再热抽汽式汽轮机中压缸末级叶片压差保护控制

于达仁　王西田 (哈尔滨工业大学)
刘　野　朱苏里 (哈尔滨汽轮有限责任公司)

〔摘要〕文中对 200MW 再热抽汽式汽轮机中压缸末级叶片的压差保护控制进行了探讨。通过对数学模型仿真结果的分析,总结出了叶片压差保护控制的基本措施。

关键词　再热抽汽式汽轮机　叶片　压差保护控制
分类号　TK263.72

0 概述

200 MW 再热单可调抽汽式汽轮机中压缸的排汽压力根据热用户的要求基本上等于常数。在大抽汽量时中压缸的焓降将大于凝汽工况时的值,增大的焓降主要由中压缸末级来承担,这对于末级叶片的强度是不利的[1]。为了保证汽轮机的安全运行,需要采取保护措施。对于再热抽汽式汽轮机,由于再热容积和自整网络的影响,在中压缸末级叶片强度达到危险值的情况下,如果按一般的做法直接减小热负荷给定值,将会导致末级叶片压差的瞬时值进一步提高,可能发生事故。为此,需要研究应采取更可靠的保护措施。

当几何尺寸确定后,叶片受到的气流力与级的焓降以及动叶前后的压差有关[2]。为了改善动叶的通流状况,通常末级具有不小的反动度。而且中压缸末级叶片又比较长,在这样大的反动度条件下,实例计算表明动叶前后的压差对叶片气流力的影响是主要的。因此,本文选定叶片的压差为控制量,进行中压缸末级叶片保护控制的探讨。

1 控制对象的数学模型

图 1是 200 MW 再热单可调抽汽式汽轮机的结构示意图。高压热用户的供汽来自高压缸排汽,供汽压力随机组负荷变化而变化,是不可调节的;低压供热从中压缸排汽引出,其压力依据低压热用户的要求可以进行调节。中压阀是为甩负荷而设置的,在开始供热后保持全开。

设给定工况下,中压缸进口、末级前后的压力分别为 $P_2 P_X P_C$,工况变动后参数相应为 P_{21}、P_{X1}、P_{C1},

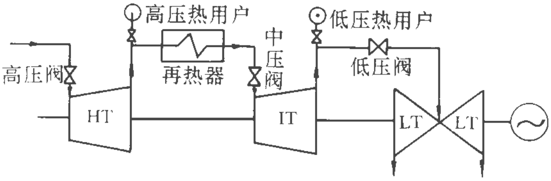

图 1

收稿时间　1995-01-06　修改稿　1996-07-25
本文联系人　于达仁　男　31　教授　150001　哈尔滨工业大学汽轮机教研室

并且可令

$$\left.\begin{aligned} p_{21} &= p_2 + \Delta p_{21} \\ p_{X1} &= p_X + \Delta p_{X1} \\ p_{C1} &= p_C + \Delta p_{C1} \end{aligned}\right\} \qquad (1)$$

作为实例而选定的 200 MW再热抽汽机组,最大工况亦末达临界。根据非临界工况下级和级组的变工况计算,有

$$P_{X1}^2 = \frac{P_X^2 - P_C^2}{P_2^2 - P_C^2} P_{21}^2 + \frac{P_2^2 - P_X^2}{P_2^2 - P_C^2} P_{C1}^2 \qquad (2)$$

代入式(1),把式(2)线性化得

$$\Delta P_{X1} = \frac{P_X^2 - P_C^2}{P_2^2 - P_C^2}\frac{P_2}{P_X}\Delta D_{21} - \frac{P_2^2 - P_X^2}{P_2^2 - P_C^2}\Delta P_{C1} \qquad (3)$$

则末级动叶前后压差为

$$\Delta D = \Delta D_{X1} - \Delta D_{C1}$$

$$= \frac{P_X^2 - P_C^2}{P_2^2 - P_C^2}\frac{P_2}{P_X}\Delta D_{21} - \left(1 - \frac{P_2^2 - P_X^2}{P_2^2 - P_C^2}\frac{P_C}{P_X}\right)\Delta P_{C1} \qquad (4)$$

