

三压再热汽水系统 IGCC 的设计工况和变工况性能

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摘要:以三压再热式汽水系统 IGCC(整体煤气化燃气—蒸汽联合循环)为研究对象组成了整体空分 IGCC 系统方案,建立了气化炉、净化系统、燃气轮机、空分装置、余热锅炉、汽轮机各组成部件的数学模型,对 IGCC 系统的设计工况和变工况特性进行计算,分析了燃气轮机采用不同调节规律和汽轮机采用不同运行方式时对系统变工况性能的影响,并提出了合理的运行方式。

关键词:整体煤气化燃气—蒸汽联合循环;整体空分;变工况;调节规律

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1 前言

整体煤气化燃气—蒸汽联合循环(简称 IGCC)是一种很有前途的高效低污染的发电方式。空分装置和燃气轮机的整体优化设计与独立空分装置相比,提高了 IGCC 系统的功率和效率,有利于 IGCC 的商业化应用。本文以三压再热式汽水系统组成的整体空分 IGCC 系统为研究对象,进行了变工况计算,研究分析了燃气轮机不同调节规律和汽轮机不同运行方式对系统性能的影响,提出了三压再热式整体空分 IGCC 系统合理的运行方式,得到了一些有益的结论,为我国今后建立 IGCC 示范电站做了理论上的准备工作。

2 三压再热式汽水系统和整体空分的 IGCC 系统方案

2.1 气化炉

目前,就煤的气化床的床型而言,共有三种典型的气化炉装置,喷流床、流化床和固定床气化炉,三种气化炉各有利弊,都在发展之中。本文 IGCC 系统中气化炉的型式选用喷流床气化炉 shell 炉,计算数据取自文献[1]。

2.2 煤气净化系统

由于高温除灰和脱硫技术还不成熟,本文仍采

用湿法除尘和低温脱硫技术。

2.3 燃气轮机

为了提高联合循环的效率,选用 GE 公司生产的 MS9001FA 型燃气轮机,输出功率 226 500 kW,效率为 35.7%。

2.4 空分系统

采用整体空分系统的方案。即空分装置所需空气一部分由独立空气压缩机提供,另一部分来源于燃气轮机压气机抽气,后者所占比例多少称作集成度 K_{asu} 。

2.5 余热锅炉和汽轮机

为了提高 IGCC 的供电效率,所用余热锅炉和汽轮机,本文采用再热的三压系统。压力和温度参数参照 GE 公司生产的三压再热式余热锅炉来决定,汽轮机与余热锅炉相配。

2.6 IGCC 系统的方案的确定

通过对 IGCC 系统各子系统部件分析,选择三压再热式汽水系统作为本文分析研究的对象,并采用整体空分的 IGCC 系统且剩余氮气全部回注到燃气轮机燃烧室参加作功的方案。示于图 1。

2.7 在设计工况下空分装置集成度对 IGCC 性能的影响

在设计工况下,如何选择图 1 所示的 IGCC 系统空分装置的集成度是至关重要的,因其直接影响到装置的功率和效率。IGCC 系统功率和效率随集成度的变化示于图 2 和图 3。经研究分析有以下几点结论:当 $K_{asu}=0.53$ 时,可调静叶关小角度为 0° ,燃机达最大功率,系统的功率和效率也达到最大值;当 $K_{asu}<0.53$ 时,燃机因受最大功率的限制,需要调整静叶,关小角度,减少空气流量,使得系统的功率和效率会逐渐地下降。因此,对于整体空分 IGCC 而言,在系统设计时,寻求最大功率和最佳效率时的空分装置集成度是一项有意义和必须做的工作。

