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无旁通烟囱燃气－蒸汽联合循环机组的运行维护和停运

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摘　要: 论述了无旁通烟囱燃气——蒸汽联合循环机组运行维护和停运的特点, 探讨了它与火力发电厂和有旁通烟囱联合循环的不同之处, 总结了机组运行维护和停运的经验, 可供运行人员和设计人员参考。

关　键　词: 无旁通烟囱　联合循环　电厂运行维护

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1　引言

通常燃气－蒸汽联合循环都设有旁通烟囱, 它使机组运行灵活方便, 又对余热锅炉起到保护作用。然而为了减少设备初始投资, 现在有的联合循环不设置旁通烟囱[1], 如图 1 所示。这类机组的运行维护和停运既不同于火力发电厂, 也有别于有旁通烟囱的联合循环, 具有新的特点。

故而无旁通烟囱联合循环的运行维护和停运, 应充分认识到它自身的特点, 采取合理的操作措施, 才能确保机组安全、经济运行。

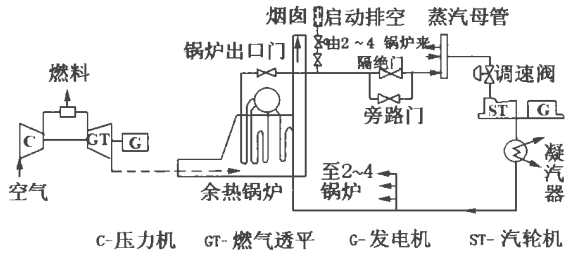

图 1　无旁通烟囱的燃气－蒸汽联合循环

2　无旁通烟囱联合循环机组运行的整体性

联合循环不设置旁通烟囱, 燃机、余热锅炉、汽机三者就连为一个整体。因余热锅炉不能干烧, 机组只得以联合循环方式运行, 燃机不能再以简单循环方式运行。机组的机动性明显下降了, 若锅炉、汽机及其辅助设备出现故障需停机检修, 那么燃机也得停止运行。

这样运行中各专业的联系就会更加紧密, 每个岗位任何一个细小的操作都有可能引起其它岗位做相应调整, 可谓牵之一发, 动之全身。因此要时时保证电话等通讯工具的畅通、完好, 最好还有应急措施, 可在主要岗位配备对讲机。既使机、炉、电是集中控制, 彼此联系很方便, 然而仍需经常相互通报设备的运行状况。

再有机组的应变性也将下降, 一旦发生事故, 各专业不能只是各自为政, 完成自身的操作就可以了, 必须兼顾其它专业设备的运行情况, 综合考虑, 密切配合, 也就是说事故处理过程更为复杂, 尤其保厂用电的事故处理特别重要。联合循环有个最大的特点, 厂用电源突然中断, 燃机一般不会马上跳机, 只要操作及时果断, 通过电厂自身的一次系统, 就可以用燃机重新恢复厂用电。这对运行人员的综合能力要求极高, 必须制定科学合理的保厂用电措施, 并反复模拟操练, 才能增强抗击突发性事故的能力。

正是如此运行人员不仅应具有本专业知识, 熟悉本专业系统设备, 而且还应掌握机(燃机、汽机)、炉、电、化、燃的综合知识。特别是值长必须具备全面的综合素质, 才能起到统一指挥、协调工作、果断处理事故的作用。

可见无旁通烟囱的燃气－蒸汽联合循环与有旁通烟囱的燃气－蒸汽联合循环相比, 机组运行的整体性提高了, 系统化增加了, 运行操作随之增添了新的内容。燃机、锅炉、汽机、电气、化学、燃油各专业除应象火力发电站或有旁通烟囱联合循环那样完成日常维护工作外, 还需结合不设置旁通烟囱系统操作更为复杂的特点, 进行相应的调整。

3　无旁通烟囱联合循环主蒸汽参数的调节

同火力发电机组一样, 烟气侧和蒸汽侧原因是

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主汽温度变化的主要因素，主汽压力的稳定则取决于锅炉蒸发量和外界负荷。不过燃气—蒸汽联合循环还有独特之处，着重体现在外界环境温度的变化会引起燃机排烟工况的改变，从而影响主汽参数。另外无旁通烟囱联合循环主汽参数的调节手段少于有旁通烟囱的联合循环，它不可能再用旁通烟囱灵活地调节烟气流量。

