# Stress Calculation and Analysis of a 600MW Supercritical Boiler's Steam-water Separator

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**Abstract.** The steam-water separator of a 600MW boiler has been chosen as the research object. By theoretical analysis's method and finite element analysis, the stress and secure research has been carried out in the steam-water separator as the thick-walled pressure vessel. For its start-up and normal operation of the working process and features and considering the internal pressure load and thermal stress loading conditions, the initiation of separation stress and security analysis have been carried out about the steam-water separator. The primary stress at the continuum of the cylinder structure can be calculated by the formula, and the calculated results are basically in agreement with the simulated graphic results. And the research work provides a theoretical basis for on-line stress monitoring and life assessment.

# 1 Introduction

The supercritical boiler's steam-water separator is the connector between the water wall and the superheater. The normal operation of the steam-water separator is an important guarantee for the power unit's safe operation. And the start-up characteristics of the steam-water separator determine the steam parameters (pressure, temperature) and steam flow. Its stability and flexibility determine the regulation characteristics of once-through boiler under low load. In this paper, the safety of the steam-water separator of 600MW supercritical unit is analyzed by means of theoretical analysis, which is simplified as a thick-walled cylinder model. And the wall temperature and stress of the steam-water separator are calculated and analyzed under the actual start-up and stop conditions. The safety and strength of the separator are checked under each working condition[1-2].

Each of steam-water separators has six tangential inlet pipes and each a declination of 15°, which are introduced into the top pipe of the steam-water separator. The mixture of steam and water rotates in the separator at a high speed. Steam and water in the vessel are separated by centrifugation and gravity. A dehydrating device is arranged in the middle and upper position of the steamwater separator. The function of the dehydrating device is to eliminate the kinetic energy of the medium rotation and downward, and to make the water level in the starting separator and the water storage tank connected with it stable [3]. The start separator structure views are shown in Figure 1.

The steam-water separator is a three-dimensional cylinder, four separators are arranged above the front part of the boiler. The distance between the separator and the center line of the water wall is 3.575 m, and the distance

between two separators is 5.25 m. The outer diameter of the steam-water separator is 610mm, the wall thickness is mm, and the height of the cylinder is 8.363m. The separator's material is low alloy steel WB36(Ni-Cu-Mo Steel), which is special for boiler and pressure vessel. Each steam-water separator is suspended on the top plate of the boiler through two suspender[4].



Fig. 1. Model views of the steam-water separator.

# 2 Stress Calculation of the Separator

#### 2.1. Mechanical Stress Calculation

From the cold start curve which is shown in Figure 2, six points have been taken to analyze the object. Their respective time, corresponding pressure and temperature are listed in Table 1.

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It can be seen that the area with the greatest mechanical stress occurs on the inner wall or the outer wall, which is based on the the analysis. Then the inner wall and the outer wall are respectively substituted into the formula:

$$\sigma_{r} = \frac{p_{n}R_{n}^{2}}{R_{w}^{2}-R_{n}^{2}} \left(1 - \frac{R_{w}^{2}}{r^{2}}\right)$$
(1)

$$\sigma_{\theta} = \frac{p_n R_n^2}{R_w^2 - R_n^2} \left( 1 + \frac{R_w^2}{r^2} \right)$$
(2)

It can be concluded that the stresses on the inner and outer walls are expressed as follows:

The inner wall:

$$\sigma_{r} = -p_{n}, \sigma_{\theta} = p_{n} \frac{k^{2}+1}{k^{2}-1}, \sigma_{m} = 0$$
(3)

The outer wall:

$$\boldsymbol{\sigma}_{r} = 0, \boldsymbol{\sigma}_{\theta} = p_{n} \frac{2}{k^{2} - 1}, \boldsymbol{\sigma}_{m} = 0$$
<sup>(4)</sup>

In formula(3)&(4):



Fig. 2. The cold start-up curve of the power unit.

The parameters in Table 1 are substituted into the formula (3) & (4).