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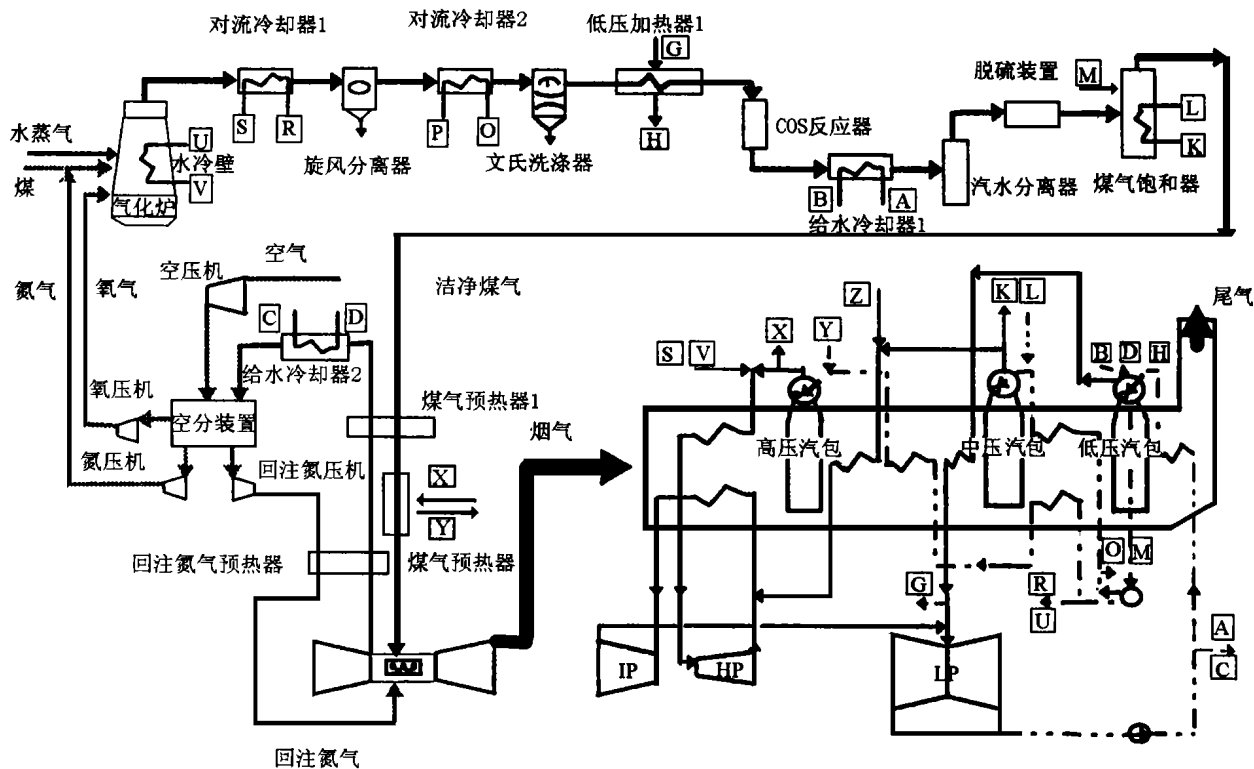


图1 IGCC系统简图:整体空分系统

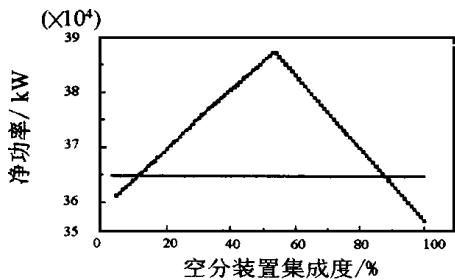


图2 系统净功率随集成度的变化

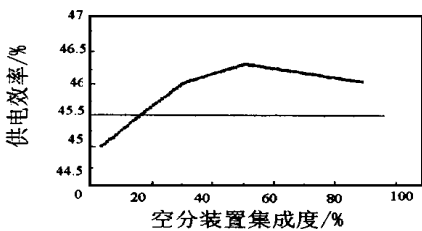


图3 系统供电效率随集成度的变化

3 三压再热式汽水系统 IGCC 的变工况计算的模型

3.1 气化炉变工况模型

气化炉变工况模型引入了以下假设:

