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Operation optimization mode for nozzle governing steam turbine unit

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Abstract: Based on tests and theoretical calculation, an optimum steam admission mode is proposed, which can effectively solve the steam-excited vibration. An operation mode jointly considering the valve point and operation load is proposed based on the analysis and study of a large number of unit operation optimization methods. According to the steam-excited vibration that occurs during the optimization process when the nozzle governing steam turbine switches from a single valve to multi-valves, a steam admission optimization program is proposed. This comprehensive program considering the steam-excited vibration is applied to a 600 MW steam turbine unit to obtain the optimum sliding pressure curve and the optimum operation mode, and the steam-excited vibration is solved successfully.

Key words: nozzle governing; steam-excited vibration; operation optimization; unit efficiency
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In China, the structure of the electricity market has changed significantly. Many 600 MW units are running into operation. These units often operate under part-load conditions, which will lead to lower economy and more security risks. How to ensure the economy and safety is the focus of manufacturers and operators.

Nozzle governing is the most popular admission mode of the unit. However, risk problems are exposed more than before. For example, the action of the valve always changes the state of steam flow, which will cause steam-excited vibration.

At present, many studies have been done on this issue. Ref. [1] showed the influence of the admission mode on the units' rotor systems and gave the admission optimization methods. Ref. [2] calculated the destabilizing force acting on the rotor blades of the control stage. Refs. [3 - 4] also showed the influence of the admission on the stability of the rotor. An optimum mode of the steam distribution system was proposed. In Refs. [5 - 8], the numerical calculation method was employed to analyze the amplitude response of steam-excited vibration. The results show the correctness of the catastrophe analysis method based on the catastrophe theory.

1 Steam Admission Optimization

1.1 Theoretical analysis

Steam force F_b appears when steam flow acts on the blades. F_b usually can be divided into axial force F_a and tangential force F_t, as shown in Fig. 1. The two forces affect the bearing load, which indicates that the partial admission has an impact on the stability of the high pressure (HP) rotor, as shown in Fig. 2.

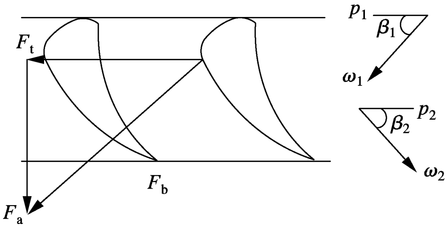

Fig. 1 Flow diagram of steam in regulation rotor cascade

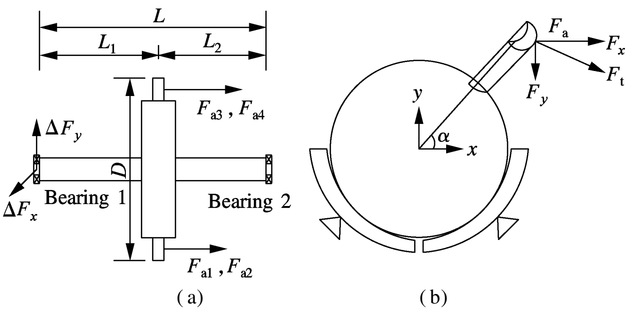

Fig. 2 Rotor and shaft bearing system. (a) Governing stage; (b) Left view of governing stage

1.1.1 Tangential force F_t

F_t can be divided into horizontal force F_x and vertical force F_y as

$$F_x = \int_{\alpha_0}^{\alpha_1} F_t \sin\alpha \mathrm{d}\alpha, \quad F_y = -\int_{\alpha_0}^{\alpha_1} F_t \cos\alpha \mathrm{d}\alpha \tag{1}$$

where α_0 is the starting angle and α_1 is the finishing angle of the nozzle arc.

It is indicated from Eq. (1) that, the integration is zero during full admission and the integration is not zero dur-

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ing partial admission. It means that different admission modes have different impacts on rotor vibration and bearing loads.

1.1.2 Axial force F_a

As shown in Fig. 1, F_a can be calculated as

$$F_a = G(w_1 \sin\beta_1 - w_2 \sin\beta_2) + A_z(p_1 - p_2) \tag{2}$$

where G is the steam flow that passes through the blade cascade per unit time; $A_z(p_1 - p_2)$ is the force generated by pressure difference; w_1, w_2 are the relative velocities.

It can be seen from Eq. (2) that F_a is proportional to G. Set $k = (w_1 \sin\beta_1 - w_2 \sin\beta_2)$, $R = A_z(p_1 - p_2)$, and Eq. (2) is simplified as

$$F_a = kG + R \tag{3}$$

Set G_1, G_2, G_3 and G_4 as the steam quantities corresponding to nozzle groups 1, 2, 3 and 4, respectively. F_{a1}, F_{a2}, F_{a3} and F_{a4} are the axial forces that affect the control stage of the rotor, respectively.

