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THE SIMULATING CALCULATION OF WATERHAMMER IN MFWS OF PWR NUCLEAR POWER PLANT

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ABSTRACT

It is very important to analyse the waterhammer in MFWS (main feed water system) because many events of waterhammer happened in it. The system is very complex and includes some important equipment. The theory of fluid transients is used to do simulation. The mathematical–physical model and the fundamatal equations have been estabilshed. The complex boundary conditions have been treated. For simulating calculation, the computer programs have been compiled. At every calculating section, the results are given with H–t figures for more than 13 kinds of events.

1. INTRODUCTION

The simulating analysis of waterhammer in coolant systems of three loops of PWR nuclear power plant has been completed and appraised in China. This paper introduces the waterhammer analysis of MFWS which is the most complex one of the coolant systems. Depending on the reports from the abroad and the experience of China, many events of waterhammer happened in this loop. They caused some serious destructions.
There are some important equipment contacted with the pipeline of MFWS shown in Fig.1. such as condenser, steam generator, 3 groups of pumps, 6 heaters, salt remover, oxygen remover and many kinds of valves etc. Waterhammer is often caused by pump staring and stopping, power failure, valve openning and closing, pipe breaking and blocking up and seriously caused by cavity collapsing.
There were 2 researching growps (A) and (B) worked on the simulation of MFWS. In order to check the results, the group (A) and (B) were aimed at the same system and worked independently, respectively and simulaneously. The theory of fluid transients was used to do the simulations. The mathematical–physical model and the fundamatal equations have been estabilished. The complex boundary conditions have been compiled. The simulating results given by (A) coincided with the results given by (B) very well.

2. CALCULATING ANALYSIS OF WATERHAMMER OF MFWS

2.1 Introduction of the system

The configuration of MFWS is shown in Fig.1.

There are some important equipment in it, such as condenser, steam generator, 3 groups of pumps, 6 heaters, salt remover, oxgen remover and many kinds of valves ect.

