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Linearization of Valve Flow Characteristics for Steam Turbine Control

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1. Introduction

The control valve for a large steam turbine must be operated linearly to be run by an automatic control system in a power plant. It is, however, found that the flow increase is much greater for a given valve position change near the closed end of travel than it is near the open end. Accordingly, the desired linearization will be achieved if the valve is opened less near the closed end of travel and greater near the open end. The previous way for linearization was to utilize the cams, which is called the mechanical hydraulic control (MHC). The MHC was afterward improved by producing the nonlinear electric compensation to the nonlinear system of control valves, viz. the electro hydraulic control (EHC). This paper addresses the principle of linearization.

2. Linearization principle

According to servomechanism terminology, it is known that the transfer function gain compensating for nonlinearities is the reciprocal of the valve curve slope. For this reason, we focused on the reciprocal relation in the control system and tried to design a diagram model which can compensate for the nonlinear characteristics of control valves [1,2].

2.1 Control valve position loop and approximation

The usual form of a valve position loop is shown in block diagram Fig. 1 along with a block to indicate the position (X)-to-flow (Q) nonlinearity of the valve [3].

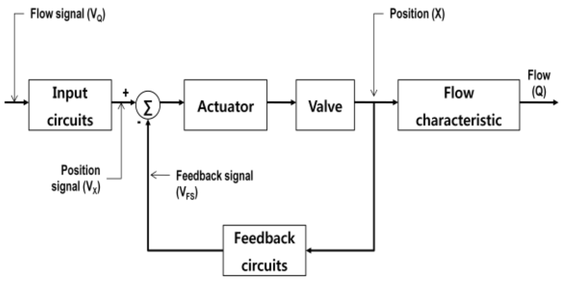

Fig. 1. Closed-loop block diagram of the control valve.

For convenient modeling of control system, it is necessary to approximate the valve curve with two straight lines as is shown in Fig. 2. The two slopes K_3 and K_4 are substituted for the flow characteristic of Fig. 2 and utilized for gains of the control loop. This approximation is a usual practice in setting up the control system of power plants.

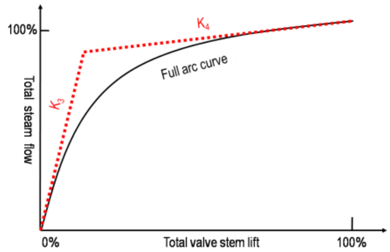

Fig. 2. Approximation of the valve curve in the full arc.

2.2 Compensation Loop Types

As a general rule, two possibilities exist by which nonlinear compensation can be achieved. They are segregated into two types in accordance with the location generating nonlinear compensation signal. The two compensation networks have nevertheless the same logic, viz. the reciprocal of the flow characteristics.

2.2.1. Feedforward compensation network

Fig. 3 gives an idea about a valve position loop with nonlinear compensation at the input circuits and the unit gain is used at the feedback circuits in Fig. 1 [3]. This network is simplified to a pure integrator instead of the complicated transfer function of a real actuator.

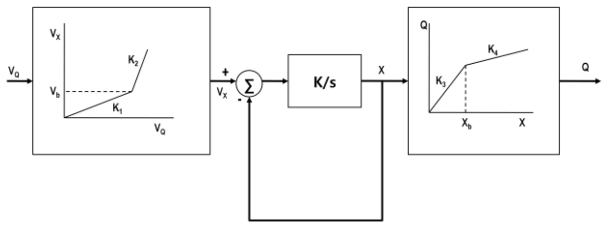

Fig. 3. Example of feedforward compensation.

One can derive the transfer function of the control system above as

$$\frac{Q}{V_Q} = \frac{K_1 K_3}{1+\frac{s}{K}} \text{ for } X < X_b \text{ and } V_X < V_b \quad (1)$$

and

$$\frac{Q}{V_Q} = \frac{K_2 K_4}{1+\frac{s}{K}} \text{ for } X > X_b \text{ and } V_X > V_b \quad (2)$$

Equations (1) and (2) show that linear operation of the valves will end up between V_Q and Q for the flow if the following requirements are satisfied:

$$K_1 = \frac{1}{K_3} \quad (3)$$

$$K_2 = \frac{1}{K_4} \quad (4)$$

and $V_X = V_b$ at a point corresponding to $X = X_b$
Under these conditions

$$\frac{Q}{V_Q} = \frac{1}{1+\frac{s}{K}} \quad (5)$$

for values of flow from 0 to 100 %.

