Analysis of the High-Speed Servo-System with an SCR Servo-Amplifier

By

Yoshikazu SAWARAGI*, Hajime AKASHI**, Minoru TERAISHI*
and Takehito FUKUDA***

In this paper we will analyze the high-speed servo-system with an SCR servo-amplifier. The improvement of the system performance is made by stabilizing the system and obtaining a fast response. For these purposes, two nonlinear compensation networks, a nonlinear low-pass filter and a nonlinear compensation with a Zenor diode, are inserted into the feedback loop. The effects of such compensations are investigated by the model experiments and are discussed, considering them as a nonlinear gain adjustment.

1. Introduction

Various attempts have been made to increase the speed of the servo-systems used as machine tools. Such systems can be applied to the marking operation which demands much higher-speed than the operation of an automatic flame cutting machine[1]. An ideal system is one that can be operated in high-speed with transient errors held within a given tolerance. In order to design such systems, high performance controllers with suitable compensators have been developed. We already treated a servo-system with a magnetic amplifier[2].

Here, an SCR servo-amplifier will be introduced and the experiment will be analyzed. The SCR's (the abbreviation of the silicon controlled rectifiers) are semiconductor rectifiers having similar control performance to thyratron tubes in that it is possible to manufacture those with larger capacity, smaller loss and longer life. Therefore, SCR amplifiers are very effective and useful for raising the speed of servo-systems[3].

2. Synchro-Servo System with an SCR Servo-Amplifier

The block diagram of the servo-model is shown in Fig. 1. The values of the

* Department of Applied Mathematics and Physics
** Department of Precision Mechanics
*** Department of Mechanical Engineering, Osaka City University

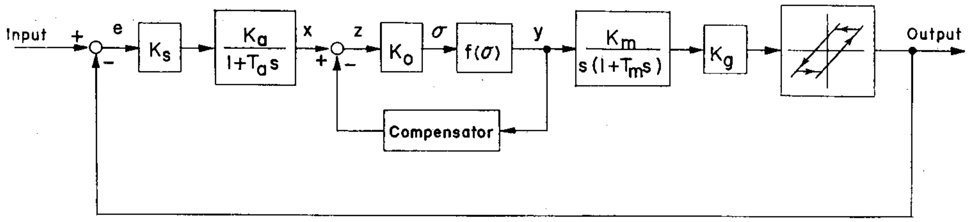

Fig. 1 Block diagram of SCR servo system.

constants of the elements are as follows:

$$K_s = 0.5, \quad K_a = 1.03, \quad T_a = 0.007, \quad K_0 = 0.742, \quad K_m = 15.5,$$
$$T_m = 0.2, \quad K_g = 1/52.$$

An SCR servo-amplifier consists mostly of a summer, gate circuit and SCR units. Moreover, the present amplifier has a feedback compensator. Here a gate circuit, the core of this amplifier and the operation principle of its conduction are explained in detail.

The SCR gate circuit controls the voltages and electric currents of the main circuit by triggering pulses between the gate and the cathode and then switch the SCR on. Such a state is called conduction.

Conduction principle of the gate-circuit is summerized as follows:

(1) In the interlocking circuit, the wave-form is made as shown in Fig. 2-a, synchronized to that of the power-supply with the frequency of 60 c/s.

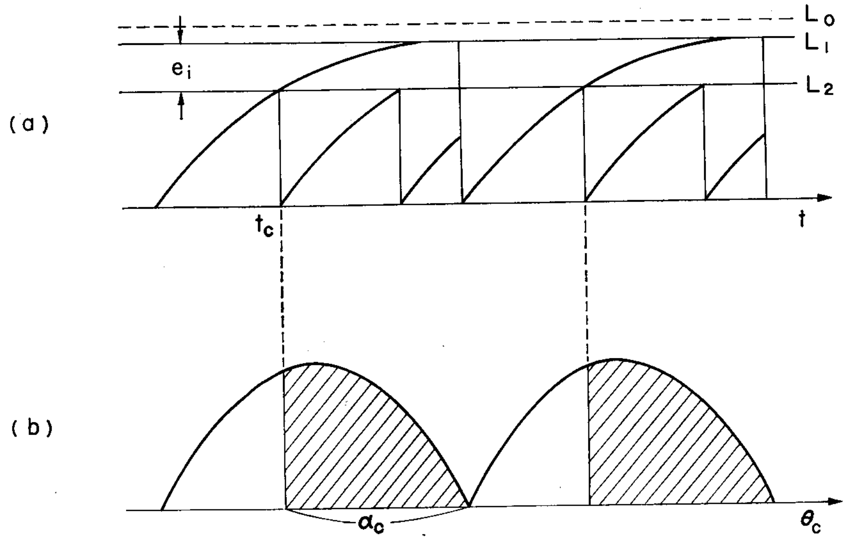

Fig. 2 Conduction principle of the gate circuit.

