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A Fuzzy Logic Controller for the Level Swell and Shrinkage of the Nuclear Steam Generators

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Abstract

Based on a thermohydraulic estimation of the level swell and shrinkage of the nuclear steam generators, a fuzzy logic controller is designed and tested to handle the problem of controlling the level swell and its restoration. The estimation is used to form an artificial system which is nearly the opposite of the level swell and shrinkage and a PD type controller is designed to control this system. This controller is added to a PI type ordinary fuzzy logic controller to form the proposed controller which is tested through various experiments on a scaled-down steam generator. It is found to perform efficiently so that the divergence of the level to a low limit can be avoided.

1. Introduction

There are reports of simulation studies on the control of the level swell and shrinkage for the nuclear steam generators [1,2]. In this study, we have utilized a scaled-down steam generator whose size is about one tenth of the one for the Westinghouse 900MWe nuclear power plants. In order to make the level swell and shrinkage or to restoration, we open the steam dump valve stepwise, leave open for some time, and close fully afterwards. The same cycle of dump valve operation is repeated as many as desired.

The major cause of the level swell and shrinkage occuring during this experiment is found to be the bulk boiling, i.e.the steam generated inside the water during the depressurization[3]. The steam lifts the water level and pushes water down toward the downcomer region, causing the differential pressure gauge to rise. Using this fact, we try to eliminate the unnecessary feedwater valve operations by which the possible divergence of the water level to the low limit can be avoided.

2. A Fuzzy Logic Controller

We start with a standard form of a fuzzy logic controller for the single input system; the input being the level error. Note that the flow error is not used as an input since it is erroneous during the low power operation. The fuzzy sets, fuzzy logic inference, and the defuzzification method used are as described in [4,5]. We use a PD type controller in velocity algorithm form so that

$$\begin{aligned} u_n &= u_{n-1} + \alpha e_n + \beta \Delta e_n \\ \Delta e_n &= e_n - e_{n-1} \end{aligned} \qquad \text{-- (1)}$$

where e_n is the level error at the nth scanning period and u_n is the controller output. A typical example of the control experiment for a case of the water level swell and shrinkage is as shown in fig.1.

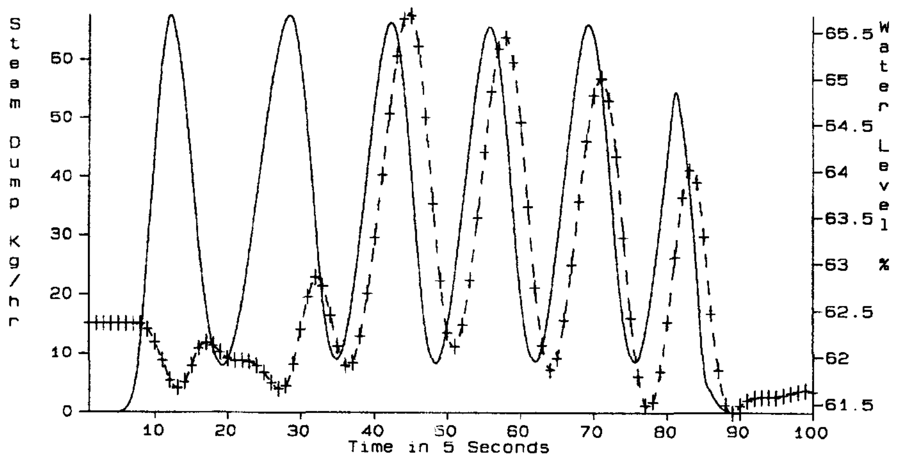

Fig.1 Steam Dump vs Water Level

In [3], we showed that the swell and shrinkage of the water level during the steam dump operation can be estimated by

$$\Delta h = \frac{\Delta G - \Delta m}{A\rho_g} - \frac{\Delta S}{\rho_l f} \qquad \text{------------------------------------(2)}$$

where Δh is the level change, ΔG is the amount of steam generated by the depressurization during a time period Δt, ρ_g is the steam density, ρ_l is the liquid density, Δm is the change of vapor mass, ΔS is the mass of the two-phase fluid dumped out, and f is the steam mass fraction in the dumped two-phase fluid.

The major control problem is that the level swell is not the same as the normal rise of the water level since the swollen level gets restored soon afterwards to nearly the same positions. Another major problem is that the level swells for a longer period of time than when it restores This happens because the steam dump value gets opened stepwise and closed instantly.

Thus, we try to design a controller which does not react to the level swell or to its restoration. To do that, we form a system z(t) to be controlled whose output is the negative cumulative sum of (2) and apply a PD type controller to it in a position algorithm form. Thus, we have

$$(\Delta Z)_n = -(\Delta G/(\rho_g A))_n$$

$$Z = \sum_{i=1}^{n}(\Delta Z)_i \qquad \text{------------------------------------(3)}$$

$$\upsilon_n = \alpha Z_n + \beta(\Delta Z)_n$$

where υ_n is the controller output. The resulting output υ_n is added to the output of the original fuzzy logic controller, i.e.

$$w_n = u_n + \upsilon_n \qquad \text{------------------------------------ (4)}$$

where u_n is given by (1) and w_n is the desired controller output.

