# The Application of Optimal Control in the Constant-Speed Control of Rotary Screen Rack

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**Abstract:** Aiming to the defects in the traditional speed-control of rotary screen rack, such as poor dynamic performance, poor noise immunity, untimely regulation and strong dependence on personnel and experience and so on, this paper proposes a linear quadratic regulator with status feedback, which was used in the constant-speed control of LHG type rotary screen rack. It can be easily and quickly solve riccati equation by using Matlab software to get the optimal state feedback gain matrix. The simulation result shows that the proposed method is obviously superior to the unit negative feedback control method in dynamic performance, noise immunity and steady precision.

**Key Words:** LHG rotary screen rack; quadratic optimal control; state feedback; secondary regulation technology

## 1 Introduction

The rotary screen rack is often used to remove the bigger suspended matter and impurity which can possibly block the pumping unit and pipeline valve in the conservancy and wastewater treatment engineering and to guarantee the normal operation of the following processing equipments [1]. While the quick and efficient constant-speed operation of screen rack is the fundamental premise to ensure the following sets normal operation. At present the most screen racks apply simple unit-negative feedback constant control or open-loop control to drive the transmission structure, and it only sets over-load protection equipments. When intercepting the quick deposit suspended matter the grid is often jammed resulting in stopping the machine, then it needs operators to clean it and continue the work. If the cleaning is not in time it will lead the water pressure before the grid and after to leap. The grid distortion will get bigger and bigger, finally the grid will collapse, the dirt will inrush units and stop the machine, even make serious accident [2, 3]. The traditional control system has low efficiency, poor noise immunity and dynamic performance.

In this paper the double closed-loop feedback control system is used to control the speed of RHG rotary screen rack and Matlab programming is applied to solve Riccati equation to get optimal state gain feedback parameters. In this system, the arithmetic is simple and the parameter is easy to adjust, it also needn't interfere by manual work and improves the system automation. The simulation result shows that the system improves its dynamic performance, decreases its steady error and enhances its noise immunity.

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## 2 The principle of constant-speed control system for LHG rotary screen rack

The design of LHG rotary screen rack adopts frame-type integral structure and buffer skim drive structure with hydraulic type. The transmission structure is an oil- pump and hydraulic system which is based on the hydrostatic transmission technology of secondary regulation, and on the load this system can regulate its angle (position), speed, torque and power directly. The speed control system of oil-pump and hydraulic transmission for LHG rotary screen rack consists of secondary component, variable control cylinder, proportional valve and so on [4] (as show in figure 1)

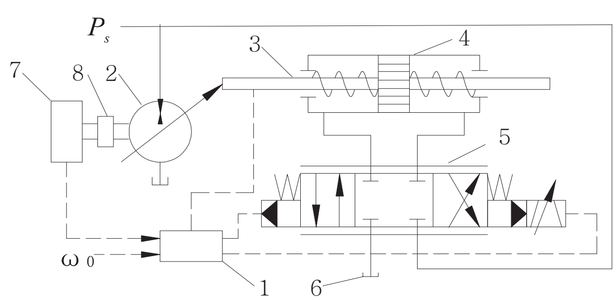


Fig.1 Hydraulic oil-pump speed control schematic diagram.
1-Controller, 2-Secondary component, 3-Position sensor, 4-Variable cylinder, 5-Proportional reversing valve, 6-Cinlyder, 7-Speed sensor, 8-Torque sensor

The secondary component 2 connects with the constant voltage network directly and its discharge capacity is controlled by variable cylinder 4, the control flow of variable cylinder is generated by velocity measurement sensor 7 (velocity measurement pump) which is joined on coaxial by the secondary component 2. $\omega_0$ is the system setting speed. With the load torque changing, the speed of the secondary component will change. At that time the difference between the factual speed signal $\omega$ measured by speed measurement pump and the set speed $\omega_0$ generates a pressure difference which is proportional to the secondary component speed using control strategy to control the proportional reversing valve 5. In this pressure difference the variable cylinder 6 will move to left or right, change the plate dip and change the secondary component displacement which leads load torque to change until the two ends of variable cylinder get a force balance [5]. This balance state can generate any setting speed $\omega_0$ of the secondary component.