3.1 主汽温度的调节

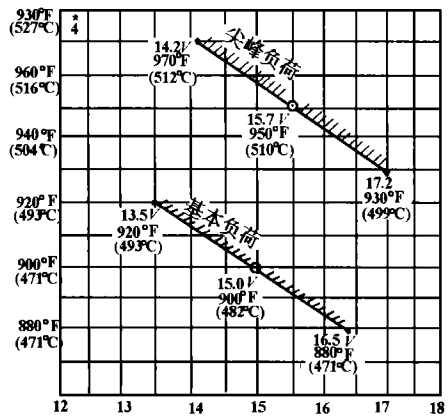

图 2 排烟温度 $t_4^{\times}$ 随 VCE 变化曲线

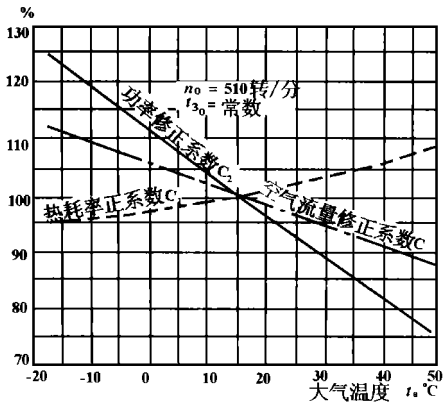

图 3 大气温度对机组的修正曲线

目前燃气—蒸汽联合循环的余热系统多为中压参数，燃机进入温控后的排烟温度一般在 500 ℃左右，而过热蒸汽的额定温度为 435 ℃，与排烟温度相差不大。

燃机带满负荷后，将按温控线运行(见图 2)，负荷及排烟工况都由温度控制系统自动控制，不必人为调整。这时烟气工况会随外界客观条件发生变化，如大气温度，大气压力等，其中主要是受外界环境温度的影响(见图 3)。

图 2 和图 3 描绘的是 PG5331 型机组的曲线，其它机组与此类似。环境温度升高，燃机负荷下降，空气量、排烟量减少，而热耗率及排烟温度会升高。如环境温度降低，则情况相反。仔细分析图 2 和图 3 可知，环境温度对空气量及排烟量的影响超过对排烟温度的影响。例如大气温度－15 ℃与标准工况 15 ℃对比，空气流量增加了 11.3%，机组负荷提高了 23%，热耗率只下降了 4%，排烟温度降低不超过 11 ℃，仅 2.3%。进一步计算可得，机组在大气温度－15 ℃运行，每小时耗油量会增加 18%，烟气量将增加 11.4%，可见烟气量的变化幅度更大。

燃机排烟工况的改变，必然引起余热锅炉换热情况发生变化，主汽温度也将产生波动。在南方每天环境温度变化不大，再加上燃机排烟量和排烟温度变化趋势正好相反，故余热锅炉主汽温度所受影响要小一些，主汽温度的调节量也不大。例如深圳通常早晚温差在 10 ℃以内，燃机排烟温度仅变化 3 ℃左右，对主汽温度的影响很小，一般不超过正常值。但北方早晚温差很大，因此排烟工况变化比较明显，主汽温度随之调节就较为频繁。即使同一地区，不同季节环境温度变化也不同，对燃机、锅炉、汽机的影响有差别。冬季温度低，燃机负荷高，排烟量多，锅炉蒸发量必然增大，因此主汽温度的调节力度需加大；而夏天却正好相反。

燃机满负荷运行时效率最高、最经济，若不进入温控，则效率下降很快。所以燃机应尽量在温控线上运行，余热锅炉主汽温度则主要采取蒸汽侧调节方法，除非不得已才调整燃机负荷，改变排烟工况来调节主蒸汽温度。

蒸汽侧调节汽温就是采用减温水的调节方法，其操作比较简单，只要根据汽温变化适当变更减温水调节门开度即可。由于主蒸汽温度与燃机排烟温度相差不大，因此减温水量应耐心调节，以防主汽温度发生较大波动。尤其燃机甩负荷时，应及时减少直至关闭减温水，避免主汽温度骤降，发生水击事故。