Table 1.	<b>Parameters</b>	related to	the	analysis	state.
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State	<b>Operating Conditions</b>				
State	Time(r/m	Pressure(MP	Temnerature		
1	70	1 667	203 056		
2	110	5 278	267 383		
3	150	8 920	302 744		
4	350	8 920	342 744		
5	414	22.064	413 99		
6	423	24 167	413 99		

Then the mechanical stress at each state point of the steam-water separator can be calculated, which is shown as Table 2.

Table 2. Mechanical stress at each state point of the separato	or.
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State		$\sigma_{\theta}$ (Mpa)	$\sigma_r$ (Mpa)	$\sigma_{m}$ (Mpa)	
1	Inner wall	7.088	-1.667	0	
	Outer wall	5.421	0	0	
2`	Inner wall	22.442	-5.278	0	
	Outer wall	17.164	0	0	
3/	Inner wall	38.819	-8.92	0	
4	Outer wall	29.007	0	0	
5	Inner wall	93.815	-22.064	0	
3	Outer wall	71.751	0	U	
6	Inner wall	102.757	-24.167	0	
	Outer wall	78.590	0	0	

#### 2.2. Thermal Stress Calculation

The analysis shows that the maximum point of thermal stress also occurs at the inner wall or the outer wall. The thermal stress of the inner and outer walls is expressed as follows [5]:

The inner wall 
$$(r=R_n)$$
:  
 $_T \sigma_r = 0,$  (5)  
 $_r \sigma_{\theta} = _T \sigma_{\varepsilon} = \frac{\alpha E}{1-\mu} \left[ \frac{2}{R_{w}^2 - R_{n}^2} \int_{R_n}^{R_w} T(r) r dr - T(R_n) \right]$ 

The outer wall( $r=R_w$ ):

$$T \boldsymbol{\sigma}_{r} = 0,$$

$$T \boldsymbol{\sigma}_{r} = 0,$$

$$T \boldsymbol{\sigma}_{r} = T \boldsymbol{\sigma}_{z} = \frac{\alpha E}{1 - \mu} \left[ \frac{2}{R_{w}^{2} - R_{s}^{2}} \int_{R_{s}}^{R_{w}} T(r) r dr - T(R_{w}) \right]$$

$$(6)$$

Equation of temperature field:

$$t(r,\tau) = t_0 + V_{\tau} + \frac{V_{\tau}}{4a} \left( r_2 - R_1^2 - 2R_2^2 \ln \frac{r}{R_1} \right)$$
(7)

The resultant as follows: The inner wall:

$$T\boldsymbol{\sigma}_{r} = 0,$$

$$T\boldsymbol{\sigma}_{\theta} = T\boldsymbol{\sigma}_{z} = -0.0015894 \frac{\alpha E}{1-\mu} \frac{V}{a}$$
(8)

The outer wall:

$$T\boldsymbol{\sigma}_{r}=0,$$

$$T\boldsymbol{\sigma}_{\theta}=T\boldsymbol{\sigma}_{z}=0.00070216\frac{\alpha E}{1-\mu a}V$$
(9)

In the formula (8) and (9):  $\alpha$  is linear expansion coefficient;  $\mu$  is Poisson's ratio, equal to 0.3; E is elastic modulus; V is temperature change rate; a is thermal conductivity and  $a = \lambda / \rho$  c.

The radial thermal stress is 0, and the circumferential stress and axial stress of the inner and outer wall of each state (both are equal) are listed in Table 3.

The mechanical stress and thermal stress after stress concentration are considered.

The maximum stress of the supercritical boiler's steam-water separator is concentrated at the joint of six outgoing pipes, and the inclined cutting is 52  $^{\circ}$  and the droop is 15  $^{\circ}$ .

The formula as follows:

$$k = k_t \left[ 1 + (\tan \varphi)^{4/3} \right] = 1.53k$$
 (10)

So the stress concentration factor of mechanical stress is obtained which is as shown in Table 4.

Table 3. Thermal stress at each state point of the separator.