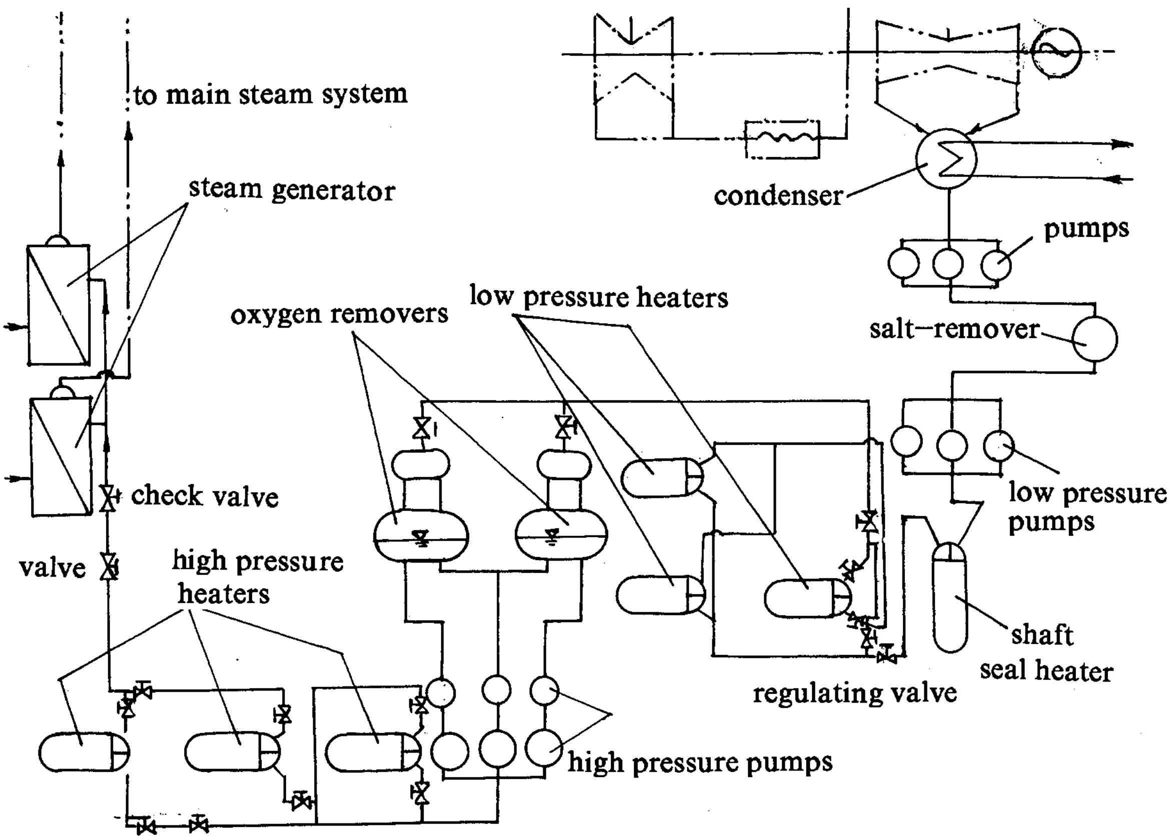


Fig.1 The configuration of MFWS

2.2 Mathematical–physical model

The mathematical–physical model for simulating calculation is also shown in Fig.1.

2.3 The fundamatal equations

Characteristic equations for one dimension flow

$$c^{+} \quad \frac{g}{a}\frac{dH}{dt} + \frac{dV}{dt} + \frac{fV|V|}{2D} = 0 \tag{1}$$

$$\frac{dx}{dt} = a \tag{2}$$

c^-

$$-\frac{g}{a}\frac{dH}{dt} + \frac{dV}{dt} + \frac{fV|V|}{2D} = 0 \tag{3}$$

$$\frac{dx}{dt} = -a \tag{4}$$

2.4 Boundary conditions

(1) Condenser

As a upstream boundary condition of MFWS, there is a essential stable pressure having been given.

(2) Pumps equations

The pumps equations for transients analysis are as follows:

① For power failure: with a equivalent pump to simulate the 2 pumps in parallel:

$$F_1 = HPM - BSQN \cdot v + H_R(\alpha^2 + v^2)\left[A_0 + A_1(\pi + tg^{-1}\frac{v}{\alpha})\right] - \frac{\Delta H v|v|}{\tau^2} = 0 \tag{5}$$

$$F_2 = (\alpha^2 + v^2)\left[B_0 + B_1(\pi + tg^{-1}\frac{v}{\alpha})\right] + \beta_0 - C_{31}(\alpha_0 - \alpha) = 0 \tag{6}$$

② As one working pump suddenly stops, the reserve pump starts immediatly. (P_1stops, P_3 starts)

when P_3 starts, the speed of which is $\alpha_3 = t / ts$, when $t < ts$, while $\alpha_3 = 1$ for $t > ts$.

if $\alpha_3^2 H_s > H_e$, the valve open. This time P_1 stop gradually and P_3 start gradually. $\alpha_2 = 1$, pumps equations are F_1, F_2, F_3, F_5, F_6. calculating unitl $t = t_s$, after $t = t_s$, $\alpha_3 = 1$, F_6 no use.

For this case, the equations for solving pumps are as follows:

$$F_1 = HPM - BSQ(v_1 + v_2 + v_3) + H_R(\alpha_1^2 + v_1^2)\left[A_{01} + A_{11}(\pi + tg^{-1}\frac{v_1}{\alpha_1})\right] - \frac{\Delta H_1 v_1 |v_1|}{\tau_1^2} = 0 \tag{7}$$

$$F_2 = (\alpha_1^2 + v_1^2)\left[B_{01} + B_{11}(\pi + tg^{-1}\frac{v_1}{\alpha_1})\right] + \beta_{01} - C_{311}(\alpha_{01} - \alpha_1) = 0 \tag{8}$$

$$F_3 = HPM - BSQ(v_1 + v_2 + v_3) + H_R(1 + v_2^2)\left[A_{02} + A_{12}(\pi + tg^{-1} v_2)\right] - \frac{\Delta H_2 v_2 |v_2|}{\tau_2^2} = 0 \quad (9)$$

$$F_5 = HPM - BSQ(v_1 + v_2 + v_3) + H_R(\alpha_3^2 + v_3^2)\left[A_{03} + A_{13}(\pi + tg^{-1}\frac{v_3}{\alpha_3})\right] - \frac{\Delta H_3 v_3 |v_3|}{\tau_3^2} = 0 \quad (10)$$

$$F_6 = (\alpha_3^2 + v_3^2)\left[B_{03} + B_{13}(\pi + tg^{-1}\frac{v_3}{\alpha_3})\right] + \beta_{03} - C_{313}(\alpha_{03} - \alpha_3) = 0 \quad (11)$$

if $\alpha_3^2 H_s \leqslant H_c$, the valve located at the discharge of pumps couldn't open, $v_3 = 0$, $\alpha_2 = 1$. Three equations F_1, F_2, F_3 are needed only for v_1 v_2 and α_1.