3.2 主汽压力的调节

冬季环境温度低，燃机排烟量大，锅炉蒸发量多，汽机所能带的负荷比夏季高。以 PG5331 型燃机为例，在深圳地区，因环境温度影响，冬季余热锅炉蒸发量比夏季高出 10%，汽机可多带负荷 1 ~ 2 MW。但不论什么季节，同一天锅炉蒸发量变化却很小，一般不超过 2%。

余热锅炉蒸发量增加，主汽压力将升高，这时汽机当增大调速汽门开度，提高负荷，维持主汽压力在正常范围内；蒸发量减少则降低汽机负荷。机组正常运行时，主要就采取这种方式调节主汽压力。如果主汽压力升得太快，就需加大调节力度，可以开启锅炉对空排汽门和主蒸汽旁路；在紧急情况下还可以调节燃机负荷。但后两种调节方法不到万不得已时不要使用，因为它们会降低机组运行的经济性，可做为应急事故的手段。

燃机突然发生甩负荷事故，应立即降低汽机负

荷，直至打闸停机，以防主汽压力下降太快，发生蒸汽带水或汽机水击事故，而且还要尽快将甩负荷的余热锅炉与蒸汽母管解列。

4　无旁通烟囱联合循环的停运

燃气—蒸汽联合循环既可采取定参数也可滑参数停运方式。额定参数停机就是在停机过程中，汽机电动主汽门前的蒸汽参数一直保持额定值；滑参数停机特点是在汽机调速汽门全开的情况下，由锅炉控制主蒸汽压力和温度逐渐滑降，来降低机组负荷进行停机，这样可以回收锅炉余热发电，并能降低汽轮机各部件的温度。

由于燃气—蒸汽联合循环余热系统多为中压参数，相比高参数机组，额定参数停机后汽机各部件冷却速度比较快，一般只要 28 小时就可以停止盘车。尽管滑参数停机能加快汽机的冷却速度，对停运后要检修的机组，可缩短从停机到开缸的时间，然而中压参数机组所能节省的时间有限，意义不大。

另外无旁通烟囱联合循环如采用滑参数方式停机，余热锅炉本身可滑降的温度和压力范围很窄，必须依靠降低燃机负荷。而燃机负荷越低，效率下降就越快，油耗率也越高，若燃机在低负荷下运行时间过长，那么很不经济，得不偿失。

再有为保护余热锅炉安全，无旁通烟囱联合循环要多在热态或温态下启动，并减少冷态启动次数[2]。为做到这一点，就得想尽办法使锅炉、汽机停运后更多、更持久地保留余热，可以不必考虑回收余热用来发电。

不设置旁通烟囱，余热锅炉烟气侧无挡板将其与外界隔离，那么机组停运后，由于烟囱的抽吸作用，外界空气会经燃机空气道流过压气机和轮机，进入余热锅炉，使锅炉余热，余压损失得更快。因此为减缓余热锅炉的冷却速度，也需要停机时尽量多地保留余热，而且锅炉余压维持时间长一些，还方便停炉后的保养。

基于以上考虑，对于无旁通烟囱联合循环机组的停运，无疑额定参数停机方式更适合，而滑参数停机方式应尽量少用。

为使停运操作即简便又安全可靠而且经济合算，燃机和锅炉应逐台解列，不要同时进行。为了多保留锅炉的余热和余压，汽机尽快减去全部负荷，就可迅速打闸停机，不必在低负荷下停留时间过长。燃机也应缩短在低负荷的运行时间，在锅炉解列后，马上减负荷到零停机。随后锅炉应当及时开闭对空排汽门，避免主汽压力下降太大。

5　结论

（1）　联合循环不设置旁通烟囱，机组运行的整体性和系统化提高了，操作更为复杂，各专业的协调、配合十分重要，尤其对值长机（燃机和汽机）、炉、电、化、燃综合素质的要求极高。

