Signal and System•Control Theory Series

THKKL-1

Control Theory Experimental Apparatus

Laboratory Manual

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Contents

1 THKKL-1 Operating Instructions of Control Theory Experimental Apparatus

This experiment apparatus can complete the main experiment content of the course of "Automatic Control Theory" in the university, it can simulate various typical segments and control systems in the control engineering, and carry out simulation research on the control system.This laboratory box is a combination of experimental module, sweep power supply, DC digital voltmeter, ac millivoltmeter, voltage regulator, signal source, frequency meter, compact structure, stable and reliable performance, flexible and convenient experiment, which is conducive to the cultivation of students' practical ability.

1.1 Composition and Use

1. Power supply

A three-core 220V single-phase AC power outlet with fuse tube (1A) is provided at the rear of the test box, and another three-core plug power cord is provided. Four step-down transformers are arranged in the box to provide multiple sets of low-voltage AC power supply for the test panel.

2. Composition

A large (435mm×325mm) single-sided copper-coated printed circuit board, printed on the front with clear graphics, lines and characters of each component and component, and welded with components required for the experiment.

The experimental board contains the following compotents:

(1) A master power switch is installed at the lower right of the front to control the power supply.

(2) More than 100 highly reliable self-locking, anti-rotation, stacked plug sockets. They have been designed on the printed circuit board.This kind of plug-in, when the plug is inserted and after a little rotation, you can get a great axial locking force, as long as turn along negative direction can be easily pulled out.

(3) Sweep frequency power supply.Sweep frequency can be output in the full range of 15Hz ~ 80KHz, and 11 sweep speeds are provided. Please refer to the appendix for instructions.

(4) DC stabilized power supply. Provide a ±15V and ±5V DC stabilized voltage power supply. When main power switch is turned on, as long as the signal source switch is turned on, there will be corresponding voltage output.

(5) Signal source.The signal source of the experiment apparatus includes two parts: step signal generator and function signal generator.

Step signal generator: the step signal generator is mainly designed to provide unit step signal for this experimental box.When the switch is pushed to the "负" end and the white button is pressed, the "阶跃输出" port outputs a negative step signal; when the switch is pushed to the "正" end and the white button is pressed, the "阶跃输出" port outputs a positive step signal.Its amplitude (± 0.9v ~ ± 3.7v) can be adjusted by "幅度调节" knob.As long as the white button is pressed, the "锁零输

出" port outputs the voltage signal of "-15v". When the white button is not pressed, the "锁零输出" port outputs the voltage signal of "0V".

Low frequency function signal generator: can choose sine wave, square wave, triangular wave, output frequency range 0.25Hz ~ 2kHz, sine wave amplitude 0~12V_{p-p} continuous adjustable, square wave amplitude 0~12V_{p-p} continuous adjustable, triangular wave amplitude 0~10V_{p-p} continuous adjustable.

(6) Frequency meter. The measuring frequency range is 0.1Hz ~ 10kHz. As long as the "函数信号发生器" switch is turned on, the frequency meter will enter the state to be tested.The signal output frequency of the function signal generator itself can be measured by placing the switch (内测/外测) at the frequency meter in the "内测". If the switch is placed in "外测", the frequency meter shows the frequency of the measured signal input from the "输入" socket. In case of instantaneous strong interference, the frequency meter may be deadlocked. At this time, as long as the "复位" key is pressed, it can automatically return to normal work.

(7) AC/DC digital voltmeter (equivalent to two voltmeter functions)

DC digital voltmeter: measuring range 0~20V, divided into 200mV, 2V, 20V three ranges, straight key switch switch, $3\frac{1}{2}$-digit display, accuracy 0.5%.

Digital true RMS AC millivoltmeter: measurement range 0~20V, divided into 200mV, 2V, 20V three ranges, straight key switch switch, three-half display, frequency band range 10Hz~1MHz, basic measurement accuracy ±0.5%±2.

(8) lock zero circuit.The lock zero circuit is used to discharge capacitance to the integral segment in the analog circuit.When the "lock zero output" is connected with the gate G of JFET by a wire, the lock zero can be realized. When the white button in the "step signal generator" circuit is pressed, the lock zero ends.

(9) It is provided with an set of special wires with different lengths.

1.2 Experimental Content

The following experimental projects can be completed:

(1) Simulation of typical segments of the control system.

(2) Time-domain response and parameter determination of first-order system.

(3) Transient response analysis of second-order system.

(4) Transient response and stability analysis of third-order system.

(5) Dynamic performance analysis of PID controller.

(6) Dynamic correction of automatic control system.

(7) Test the frequency characteristics of typical segments.

(8) Frequency characteristic test of linear system.

(9) Signal sampling and recovery.

(10) Simulation of typical nonlinear segments.

(11) Phase plane analysis of nonlinear systems.

1.3 Precautions

1.Before use, check whether the power supply is normal. The check steps are as follows:

(1) First turn off all the power switches of the experimental apparatus, and then connect to 220V AC power supply with the three-core power cord attached to the box.

(2) Turn on the main power switch on the experimental apparatus, and the switch indicator light will be lit.

(3) Measure the ±15V and ±5V on the panel with the multimeter (or directly with the DC digital voltmeter on the panel) to see if there is a correct voltage output.

(4) Turn on function signal generator switch, there should be signal output; When the frequency meter turn to internal measurement, the corresponding frequency should be displayed.

(5) Turn on the AC millivoltmeter and the digital tube shoild be lit.

(6) Turn on DC digital voltmeter, the digital tube should be lit.

2.Be familiar with the principle and method of experimental circuit before wiring.

3.Disconnect the main power supply and oyher power switches before the experiment connection. The experiment can be carried out only after the wiring is completed and the check is correct.

4.The experiment board should be kept clean and tidy to avoid short circuit and other faults.

5.After experiment, all power switches shall be turned off in time, and the experimental board shall be cleaned in time, and the connecting wires shall be arranged and placed in the specified position.

6.Instruments with external AC power , such as oscilloscopes, the enclosure should be properly grounded.

2 THKKL-1 Experiment Part of Control Theory Experiment Apparatus

2.1 Simulation of Typical Segments of Control System

1.Objectives

1) Familiar with the use of ultra-low frequency scanning oscilloscope.

2) Master the electronic circuits that constitute typical segments of the control system with operational amplifier.

3) Measure the step response curve of typical segments.

4) Understand the influence of parameter changes in typical segments on output dynamic performance through experiments.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3.Principle

The wiring diagram, step response and transfer function of typical segments.

1) The proportion segment wiring diagram and step response are shown in Figure 2.1.1.

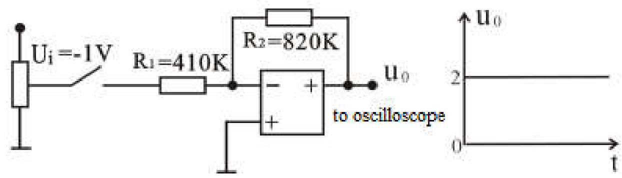


Figure 2.1.1 Proportion segment

The transfer function of proportion segment is shown in equation (2.1.1).

$$G(s) = \frac{R_2}{R_1} = K \qquad (2.1.1)$$

2) Inertial segment wiring diagram and step response are shown in Figure 2.1.2.

