)^T V(A + \Delta A) - E^T V E)x(k)^2 \le -\alpha ||x(k)||^2, \ \forall x(t) \in \mathbb{R}^n$$
(4)

$$E^T V E \ge 0 \tag{5}$$

Obviously, when the discrete singular system (1) is quadratically stable, it is regular, stable and causal.

According to (1) and (2), we construct the following discrete singular system with output feedback control law as

$$Ex(k+1) = Ax(k) + Dw(k)$$
$$z(k) = Gx(k)$$
(6)
$$w(k) = F(k)z(k)$$

The transfer function matrix from input w to output z is

$$T(z) = G(zE - A)^{-1}D$$

The following lemma will be used later.

**Lemma 1:** For discrete singular system (1), the following statements are equivalent. (i) Discrete singular system (1) is regular, stable, causal and

$$\|G(zE-A)^{-1}D\|_{\infty} < 1$$

(ii) There exists a nonsingular symmetric matrix V satisfying the following inequalities

$$A^{T}(V^{-1} - DD^{T})^{-1}A - E^{T}VE + G^{T}G < 0$$
$$I - D^{T}VD > 0$$
$$E^{T}VE \ge 0$$

The following assumption is made in this paper. (A1)  $rank [E \quad D] = rank [E]$ 

#### QUADRATICAL STABILITY AND STABILIZABILITY

In this section we first discuss the relation between quadratic stability of discrete singular system (1) and  $H_{\infty}$  norm of its transfer function matrix T(z) of discrete singular system(6) and then investigate the problem of stabilization by state feedback control law.

We have the following result about the quadratic stability.

Theorem 1: Suppose that assumption (A1) holds, the following statements are equivalent.

(i) Discrete singular system (1) is quadratically stable.

(ii) Discrete singular system(6) is regular, stable, causal and

$$\|G(zE-A)^{-1}D\|_{\infty} < 1$$

**Proof:** (ii)  $\Rightarrow$  (i) Let  $\alpha > 0$ ,  $D_1 = \sqrt{\alpha}D$ ,  $G_1 = \frac{1}{\sqrt{\alpha}}G$ . Then discrete singular system

 $(E, A, D_1, G_1)$  is regular, stable, causal and  $||G_1(zE - A)^{-1}D_1||_{\infty} < 1$ 

From Lemma 1, there exists a nonsingular symmetric matrix V satisfying the following inequalities

$$A^{T}(V^{-1} - \alpha DD^{T})^{-1}A - E^{T}VE + \alpha^{-1}G^{T}G < 0$$
$$S := \alpha^{-1}I - D^{T}VD > 0$$
$$E^{T}VE \ge 0$$

since [19], we have

$$(A + DFG)^{T}V(A + DFG) - E^{T}VE$$

$$\leq A^{T}VA - E^{T}VE + A^{T}VDS^{-1}D^{T}VA + \alpha^{-1}G^{T}F^{T}FG$$

$$\leq A^{T}VA - E^{T}VE + A^{T}VDS^{-1}D^{T}VA + \alpha^{-1}G^{T}G$$

$$= A^{T}(V^{-1} - \alpha DD^{T})^{-1}A - E^{T}VE + \alpha^{-1}G^{T}G < 0$$
(7)

Let  $W = -(A^T (V^{-1} - \alpha DD^T)^{-1} A - E^T V E + \alpha^{-1} G^T G)$ 

From (7) we know that the matrix W>0. Let  $\lambda_{\min}(W)$  denote the minimum eigenvalue of the matrix W, then  $\lambda_{\min}(W) > 0$ . Hence,

$$x^{T}(k)((A + DFG)^{T}V(A + DFG) - E^{T}VE)x(k) \le -\lambda_{\min}(W) ||x(k)||^{2}$$

and

$$E^T V E \ge 0$$

By Definition 1 discrete singular system (1) is quadratically stable.

