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# Force and moment analysis of pipe system for a double-end break loss-of-coolant accident in primary circuit of PWR

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ABSTRACT The loss of LOCA in the primary circuit system of nuclear power plant is due to the situation and size of break point. Meanwhile, because of its complex, Many previous research works are based on experience data and formulae. This paper has researched and analyzed LOCA in primary circuit, especially about the Double-end break accident, which based on the theory and methods of fluid transients and fluid mechanics. The force and moment of pipe system are also accurately obtained by using control-volume integrating method. All these works are very important for nuclear safety design and analysis.

Keywords: Primary Circuit, A Double-end Break LOCA, Force and Moment, PWR

## 1 INTRODUCTION

The primary curcuit is the most important curcuit in PWR, Its structral figure and imaged breaked points are shown in figure 1. It is a closed system, which includes core, stream generater(S.G.) , main pump and pressurizer. The high tempratre and high pressure water which come from core to stream generater's one side exchange heat with the second circuit system, After temprature and pressure decreased, which will be increaseed by core and main pump respectively. Being nuclear radiation, this heat circulate system should be guaranteed against the occurence the leakage accident. However, many reasons could cause the break accident of main pipe, such as pressure wave, welding faults, metal fatigue and even earthquake. the loss of coolant is obviously when the break accident occured, which is called LOCA. Though the loss of LOCA is due to the situation and size of break point, LOCA is the most serious accident, especiallly Double-end Break.

Many auxiliary system are not considered, for its pipe diameter is far less than main pipe. Even it occurred LOCA, the loss of coolant is small and slow. In contrast, if LOCA (especially Double-end Break) occurred in main pipe, the coolant will loss very quickly, and the temperature of core will be risked sharply, which will lead to core melted. The consequences would be disastrous. At the same time, under the fluid flow force, the pipe will vibrate strongly, even swing at large displacement if no limited. The swigged pipe will destroy the other equipment or structures. For this reasons, based on some reasonable rule, force and moment analysis of main pipe for double-end break LOCA is very important for nuclear safety design and analysis.

## 2 THE CALCULATION PRINCIPLE AND METHOD

### *2.1 ONE-DIMENSIONAL GOVERNING EQUATIONS OF WATER HAMMER*[1,2]:

conservation equation
$$\frac{\partial V}{\partial t}+V\frac{\partial V}{\partial x}+g\frac{\partial H}{\partial x}+\frac{fV|V|}{2D}=0 \qquad (1)$$

momentum equation
$$\frac{\partial H}{\partial t}+V\frac{\partial H}{\partial x}-V\sin\alpha+\frac{a^2}{g}\frac{\partial V}{\partial x}=0 \qquad (2)$$

The flow equations are discretized with a finite volume method. Using characteric line method, the calculation will begin at stable statement, Here there are some bound conditions which is described in detail by reference [1.2] such as core, S.G., Main pump, ECCS, pressurizer and breake point.

### *2.2 FLUID FLOW FORCE OF PIPE*

2.2.1 Some contry's standard prescribed simplify method of fluid flow force [3,4]

(1). Based on American ANSI/ANS-58 · 2(1980), the simplify formula of fluid flow force is following as:

$$P_{B1}=C_T P_0 A \qquad (3)$$

where, $C_T$ is force coefient, $P_0$ is stable pressure, A is flow area of pipe. If break is double-end break, the force opposely added the end of two pipes, its direction is opposite and direct to center of each pipe. If break is little aera break, the force add the position of break, its direction is perpendicular to the centline of pipe.

(2). Former of 1970's, preliminary design of Some PWR nuclear power plants in American are based on the following formula to anasis the effects of LOCA of pipe system.

$$P_{B2}=2.4P_S A \qquad (4)$$

where, $P_S$ is saturation pressure

(3). Based on Gemerny standard, some main struments should be kept steady by the added force. The force is:

$$P_{B3}=2.0P_0 A \qquad (5)$$

2.2.2 The calculation of fluid force using theory and methods of fluid transients and fluid mechanics [5]

The previous formulae are based on experience data to some degree. It is not accurate. By contrast, Here we can accurately obtain the pressure and velocity of each section of pipe with time using the transient flow theory. After that, using control-volume integrating method and as following formula, the fluid flow force can be accurately gotten.