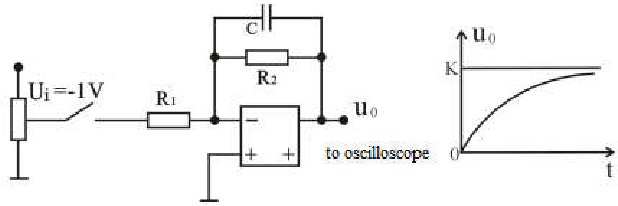


Figure 2.1.2 Inertia segment

The transfer function of the inertia segment is shown in equation (2.1.2).

$$G(s) = \frac{R_2}{R_1} \bullet \frac{1}{R_2 Cs + 1} = \frac{K}{Ts + 1} \qquad (2.1.2)$$

3) the integration segment wiring diagram and step response are shown in Figure 2.1.3.

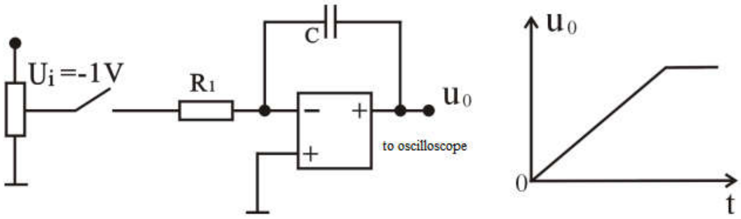


Figure 2.1.3　Integration segment

The transfer function of the integral segment is shown in equation (2.1.3).

$$G(s)=\frac{1}{R_1Cs}=\frac{1}{Ts} \qquad (2.1.3)$$

4) Proportional differential segment (PD) wiring diagram and step response are shown in Figure 2.1.4.

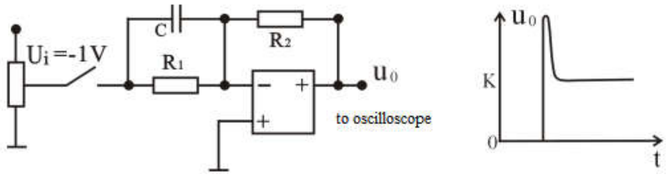


Figure 2.1.4　Proportional differentiation segment

The transfer function of proportional differentiation is shown in equation (2.1.4).

$$G(s)=\frac{R_2}{R_1}\bullet(R_1Cs+1)=K(T_Ds+1) \qquad (2.1.4)$$

5) the PI wiring diagram and unit step response are shown in Figure 2.1.5.

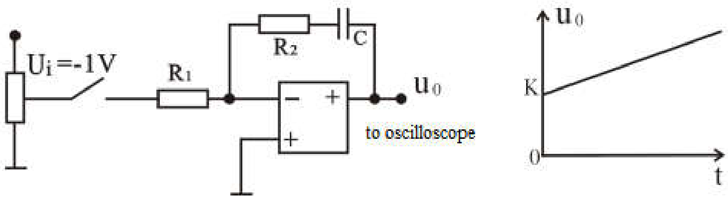


Figure 2.1.5　proportional integration segment

The transfer function of proportional integral is shown in equation (2.1.5).

$$G(s)=\frac{R_2}{R_1}\bullet(1+\frac{1}{R_2Cs})=K(1+\frac{1}{T_2s}) \qquad (2.1.5)$$

6) Block diagram and unit step response of the oscillation segment are shown in Figure 2.1.6, and the wiring diagram of the oscillation segment is shown in Figure 2.1.7.

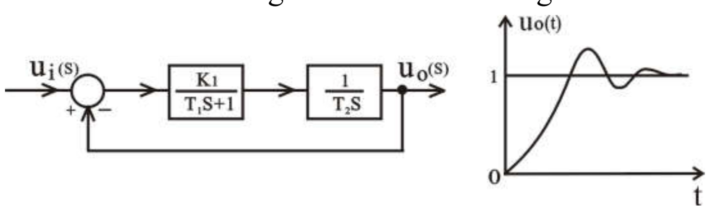


Figure 2.1.6　Block diagram of the oscillation segment and unit step response

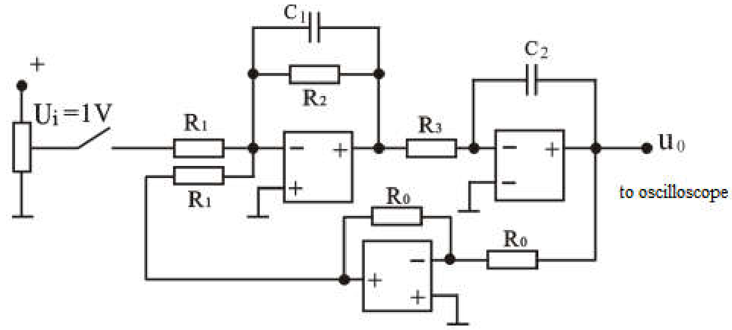


Figure 2.1.7 Wiring diagram of the oscillation segment

The transfer function of the oscillation segment is shown in equation (2.1.6).

$$G(s)=\frac{K/T_1}{s^2+s/T_1+K/T_1} \qquad K=R_2/R_1 \quad T_1=R_2C_1 \quad (2.1.6)$$

4.Steps

According to the transfer function of the following typical segments, adjust the parameters of the corresponding analog circuit, observe and record its unit step response waveform.Note: the unit step signal is taken from the function signal generator in the experimental box.

1) Proportion segment   G1(S)=1 and G2(S)=2

2) Integration segment   G1(S)=1/S and G2(S)=1/(0.5s)

3) Proportional differentiation segment   G1(S)=2+S and G2(S)=1+2S

4) Inertia segment G1(S)=1/(S+1) and G2(S)=1/(0.5s +1)

5) Proportional integral segment G1(S)=1+1/S and G2(S)=2(1+ 1/2s)

6) Oscillation segment $G(S)=\frac{K}{T_1S^2+S+K}=\frac{10}{0.1S^2+S+10}$

2.2 Dynamic Response and Parameter Measurement of First-order System

1.Objectives

1) Observe the dynamic response of first-order system under the action of unit step and ramp input signal.

2) Determine the time constant of the first-order system according to the unit step response curve of the first-order system.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3.Principle

The analog circuit of the first-order system is shown in Figure 2.2.1.

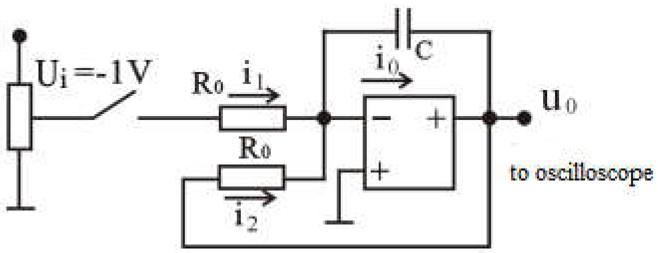


Figure 2.2.1 first-order system simulation circuit diagram

The transfer function of the first-order system is shown in equation (2.2.1).

$$\frac{U_0(s)}{U_i(s)} = \frac{1}{Ts+1} \qquad T = R_0C \qquad (2.2.1)$$

4.Steps

1) According to the analog circuit shown in Figure 2.2.1, adjust the values of R0 and C to make the time constant T=1S and T= 0.1s.

2) When Ui(t)= -1v, observe and record the unit step response curve of the first-order system when the time constant t is 1S and 0.1s respectively, and label the time coordinate axis.

3) When Ui(t)= t, observe and record the response curve of the first-order system when the time constant t is 1S and 0.1s, where the ramp signal can be obtained by the triangular wave signal in the experimental box, or the unit step signal can be obtained by an integrator.

2.3 Dynamic Response of Second-order System

1.Objectives

1) Familiar with the composition of second-order simulation system.

2) The unit step response of the second-order system under three states of =1, 0< <1, and 1 is studied.