(i)  $\Rightarrow$  (ii). Because discrete singular system (1) is quadratically stable, there exists a nonsingular symmetric matrix V so that

$$(A + DFG)^{T}V(A + DFG) - E^{T}VE < 0$$
$$E^{T}VE \ge 0$$

Together with assumption (A1) we have  $D^T V D \ge 0$ . Since the matrix D is of full column rank and the matrix V is nonsingular symmetric, we obtain  $M := D^T V D > 0$ . Thus,

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$$(A + DFG)^{T}V(A + DFG) - E^{T}VE$$
  
=  $A^{T}VA - E^{T}VE + A^{T}VDFG + G^{T}F^{T}D^{T}VA + G^{T}F^{T}D^{T}VDFG$   
=  $A^{T}VA - E^{T}VE - A^{T}VDM^{-1}D^{T}VA + (A^{T}VD + G^{T}F^{T}M)M^{-1}(D^{T}VA + MFG)$   
< 0

We further obtain

$$\begin{bmatrix} \Theta & A^{T}VD + G^{T}F^{T}M \\ D^{T}VA + MFG & -M \end{bmatrix} < 0$$
  
where  $\Theta = A^{T}VA - E^{T}VE - A^{T}VDM^{-1}D^{T}VA$   
Rewriting it as  
$$\begin{bmatrix} \Theta & A^{T}VD \\ D^{T}VA & -M \end{bmatrix} + \begin{bmatrix} 0 & G^{T}F^{T}M \\ MFG & 0 \end{bmatrix} < 0$$

then there exists a constant  $\varepsilon > 0$  satisfying the following inequality

$$\begin{bmatrix} \Theta + \varepsilon^{-1} G^T G & A^T V D \\ D^T V A & -M + \varepsilon M^2 \end{bmatrix} < 0$$

Using Schur-complement yields

$$A^{T}VA - E^{T}VE + \varepsilon^{-1}G^{T}G + A^{T}VD((M - \varepsilon M^{2})^{-1} - M^{-1})D^{T}VA < 0$$

Since  $(M - \varepsilon M^2)^{-1} - M^{-1} = (\varepsilon^{-1}I - D^T V D)^{-1}$ 

we have

$$A^{T}VA - E^{T}VE + \varepsilon^{-1}G^{T}G + A^{T}VD(\varepsilon^{-1}I - D^{T}VD)^{-1}D^{T}VA$$
$$= A^{T}(V^{-1} - \varepsilon DD^{T})^{-1} - E^{T}VE + \varepsilon^{-1}G^{T}G < 0$$

Therefore, the discrete singular system  $\left(E, A, \sqrt{\varepsilon}D, \frac{1}{\sqrt{\varepsilon}}G\right)$  is regular, stable, causal and  $\left\|\frac{1}{\sqrt{\varepsilon}}G(zE-A)^{-1}\sqrt{\varepsilon}D\right\| < 1$ 

i.e., the discrete singular system (6) is regular, stable, causal and

$$\|G(zE-A)^{-1}D\|_{\infty}<1$$

This completes the proof.

This result tells us that the quadratic stability of an open loop discrete singular system is equivalent to that a discrete singular system is regular, stable and causal with  $H_{\infty}$  bound. Thus, the quadratic stability can be checked by means of Riccati inequalities.

Now we consider quadratic stabilization of a discrete singular system using state feedback control law. The system with input is given by

$$Ex(k+1) = (A + \Delta A)x(k) + Bu(k)$$
(8)

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where  $u(k) \in \mathbb{R}^m$  is the input. *B* is the input matrix with appropriate dimension. The state feedback control law is

$$u(k) = Kx(k) \tag{9}$$

where  $K \in \mathbb{R}^{m \times n}$  is a feedback matrix. We give the following definition.

**Definition 2:** Discrete singular system (8) is said to be quadratically stabilizable, if there exists a state feedback control law (9) such that the resultant closed loop singular system

$$Ex(k+1) = (A + \Delta A + BK)x(k)$$
(10)

is quadratically stable.