(3) Heater

The principle construction of heater is shown in Fig.2. The equations of the water box of heater are as follow.

$$H_{p2} = H_2 + \frac{k'\Delta t}{2Vr} Q_2 + \frac{k'\Delta t}{2Vr} Q_{p2} \quad (12)$$

$$H_{p4} = H_4 + \frac{k'\Delta t}{2Vr} Q_4 + \frac{k'\Delta t}{2Vr} Q_{p4} \quad (13)$$

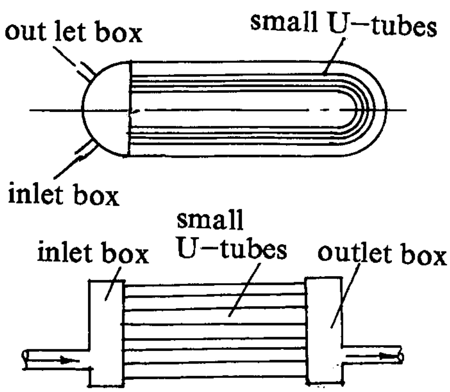


Fig.2 The principle construction of heater

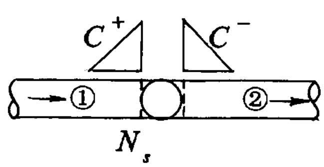


Fig.3 valve's position

(4) Valves

Valve located between two pipes, shown in Fig.3. Valve equation is (14) and (15)

$$\text{For forward flow: } Q_{p2.1} = Q_{p1.NS} = \frac{Q_0 \tau}{\sqrt{H_0}} \sqrt{H_{p1.NS} - H_{p2.1}} \quad (14)$$

$$\text{For reverse flow: } Q_{p1.NS} = Q_{p2.1} = -\frac{Q_0 \tau}{\sqrt{H_0}} \sqrt{H_{p2.1} - H_{p1.NS}} \quad (15)$$

(5) Salt romover

It has been treated as a resistance $\Delta H = fQ^2$, f is a friction factor which is regulated by steady state calculating.

(6) Oxygen remover and steam generator

According to the designing technological process. Oxygen remover and S.G. have been treated as a fixed pressure boundary condition of the middle and the end of MFWS.

2.6 Events and results

Waterhammer simulating calculation of MFWS have been completed for thirteen kinds of kinds of events. Two events of the most dangerous waterhammer are caused by check valve suddenly closure or by cavity collapsing. The simulating results were given by the H–t and Q–t picture at the 26 computer section which are shown in Fig.1. Some of the results are shown in Fig.4. given by H–t from group (A) and group (B). It shows that the results from (A) coincide with from (B) very well.

3. CONCLUSION

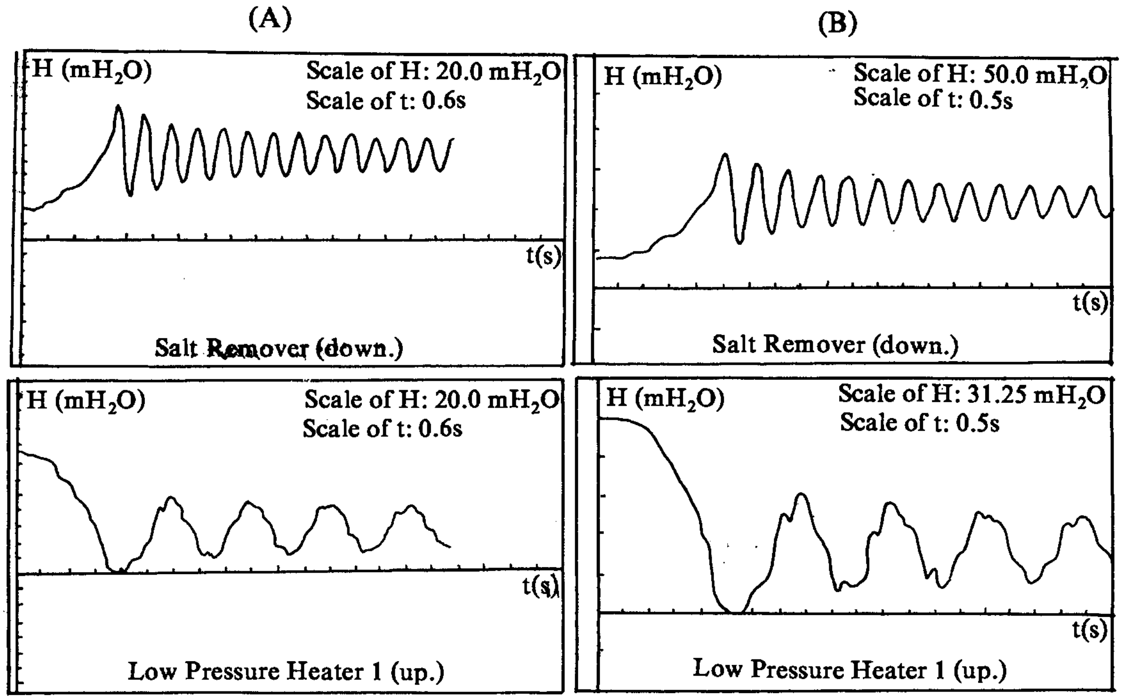
Waterhammer analysis of MFWS is the very important nuclear safty technology. It must been done from the design to debugging whole period. Simulations are of interchange ability and very useful for nuclear power plant to designing, safe appraising and debbuging.