3) Analyze the overshoot amount p, peak time tp and adjustment time ts of the unit step response of gain K to the second-order system.

4) Study the steady-state tracking errors of the system for the input of the slope at different K values.

2.Apparatus

1) one control theory electronic simulation experiment apparatus.

2) one ultra-low frequency slow scanning oscilloscope.

3) one multimeter.

3.Principle

The analog circuit of the second-order system is shown in Figure 2.3.1, which is composed of an inertial segment, an integration segment and a phase inverter.

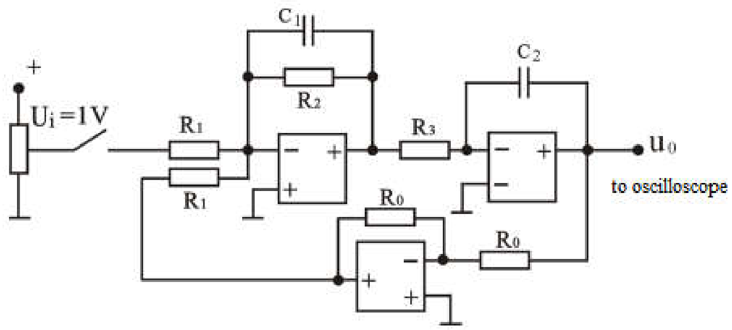


Figure 2.3.1 Analog circuit of second-order system

Block diagram of analog circuit is shown in Figure 2.3.2, where K1=R2/R1, T1=R2C1, T2=R3C2.

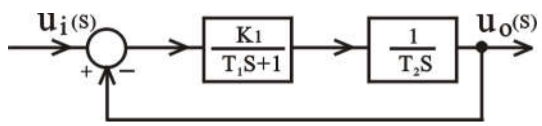


Figure 2.3.2 Block diagram of second-order system

4.Steps

1) According to Figure 2.3.1, adjust the corresponding parameters so that the open-loop transfer function of the system is:

$$G(s) = \frac{K_1}{0.5s(0.2s+1)}$$

2) Set Ui(t)=1V, observe the waveform of unit step response at different K (K= 10,5,2,0.5) on the oscilloscope, and obtain the corresponding p, tp and ts values by experiment.

3) Adjust the open-loop gain K1 to make the damping ratio of the second-order system, observe and record the unit step response waveform and the values of p, tp and ts at this time.

4) Triangular wave output from apparatus or integrator with unit positive step signal is used as the ramp input signal of the second-order system.

5) Observe and record the steady state error when the system tracks the ramp signal at different K values.

2.4 Dynamic Response and Stability Analysis of Third-order System

1.Objectives

1) Master the analog circuit diagram of the third-order system.

2) The influence of open-loop gain K on the dynamic and stable performance of third-order system is proved by experiments.

3) Study the influence of time constant T on the stability of the third-order system.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3.Principle

The analog circuit of the third-order system is shown in Figure 2.4.1.

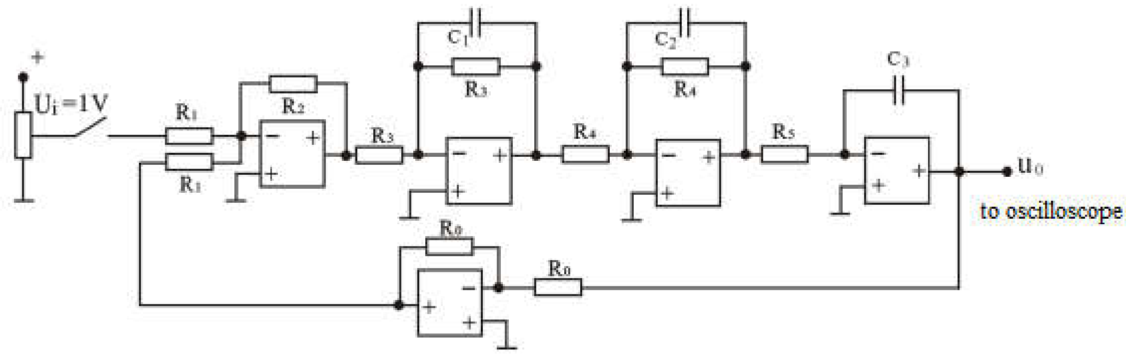


Figure 2.4.1 analog circuit of third-order system

The block diagram of the third-order system is shown in Figure 2.4.2, where K=R2/R1, T1=R3C1, T2=R4C2, T3=R5C3.

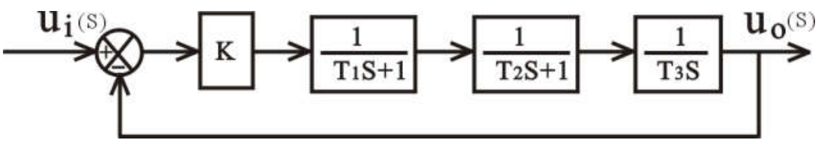


Figure 2.4.2 Block diagram of the third-order system

4.Steps

Third-order system's open-loop transfer function shown is:

$$G(s)=\frac{K}{T_3 s(T_1 s+1)(T_2 s+1)}$$

1) Adjust the corresponding parameters in Figure 2.4.1 according to the requirements of K=10, T1= 0.2s, T2= 0.05s, and T3= 0.5s.

2) Slow scan oscilloscope is used to observe and record the unit step response curve of the third-order system.

3) Set T1= 0.2s, T2= 0.1s, and T3= 0.5s, and observe and record the unit step response curves under K values of 5, 7.5, and 10.

4) Set K=10, T1= 0.2s, and T3= 0.5s. Observe and record the unit step response curve when T2 is 0.1s and 0.5s respectively with an oscilloscope.

2.5 Dynamic Characteristics of PID Controller

1.Objectives

1) Familiar with the analog circuits of PI, PD and PID controllers.

2) Deeply understand the step response characteristics of PI, PD and PID controllers and the influence of related parameters on their performance through experiments.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3. Principle

PI, PD and PID controllers are widely used in industrial control systems. Where PD is the lead correction device, it is suitable for the occasions where the steady-state performance has met the requirements and the dynamic performance is poor. PI is a hysteresis correction device, which can change the steady state performance of the system. PID is a kind of hysteresis and lead correction device, it has the advantages of both PI and PD.

1) PD controller, the circuit is shown in Figure 2.5.1.

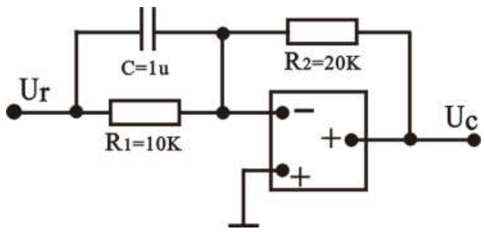


Figure 2.5.1 PD controller circuit diagram

2) PI controller, the circuit is shown in Figure 2.5.2.

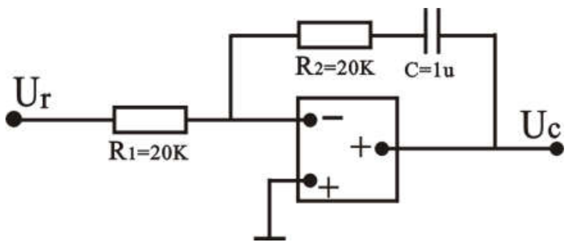


Figure 2.5.2 PI controller circuit diagram

3) PID controller, and the circuit is shown in Figure 2.5.3.