## 3 System model

The open-loop block diagram of hydraulic oil-pump speed control system for LHG rotary screen rack is shown in figure 2.

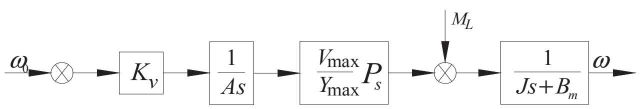


Fig.2 The open-loop block diagram of hydraulic oil-pump speed control system

Where, $K_v$ is the conversion coefficient, the unit is $m^3/rad$ ; $A$ is the useful effective area of variable cylinder, the unit is $m^2$ ; $V_{max}$ is the maximum discharge capacity of the secondary component, the unit is $m^3/r$ ; $Y_{max}$ is the maximum displacement of variable cylinder, the unit is $m$ ; $P_s$ is the pump output pressure, the unit is $MP_a$ ; $J$ is the total moment of inertia between variable motor and variable pump, the unit is $N\cdot m^2$ ; $B_m$ is the viscosity damping coefficient, the unit is $N\cdot m/(rad/s)$.

The system open-loop transfer function is as follows:

$$G(s)=\frac{\frac{K_v}{A}\cdot\frac{V_{max}}{Y_{max}}P_s}{Js^2+B_ms} \qquad (1)$$

In order to make system work on its setting speed steadily the liner quadratic form optimal control theory [6] is applied to solve the optimal state gain feedback coefficient. The double closed-loop optimal state feedback control system is designed to improve the dynamic performance, increase its steady precision, enhance its noise immunity and reach its design requirements.

## 4 The design of controller

Change the transfer function of equation (1) to equation (2).

$$G(s)=\frac{\frac{K_v}{A}\cdot\frac{V_{max}}{Y_{max}}P_s}{Js^2+B_ms}=\frac{\frac{K_vV_{max}P_s}{AJY_{max}}}{s^2+\frac{B_m}{J}s} \qquad (2)$$

Change equation (2) to its standard form.

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix}=\begin{bmatrix}0 & 1\\ 0 & -\frac{B_m}{J}\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}+\begin{bmatrix}0\\ \frac{KV_{max}}{AJY_{max}}P_s\end{bmatrix}u$$
$$y=\begin{bmatrix}0 & 1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} \qquad (3)$$

The measured engineering parameter values are as follows:

$K_v=4\times10^{-6}\,m^3/rad$ ; $A=1.135\times10^{-2}\,m^2$ ;
$V_{max}=1.12\times10^{-4}\,m^3/r$ ; $Y_{max}=\pm0.1m$ ;
$P_s=10\,MPa$ ; $J=3.3332\,N\cdot m^2$ ;
$B_m=0.2\,N\cdot m/(rad/s)$ ;

Bring these values into equation (3), and the equation (4) is obtained.

$$\begin{bmatrix}\dot{x}_1\\ \dot{x}_2\end{bmatrix}=\begin{bmatrix}0 & 1\\ 0 & -0.060\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix}+\begin{bmatrix}0\\ 1.168\end{bmatrix}u$$
$$y=\begin{bmatrix}0 & 1\end{bmatrix}\begin{bmatrix}x_1\\ x_2\end{bmatrix} \qquad (4)$$

From equation (4) the coefficient matrix of quadratic form liner system is obtained as follows.

$$A=\begin{bmatrix}0 & 1\\ 0 & -0.060\end{bmatrix},\quad B=\begin{bmatrix}0\\ 1.168\end{bmatrix},\quad C=\begin{bmatrix}1 & 0\end{bmatrix}$$