(2) Let the level be the zero-level L_1 when the output of the summer is zero. Then if the output of the summer becomes e_i, then the level shifts to the level L_2, just when a pulse is triggered at time t_c in the figure.

(3) This pulse switches on the gate of the SCR and just at this time the SCR conducts with firing agnle α_c.

(4) As the sinusoidal wave with frequency 60 c/s is given at both terminals of the SCR, in the conduction state the output corresponding to the hatched area of the sinusoidal wave in Fig. 2-b is produced from the SCR. This is the manipulating signal to the servo-motor during the conduction.

(5) When the alternating voltage of the power-supply becomes zero, the SCR turns off and then the excitation voltage is removed.

In other words, the input voltage to the SCR amplifier (i.e. the output of the summer) is converted to the triggering angle, and consequently the output of the SCR is taken during the conduction time. Therefore, if the amplitude of the input signal to the SCR amplifier, or the error signal in the amplifier is controlled, then the servo-motor is manipulated.

Note that there exists a dead zone between level L_0 and level L_1 so as to keep the mistriggering from small disturbances.

3. Improvement of the Static Characteristics of the Amplifier

In order to examine the static characteristics of the amplifier, the following relations are checked.

In Fig. 3, the static characteristics of the amplifier, i.e. the experimental plots of the output voltage of the SCR vs the input voltage of the summer are obtained as curve (a). This characteristic has a saturation. It can be found theoretically and experimentally that the relation between the output voltage of the SCR and the firing angle is also nonlinear. Therefore the static characteristic of the amplifier with SCR is not suitable for amplifier as it is. Then it must be linearized by utilizing the compensation technique.

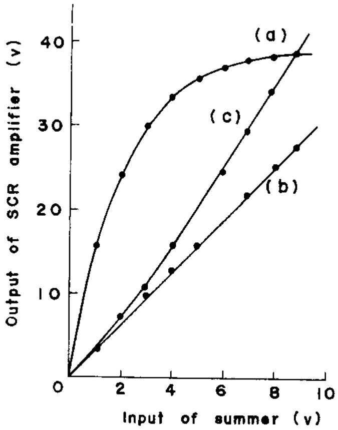

Fig. 3 Static characteristics of the SCR amplifier.

3.1 Insertion of low-pass filter

The output signal of the SCR is irregular in transient and it is necessary to make it smooth. For this purpose, a low-pass filter as shown in Fig. 4 is introduced experimentally. This low-pass filter

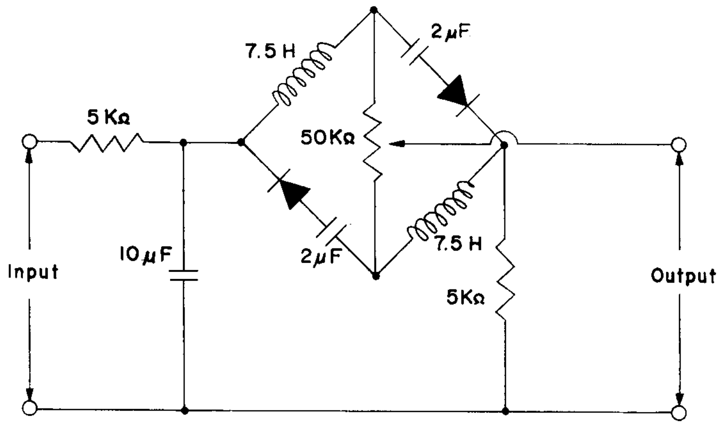

Fig. 4 LPF used as Compensator H_s.

will be noted LPF.

The static characteristics of the amplifier with LPF as a compensator can clearly be linearized as shown by curve (b) of Fig. 3. We call the compensator intended for the improvement of the static characteristics, Compensator H_s.