可令:

$$\left.\begin{aligned} \Delta D &= (D_x - D_C) X_{\Delta D} \\ \Delta D_{21} &= P_2 X_{P2} \\ \Delta D_{C1} &= P_C X_{PC} \end{aligned}\right\} \qquad (5)$$

于是可将式(4)无量纲化为

$$X_{\Delta D} = \frac{P_x^2 - P_C^2}{P_2^2 - P_C^2}\frac{P_2}{P_X}\frac{P_2}{P_X - P_C} X_{P2}$$

$$- \left(1 - \frac{P_2^2 - P_X^2}{P_2^2 - P_X^2}\frac{P_C}{P_X}\right)\frac{P_C}{P_X - P_C} X_{PC} \qquad (6)$$

又 $P_2 \gg P_X$, $P_2 \gg P_C$,故式(6)可化简为

$$X_{\Delta D} = K_f X_{p2} - K e X_{PC} \qquad (7)$$

式中:
$$\left.\begin{aligned} K_f &= 1 + P_C / P_X \\ Ke &= P_C P_X \end{aligned}\right\} \qquad (8)$$

由式(8)可知,不同工况下系数 K_f 和 Ke 是不同的,如图 2所示。不过可以看出,系数随工况变化差别不大,具有较好的线性。

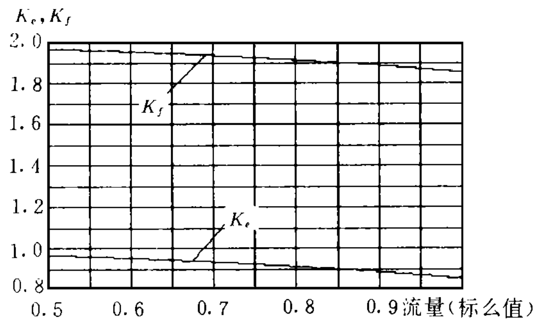

图 2　q_1 为不同工况与额定工况下的流量比

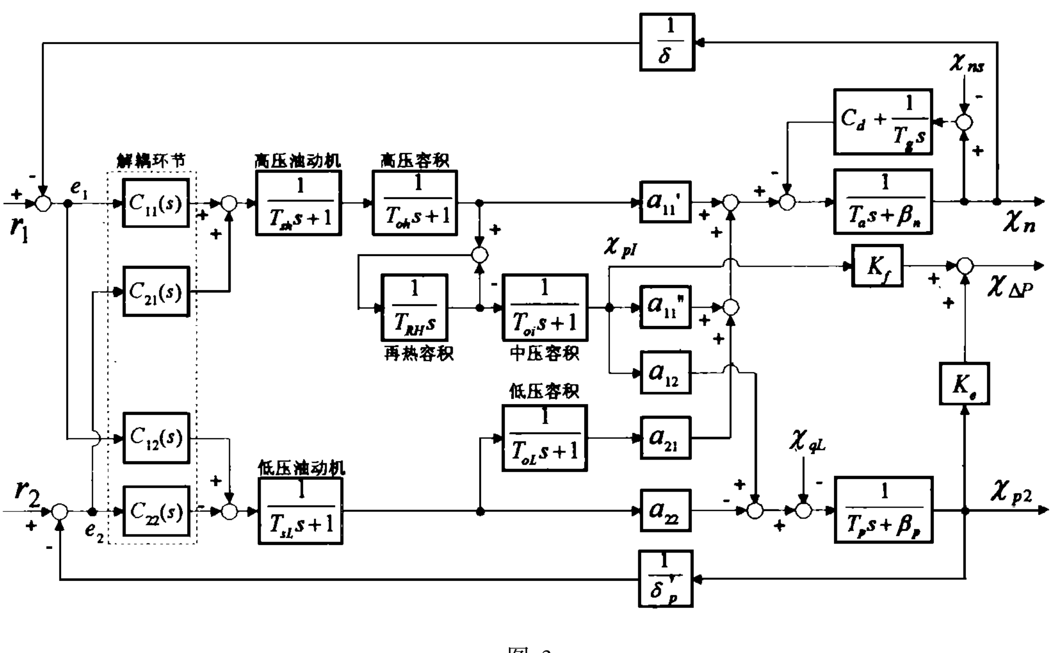

图 3

作为算例,选取额定工况为给定工况,通过热力计算可以求出 P_2、P_X、P_C,于是系数 K_f 和 K_e 就确定下来。

参考文献〔3〕〔4〕的相关内容,建立 200 MW 再热单可调抽汽式汽轮机抽汽运行工况下的数学模型,如图 3所示。

图 3中 $X_{\Delta P}$即为压差控制量。

其中

$$\left.\begin{aligned} X_{\Delta D} &= \Delta D / (P_X - P_C) \\ X_{P2} &= \Delta D_{21} / P_2 \\ X_{PC} &= \Delta D_{C1} / P_C \end{aligned}\right\} \quad (9)$$

