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蒸汽动力系统可调节性分析

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摘　要: 工厂中经常出现的变动情况决定蒸汽动力系统须具有一定的可调节性。本文以总复合曲线为工具, 分析比较了采用背压式汽轮机组和采用抽汽凝汽式汽轮机组的蒸汽动力系统, 并用一个例子说明如何借助总复合曲线设计可调节性好的蒸汽动力系统。

关　键　词: 蒸汽动力系统; 调节性; 总复合曲线; 汽轮机

中图分类号: TK269　　文献标识码: A

蒸汽动力系统是石化企业的重要组成部分, 它消耗燃料, 为整个生产过程提供蒸汽、电力、冷却水等公用工程。蒸汽动力系统是否合理, 直接决定企业的能耗水平。同时, 由于企业生产中存在波动, 产品品种变化及季节不同, 必然引起公用工程量的变化, 相应的蒸汽动力系统能否适应所发生的变化, 是否具有可调节性, 将决定企业的产品成本、经济效益和能源利用程度。在我国, 大部分石化厂的蒸汽动力系统, 采用背压式汽轮机组或抽汽背压式汽轮机组, 接机泵或发电机组, 产生的背压蒸汽用于工艺或生活热用户。背压机组由于没有凝汽器中的冷端损失, 在经济上是优越的, 对蒸汽的利用率比较高, 但背压机组存在不能同时满足热用户和输出功率需要的缺陷, 制约了整个蒸汽动力系统的可调节性。本文采用总复合曲线对蒸汽动力系统进行分析, 讨论适应各种蒸汽供需变化的蒸汽动力系统方案。

1　用总复合曲线确定公用工程量的原理

总复合曲线是过程系统中热流量沿温度的分布在 $T\sim H$ 图上的标绘, 它形象地描述了过程系统中不同温位处的能量流, 提供处在什么温位需要补充外加能量, 以及在什么温位可以回收能量的定量信息[1]。热通量为零处就是夹点。从能量流角度来讲, 夹点把过程系统分隔成两个独立的子系统, 夹点上方, 为净热阱, 只需加热公用工程, 没有热量向外排出; 夹点下方, 为净热源, 只需冷却公用工程, 不从系统外吸收热[2]。因本文只考虑加热公用工程, 因此只需考虑总复合曲线中的夹点以上部分, 如图 1 所示。

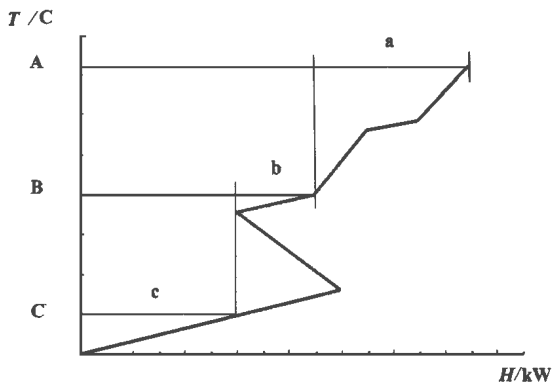

图 1　用总复合曲线确定加热公用工程

通过总复合曲线可以确定不同温位下的公用工程量, 即需用的不同级别的蒸汽量。

为减少加热公用工程的费用, 根据总复合曲线应选择尽量接近净热阱的加热公用工程级别。例如在图 1 中采用 A, B, C 三个温度级别的加热蒸汽, 其用汽量分别为 a, b, c 三段蒸汽量。A 级蒸汽一般为锅炉新汽, B 级蒸汽可以为抽汽, C 级蒸汽为背压蒸汽, 这样就分别确定了各级公用工程的用量。这种分段加热处理实际上就是用温位较低的蒸汽加热夹点以上温位较低的物流。公用工程划分的级别越多, 高温位的加热公用工程用量越少, 可减少运行费用, 但增加了换热网络的复杂性与投资, 所以要结合工程实际全面考虑[2]。