The control volume is shown as Figure 2, the momentum equation of control volume is:

$$\iiint_{\tau} \rho f d\tau + \oiint_{A} P_N dA + \iint_{A_1} (n_1 \cdot V \cdot \rho) V dA - \iint_{A_2} (n_2 \cdot V \cdot \rho) V dA = \frac{\partial}{\partial t} \iiint_{\tau} \rho V d\tau \tag{6}$$

where $\iiint_{\tau} \rho f d\tau$ is mass force, $\oiint_{A} P_n dA$ is area force, $\iint_{A_1} (n_1 \cdot V \cdot \rho) V dA$ is flow in momentum, $\iint_{A_2} (n_2 \cdot V \cdot \rho) V dA$ is flow out momentum, $\frac{\partial}{\partial t} \iiint_{\tau} \rho V d\tau$ is momentum increment.

Divided the line into N sections (N sections are same as grids of transient flow calculation), from the transient calculation, each parts of the formula can be gotten, then the force of each section added on the pipe can be obtained. As results, the force and moment of whole pipe can be gotten.

For I section control volum, the added force of it are:

X direction: $$F_{ix} = (V_{i+1}^2 \cdot \rho \cdot A + P_{i+1} \cdot A)\cos\alpha_{i+1} - (V_i^2 \cdot \rho \cdot A + P_i \cdot A)\cos\alpha_i + \rho(V_{i+1} - V_{P,i+1}) A \cdot a\Delta t \cos\alpha_{i+1} \tag{7}$$

Y direction: $$F_{iy} = (V_{i+1}^2 \cdot \rho \cdot A + P_{i+1} \cdot A)\sin\alpha_{i+1} - (V_i^2 \cdot \rho \cdot A + P_i \cdot A)\sin\alpha_i + \rho(V_{i+1} - V_{P,i+1}) A \cdot a\Delta t \sin\alpha_{i+1} \tag{8}$$

where $\alpha_i = (\theta_2 - \theta_1) \times i / N + \theta_1$

For horizontal line, $F_{iy} = 0$

Where $\alpha_i$ is angle of fluid flow, $\theta_1, \theta_2$ are angle of inlet and outlet of pipe, subscript "p" denote the last time step, a is waterhammer wave velocity, A is area of pipe.

Based on preceding formulae and some theory of structural mechanics and elastic mechnics [6,7], the force and moment of each point of pipe can be obtained when a welding point occured double-end break.

## 3 CALCULATION RESULT

### *3.1 WATER HAMMER ANALYSIS*

According the different work situation the pressure and flow at 11 typical break points of main loop are calculated in this paper. The P-t curve of point 1 and point 2 are shown in

Figure and Figure. The first stage of breakage is a process of spraying of supercooled water . Then the water vaporized due to the sharp decrease of pressure at break point , and the water pressure reach the saturation pressure of steam. Therefore a rarefaction wave generates and propagates in the pipeline system. The time of spraying is various as the difference of size and position of break points. The spraying process is very rapid, but it would cause the high pressure gradient and pressure vibration at both ends of system equipment .

Under the Double-end Break Accident , the affect factors are as follows:

(1) Core Emergency Cooling System (CECS)

When the inlet pipe of pressure container is broken , the Emergency water would be resisted by coolant from lower chamber and it could not go to the inlet of core , because it goes to the break point along the bypass of core. Under this situation, CECS could not provide the cooling effect to the core . It is very dangerous for the safety of core .

(2) Position of break point

If the inlet pipe of pressure container is broken , the pressure of loop will reach the saturation pressure of steam , and the pressure vibration will be a little. If the breakage occurs in the outlet pipe of container, the pressure vibration will keep a more time, and the amplitude of vibration will be larger than that in the inlet pipe . On other hand , considering the decrease of coolant flow in the core , the breakage in the outlet pipe is more dangerous .

(3) Area of breakage

The larger the area of breakage is, the coolant loss is more rapid. In addition , the pressure in system decreases more rapidly .

(4) Released gas

With the decrease of system pressure , a piece of gas dissolved in water would be released . Nevertheless in the accident of main loop , the released gas from under cooling water is negligible. So the effect of Released gas is ignored in the calculation of water hammer.