2.2.2. Feedback compensation network

Fig. 4 illustrates the method to obtain feedback compensation with [3].

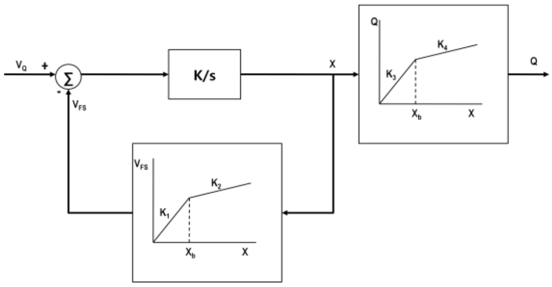

Fig. 4. Example of feedback compensation.

Descriptive equations may be written from transfer function theory as

$$\frac{Q}{V_Q} = \frac{K_3}{K_1}\left[\frac{1}{1+\frac{s}{(K_1)(K)}}\right] \text{ for } X < X_b \qquad (6)$$

and

$$\frac{Q}{V_Q} = \frac{K_4}{K_2}\left[\frac{1}{1+\frac{s}{(K_2)(K)}}\right] \text{ for } X > X_b \qquad (7)$$

If $K_1 = K_3$ and $K_2 = K_4$, the steady-state gain of the system is unity for all values of flow. There is, however, a difference in closed-loop lag time constants for the two gains as can be seen in Equations (6) and (7). The feedback compensation differs from the feedforward one in this respect and a stability analysis of any subsequent loops of the system must take this into account. The stability analysis is not performed since we are primarily considering the linearization by using nonlinear compensation signal.

3. Simulation

Simulink® was utilized to simulate two types of compensation, which are feedforward and feedback, by setting up the control loop depicted in Figs. 3 and 4, respectively.

3.1 Feedforward control

Equations (3) and (4) were employed to generate the compensation signal reciprocal of the flow characteristics. The simulation result is plotted in Fig. 5.

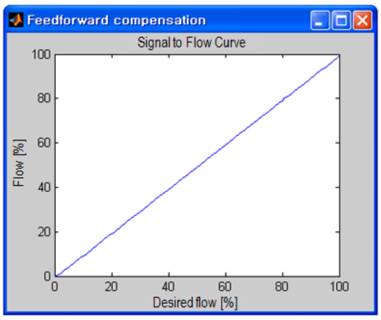

Fig. 5. Feedforward compensation result.

3.2 Feedback control

The nonlinear signal is the same as the flow characteristic since the transfer function of Equations (6) and (7) ends up identical.

The result of the feedback compensation is plotted in Fig. 6. It is found that the slope near 80 % desired flow varied a little compared to the feedforward case and that 100 % desired flow did not make it. These findings were attributed to the effect of the actuator. But it is known that further linearization can readily be achieved by an additional feedback of turbine to stage pressure around the entire valve flow loops. In this respect, the feedback compensation for valve characteristics is deemed practicable.

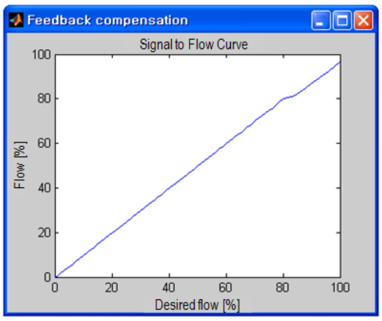

Fig. 6. Feedback compensation result.

4. Conclusions

The results from this simulation lead to conclusion that the compensation of valve nonlinearities can readily be achieved by performing the piecewise-linear analysis method.

Further research is in progress along with the technical means to generate nonlinear signals by using diodes and operational amplifiers setting up the electric circuits such as a mechanical function generator.

NOMENCLATURE

K_i	gain of part *i* of the system
Q	actual steam flow [%]
V_b	breakdown voltage of diode [V]
V_Q	steam flow demand voltage [V]
V_X	valve position demand voltage [V]
X	actual valve position [%]
X_b	position at which slope of valve characteristic changes when two-slope approximation is used [%]

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