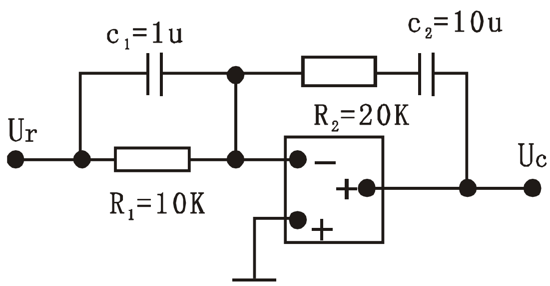


Figure 2.5.3 PID controller circuit diagram

4.Steps

1) Set U_r=1V, C=1μF, and test the output waveform of PD controller when R_1=10K and 20K

respectively with slow scan oscilloscope.

2) Set U_r=1V,C=1μF, and test the output waveform of PI controller when R_2=10K and 20K with oscilloscope respectively.

3) Set U_r=1V and test the output waveform of PID controller with oscilloscope.

2.6 Dynamic Correction of Automatic Control System

1.Objectives

1) Students are required to design a calibration device by themselves, and use the apparatus to constitute a simulation system for experimental correction and actual debugging, so that students can deeply understand the importance of the calibration device in the system.

2) Master the engineering design methods of second-order systems and third-order systems commonly used in engineering.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3.Principle

When the open-loop gain of the system meets the requirements of its steady-state performance, its dynamic performance is generally not ideal or even unstable.For this reason, a calibration device should be connected in series in the system, so that the open-loop gain of the system remains unchanged and the dynamic performance of the system meets the requirements.The common design methods are root locus method, frequency method and engineering design method.This experiment requires the engineering design method to correct the system.

1) The analog circuit of the second-order system is shown in Figure 2.6.1.

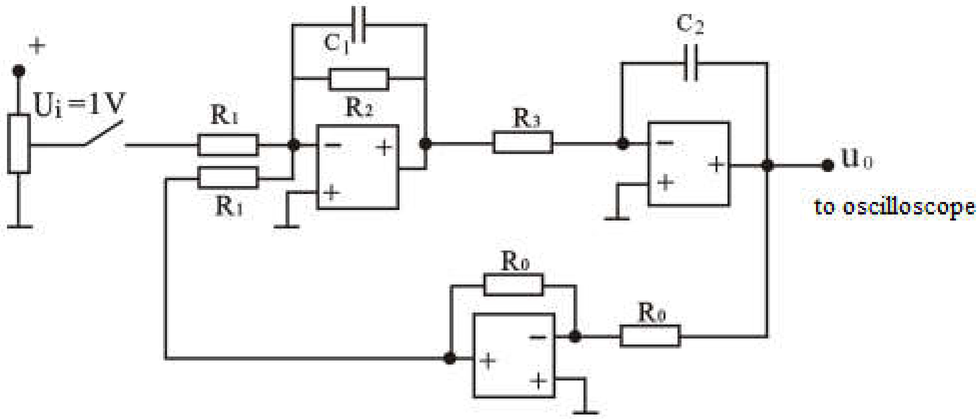


Figure 2.6.1 Analog circuit diagram of second-order system

2) The analog circuit of the third-order system is shown in Figure 2.6.2.

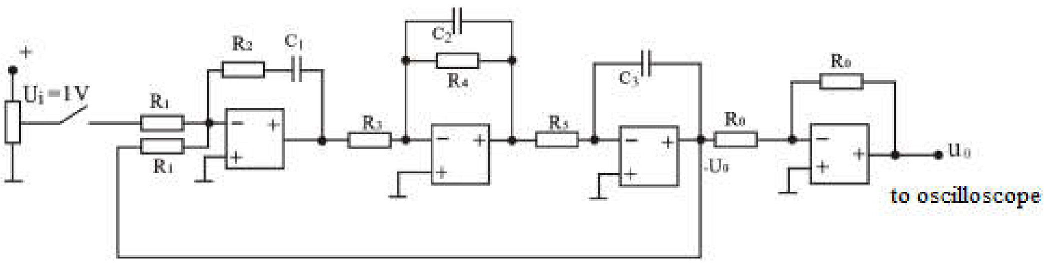


Figure 2.6.2 Analog circuit diagram of third-order system

4.Steps

4.1 Dynamic correction of second-order system

According to the engineering design method of the second order system, design the calibration devices of the following systems.

1) The object is composed of two large inertia segments, as shown in Figure 2.6.3.

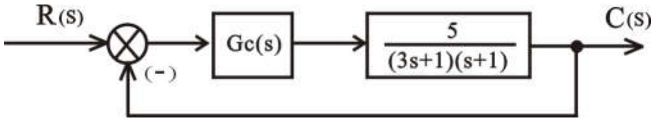


Figure 2.6.3 Two large inertia segment

2) The object is composed of three large inertia segments, as shown in Figure 2.6.4.

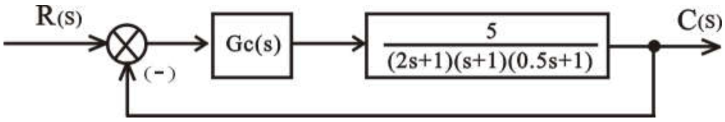


Figure 2.6.4 Three large inertia segment

3) The object is composed of an integral segment, and an inertial segment, as shown in Figure 2.6.5.

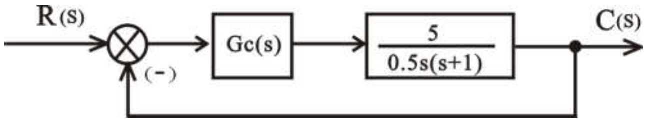


Figure 2.6.5 An integral segment and an inertial segment

4.2 Dynamic correction of third-order system

According to the third order system engineering design method, design the calibration device of the following systems.

1) The object is composed of two large inertia segments and an integral segment, and its block diagram is shown in Figure 2.6.6.

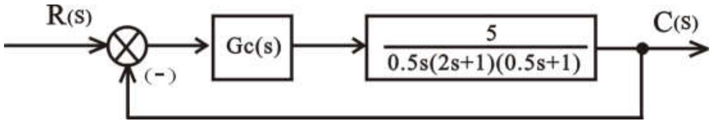


Figure 2.6.6 Two large inertia segments and an integral segment

2) The object is composed of two inertia segments, and its block diagram is shown in Figure 2.6.7.

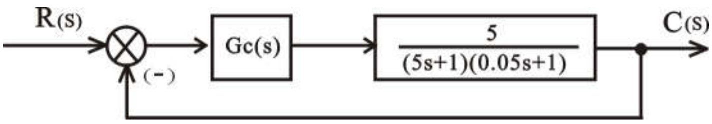


Figure 2.6.7 Two inertial segments

2.7 Frequency Test Characteristics of Typical Segments

1.Objectives

1) Master the method of li sha yu Figure to measure the frequency characteristics of each typical segment.

2) According to the measured frequency characteristics, the bode diagram is made, and the transfer function of the segment is obtained accordingly.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3.Principle

It uses Lissajous pattern menthod, Figure 2.7.1 is the block diagram of the test system.