- (1)当煤种不变时,气化炉在部分负荷下的平衡温度不变。
- (2)当煤种不变时,气化炉在部分负荷下产生的粗煤气成分不变,产气率也不变。

有了以上两点假设,气化炉变工况的特性参数

看作与设计工况时的参数成线性比例关系即可,以简化计算。

3.2 燃气轮机变工况模型

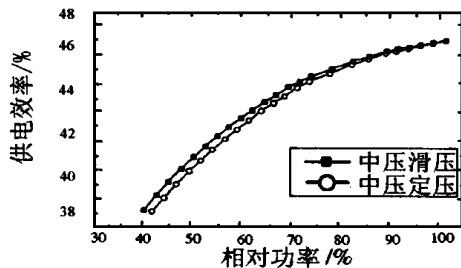


图4 供电效率随系统净功率变化曲线

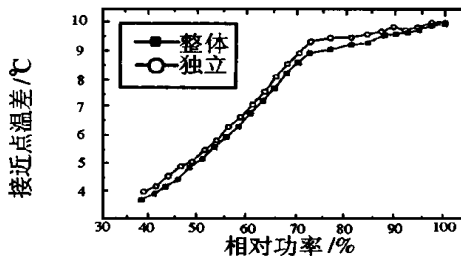


图5 高压接近点温差随系统净功率的变化曲线

由于在变工况计算时,没有MS9001FA的压气机性能曲线,在本论文中,借用了ASME上的文献[3]中所提供的压气机特性曲线,以设计工况点为基

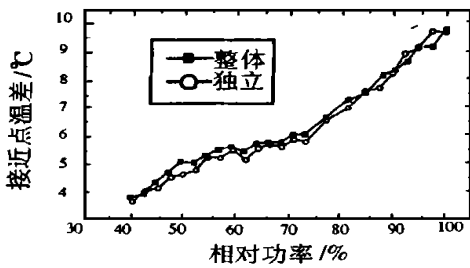


图 6 中压接近点温差随系统净功率的变化曲线

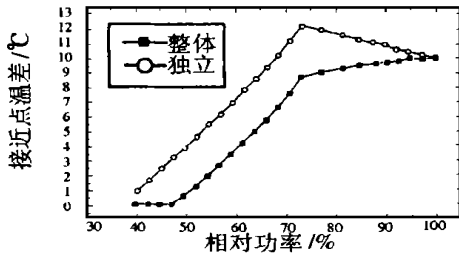


图 7 低压接近点温差随系统净功率的变化曲线

3.3 汽轮机变工况模型

3.3.1 汽轮机定压运转模型

汽轮机定压运行时, 汽轮机的进气流通面积需要调整, 因此不能用抛物线方程来计算汽轮机的效率, 现用以下方法来求汽轮机在定压控制规律下变工况时的效率 η_{st} :

$$\eta_{st} = \eta_{sto} \times \frac{1}{0.93} \times (1.0 - \frac{0.07}{D_1})$$

式中:

D_1 为相对流量, 定义为: $D_1 = D / D_0$,

“0”下标表示设计工况。

有了汽轮机的效率和进口参数, 就可以得到汽轮机的其它参数了。

3.3.2 汽轮机的滑压运行模型

汽轮机在滑压运行时, 它的流量用 Flogul 公式计算, 效率用抛物线方程计算, 有了流量和效率, 即可以计算汽轮机的其它参数了。

3.4 余热锅炉内单个换热器的变工况模型

余热锅炉内有多个换热部件, 对余热锅炉的各个换热部件来说, 变工况下要满足热平衡方程: 放热=传热=吸热

3.5 IGCC 系统的变工况计算

准, 对压气机压比, 流量和效率进行修正后用于本文压气机的性能计算。涡轮性能采用考虑临界压比的 Flogul 公式, 且考虑工质热力性质的变化。

通过以上对 IGCC 系统中各个子系统变工况模型的分析, 把各个子系统变工况模型结合起来即可进行 IGCC 系统的变工况计算。

4 整体和独立空分 IGCC 系统的变工况性能比较

在燃气轮机采用等 T_4 调节规律, 汽轮机全滑压运行方式下, 分析比较一下整体和独立空分装置的变工况性能, 计算结果示于图 4。整体和独立空分装置的 IGCC 系统的供电效率随系统净功率的变化趋势基本相同。

接近点温差在余热锅炉中是一个重要参数, 如果接近点温度为零, 则表明在省煤器中发生了汽化现象, 这对余热锅炉的安全运行不利, 应该避免。计算结果示意图 5, 图 6 和图 7。

IGCC 系统高压、中压、低压锅筒接近点温差均随功率的降低而减少, 其中, 低压锅筒接近点温差下降得最快, 当负荷低于设计工况的 50% 时, 整体空分 IGCC 系统余热锅炉的低压接近点温差趋于 0°C, 给水加热器中会发生部分给水蒸发汽化的问题, 将导致部分管壁过热的现象, 甚至出现故障, 不利于安全运行。当负荷降低到 40% 时, 整体和独立空分 IGCC 系统高压锅筒的接近点温差都趋于 0°C, 高压经济器都将发生汽化现象。因此, 为使较低负荷下, 接近点温差仍大于 0°C, 必须增大其设计值, 从而保证给水加热器和经济器在低负荷下也能安全运行, 是设计时应引起注意的。