The following result is obtained for quadratic stabilization.

**Theorem 2:** Discrete descriptor system (8) can be quadratically stabilized by state feedback control law (9), if there exists a nonsingular symmetric matrix V as well as a scalar  $\varepsilon_0 > 0$  satisfying the following inequalities

$$Q < 0 \tag{11}$$

$$E^T V E \ge 0 \tag{12}$$

where

$$Q = A^{T}VA - E^{T}VE + A^{T}VD\Sigma^{-1}D^{T}VA + G^{T}G - \Omega^{T}\Psi^{-1}\Omega$$
$$\Sigma = I - D^{T}VD > 0$$
$$\Psi = \varepsilon_{0}I + B^{T}VB + B^{T}VD\Sigma^{-1}D^{T}VB > 0$$
$$\Omega = B^{T}VA + B^{T}VD\Sigma^{-1}D^{T}VA$$

In this case, the state feedback control law is given by

$$u(k) = Kx(k), \quad K = -\Psi^{-1}\Omega \tag{13}$$

**Proof:** According to Theorem 1 we only need to prove that there exists a nonsingular symmetric *V* satisfying the following inequalities

$$(A + BK)^{T} (V^{-1} - DD^{T})^{-1} (A + BK) - E^{T} VE + G^{T} G < 0$$
  
 $I - D^{T} VD > 0$   
 $E^{T} VE \ge 0$ 

This is true because

$$(A + BK)^{T}V(A + BK) - E^{T}VE + (A + BK)^{T}VD\Sigma^{-1}D^{T}V(A + BK) + G^{T}G$$
  

$$\leq A^{T}VA - E^{T}VE + A^{T}VD\Sigma^{-1}D^{T}VA + G^{T}G + K^{T}\Omega + \Omega^{T}K + K^{T}\Psi K$$
(14)  

$$= Q + (K + \Psi^{-1}\Omega)^{T}\Psi(K + \Psi^{-1}\Omega)$$

Substituting (13) into (14) we obtain

$$(A + BK)^{T}(V^{-1} - DD^{T})^{-1}(A + BK) - E^{T}VE + (A + BK)^{T}VD\Sigma^{-1}D^{T}V(A + BK) + G^{T}G \le Q < 0$$

Hence we conclude that the result is correct.

From Theorem 2, we can design a controller (state feedback control law) to make the resultant closed loop singular system quadratically stable.

### FAULT TOLERANT CONTROL

In this section we consider fault tolerant control problem for uncertain discrete singular systems when the system actuator is at fault.

We use a matrix L to describe actuator failures, this matrix is defined as

$$L = diag\{l_1, l_2, \dots l_m\} \quad l_i \in [0, 1], i = 1, 2, \dots m$$
(15)

where " $l_i = 1$ " means that the i-th system actuator is in normal operation, " $l_i \in (0.1)$ " ' presents that the i-th system actuator is at fault to some extent and " $l_i = 0$ " implies that the i-th system actuator is invalid. In all cases, when the state feedback control law (9) is applied to discrete singular system (8), the resultant closed loop singular system is denoted by

$$Ex(t+1) = (A + \Delta A)x(t) + BLKx(t)$$
(16)

We have the following result.

**Theorem 3:** Uncertain discrete descriptor system (16) with the possible failures can be quadratically stabilized by the state feedback control law (9) if there exists a nonsingular symmetric matrix *V* as well as a scalar  $\varepsilon > 0$  satisfying the following inequalities

$$\varepsilon_0 I + B^T V B + B^T V D \Sigma^{-1} D^T V A < \varepsilon I < \Xi - D_0 Q D_0^T$$
(17)

$$B_0^{\perp} Q B_0^{\perp^T} < 0 \tag{18}$$

$$E^T V E \ge 0 \tag{19}$$

where

$$\Xi = (D_0 Q B_0^{\perp^T}) (B_0^{\perp} Q B_0^{\perp^T})^{-1} (B_0^{\perp} Q D_0^T)$$
$$D_0 = (B_r B_r^T)^{-\frac{1}{2}} B_l^+, \ B_0 = (\Psi^{-1} \Omega)^T$$