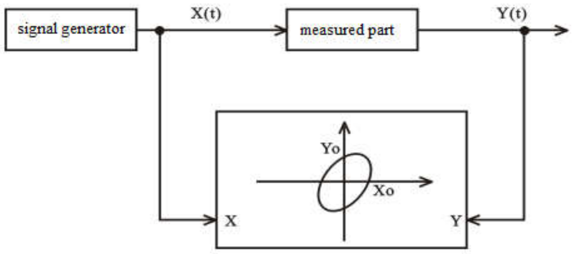
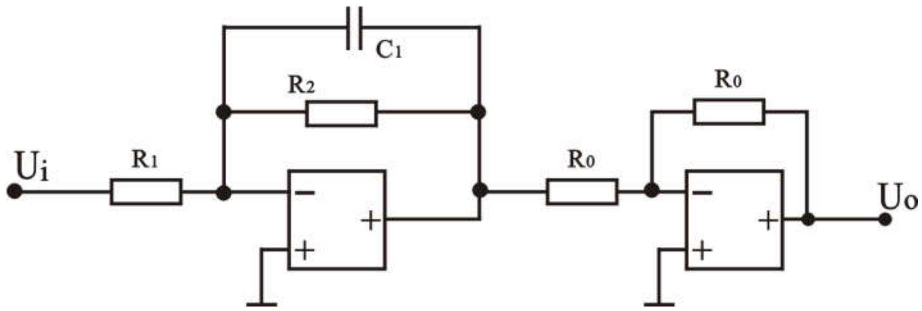


Figure 2.7.1 Block diagram of the test system

4.Steps

4.1 Frequency characteristics test of inertia segment

The transfer function of the segment to be tested is G (S) =1/ (0.5s +1), and the corresponding analog circuit is shown in Figure 2.7.2.



(Set R1=R2=510K, C1=1μF)

Figure 2.7.2 Analog circuit of inertia segment

1) Connect according to Figure 2.7.3 for the test of phase frequency characteristics.When measuring, the oscilloscope's X-axis stops scanning, and the sinusoidal signal of the sweep power supply is sent to both the input end of the measured segment and the X-axis of the oscilloscope, while the output of the measured segment is input to the Y-axis of the oscilloscope.

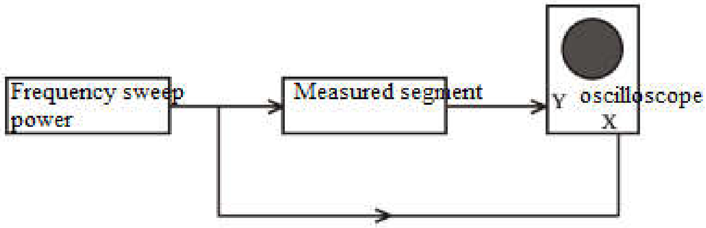


Figure 2.7.3 Wiring diagram of phase-frequency characteristic test

When the sweep power output a sinusoidal signal, then on the oscilloscope screen presents a Lissajous pattern-ellipse. Accordingly, the phase value at the input signal frequency can be measured:

$$\varphi = Sin^{-1}\frac{2X_0}{2X_m} \qquad (2.7.1)$$

Where $2X_0$ is the distance between the ellipse and the intersection of the X-axis, and $2X_m$ is the double amplitude of X (t).

A series of corresponding phase values can be obtained by changing the frequency of the output signal of the sweep power supply. In Table 2.7.1, write down the $2X_0$ and $2X_m$ values under different ω value. When measuring, the frequency of the input signal should be uniform, and the frequency range is 15Hz~40kHz.

Table 2.7.1 Test of phase frequency characteristics

ω	
$2X_0$	
$2X_m$	
φ	

2) Connect according to Figure 2.7.4 to test amplitude and frequency characteristics.When measuring, the oscilloscope's X-axis stops scanning, the sinusoidal signal of the sweep frequency power supply is sent to the input end of the measured segment and the Y2 channel of the oscilloscope at the same time, and the output of the measured segment is sent to the Y1 channel of the oscilloscope.

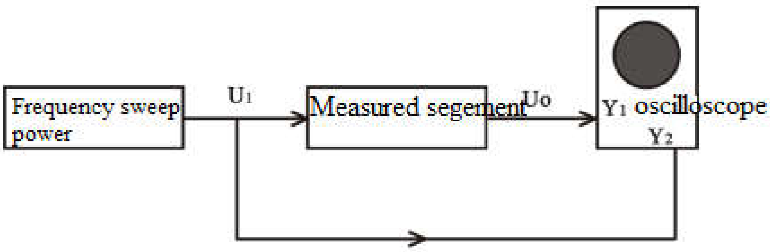


Figure 2.7.4 Wiring diagram of frequency characteristic test

When oscilloscope (or the AC voltage range of the multimeter) display double-amplitude $2Y_1m$ of the output signal under test and the double-amplitude $2Y_2m$ of the input signal The gain value under the input signal frequency can be measured as follows:

$$|G(j\omega)| = \frac{2Y_{1m}}{2Y_{2m}} \qquad (2.7.2)$$

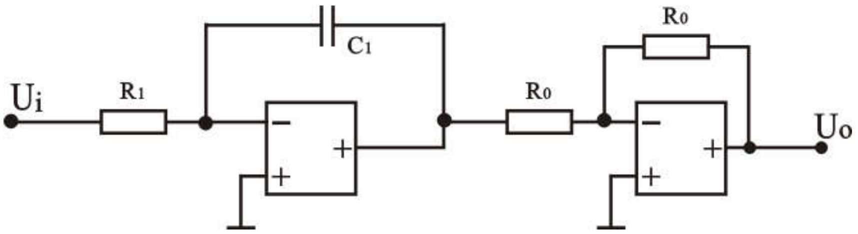
Change frequency sweep power output signal frequency, they can get a series of corresponding gain value, write down $2Y_2m$ and $2Y_1m$ under different ω value in the table 2.7.2, and calculate the $20\ell g2Y_1m/y_2m$ (2) value.

Table 2.7.2 measurement of amplitude-frequency characteristics

ω	
$2Y_1m$	
$2Y_2m$	
$2Y_1m/2Y_2m$	
$20\ell g2Y_1m/(2Y_2m)$	

4.2 Frequency characteristics test of integration segment

The transfer function of the segment under test is G(S)=1/(0.5S), and its analog circuit is shown in Figure 2.7.5.



(R_1=510K, C_1=1 μF, R_0=100K)

Figure 2.7.5 analog circuit of integration segment

According to the wiring diagram in Figure 2.7.3 and Figure 2.7.4, the phase-frequency characteristic and amplitude-frequency characteristic of the integral segment are measured respectively.

4.3 Frequency characteristics test of R-C network

Figure 2.7.6 is the circuit diagram of the hysteresis-lead correction network, whose phase-frequency characteristics and amplitude-frequency characteristics are tested respectively.

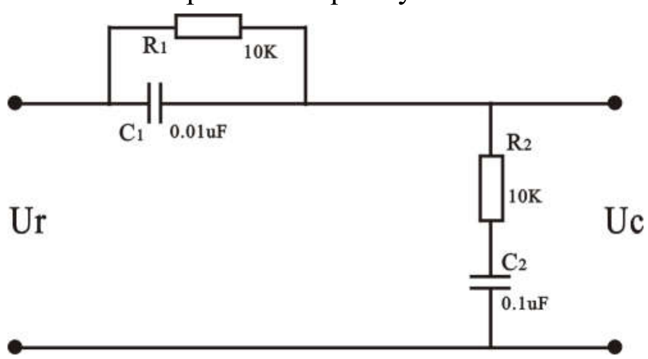


Figure 2.7.6 Circuit diagram of hysteresis-lead compensation network

2.8 Frequency Characteristics Test of Linear System

1.Objectives

1) Master frequency characteristics test of linear system by Lissajous pattern method.

2) Write down the transfer function of the system according to the measured frequency characteristics.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3.Principle

It is the same as that in 2.7.