3.2 Theoretical considerations

The reason why LPF is effective for the improvement of the static characteristics is explained as follows:

The block diagram of Fig. 5 shows the relation between the input and the output of the SCR amplifier, where x is the input, y the output, $f(\sigma)$ the static characteristics of the SCR, K_0 the gain constant of the summer and $g(y)$ the unknown static characteristics to be introduced.

Note that it is not exact to consider the static characteristics only with the direct current components. However, it will be allowable because the alternative current components are actually small in comparison with the direct current components.

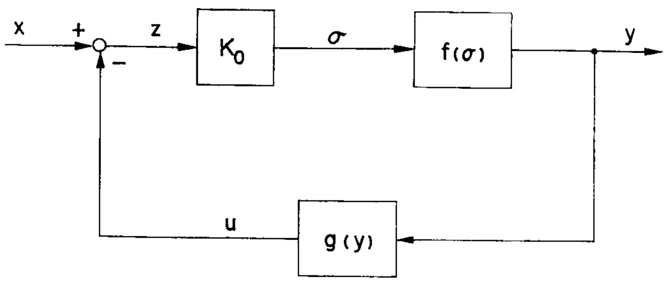

Fig. 5 The input-output relation of the SCR amplifier.

From curve (b) of Fig. 3, with the assumption of linearity of its characteristics, we have

$$y = cx, \quad (c = 3.21) \tag{1}$$

We have the following relations,

$$z = x - u, \tag{2$_1$}$$

$$u = g(y), \tag{2$_2$}$$

$$y = f(\sigma), \tag{2$_3$}$$

$$\sigma = K_0 z. \tag{2$_4$}$$

Using $X = cx$, the above-mentioned relations can be rewritten as

$$g(X) = 1.348(0.313X - f^{-1}(X)), \tag{3}$$

where $f^{-1}(X)$ is the inverse function of $f(X)$ and its values can be known from the plotted curves.

Utilizing Eq. (3) and plotting $g(X)$, we have curve (b) in Fig. 6. This agrees with curve (a) of the practical static characteristics of LPF within the range of input voltage of 35V, corresponding to the bounded value within which the servo-system is able to follow up.

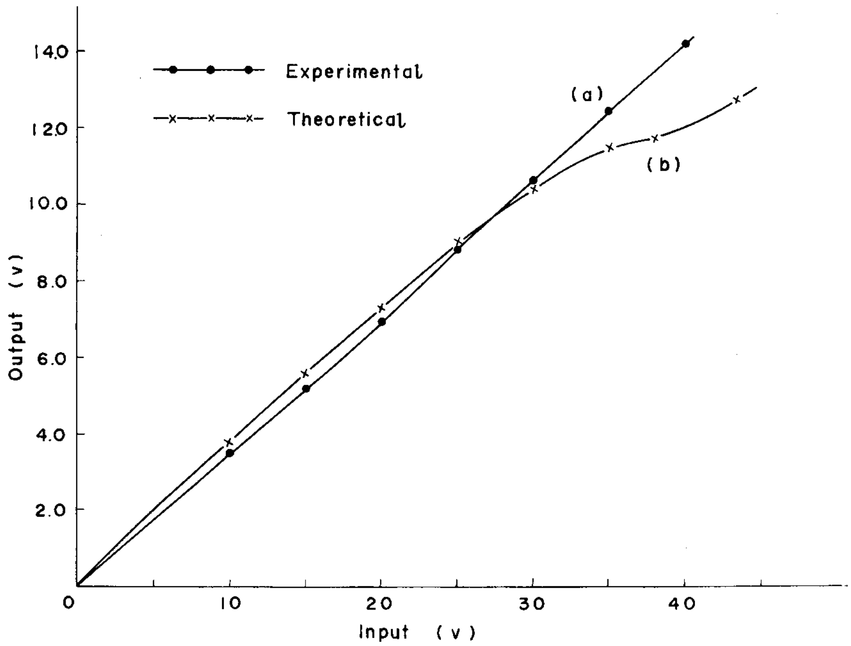

Fig. 6 Comparison of the static characteristics of LPF and its theoretical value.