where matrix  $B_r$  is of full row rank, matrix  $B_l$  is of full column rank, and matrix  $B_0 = B_l B_r$ 

$$A_{K}^{T}VA_{K} - E^{T}VE + A_{K}^{T}VD\Sigma^{-1}D^{T}VA_{K} + G^{T}G$$
  

$$\leq A^{T}VA - E^{T}VE + A^{T}VD\Sigma^{-1}D^{T}VA + G^{T}G$$
  

$$+ K^{T}L\Omega + \Omega^{T}LK + K^{T}L\Psi LK$$
  

$$= Q + (LK + \Psi^{-1}\Omega)^{T}\Psi (LK + \Psi^{-1}\Omega)$$

where  $A_K = A + BLK$ , we have

$$(A + BLK)^T (V^{-1} - DD^T)^{-1} (A + BLK) - E^T VE + G^T G$$
$$= Q + (\Psi^{-1}\Omega)^T (I - L) \Psi (I - L) (\Psi^{-1}\Omega)$$
$$= Q + B_0 \Pi B_0^T$$

where  $\Pi = (I - L)\Psi(I - L)$ . Let  $T = \begin{bmatrix} D_0 \\ B_0^{\perp} \end{bmatrix}$  be a nonsingular matrix, we have

$$T(Q + B_0 \Pi B_0^T) T^T = \begin{bmatrix} D_0 Q D_0^T + D_0 B_0 \Pi B_0^T D_0^T & D_0 Q B_0^{\perp T} \\ B_0^{\perp} Q D_0^T & B_0^{\perp} Q B_0^{\perp T} \end{bmatrix}$$
(20)

Form (17) we further have

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$$\Psi = \varepsilon_0 I + B^T V B + B^T V D \Sigma^{-1} D^T V B < \varepsilon I$$

and

$$\Pi = (I - L)\Psi(I - L) \le \varepsilon(I - L)^2 \le \varepsilon I$$
(21)

From (21) we obtain

$$D_{0}QD_{0}^{T} + D_{0}B_{0}\Pi B_{0}^{T}D_{0}^{T} - \Xi$$
  
$$\leq D_{0}QD_{0}^{T} + (B_{r}B_{r}^{T})^{-\frac{1}{2}}B_{r}(\varepsilon I)B_{r}^{T}(B_{r}B_{r}^{T})^{-\frac{1}{2}} - \Xi = \varepsilon I + D_{0}QD_{0}^{T} - \Xi$$

From (17) again we have

$$D_0 Q D_0^T + D_0 B_0 \Pi B_0^T D_0^T - \Xi < 0 \tag{22}$$

Using Schur-complement yields

$$Q + B_0 \Pi B_0^T < 0$$

i.e.,

$$(A + BLK)^{T}(V^{-1} - DD^{T})^{-1}(A + BLK) - E^{T}VE + G^{T}G < 0$$

This completes the proof.

In fact, this result shows us how to control system normally when the system actuator fails. In other words, we may take the system actuator failures as a kind of uncertainty occurring in the input matrix. In this case, we design controller called fault tolerant controller to quadratically stabilize the system.

### Example

In this section we present an example to illustrate the main results. Consider the discrete singular system (16) with:

$$E = \begin{bmatrix} 1 & 10 \\ 0 & 0 \end{bmatrix}, A = \begin{bmatrix} -0.12 & 0 \\ 1 & 0 \end{bmatrix}, D = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, G = \begin{bmatrix} 0 & 1 \end{bmatrix}, B = \begin{bmatrix} 1 \\ 1 \end{bmatrix}$$

where rank [E D] = rank [E]. D is of full column rank.