	State 1	State 2	State 3	State 4	State 5/6
Innerwall (MPa)	-11.27	-13.49	-13.66	-17.92	-18.50
Outwall (MPa)	9.96	5.96	6.03	7.92	8.18

Table 4. Stress concentration factor of the separator

	Longitudinal section		Cross section		
	Inner Wall	Outer wall	Inner Wall	Outer wall	
$\sigma_{_{ heta}}$	4.743	1.836	1.53	3.213	
$\sigma_{r}$	-0.223	0	-0.223	0	
$\sigma_z$	0.306	1.53	-0.306	3.978	

#### 2.3. Stress safety analysis

As the mechanical stress and thermal stress of thick wall vessel are secondary stress, they can be directly added to obtain the comprehensive stress value. And in order to facilitate the stress safety calculation, the stress intensity  $S_3$  and the total stress  $S_4$  are calculated as shown in Table 5.

According to Table 4. and the material yield limit change rule, the most dangerous point is in the inner wall of the longitudinal section of State 6. The WB36's yield strength $\sigma$ s is 441MPa.

According to the formula  $[\sigma]=\sigma_s/n_s$ , the allowable stress  $\sigma$  is 294MPa[6].

The S<sub>3</sub> is 487.375 Mpa and the S<sub>4</sub> is 475.879 Mpa for the  $\sigma_{max}$  section here, and these values are greater than allowable stress. It means that the third strength theory and the fourth strength theory are not satisfied. The stability refers to the continuous cycle of plastic deformation in the process of repeated changes in load, temperature, etc. According to the stability test:

$$(S_{2} = 487.375Mp) \le (3[\sigma] = 661.5Mp)$$
 (11)

# 3 Calculation results and analysis of primary stress of the separator

In order to analyze the influence of the working fluid pressure's change on the primary stress of the steamwater separator, the ANSYS software is used to analyze and simulate the primary stress of the steam-water separator. And the process of calculation is similar to the thermal stress. When the software is used to calculate the primary stress, the corresponding displacement constraints must be loaded on the analysis model.

The displacement constraints on the upper and lower sections. And the model in the direction is the Y-axis,

the X-axis is on the left and right sections of the model, and symmetric displacement constraint is in the Z direction. The pressure acting on the inner wall is equivalent to the saturated pressure of the working medium. The uniform action of the working medium's saturated pressure on the inner wall of the starting separator cylinder. And the steam-water leading-in tube will produce an axial tension force[7-8].

The maximum distribution of the steam-water separator's primary stress is on the upper part of the internal phase connection of the cut-in part. The stress at the junction of the outer wall is also greater than that at other parts. The stress distribution gradient at the inlet of the steam-water separator is larger, and there is a prominent stress concentration at this part.



Fig. 3. Distribution diagram I of equivalent stress.

Fig. 3 and Fig. 4 both show the variation of stress with time at the point of maximum stress at the start of the separator during cold start-up. It can be seen that the change trend of the primary stress of the steam-water separator is basically the same as the pressure of the working medium. And the stress is the minimum at the beginning of the cold start-up at the end of the start-up process.



Fig. 4. Distribution diagram II of equivalent stress.



Fig.5. Variation curve of maximum point stress of primary stress with time

According to the post-processing analysis, the trend of the primary stress and the maximum stress point in the other parts of the steam-water separator are basically the same. The primary stress of the steam-water separator is mainly affected by the pressure of the working medium, and the maximum primary stress is mainly concentrated on the connecting part of the steam-water separator cylinder. The magnitude of peak stress is influenced by both thermal stress and primary stress[9].

# 4 Conclusion

The analysis of the supercritical boiler's steam-water separator shows that the research object is safe. Although it is limited by the stress intensity theory, it is also a reasonable application of the stress classification theory and makes full use of the potential of materials. According to the data analysis, the main influence stress of the research object is mechanical stress, especially near the maximum stress (state 6).

However, when the pressure is very small, thermal stress can also play a major role (State 1). When the start-up generator state is abnormal or thermal shock occurs, which makes the temperature change rate very high, the value of thermal stress must not be underestimated. These calculation and analysis work provide effective theoretical calculation support for fault diagnosis and life analysis system of Steam-water separator, and it have certain guiding significance for optimal design and type selection of steam-water separator.

The primary stress of start-up separator is caused by the internal pressure of working medium, and the magnitude of primary stress increases with the increase of working medium pressure. The primary stress at the continuum of the cylinder structure can be calculated by the formula, and the calculated results are basically in agreement with the simulated graphic results.

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