As the results of this investigation under the assumption that the static characteristics of LPF is linear from curve (b) of Fig. 6, it may appear that the compensator with the linear static characteristics is enough to linearize the static characteristics of the SCR amplifier, but actually it is not so. When we use a compensator consisting only of resistors as Compensator H_s, the static characteristics of the amplifier can be linearized as shown by curve (c) of Fig. 3. If it is actually applied to drive the servo-motor, the revolution of the motor will become unsteady, owing to the irregular wave-form of the output of this compensator.

On the other hand, when we use LPF as Compensator H_s, the wave-form of the output whose higher frequency components are removed is smooth and so the revolution of the motor is smooth too. In other words, the static characteristics of the amplifier can be effectively improved by smoothing pulse waves of the SCR output and then feeding it back.

The insertion of Compensator H_s has also the following effect. In order to stabilize a system, the method of feeding back the output of the servo-motor together with the velocity through tachometer generator is often used. In the present servo-model, however, this cannot be used because the mechanical lag between the servo-motor and the tachometer generator is too large in comparison with the response of the amplifier and the servomotor. Introduction of Compensator H_s makes it possible to utilize the counter-electromotive force of the servo-motor as the compensating signal.

4. Improvement of the Transient Characteristics of the Servo-System

The purpose of this section is to improve the transient characteristics of the servo-system and check the qualitative effects of the nonlinear compensator inserted for this.

To improve the transient characteristics means to make the transient error as small as possible. Here the transient error means the one arising at the time when the ramp rate becomes suddenly zero after the steady-state following the ramp input.

The important problem, however, is how to speed-up the apparatus. According to the experimental results of the servo-model with a magnetic amplifier, the follow-up performance was 200 deg/sec* at most. For the application of this servo-system to the marking operation, however, more speed is required to satisfy the specifications.

* The unit "deg/sec" means the angular velocity of the synchro transmitter.

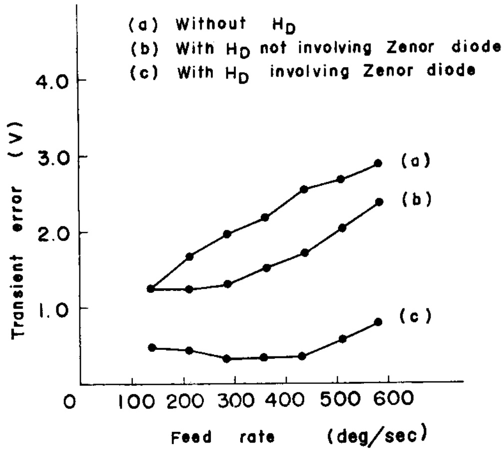

Fig. 7 Experimental plots of transient error vs feed rate.

4.1 Experimental results

The transient error can be made small to some extent by using Compensator H_s which is for the purpose of improving the static characteristics of the amplifier, but it is known from curve (a) of Fig. 7 that the error becomes larger as the input rate increases. Therefore it is necessary to devise another compensator for the improvement of the transient characteristics. From now on this will be called Compensator H_D.

Compensator H_D devised experimentally is shown in Fig. 8. This is a non-linear compensator involving a Zenor diode with the Zenor voltage of 4V. Compensator H_D is introduced after Compensator H_s. As the result of experimental examination of the change of the transient error for various ramp inputs, it was found that the transient errors can be eliminated for ramp rate changes when the potentio-meter after the output-side of Compensator H_s indicated 0.45. The com-

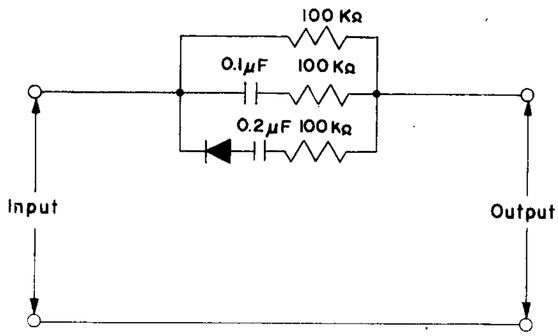

Fig. 8 Compensator H_D with a Zenor diode.

pensator used here is LPF. Curve (c) of Fig. 7 shows the results. It must be noticed that the follow-up performance can be improved up to 600 deg/sec, i.e. three times that in the case of using the magnetic amplifier. When we carried out the same experiments with Compensator H_D without a Zenor diode, satisfactory results were not obtained, for large ramp rates, as shown by curve (b) of Fig. 7. This means that a Zenor diode is very effective as Compensator H_D.