Suppose that  $\varepsilon_0 = 1$ . Solving the Riccati equation we obtain

$$V = \begin{bmatrix} 0.32 & -0.001 \\ -0.001 & -0.3 \end{bmatrix}$$

We further have

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$$E^{T}VE = \begin{bmatrix} 0.32 & 3.2 \\ 3.2 & 32 \end{bmatrix} \ge 0 \qquad Q = \begin{bmatrix} -0.7225 & -3.2 \\ -3.2 & -31 \end{bmatrix} \ge 0$$
  
$$\Sigma = 0.68 > 0, \Psi = 1.1676 > 0, \Omega = \begin{bmatrix} -0.3578 & 0 \end{bmatrix}$$

Thus the conditions of Theorem 2 are satisfied. We obtain the state feedback control law of the form

$$u(k) = [0.3064 \quad 0]x(k)$$

The resultant closed loop singular system is

$$\begin{bmatrix} 1 & 10 \\ 0 & 0 \end{bmatrix} x(k+1) = \left( \begin{bmatrix} 0.1864 & 0 \\ 1.3064 & 0 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} F(k) \begin{bmatrix} 0 & 1 \end{bmatrix} \right) x(t) + \begin{bmatrix} 1 \\ 1 \end{bmatrix} u(k)$$

We further obtain

$$\Delta(v) \leq -0.3880 ||x(k)||^2$$

thus discrete singular system (23) is quadratically stable,

When some actuator in (15) fails, the resultant closed loop singular system is:

$$\begin{bmatrix} 1 & 10 \\ 0 & 0 \end{bmatrix} x(k+1) = \left( \begin{bmatrix} -0.12 & 0 \\ 1 & 0 \end{bmatrix} + \begin{bmatrix} 1 \\ 0 \end{bmatrix} F(k) \begin{bmatrix} 0 & 1 \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \end{bmatrix} l_1 K \right) x(k)$$
(24)

and

$$B_0^T = \begin{bmatrix} -0.3064 \\ 0 \end{bmatrix}, B_l = B_0, D_0 = \begin{bmatrix} -3.2637 & 0 \end{bmatrix}$$
$$B_r = I, B_l^+ = \begin{bmatrix} -3.2637 & 0 \end{bmatrix} B_0^\perp = \begin{bmatrix} 0 & 1 \end{bmatrix}, \varepsilon = 2$$
$$\Xi - D_0 Q D_0^T = 4.1772 > 2 > 1.1676 = \Psi$$
$$B_0^\perp Q B_0^{\perp T} = -31 < 0$$

i.e., V satisfies the condition of Theorem 3.

When the system actuator failure occurs, directly computing we obtain

$$\Delta(v) \le -0.1658 \, \| \, x(k) \, \|^2$$

Thus discrete descriptor system (24) is quadratically stable with fault tolerant property. This agrees with the theorems.

### CONCLUSION

In this paper, we propose an approach to design controller with integrity to quadratically stabilize uncertain discrete descriptor systems, which keeps the resultant closed loop descriptor systems quadratically stable when the system actuator failures occur. The work is based on the fundamental theory of the quadratic stability and stabilizability of uncertain discrete descriptor systems in which we give some conditions for the systems to be quadratically stable using Riccati inequalities.