4.Steps

4.1 Open-loop frequency characteristics test

The open-loop transfer function of the system under test is shown in equation (2.8.1), and the analog circuit is shown in Figure 2.8.1. Set R0=51K, R1=470K, R2=510K, R3=100K, C1=2uF, C2=1uF.

$$G(s)=\frac{10}{(s+1)\quad(0.1s+1)} \qquad (2.8.1)$$

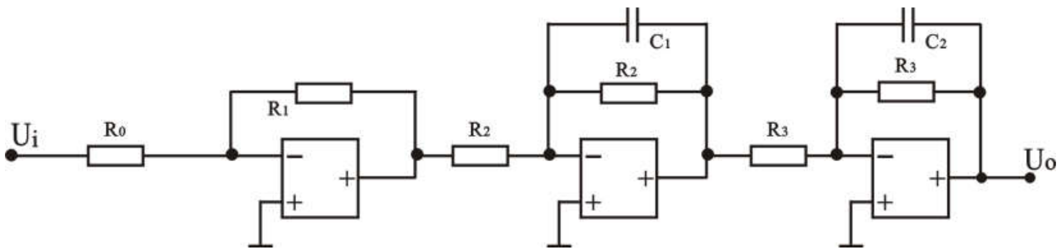


Figure 2.8.1 Analog circuit of open-loop system

Connect according to the Figure 2.7.3 and Figure 2.7.4, the phase-frequency characteristic and amplit-frequency characteristic of the open-loop system were measured respectively, and write the test data into tables 2.8.1 and 2.8.2. The frequency of the input signal should be uniform, and its value range is 15Hz~40kHz.

Table 2.8.1 Test data of open-loop phase frequency characteristics

ω	
$2X_0$	
$2X_m$	
φ	

Table 2.8.2 Test data of open-loop amplitude-frequency characteristics

ω（rad/s）	
$2Y_1m$	
$2Y_2m$	
$2Y_1m/2Y_2m$	
20ℓ g $2Y_1m/(2Y_2m)$	

4.2 Closed-loop frequency characteristics test

The analog circuit of the closed-loop system is shown in Figure 2.8.2. Set R0=51K, R1=470K potentiometer, R2=510K, R3=200K.

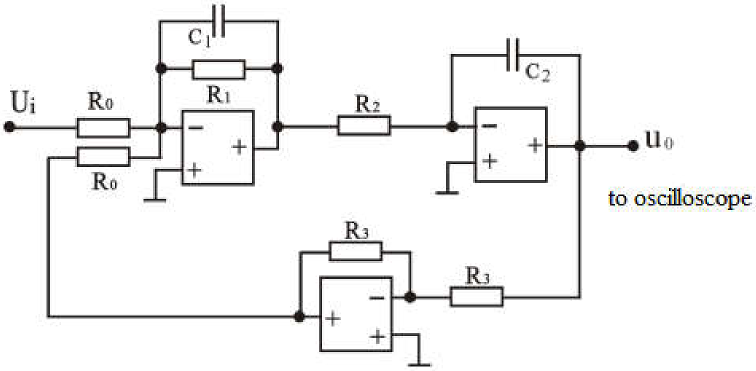


Figure 2.8.2 Analog circuit of the closed-loop system

Connect according to the wiring diagram in Figure 2.7.3 and Figure 2.7.4, the phase-frequency characteristic and amplit-frequency characteristic of the closed-loop system were measured respectively, and write the test data into tables 2.8.3 and 2.8.4.The frequency of the input signal should be uniform, and its value range is 15Hz~40kHz.

Table 2.8.3 Test data of closed-loop phase frequency characteristics

ω	
2X0	
2Xm	
φ	

Table 2.8.3 Test data of closed-loop amplitude-frequency characteristics

ω（rad/s）	
2Y1m	
2Y2m	
2Y1m/2Y2m	
20ℓ g 2Y1m/(2Y2m)	

2.9 Sampling and Recovery of Signal

1.Objectives

1) Understand the sampling method and process of electrical signals and signal recovery .

2) Verify the sampling theorem.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3.Principle

In the experiment, three samplings with frequencies fs<2B, fs=2B and fs>2B are selected to sample the continuous signal, so as to verify the sampling theorem. If the signal can be restored without distortion after sampling, the sampling frequency fs must be much more than twice of the highest frequency B in the signal frequency.The sampling frequency is generally more than four times of the signal frequency. In this experiment, continuous signal sampling and signal recovery should be realized. The principle block diagram is shown in Figure 2.9.1.

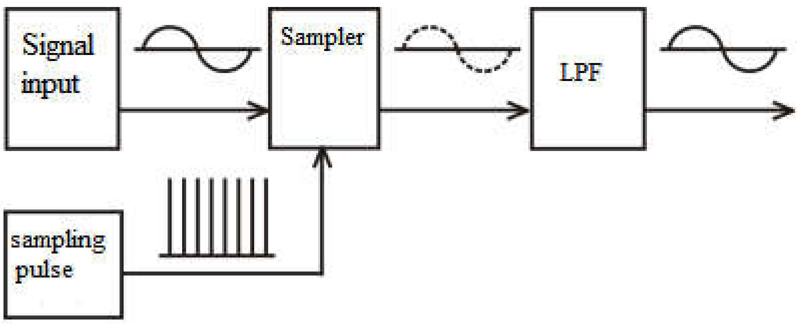


Figure 2.9.1 Schematic block diagram of signal sampling and recovery

4.Steps

1) Continuous time signal f (t) uses sine wave and triangular wave with frequency of 200Hz ~ 300Hz, and calculates their effective frequency band width. After the signal is sampled by periodic pulse s (t) with fs frequency, if we expect the distortion of the signal through the filter to be small, then how mach the sampling frequency and the cut-off frequency of the low-pass filter are, and designe a low-pass filter satisfying the above requirements.

2) According to the above analysis and design, continuous signal f (t) and switching function s (t) are input into the sampler, observe the sampled square or triangular wave signals.

3) Change the sampling frequency to fs≥2B and fs<2B, observe the recovered signal and compare its distortion degree.

2.10 Simulation of Typical Nonlinear Segment

1.Objectives

1) Understand the simulation method of typical nonlinear segment.

2) Master the measurement method of nonlinear characteristics.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3.Principle

The measurement wiring diagram of the nonlinear segemntis shown in Figure 2.10.1. The output of the sinusoidal signal is connected to both the input end of the nonlinear segment and the X-axis of the oscilloscope, and the output of the nonlinear segments connected to the Y-axis of the oscilloscope.The X-axis selector switch is placed in the stop scan position so that the corresponding nonlinear characteristics can be displayed on the oscilloscope.

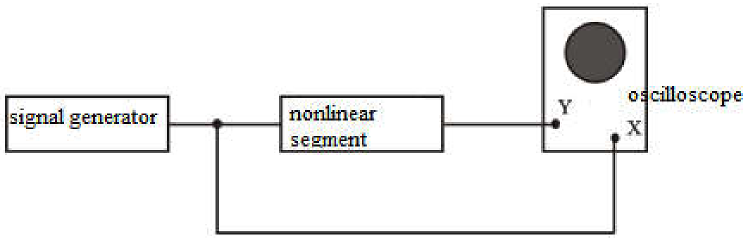
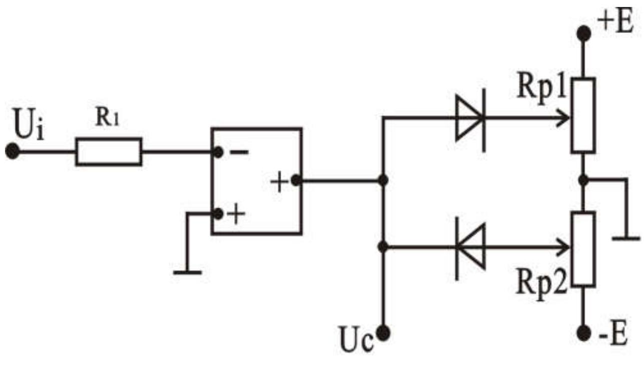


Figure 2.10.1 Connection diagram of nonlinear segment

There are five types of nonlinear characteristics to be tested:

1) Relay characteristics. The circuit of relay characteristics is shown in Figure 2.10.2(a), and relay characteristics are shown in Figure 2.10.2(b). By adjusting the sliding ends of the two potentiometers, the output limiting value M can be adjusted.