（2）　环境温度的变化会引起燃机排烟工况的改变，从而影响余热系统的主蒸汽参数，环境温度对排烟量的影响程度超过对排烟温度的影响。

（3）　机组正常运行时，主汽温度比较稳定，受环境温度影响较小；主汽温度主要采取蒸汽侧调节方式，在紧急情况下可以调整燃机负荷来改变主汽温度。

（4）　主汽压力受环境温度和外界负荷的影响较大，调节比较频繁，一般通过调整汽机负荷来进行调节，改变燃机负荷和开启锅炉对空排汽门可做为应急手段。

（5）　无旁通烟囱联合循环最好采用额定参数停机方式，使余热锅炉尽量多、尽量持久地保留余热和余压，汽机和燃机可尽快减负荷到零，并迅速停机。

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〔2〕　姚挺生、庄建能、黄海保．无旁通烟囱燃气—蒸汽联合循环的启动．热能动力工程，1999，14(2)：152～154.

（渠　源　编辑）

汽轮机调节系统故障诊断系统＝**Failure Diagnosis System for a Steam Turbine Regulating System** [刊, 汉] / Bao Wen, Yu Daren, Li Wenzhu, *et al* (College of Energy Science and Engineering under the Harbin Institute of Technology, Harbin, China, Post Code 150001) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —298～300

With the help of the failure diagnosis system of a steam turbine regulating system it is possible to record the variation trend of the key parameters of the said system. The realization of such functions as the on-line calculation of steam turbine static characteristics, the detection of pilot valve stuck status and the regulating system oscillation failure diagnosis can result in a significant enhancement of the operating safety of the regulating system. Moreover, the above also plays a positive role in the preventive maintenance and repair of the regulating system. **Key words**: steam turbine, regulating system, failure diagnosis

案例推理在汽轮发电机组故障诊断中的应用＝**The Application of Case-based Reasoning in the Failure Diagnosis of Turbogenerator Units** [刊, 汉] / Ruan Yue (Envada Co. of Northern China Electric Power Research Institute, Beijing, China, Post Code 100045) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —301～303

On the basis of the specific features of a failure diagnosis the author has standardized the method of organization and representation of cases. The symptoms of a case are divided into essential symptoms of certainty and other symptoms. Based on the certainty and fuzzy weight a retrieval strategy of cases is proposed. Moreover, a correction was performed regarding the calculation of similarity degree, thereby enhancing the reliability of case-based reasoning. **Key words**: case-based reasoning, failure diagnosis, turbogenerator unit

惯性浓淡旋流燃烧器的原理及其在 50 t/h 锅炉上的应用＝**The Theory of an Inertial Bias Swirl Burner and Its Application on a 50 t/h Boiler** [刊, 汉] / Li Zhengqi, Sun Rui, Wang Lei, *et al* (College of Energy Science and Engineering under the Harbin Institute of Technology, Harbin, China, Post Code 150001) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —304～305, 308

On the basis of pulverized-coal swirl burners of a radial bias combustion mode this paper proposes a new type of burner, the so-called inertial bias combustion (IBC) swirl burner. In such a burner a pulverized-coal concentrator located near the burner nozzle has been incorporated in a primary air passage. After the primary air has been admitted through the pulverized-coal concentrator there will emerge from the burner center outward a distribution trend of pulverized-coal concentration ranging from a high to a low value. Thanks to the inertia of the pulverized-coal particles such a distribution trend can be maintained right up to the burner outlet. A layout of the burners pertaining to a pulverized bituminous coal-fired boiler of 59 t/h is presented with a brief account being given concerning the pre-modification operating conditions. **Key words**: boiler, swirl burner, pulverized-coal bias combustion

新型旋流燃烧技术应用于漳泽电厂 210 MW 机组锅炉低负荷改造＝**Novel Swirl Burners and Their Application at Zhuangze Power Station for the Low-load Stable Combustion of Boilers of a 210 MW Unit** [刊, 汉] / Tan Houzhang, An Enke, Hui Shien, *et al* (Xi'an Jiaotong University, Xi'an, Shaanxi, China, Post Code 710049) // Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —306～308

Novel axial-blade swirl burners were put into use at Zhuangze Power Station in connection with the technical modification of boilers No. 3-6 (4 units) of a 210 MW unit. As a result, problems specific to original burners, such as combustion instability and loss of flame, etc have been solved. Moreover, attained are a flexible regulation of secondary air swirl intensity and the alleviation of wear in the primary air pipes. The switch to the new swirl burners has made it possible to realize a stable combustion of the 100 MW boilers at low loads (46% of full load) with no need for the use of fuel oil. **Key words**: swirl burner, boiler modification, low load