### Y. BO, Z. QING-LING, C. YUE-PENG

#### References

- 1. Campbell S L, Singular Systems of Differential Equations, Pitman, London, England, 1982.
- 2. Dai L, Singular Control Systems, Spring-Verlag, Berlin, German, 1989.
- Bajic,V,B., Lyapunov's Direct Method in The Analysis of Singular Systems and Networks, Shades Technical Publications, Hillcrest, Natal, RSA, 1992.
- 4. Campbell, S.L., Singular Systems of Differential Equations, Pitman. Marshfield, Mass., 1982
- 5. Lewis, F.L., A Survey of Linear Singular Systems, Circ. Syst.Sig. Proc.,5(1) (1986)3-36
- Debeljkovic, D.,Lj. Stabilty of Linear Continuous Singular Systems in Sense of Lyapunov: An Owerview, Proc. SANU (YU), April 4-5, (2001)
- Takaba, K., N.Morihira, T.Katayama, A Generalized Lyapunov Theorem for Descriptor System, Systems& Control Letters, (24)(1995)49-51
- Zhang Q. Dai G. J. Lam, Asymptotical Stability and Stabilization of Descriptor Systems. Acta Automatica Sinica, 24(2).(1998a),208-211
- Zhang Q, Decenralized and Robust Control for Large-scale Descriptor Systems, Northwestern Polytechnical University Press, Xian, China 1997.
- Yao B Zhang Q.Yang D Wang F. Analysis and Control of Asymptotic Stability for Discrete Descriptor Systems. Journal of Northeastern University (Natural science), 23(4) (2002) 315-318
- Yao B. Zhang Q Yang D,et al. Asymptotical Stability and Stabilization for Descriptor Systems via Lyapunov Methods The 5<sup>th</sup> International Conference on Optimization: Techniques and Applications. 14(2001) 557-1564
- Shimemura E and Fujjita M A, Design Method for Linear State Feedback Systems Possessing Integeity Based on a Solution of a Riccati Equation. Int. J Control, 42, (1985). 881-889.
- Ge J and Sun Y, On Analysis and Synthesis of Fault-tolerant Control, Ze Jiang University Press, Ze Jiang, China, 1993.
- 14. Fujita M and Shimemura E, A New Type of Linear State Feedback Control Possessing Integrity Based on a Solution of Generalized Riccati-type Equation, Control Theory and Advanced Technology 2, (1986) 563-575.
- Chen Y, Zhang Q, Yao B. Robust Quadratic Stabilization with Integrity for Descriptor Systems Acta Automatica Sinica, 28(4). (2002),615-619
- Chen Y, Zhang Q, and Liu W, Fault-tolerant Control about Integrity for Descriptor Systems, Proc of IEEE Conference on Decision and Control, (2000) 1359-1360.
- 17. Yao B Zhang Q Chen Y Zhang G. Design of Circular Pole Assignment Controller with Integrity for Descriptor System Joural of Northeastern University(Natural science),23(6),(2002) 535-538
- Chen Y Yao B Zhang Q Robust quadratic Stabilization Integrity for Uncertain Systems with Frobenius Norm-bounded Journal of Shenyang University of Technology G.24(2) (2002)173-177
- Garcia G, Bernussou J, and Arzelier D, Robust Stabilization of Discrete-time Linear Systems with Normbounded Time-varying Uncertainty, Systems and Control Letters, 22 (1994) 327-339.

# ROBUSNOST KONCEPTA QUADRATIC STABILNOSTI I STABILIZACIJA SA INTEGRITETOM DISCRTETNIH SINGULARNIH SISTEMA SA PRISUTNIM NEODREĐENOSTIMA U MODELU

### Yao Bo, Zhang Qing-Ling, Chen Yue-Peng

U ovom radu razmatran je problem robusnosti koncepta Quadratic stabilnosti kao i mogućnosti stabilizacije sa integritetom posebne klase diskretnih singularnih sistrema sa prisutnim neodređenostima u modelu. Ova procedura sprovedena je korišćenjem algebarske Riccatijeve jednačine.

Dovoljni uslovi quadratic stabilnosti i stabilizacije shodno tom konceptu izvedeni su na principu korišćenja povratne sprege sistema po veličinama stanja.

Zakon upravljanja implementiran u povratnoj sprezi sistema po veličinama stanja projektovan je tako da u svim prilikama, čak i kod otkaza pojedinih aktuatora, ili delova sistema, obezbeđuje quadratic stabilnost sistema u zatvorenoj sprezi tj. obezbeđuje integritet sistema u celini. Izložen je i numerički primer da bi se potvrdili izvedeni rezultati.

Ključne reči: Integritet, Quadratic stabilnost, diskretni singularni sistrem sa prisutnim neodređenostima, aktuator