From $Rank\begin{bmatrix}B & \mathrm{AB}\end{bmatrix}=2$, $Rank\begin{bmatrix}C^T & A^TC^T\end{bmatrix}=2$, we know the system can be controlled and observed completely and it satisfies the design premise of optimal controller. According to quadratic form optimal control theory and algorithm, the performance index can be obtained from equation (5).

$$J=\frac{1}{2}\int_0^\infty\left[x^T(t)Qx(t)+u^T(t)Ru(t)\right]dt \qquad (5)$$

Where Q and R is respectively the weighted matrix of state and input control variable. Q is the positive semi-definite symmetry constant matrix and R is the definite symmetry constant matrix [7]. Then the feedback controller $u^*(t)$ can be solved to output and to obtain the minimum performance index J on system (4). $u^*(t)$ and K can be reduced as follows.

$$u^*(t) = -Kx(t)$$
$$K = R^{-1}B^T P(t) \qquad (6)$$

Solve the Riccati equation by Matlab proprammING.

$$A^T P + PA - PBR^{-1}B^T P + Q = 0 \qquad (7)$$

From equation (7) the stationary solution $P(t)$ matrix is got and then the optimal state feedback gain matrix K is obtained, the system structure of optimal control is shown in figure 4.

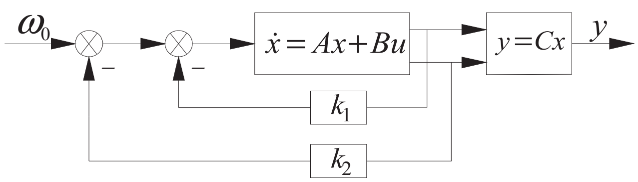


Fig.3 The Structure diagram of optimal control system

## 5 Simulation and research

### 5.1 Get the optimal control rule

In Matlab command windows we program the following commands to solve Riccati equation and can get the optimal state gain feedback matrix, as shown in figure 4.

```
>> A=[0 1;0 -0.06];B=[0;1.68];
C=[0,1];D=0;
Q=[1 0;0 1];R=1;
[K,P,r]=lqr(A,B,Q,R);
disp('System optimal state feedback matrix'),K
K1=K(1);A1=A-B*K;B1=B*K1;C1=C;D1=0;
figure(1);step(A1,B1,C1,D1);grid;
title('System zero-input response');
xlabel('Times/s');ylabel('Output');
figure(2);[y,x,t]=step(A1,B1,C1,D1);plot(t,x),grid;
title('The optimal state feedback trajectories of x1,x2');
xlabel('Times/s');ylabel('x1,x2');
set(gca,'position',[0.05 0.05 0.90 0.85]);
System optimal state feedback matrix

K =

    1.0000    1.4447
```

Fig.4 Program to obtain system state feedback matrix

Therefore，the system optimal control rule is as follows.

$$u^*(t) = -Kx(t) = \begin{bmatrix} -1.0000 \\ -1.4447 \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \end{bmatrix} \qquad (8)$$

At the same time the system optimal state trajectory is got (shown in figure 4) and the system zero-input step response curve is got （shown in figure 5）