Taking bearing 1 in Fig. 2 as an example, it can be known that bearing 1 is not only affected by the rotor, but also by the lateral force ΔF of the control stage.

Set bearing 2 as a fulcrum and bearing 1 as a free point. According to the torque balance, the following equations can be obtained:

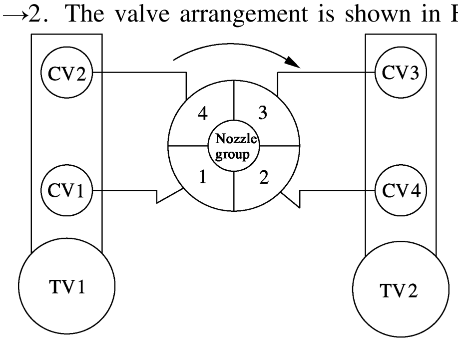
$$\Delta F_x = [(F_{a1} + F_{a3}) - (F_{a2} + F_{a4})] D\cos 45°/(2L) = k(G_1 + G_3 - G_2 - G_4) D\cos 45°/(2L) \tag{4}$$

$$\Delta F_y = [(F_{a1} + F_{a3}) - (F_{a2} + F_{a4})] D\sin 45°/(2L) = k(G_1 + G_3 - G_2 - G_4) D\sin 45°/(2L) \tag{5}$$

It can be seen that bearing 1 is affected by ΔF_x, together with ΔF_y; ΔF_x and ΔF_y can be reduced by the optimum steam admission mode.

1.2 Solution

A 600 MW steam turbine after flow reconstruction is taken as an example. The designed valve open order is 3 + 4→1→2. The valve arrangement is shown in Fig. 3.



CV—Control valve; TV—Throttle valve

Fig. 3 Valve arrangement

According to the theoretical analysis above, the optimum admission mode is 3 + 2→4→1. The bearing load F can be calculated by

$$F = \sum_{a=1}^{s} F_{ra} \cos\Phi_a \tag{6}$$

where F_{ra} is the radial force of bearing pad a; Φ_a is the position angle of bearing pad a. The comparison of original design and optimum design are shown in Figs. 4 and 5.

Monitor results are shown in Tab. 1. Bearing vibration and bearing pad temperature reach the safe value after optimization, and the steam-excited vibration caused by the imbalanced steam force is solved. The optimum design can effectively avoid the steam-excited vibration.

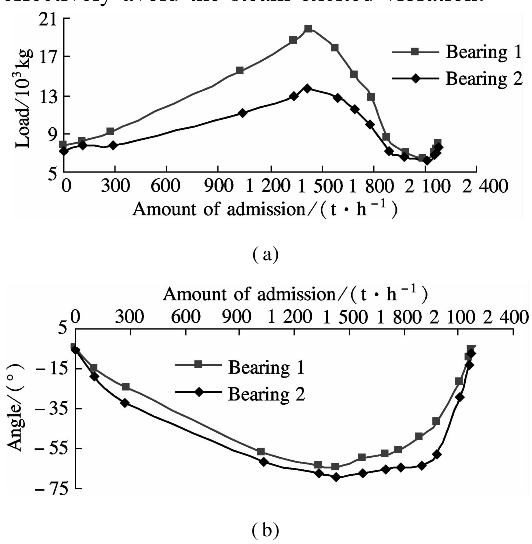


Fig. 4 Original design scheme 3 + 4→1→2. (a) Relationship between bearing load and amount of admission; (b) Relationship between bearing load direction and amount of admission

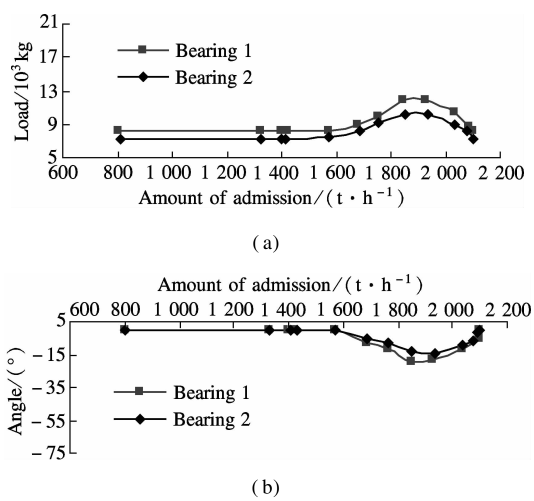


Fig. 5 Optimization scheme 3 + 2→4→1. (a) Relationship between bearing load and amount of admission; (b) Relationship between bearing load direction and amount of admission

2 Operation Optimization

A new operation curve is obtained after sliding pressure operation tests based on steam admission optimization. On the basis of the concept of valve position, the hybrid sliding operation is proposed. It means that we can keep two or three valves fully open and one partly. The relationship between the heat rate and the load is shown in Fig. 6. The economic operation is shown in Tab. 2.