### *3.2 FORCE AND MOMENT ANALYSIS*

By using the fluid mechanics theory and coupling method the forces and moments at the 11 break points are calculated and the results are shown in Figure and Figure .

Through the calculation analysis, some important conclusions are obtained :

(1) Double-end Break is the control factor in the structure safety design of pipeline system.

(2) The curve of force and moment is similar to the pressure curve in pipeline.

(3) The force and moment at the elbow are larger than the straight pipe.

(4) The peak value of vibration occurs in the middle part of pipeline.

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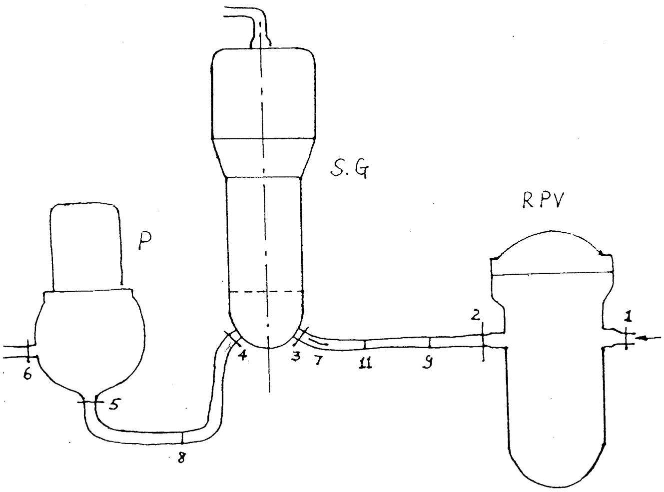


Fig. 1 Structure and 11 break points position of primary circuit of PWR

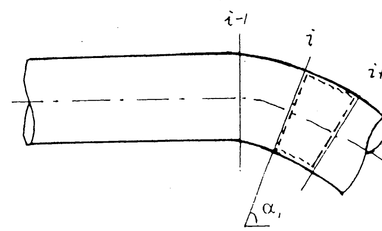


Fig. 2 Control volume

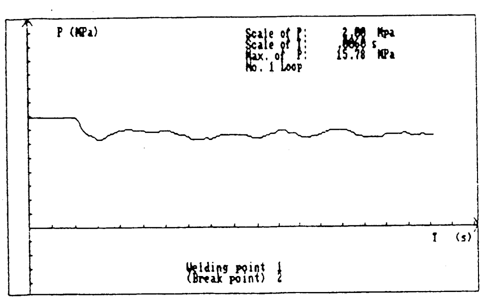


Fig. 3 P ~ t curve of point 1
at point 2 double-end break

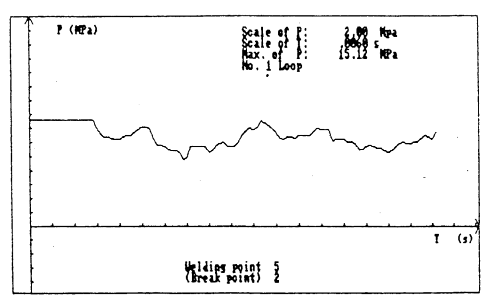


Fig. 4 P ~ t curve of point 5
at point 2 double-end break

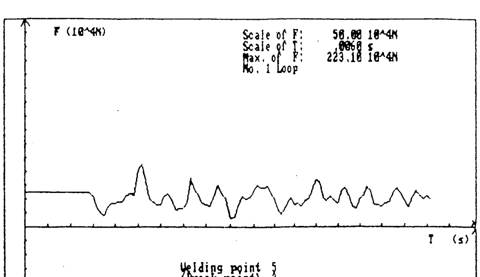


Fig. 5 F ~ t curve of point 5
at point 2 double-end break

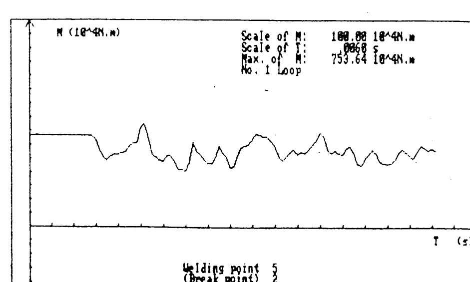


Fig. 6 M ~ t curve of point 5
at point 2 double-end break