无旁通烟囱燃气—蒸汽联合循环机组的运行维护和停运＝**The Operation, Maintenance and Shutdown of a Gas and Steam Turbine Combined Cycle Power Plant not Fitted with a Bypass Stack** [刊, 汉] / Yao Tingsheng,

Chen Ze, Wu Laigui (Guangdong Provincial Electrical Power Bureau, Shenzhen, Guangdong, China, Post Code 5181202) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —309~311

This paper focuses on the specific features of the operation, maintenance and shutdown of a bypass stack-less gas and steam turbine combined cycle power plant. Discussed is the main difference among such a power plant, a thermal power plant, and other combined cycle power plants fitted with a bypass stack. In addition, some experiences gained during the bypass stack-less power plant's operation, maintenance and shutdown have been summed up, providing a useful guide for relevant designers and operating workers alike. **Key words**: absence of bypass stack, combined cycle power plant, power plant operation and maintenance

集中供热系统中的分户供热和热量计算＝**Heat Supply on a Household Basis and Metering of the Heat thus Supplied in a Central Heat Supply System** [刊, 汉] / Xu Fuchang (Qingdao Architectural Engineering Institute, Qingdao, Shandong, China, Post Code 266033) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —312~313, 321

The author proposes a heating system design scheme incorporating such functions as heat supply on a household basis and metering of the heat thus supplied on a household basis. Meanwhile, an effective metering of the heat supplied can be implemented by the use of a simple hot-water meter. **Key words**: heat supply on a household basis, metering of heat supplied on a household basis, regulation of heat supplied, design scheme

无烟煤沸腾床锅炉掺烧煤矸石的分析＝**An Analysis of the Burning Process in a Fluidized-bed Boiler Firing Anthracite Mixed with Gangue** [刊, 汉] / Hu Rongquan (Songzao Mining Bureau Power Plant, Chongqing, Sichuan, China, Post Code 401445) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —314, 319

An analysis was conducted of a fluidized-bed boiler firing anthracite mixed with gangue. The analysis covers the following aspects: rational distribution of mixed fuel particle diameter, the quantity of gangue to be mixed with the anthracite and the resulting bed-material layer thickness, air chamber static pressure, dust removal and desulfurization, etc. The results of the analysis may serve as a guide for achieving the comprehensive utilization of resources during the construction of small-sized thermal power stations in the neighborhood of a high sulfur-content anthracite mine. **Key words**: fluidized bed boiler, anthracite, analysis

小型燃气锅炉尾部烟道的腐蚀机理及预防＝**Mechanism of the Boiler-Tail Flue Corrosion of a Small-sized Gas-fired Boiler and Proper Measures Taken to Cope with such Corrosion** [刊, 汉] / Zhao Yan, Lu Guangfa (Heilongjiang Machinery Building School, Harbin, China, Post Code 150080) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —315~316

Described in this paper is the corrosion phenomenon occurring at the tail-portion flue of a gas-fired boiler. The cause of this corrosion is analyzed and some measures to cope with it are proposed from the viewpoint of boiler structure and operation management, thus providing some useful hints for boiler designers and operation/management personnel. The measures proposed can be likewise applied to oil-fired boilers. **Key words**: gas-fired boiler, boiler flue corrosion, preventative measures

用于汽轮机叶片的钛合金材料—Ti—6A1—4V＝**Titanium Alloy Ti-6A1-4V, a Metal Used for the Fabrication of Turbine Blades** [刊, 汉] / Tu Shan, Sun Bi, Mao Jingru (College of Energy Sources and Power Engineering under the Xi'an Jiaotong University, Xi'an, Shaanxi, China, Post Code 710049) //Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —317~319

The uprating of a steam turbine power output will necessitate the increase in area of the turbine last-stage flow path and an enhancement in blade corrosion-resistance. The chrome alloy steel blades currently in use can hardly meet the relevant requirements. Hence, it is essential to conduct a comprehensive research for the application of blades made of titanium alloys. The present paper gives a brief description of the properties and the use of titanium alloy blades. **Key words**: steam turbine, last-stage blade, titanium alloy