式 (9)与式 (5)中的设定一致,式中符号的定义前后是统一的。

2 末级压差动态变化规律的仿真

根据图 3所示数学模型,在计算机上可以方便地实现末级叶片压差信号 $X_{\Delta D}$以给定值 X_{r1}、X_{r2}以及供热量 X_{qL}为参数的动态变化规律的仿真。 图 4为实例仿真曲线,其中所用到的模型参数来自某一实际运行的机组(参见附录)。

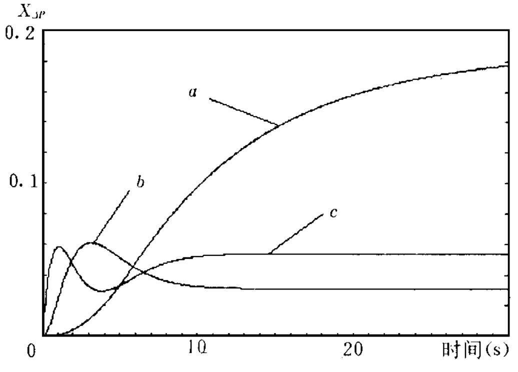

图 4

曲线 α 说明,增大给定值 X_{r1}(对应于减电负荷)时,末级压差增加较多。 曲线 b再现了降低给定值 X_{r2} (对应于减热负荷)时末级压差可能瞬时超调的现象。 经过分析可知,这主要是由于再热容积的影响,使得高低压油动机作用效果不匹配造成的。从曲线 c可以看出,供热量 X_{qL}增大,末级压差也增大较多,响应速度也比较快。

3 末级压差保护控制措施

再热抽汽式机组在减热负荷时,可能引起中压缸末级动叶压差瞬时超调。因此,减热负荷的操作不宜太快,更不能作为保护末级叶片的有效措施。适当增大低压油动机时间常数,使其与高压油动机作用效果匹配,可以降低瞬时压差。 在机组运行过程中,如果末级压差超调,可以采取以下措施:

(a)减小电负荷即降低给定值 X_{r1}。

(b)迅速解脱热网扰动即切除 X_{qL}。

参 考 文 献

1 倪维斗,徐基豫 . 自动调节原理与透平机械自动调节 . 机械工业出版社, 1991. 10

2 吴厚钰 . 透平零件结构和强度计算 . 机械工业出版社, 1988. 11

3 于达仁等 . 中间再热抽汽式汽轮机的数学模型,汽轮机技术, 1993(3)

4 徐基豫等 . 中间再热抽汽式汽轮机调节系统的自整条件 . 热能动力工程, 1994(1)

附录　模型参数

转速不等率: $W_V = 0.05$

压力不等率: $W_P = 0.15$

自整矩阵: $[C] = \begin{pmatrix} C_{11} C_{12} \\ C_{21} C_{22} \end{pmatrix} = \begin{pmatrix} 0.978987 & 1.05216 \\ 0.423165 & 0.504115 \end{pmatrix}$