Note that if the estimation (2) were exact, then Δh would be the same as Δe and the controller output w_n in (4) would become a PID type controller. In reality, however, (2) represents a rough estimation only and the controller υ_n in (3) provides an effect of reducing the unnecessary control action for the level swell and for its restoration.

3. Results of Experiments

We performed a series of experiments to control the water level while the steam is being dumped out periodically as shown in fig.1. A typical result of the experiments is as shown in fig.2 where the solid line curve is obtained by using the normal fuzzy logic controller (1) and the other curve by using the controller (4).

Initially, the steam generator was heated to about 212°C(20Kg/Cm^2) and the feedwater pump was turned on,followed by opening the feedwater valve at 20%. Then we started to run the controller (1) and a few seconds later,started the periodic steam dump valve operation. We keep the dump valve open at 15%, 30%, 45%, 60%, 75%, 90%, each for one second,fully open for 4 seconds,and fully closed for 3 seconds. This cycle was repeated 15 times to get the solid line curve in fig.2. The same experiment at the same initial condition was repeated with the controller (4) to obtain the other curve.

Note that the solid line water level keeps coming down as the number of cycles increases even though the amplitude of oscillation decreases at the trailing cycles due to the pressure drop as seen in fig.3. In the nuclear power plants,however,the pressure will not drop since the

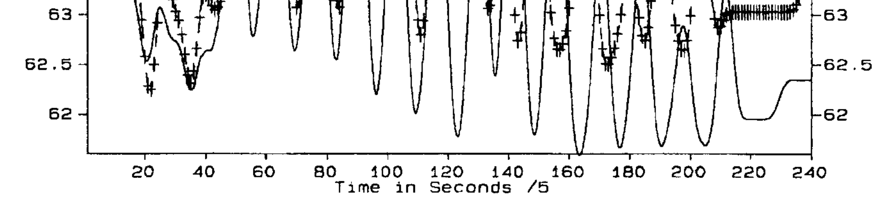

fig.2 Regular Controller vs Proposed Controller

steam dump valve is operating by pressure setpoints and hence the amplitude of oscillation will not decrease. In our steam generator,the heater capacity is not large enough to do similar experiments. The steam dump valve was forced to open and close periodically in order to observe the similar level swell and shrinkage,and hence the steam pressure is not maintained within a specified limit.

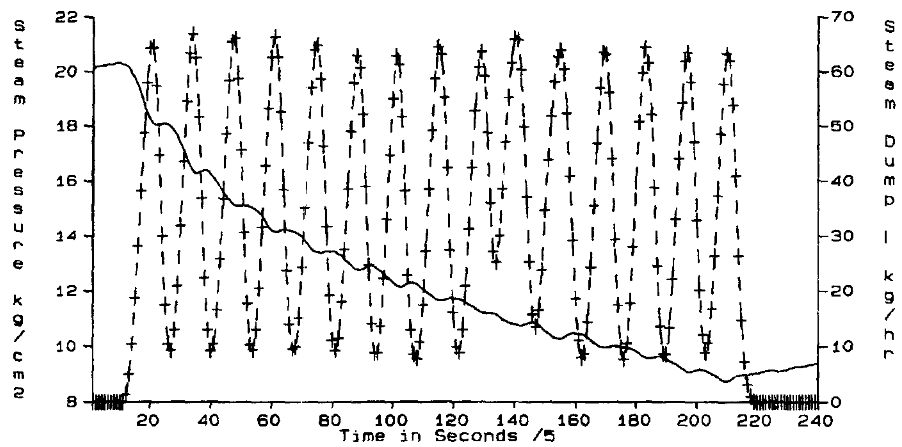

fig.3 Pressure Changes during Cyclic Steam Dump

The curve with '+' symbols in fig.2 represents the water level controlled by our proposed controller. Note that the level change from the begining to the end of the cyclic steam dump is less than 0.5% while the corresponding change in the other curve is about 1.5%. Therefore,the possibility of the water level going down to the lower limit(usually 18%-20%) gets smaller when the proposed controller is used and hence the chances of reactor trip will get reduced.

4. Conclusion

The proposed fuzzy logic controller is found to perform much better than any PI type or other fuzzy logic controllers when applied to a repetitious cycles of the level swell and shrinkage. It does handle the problem of closing the feedwater valve more often than opening it during the cyclic steam dump and hence it can prevent the water level to go down below the low limit. If there is any problem in applying the proposed controller, it should be that a steam table generating subroutine must be built in the controller, with an access to the steam pressure or the steam temperature.

References

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