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(复 编辑)

Shaanxi, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2000, 15(4). — 364 ~ 366

An analysis was performed of the flow process of a heat exchange tube bank in an ice storage tank, and a physical model featuring the actual flow process has been set up. An analytical solution was obtained through a theoretical deduction. On the basis of the above the authors have provided a theoretical method for the accurate calculation of the flow distribution and system pressure drop of the heat exchange tube bank as well as the design of the latter. **Key words:** ice storage tank, heat exchanger, flow characteristics, flow distribution, pressure drop

非线性刚性转子—轴承系统的混沌研究 = A Study on the Chaotic Motions Existing in a Nonlinear and Rigid Rotor-bearing System [刊, 汉] / ZHANG Xin-jiang, WU Xin-hua, HAN Wan-jin (College of Energy Science and Engineering under the Harbin Institute of Technology), LI Jian-zhao (Harbin No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2000, 15(4). — 367 ~ 369

In connection with the specific features of a nonlinear rotor-bearing system and under a relatively wide range of parameters a study has been conducted of the stability of a rigid Jeffcott rotor-bearing system using a short bearing model. The study was performed on the basis of the rotor dynamics and nonlinear dynamics theory and with the use of a numerical integration and Poincaré mapping method. The results of calculation show that there exist chaotic motions in the above-mentioned system. With the help of a numerical method obtained in some parameter domains of the system were the following: bifurcation diagrams, response curves, time histories, frequency spectrum and phase diagrams, shaft centerline locus and Poincaré mapping diagram. All the above gives a visual display of the operating condition of the system in some parameter domains. Meanwhile, an analysis was conducted of the effect of the bearing geometric dimensions on the stability of the system. The results of the numerical analysis can provide a theoretical basis for the design and safe operation of this type of rotor-bearing system. **Key words:** rotor dynamics, nonlinearity, rotor-bearing system, chaotic motion, stability

重载低速动压润滑推力轴承的理论分析 = Theoretical Analysis of a Dynamic-pressure Lubricated Heavy-duty and Low-speed Thrust Bearing [刊, 汉] / LI Jian-ping, LIU Rui (Harbin Boiler Co. Ltd., Harbin, China, Post Code: 150046) // Journal of Engineering for Thermal Energy & Power. — 2000, 15(4). — 370 ~ 372

A theoretical analysis was conducted of a multiple-slide pad and plane thrust bearing with respect to such a variety of parameters as elastic deformation, load-bearing capacity, rigidity, oil viscosity and oil film thickness, etc. Some of the relationships governing these parameters, thus obtained, can serve as a theoretical basis for the rational design of the above-cited bearing. **Key words:** elastic deformation, dynamic pressure lubrication, oil film thickness

三压再热汽水系统 IGCC 的设计工况和变工况性能 = Design and Off-design Performance of the Integrated Gasification Gas-steam Combined Cycle (IGCC) of a Triple-pressure Reheat Steam-water System [刊, 汉] / LU Ze-hua, ZHAO Shi-hang, SHANG Xue-wei, CAO Ren-feng (Qinghua University, Beijing, China, Post Code: 100084) // Journal of Engineering for Thermal Energy & Power. — 2000, 15(4). — 373 ~ 375

With the integrated gasification gas-steam combined cycle (IGCC) of a triple-pressure reheat steam-water system serving as an object of study proposed in the present paper is the design scheme of an integrated air separation IGCC system. Set up was a mathematical model involving the following units: a gasification furnace, a purification system, a gas turbine, an air separation unit, a heat recovery boiler and a steam turbine. A series of calculations were performed of both the design and off-design performance of the IGCC system. Analyzed was the effect on the system off-design performance in the case of the gas turbine adopting different control and regulation laws as well as in the case of the steam turbine assuming different operational modes. In addition, a rational operational mode has also been proposed. **Key words:** integrated gasification gas-steam combined cycle, integrated air separation unit, off-design operating conditions, regulation law and