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2　生产波动时的总复合曲线分析

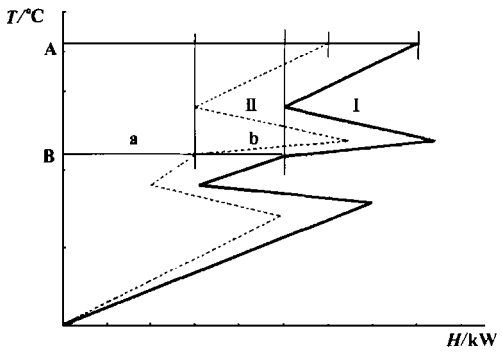

图 2　生产波动时的总复合曲线

上述的用总复合曲线确定公用工程量的原理是针对某一正常生产的工况，若仅据此来设计蒸汽动力系统，如目前文献所述那样[1—4]，则通常适应生产波动的可调节性差。而工厂实际生产过程中不可能没有波动，同时季节变化，以及由市场供需决定的产品、产量、品种的变化，均造成公用工程量的变化。图 2 为生产波动时的总复合曲线，其中曲线 1 为工厂正常运行时的曲线，曲线Ⅱ为工厂某段时期生产变化后的曲线，此时热需求减少。

目前石化企业中采用的汽轮机组多为背压汽轮机组或抽汽背压汽轮机组，其后接机泵作功或带动发电机发电。带动发电机组时还有两种情况：一是发电量用于满足本厂需要，电量用于维持正常生产需要，这时电量必须稳定；另一种是工厂从电厂电网中获得电，这时发电量可以变化。

对于采用背压机组接机泵的工厂，正常运行的情况下：工况Ⅰ时，产生的背压蒸汽恰好可以满足用户 a+b 段蒸汽的需求量，而输出功率满足机泵要求，这样既使蒸汽全部得到了利用，同时还直接用蒸汽作功带动机泵，不经过发电步骤，减少了能量损耗，从对蒸汽的利用率来看，这应是最佳方案。但在工况Ⅱ时，背压蒸汽 B 需要量减少了 b 段，在没有热用户的情况下只能放掉，造成能量浪费；若减少背压机组进汽量，使之产生的背压蒸汽减少 b 段，这样可以使热用户蒸汽达到平衡，但进汽量的减少，造成输出功率减少，而该机组直接接机泵，是必须在功率稳定下工作的，这样机泵无法运行，由机泵带动的生产将被迫停产。这时无论怎样调节都不能使输出功率和产生的背压蒸汽同时满足需要，蒸汽利用率非但不高，反而大大降低。