4.2 Theoretical considerations

In order to analyze these results, we carry out the experiments according to the following procedures and qualitatively examine them.

Procedure (1)

Obtain the step responses of Compensator H_s, i.e. LPF and find the value of the potentio-meter by which the most desirable response is found. As the result of experiments, it is known that the most desirable response can be obtained when the value of potentio-meter is 0.45.

Procedure (2)

Examine the transient error for various ramp rates introducing LPF as Compensator H_s. Find the value of potentio-meter at which the transient error is minimum, and plot the gain of LPF at the same time as in Fig. 9.

Procedure (3)

Holding the value of potentio-meter at 0.45, observe how the static charac-

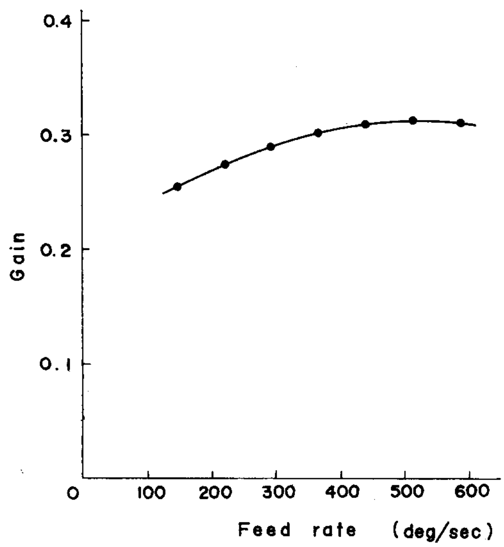

Fig. 9 The gain characteristics of LPF with which transient errors can be minimized.

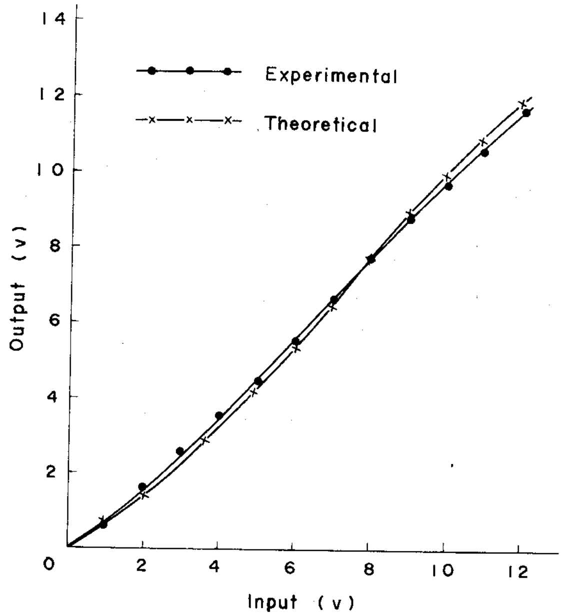

Fig. 10 Static characteristics of Compensator H_D.

teristics of Compensator H_D should be so that its gain may change as shown in Fig. 9 for various ramp rates. Fig. 10 shows the comparison of the theoretical and experimental results, which are in good agreement.

The results which can be judged from these procedures are as follows; Compensator H_D is so effective that, with the change of ramp rate, the gain of feedback compensations can be adjusted as shown in Fig. 9. Consequently, transient errors can be held within a given tolerance for various ramp rates.

As for the rise time, it is more improved by Compensator H_D than by only Compensator H_s, that is, for the latter, the rise time is about 0.050 second, while for the former it is about 0.020 second.

5. Conclusion

The follow-up performance of a nonlinear servo-system was improved three times by using the SCR servo-amplifier, in comparison with the use of the magnetic amplifier. The SCR amplifier with high-performance was very effective. Thus it will be possible to apply such an SCR servo-system to the marking operation.

The nonlinear compensation networks, that is, a nonlinear low-pass filter and a nonlinear compensator with a Zenor diode were inserted into the feedback loop. The Zenor diode especially was effective for the improvement of the transient response.

The future problem is the analysis of the SCR wave-form[4,5]. For this purpose, the digital and analog simulation of the wave-form of the SCR will be tried.

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