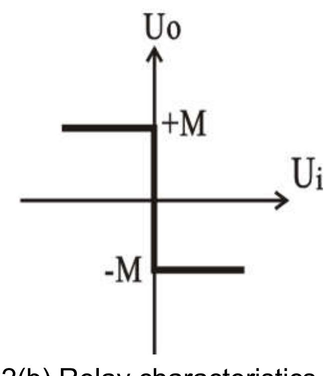
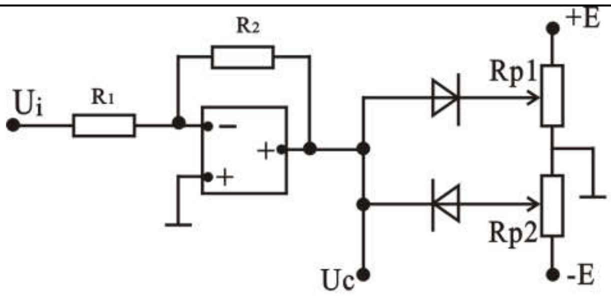


Figure 2.10.2(a) Circuit diagram of relay characteristics

Figure 2.10.2(b) Relay characteristics

2) Saturation characteristics. The circuit of saturation characteristic is shown in Figure 2.10.3(a), and the saturation characteristic is shown in Figure 2.10.3(b).



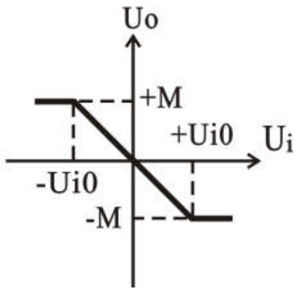
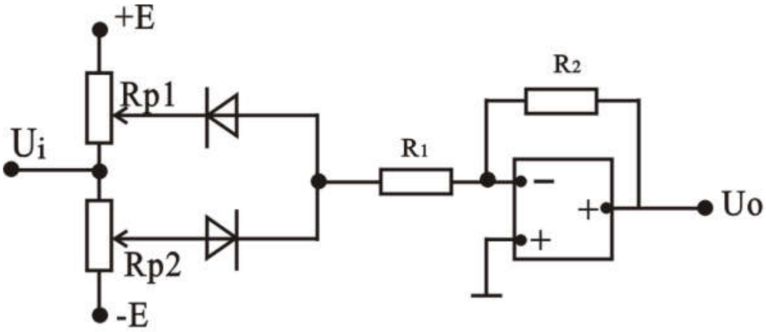


Figure 2.10.3(a) Circuit of saturation characteristics Figure 2.10.3(b) Saturation characteristic

3) Dead zone characteristics.The circuit of dead zone characteristic is shown in Figure 2.10.4(a), and the dead zone characteristic is shown in Figure 2.10.4(b).



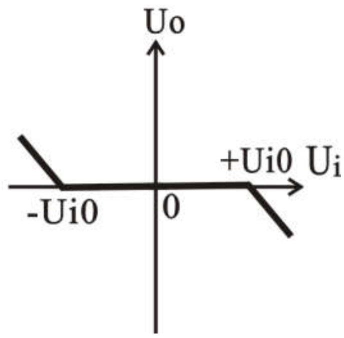
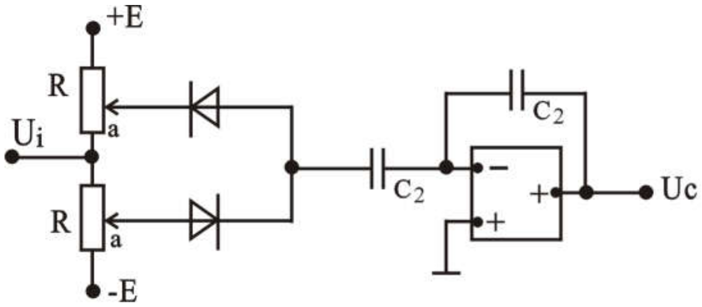


Figure 2.10.4(a) Circuit of dead zone characteristic Figure 2.10.4(b) Dead zone characteristic diagram

4. Loop nonlinearity. The circuit of loop loop nonlinearity is shown in Figure 2.10.5(a), and the loop nonlinearity is shown in Figure 2.10.5(b).



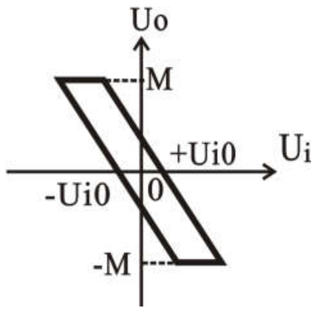
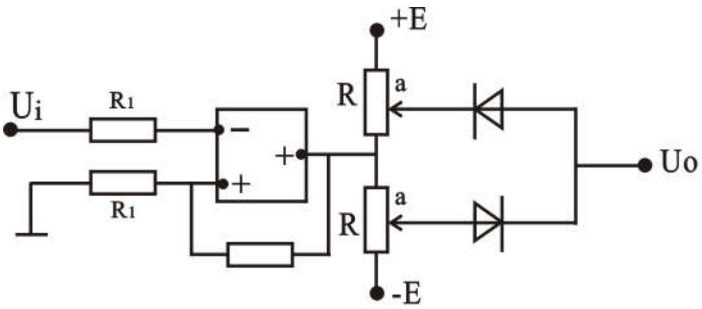


Figure 2.10.5(a) Circuit of loop nonlinearity Figure 2.10.5(b) Loop nonlinearity characteristic

5) Relay characteristics with loop.The circuit of relay characteristics with loop is shown in Figure 2.10.6(a), and the relay characteristics with loop are shown in Figure 2.10.6(b).



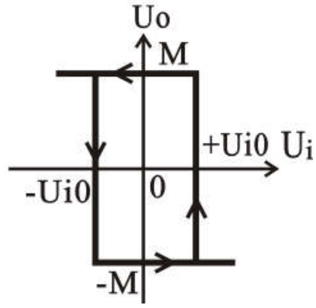


Figure 2.10.6(a) Circuit of relay characteristics with loop Figure 2.10.6(b) Relay characteristics with loop

4.Steps

1) Design corresponding analog circuit diagram according to the typical nonlinear segment.

2) Set the period of regulating the signal generator as about 1s, and connect according to Figure 2.10.1.

3) Observe and record various typical nonlinear characteristics with oscilloscope (or X-Y recorder).

4) Adjust relevant parameters and observe their influence on nonlinear characteristics.

2.11 Phase Plane Analysis of Nonlinear System

1.Objectives

1) Master the simulation method of nonlinear system.

2) Analyze the transient response and steady-state error of relaying nonlinear system and saturated nonlinear characteristic system with phase plane analysis method.

2.Apparatus

1) One control theory electronic simulation experiment apparatus.

2) One ultra-low frequency slow scanning oscilloscope.

3) One multimeter.