功率系数或抽汽流量系数: $a'_{11} = 0.303$

$a''_{11} = 0.253$

$a_{12} = 1.1$

$a_{21} = 0.444$

$a_{22} = 1.01$

容积时间常数: $T_{Oh} = 0.45$ S

$T_{RH} = 9$ S

$T_{oi} = 0.11$ S

$T_{OL} = 0.13$ S

$T_P = 0.6$ S

油动机时间常数: $T_{sh} = 0.24$ S

$T_{SL} = 0.25$ S

自平衡系数: $U_n = 0603$

$U_P = 1.05$

发电机电磁阻尼系数: $C_d = 10$

发电机时间常数 $T_g = 0.003\ 18$ S

(乡复编辑)

enhanced circulating rate of particles and the decrease in particle diameter will be beneficial to the gas /solid interphase heat transfer. Also obtained is a corresponding dimensionless equation. **Key words**: circulating fluidized bed, gas phase, solid phase, heat transfer

隔膜式气压给水设备的节能研究 = **A Study on the Energy-saving of Diaphragm Air-pressure Water Supply Installation**〔刊,中〕/Wu Xifu(Zhejiang Industrial University) //Journal of Engineering for Thermal Energy & Power. - 1997, 12(4). - 289~ 291

On the basis of energy consumption test of a diaphragm variable-pressure and constant-pressure water supply installation energy-saving analyses are performed with respect to the air feeding of air compressors, the utilization of exhaust gas, the selection of water pumps and the number of times of water pump startups. Energy-saving measures are proposed. All the above can serve as a guide for design and operation management. **Key words**: diaphragm type, water supply installation, energy-saving

复杂换热器系统的动态特性计算 = **Calculation of the Dynamic Characteristics of a Complex Heat Exchanger System**〔刊,中〕/Li Zheng, Sun Xin, Ni Weidou(Tsinghua University) //Journal of Engineering for Thermal Energy & Power. - 1997, 12(4). - 292~ 296

This paper deals with a method for calculating the dynamic characteristics of a complex heat exchanger system, which was developed during the modelling and simulation of a 220 t /h home-made CFB boiler. Based on an approximate analytical solution the said method significantly enhances the calculation speed and solves the problem of non-convergence during calculations. A decoupling method has been adopted, Which separates the balance calculation of cold and hot working mediums, making it possible to completely avoid iterative computations. By combining the approximate analytical solutions and the decoupling calculation method established is a set of generalized method for calculating the dynamic behavior of heat exchanger systems, thereby providing a general-purpose, high-efficient and simple calculation method for complex heat exchangers. **Key words**: natural circulation boiler, heat exchanger, dynamic characteristics, calculation

再热抽汽式汽轮机中压缸末级叶片压差保护控制 = **Differential-pressure Security Control of the Last-stage Blades of a Reheat Extraction Steam Turbine Intermediate-pressure Cylinder**〔刊,中〕/Yu Daren, Wang Xitian, et al (Harbin Institute of Technology) //Journal of Engineering for Thermal Energy & Power. - 1997, 12 (4). - 297~ 299

Discussed in this paper is the differential-pressure security control of the last-stage blades of a reheat extraction steam turbine intermediate-pressure cylinder. Through an analysis of the simulation results of a mathematical model basic measures for the blade differential-pressure security control have been summed up. **Key words**: reheat extraction steam turbine, blade, differential-pressure security control

螺旋板稳定性分析和计算 = **The Analysis and Calculation of a Spiral Plate Stability**〔刊,中〕/Zhou Chuanyue, et al. (Harbin No. 703 Research Institute) //Journal of Engineering for Thermal Energy & Power. - 1997, 12 (4)-300~ 303

Based on a classical linear elastic stability theory the authors have set up a mechanics model for stability analysis of a spacing column-supported spiral plate. A theoretical formula for calculating the theoretical pressure of a critical pressure has been derived with some engineering calculation examples being presented. Some conclusions helpful for performing engineering design are also proposed. **Key words**: spiral plate, stability, critical pressure

综合似然率(GLR)试验在传感器故障检测中的应用 = Application of a Generalized Likelihood Ratio(GLR) Test in Sensor Failure Detection〔刊,中〕/Huang Shanheng, Zhu Qiaobin, et al (Shanghai Jiaotong University) //Journal of Engineering for Thermal Energy & Power. - 1997, 12(4). - 304~ 306