4. REFERENCE

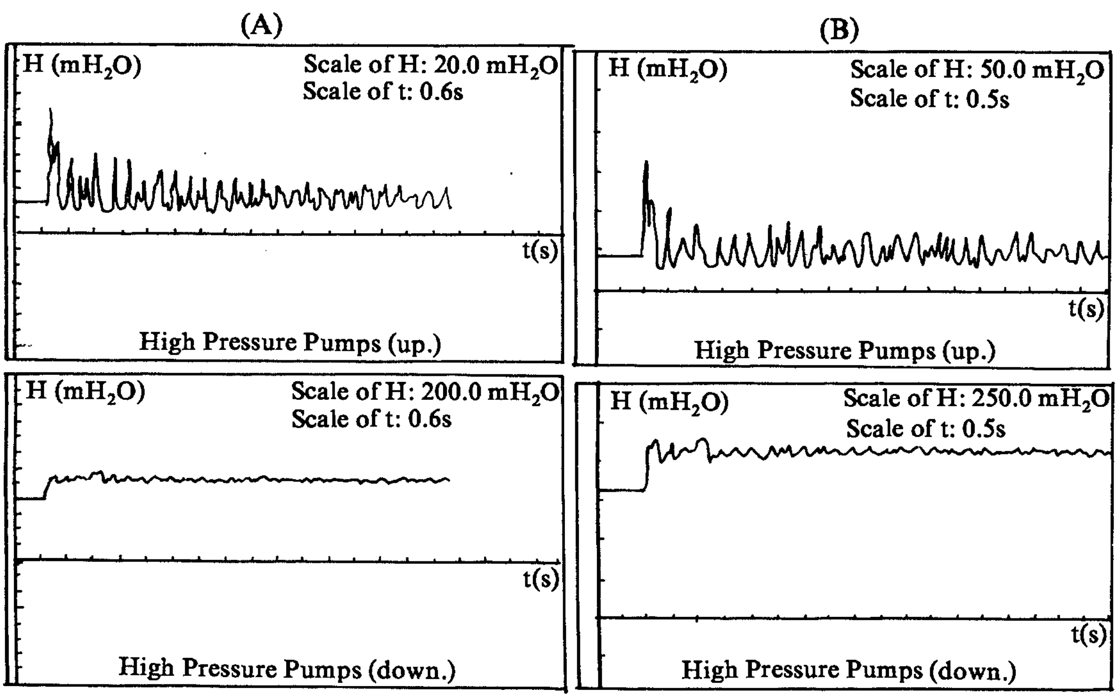
Wylie E.B. & Streeter V.L (1983) Fluid Transients. McGRAW–HILL International Book Company.

J.A.Fox, Hydraulic Analysis of Unsteady Flow in Pipe Networks. (1977)

X.F.Wang, H.K.Ye, R.M.Tang (1989). The Calculation Analysis of Waterhammer in Long Oil Pipeline Transport. proceedings of the Fourth Asian Congress of Fluid Mechanics Hong Kong V–II, B64–B67.



(a) The results from the low pressure pumps power failure



(b) The results from the check valve blocking up suddenly

Fig.4 The some results of the calculation of MFWS