Tab. 1 Bearing vibration and bearing pad temperature after optimization

Power load/MW	Valve opening/%				Bearing vibration/μm (x direction/y direction)				Bearing pad temperature/℃ (Bearing 1/bearing 2)			
	CV1	CV2	CV3	CV4	1	2	3	4	1	2	3	4
300	1	97	97	17	39/36	74/57	73/61	81/61	75/78	82/74	52/58	81/76
360	1	91	90	18	42/36	81/58	73/59	82/61	75/78	82/74	52/58	81/76
420	0	99	100	23	46/38	82/57	77/58	84/62	74/74	77/70	52/58	81/77
480	1	99	99	23	43/40	77/57	76/61	84/61	74/76	78/71	52/58	82/77
540	1	99	99	33	50/42	81/61	80/52	82/61	75/66	72/66	53/57	84/78
630	19	99	99	97	61/50	80/65	81/55	81/61	73/61	71/62	53/57	84/77

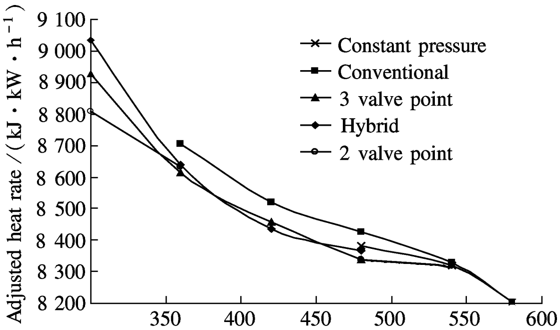


Fig. 6 Heat rate vs. electric power

Tab. 2 Optimum operation and the valve opening situation of different loads

Power load/MW	Pressure/MPa	Operation mode	Valve situation
580 to 540	16.70	Constant pressure	3 fully open 1 throttle
540 to 480	14.97 to 16.70	Hybrid sliding	3 fully open 1 throttle
480 to 450	14.85 to 14.97	3 valve point	3 fully open
450 to 370	13.44 to 14.85	Hybrid sliding	2 fully open 1 throttle
370 to 300	11.17 to 13.44	2 valve point	2 fully open

3 Conclusion

To solve the steam-excited vibration, the optimum admission mode is proposed. The hybrid sliding condition is added and the optimum sliding pressure curve is obtained, which provides a theoretical guide to the operation optimization.

References

[1] Yu D R, Duan Y F. Experimental study on fault caused by partial arc steam forces[J]. *Journal of Engineering for Gas Turbines and Power*, 2010, **132**(6): 1-4.

[2] Song G X, Chen S P. Cause analysis of steam-excited vibration in steam turbine unit[J]. *Journal of Power Engineering*, 2012, **32**(10): 770-778.

[3] Gao L, Dai Y P. Rotor dynamic stability under partial admission conditions in a large power steam turbine[C]// *Proceedings of ASME Turbo Expo* 2009. Orlando, USA, 2009: 1-15.

[4] Gao L, Dai Y P. Effect of steam distribution method on large steam turbine rotor stability[J]. *Proceedings of the CSEE*, 2008, **28**(35): 84-89. (in Chinese)

[5] Li J L. Catastrophe mode of steam flow excitation vibration in steam turbine governing stage[J]. *Proceedings of the CSEE*, 2013, **33**(11): 39-46. (in Chinese)

[6] Usón S, Valero A. Thermoeconomic diagnosis for improving the operation of energy intensive systems: comparison of methods[J]. *Applied Energy*, 2011, **88**(3): 699-711.

[7] Naoto S, Tetsuya H. Numerical study of partial admission stages in steam turbine[J]. *JSME International Journal, Series B*, 2006, **49**(2): 212-217.

[8] Krzysztof J. Method of increasing steam turbine control stage efficiency[J]. *Computational and Applied Mechanics*, 2001, **2**(1): 37-43.

喷嘴配汽方式汽轮机组运行优化

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摘要:基于试验与理论计算相结合的方法,提出了配汽优化方案,有效解决了气流激振问题.在分析和研究了大量机组运行优化方式的基础上,提出联合考虑负荷和阀点的运行优化方式,并考虑喷嘴配汽汽轮机组在单阀切换多阀运行时出现的汽流激振问题,提出相应的配汽优化方案.将该综合考虑汽流激振问题的方案应用于某600 MW汽轮机组,得到该机组的最佳滑压曲线和最优运行方式,并成功地解决了过程中出现的汽流激振问题.

关键词:喷嘴配汽;气流激振;运行优化;机组效率
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