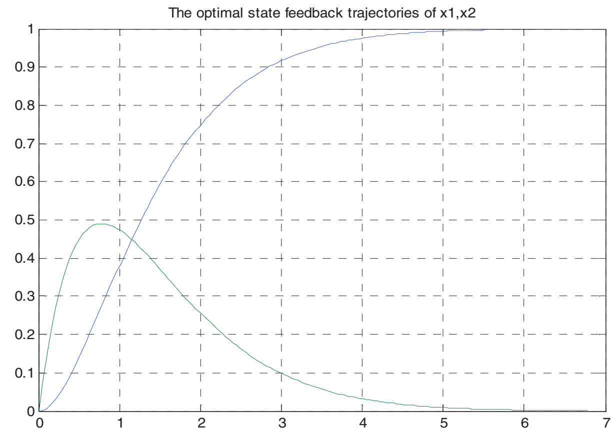


Fig.4 System optimal state trajectory

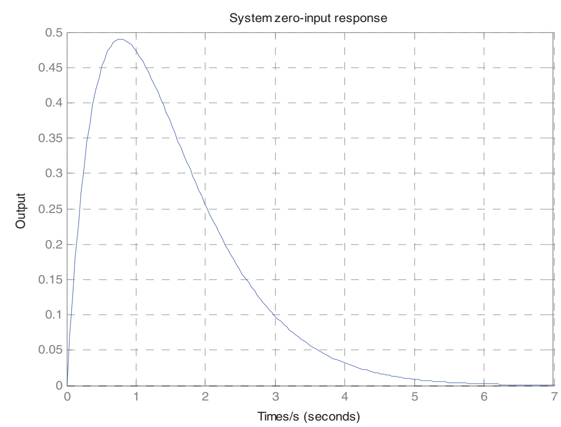


Fig.5 System zero-input step response curve

### 5.2 Simulation and its Analysis

According to the zero-input step response curve (as shown in figure 5), when the system is zero-input, put a step disturbance on it and the system can repress the outer disturb to zero quickly by itself control, and enhance its noise immunity greatly. In Simulink environment of Matlab software by building the optimal state feedback control model (shown in figure 6), we can obtain the system step response curve which is shown in figure 7. Analyzing it we have a conclusion that when the setting input of system is step signal, after optimization of state feedback parameter by optimal control algorithm, the steady-state error is zero. It decreases the system overshoot obviously, shortens the adjust-time and improves the dynamic performance and steady characteristic greatly.

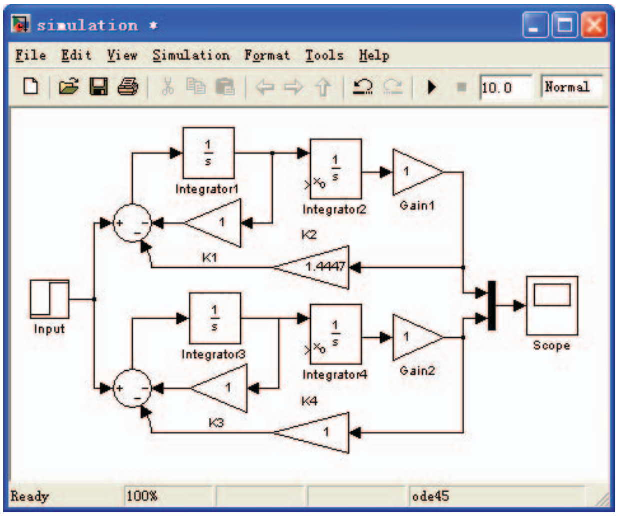


Fig.6 System simulation diagram

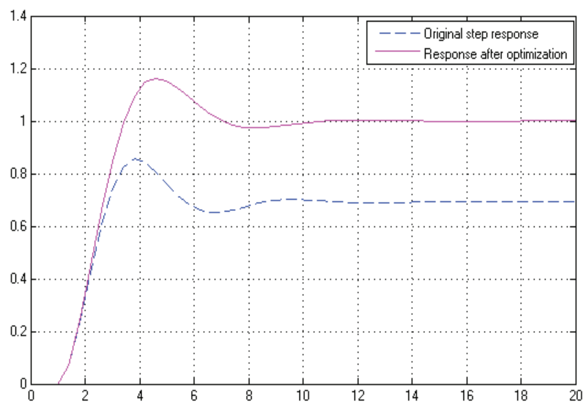


Fig.7 System step response curve

## 6 CONCLUSION

According to constant speed control problem of oil-pump hydraulic drive mechanism for LHG rotary screen rack, this manuscript has designed a state feedback controller based on old system by using the optimal control algorithm. Use Matlab computer-aided technology to calculate the optimal state feedback gain coefficient and to achieve parameter fast optimization. The result shows that this control proposal can improve the system dynamic performance, noise immunity and steady precision effectively.

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