3.Principle

The phase plane method is an effective method for the analysis of first-order and second-order nonlinear systems. By making the phase trajectory, we can intuitively know the motion of the system.

Figure 2.11.1 is the block diagram of a nonlinear system with ideal relay, and Figure 2.11.2 is the wiring diagram of the system.

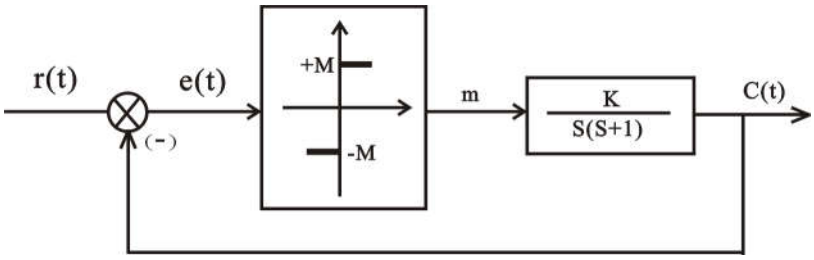


Figure 2.11.1 Block diagram of nonlinear control system

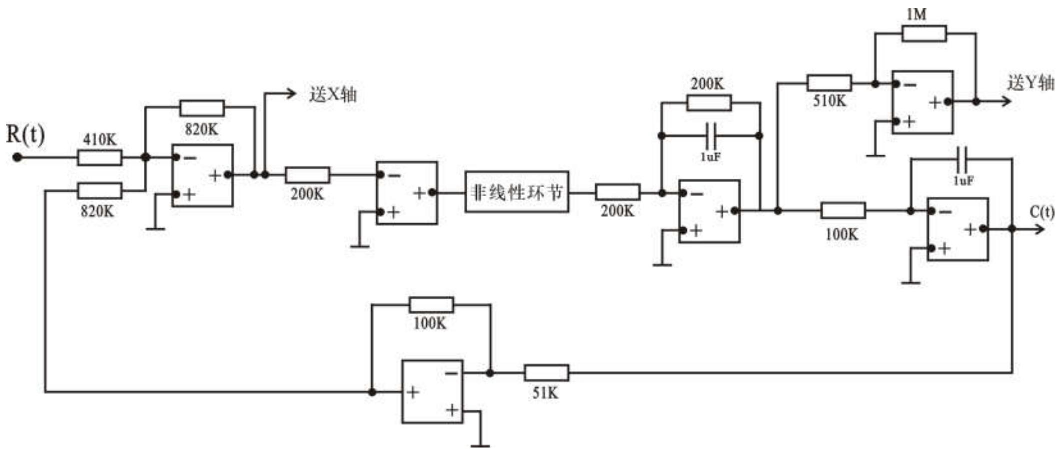


Figure 2.11.2 wiring diagram of nonlinear control system

The phase trajectory of the system is made by using the isoclinal line method, as shown in Figure 2.11.3. The system starts from the initial point A and finally moves to the origin of coordinates.

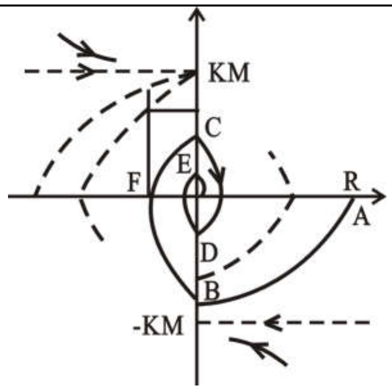


Figure 2.11.3 Phase trajectory diagram of nonlinear system

4.Steps

4.1 Nonlinear system with ideal relay characteristics

The phase trajectory is used to analyze the transient response and steady-state error of a nonlinear system with ideal relay characteristics under the action of step signal, as shown in Figure 2.11.1.

1) According to figure 2.11.1, design the corresponding experimental circuit diagram, where M=5V and K=1.

2) When the system input 1V to 3V respectively, using the oscilloscope to observe phase trajectory when system in e - ė plane, and record overshoot σρ and oscillation frequency N and steady-state error ess.

4.2 Nonlinear systems with saturated nonlinear characteristics

The phase trajectory is used to analyze the transient response and steady-state error of the saturated nonlinear system under the action of step signal as shown in Figure 2.11.4.

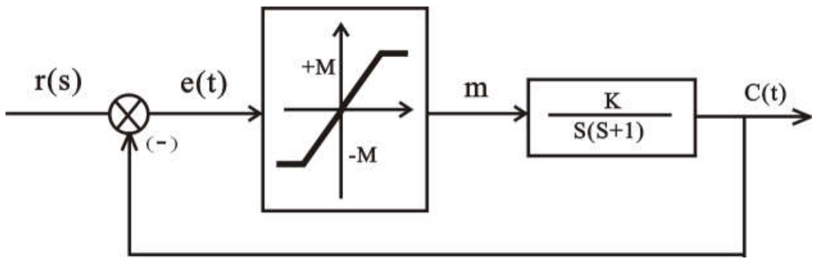


Figure 2.11.4 Block diagram of saturated nonlinear system

1) According to the nonlinear system with saturated nonlinear characteristics shown in Figure 2.11.4, the corresponding experimental circuit diagram is designed, where M=1V, slope K1=1, and K=10.

2) Set r (t) as 2V and 1V respectively, using the oscilloscope to observe phase trajectory when system in e - ė plane, and record overshoot σρ and oscillation frequency N and steady-state error ess.

Appendix

Operating Instructions of Sweep Power Supply

1. Turn on the power switch

Turn on the power switch and the monitor displays "P".

2. Sweep speed selection and output

1) Press the "扫速" button, and the display will display "SPEED O", indicating that the SPEED of sweep in the 0th gear is selected, and the "扫频速度" indicator light in the function indicator will be on.

2) Press the "扫速" button for 10 times continuously, and the end of the display will display 1 ~ F, and switch from 0 to F again and again. There are 11 sweep speed options.

3) Press the "全程扫" key, it will show "SCRn.AP.O"; Function indicator's "全域扫频" indicator light is on, suggests that "扫频电源输出" has sine wave signal with stable amplitude and selected scanning speed, the frequency sweep (i.e., output frequencyincreasing) process is frequency scale indicator "(consists of 15 LEDs) indicates the corresponding frequency band.

Note: in the process of frequency sweeping, pressing any key will not change the current state except the "复位" key.

3. Dot frequency output and frequency display

1) After pressing the "复位" key, and press the "换档" key, the red "点频换档" indicator light in the function indicator is on, select the step range of the dot frequency (there are 7 ranges), then the monitor shows "F *", where * is a certain number in 0 ~ 7.

2) Press the "点频" key, the red "点频" indicator light in the function indicator is on, and the signal output outlet will output corresponding sine wave signal with a certain frequency.

3) Press the "点频" button continuously, and the 2-digit and 3-digit of the display will alternately display "一__" and"__一" , indicating that the output signal frequency is changing incrementally in this range.

For example, after pressing the "复位" key, press the "换档" key. After selecting the step range to the 0th gear, press the "点频" key and the monitor will show "一__ F 0 ", and press "内测频 ", about after 2s, the display shows" F000015 ", indicates that the output is 15Hz sinusoidal signal frequency, and then press the "点频" button twice to change output frequency to 16 Hz, each double click "点频" button, the output signal frequency will increase 1Hz, after press "内测频" key, function indicators will switch to "内测频率" indicator light.

In the above example, if the 1st range is selected and the output frequency is 510Hz, then each click"点频" key, the output frequency increases about 6Hz.

Other gear are similar to the above, but the step amplitude varies with the range.