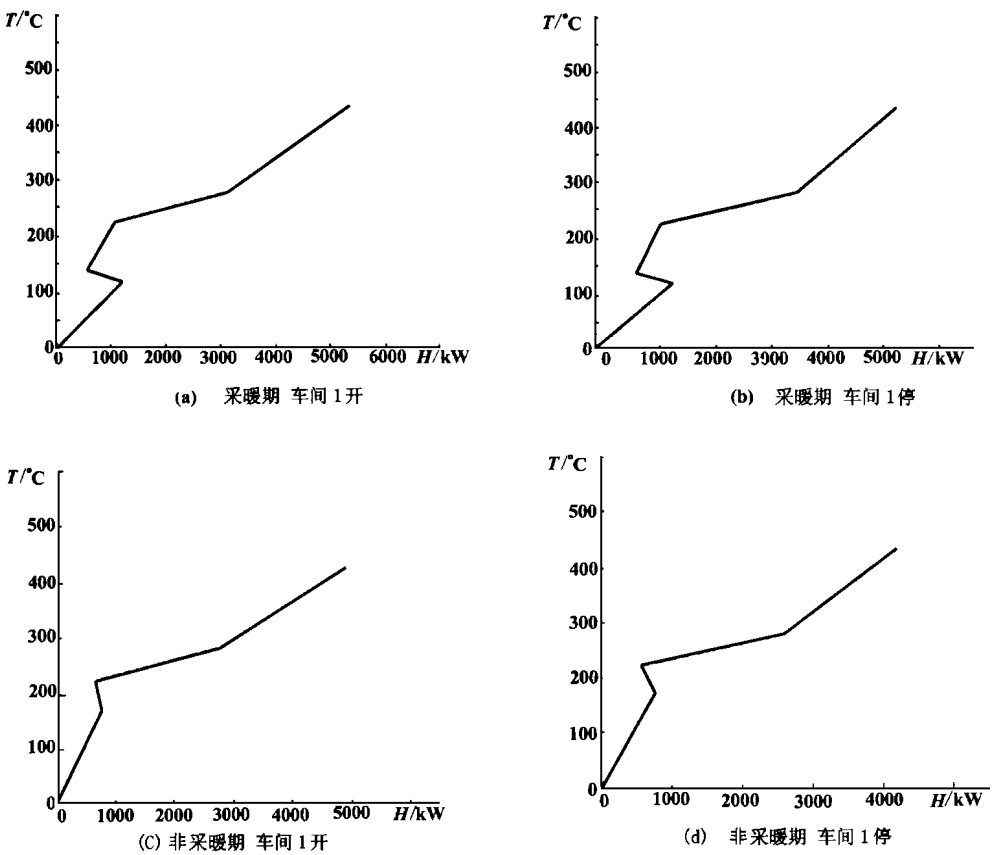

图 3　某企业总复合曲线

对于采用背压机组接发电机组，发电量要求稳定的工厂，在工况Ⅰ时，背压机组产生 a+b 段蒸汽量，同时发电量满足工厂需要，但在工况Ⅱ时，若要保证发电量，则背压机组产生的蒸汽多余 b 段；若减少背压机组进汽量，使蒸汽达到平衡，则发电量随之减少，不能满足生产需要。

对于采用背压机组接发电机组，发电量没有要

求的工厂，发电量可以随热用户的变化而变化，可以满足蒸汽平衡。

因此，对于机组直接拖动机泵和厂发电量要自给自足的情况，当公用工程需求量发生变化时，仅采用背压机组的蒸汽动力系统将不能有效地进行调节，以保证同时满足热、电（或动力）需求。为使蒸汽动力系统的可调节性好，须采用抽汽凝汽式汽轮机组，当公用工程需求量发生变化时，通过改变汽轮机的进汽量和抽汽量，同时满足热电需求。但此时进凝汽器的那部分蒸汽存在冷端损失，这意味着蒸汽动力系统可调节性的增强是以正常生产时能量利用率的降低为代价的，但从整个生产运行过程考虑，能量利用率却较仅采用背压机组时高。

此外也可以采用背压汽轮机组和抽汽凝汽机组联合运行的方式，使背压机组产生的背压蒸汽满足需求量稳定的那部分热用户。抽凝机组产生的抽汽量满足除去背压蒸汽后不足的蒸汽量。在出现蒸汽需求量变化时，改变抽凝机组的进汽量和抽汽量，使蒸汽达到平衡，同时输出功率维持稳定。这样既可以使蒸汽系统具有可调节性，同时也充分利用了蒸汽能量。

3 举例分析

某石油化工企业有 5 个车间，其中车间 1 时开时停，图 3 为该厂各种情况下的总复合曲线，并要求蒸汽动力系统提供稳定的电功率 7500kW。蒸汽动力系统拟采用 3.5 MPa 和 1.0 MPa 两种级别的蒸汽。

由图 3 可知：采暖期、车间 1 开时，需 3.5 MPa 的蒸汽 4308.256 kW（31t/h），1.0 MPa 的蒸汽 1089.18 kW（36 t/h）；采暖期、车间 1 停时，需 3.5 MPa 的蒸汽 3613.376 kW（26 t/h），1.0 MPa 的蒸汽 998.415 kW（33 t/h）；非采暖期、车间 1 开时，需 3.5 MPa 的蒸汽 4308.256 kW（31 t/h），1.0 MPa 的蒸汽 635.355 kW（21 t/h）；非采暖期、车间 1 停时，需 3.5 MPa 的蒸汽 3613.376 kW（26 t/h），1.0 MPa 的蒸汽 544.59 kW（18 t/h）[5]。

为适应这种公用工程需求，可对蒸汽动力系统设计如下配置：90 t/h 中压锅炉一台，1500 kW、3.5 MPa/1.0 MPa 背压机组一台，6000 kW 抽汽压力 1.0 MPa 的中压抽凝机组一台[6]。蒸汽动力系统如下运行：

采暖期、车间 1 开时，锅炉产生 3.5 MPa 的蒸汽 90 t/h，其中 31 t/h 供生产用，18 t/h 供背压机组，40.5 t/h 供抽凝机组；抽凝机组抽汽 18 t/h，同背压机组排汽一道供生产所需 1.0 MPa 蒸汽，总发电量 0.75 万 kW。

采暖期、车间 1 停时，锅炉产生 3.5 MPa 的蒸汽 83 t/h，其中 26 t/h 供生产用，18 t/h 供背压机组，39 t/h 供抽凝机组；抽凝机组抽汽 15 t/h，同背压机组排汽一道供生产所需 1.0 MPa 蒸汽，总发电量 0.75 kW。

非采暖期、车间 1 开时，锅炉产生 3.5 MPa 的蒸汽 82 t/h，其中 31 t/h 供生产用，18 t/h 供背压机组，33 t/h 供抽凝机组；抽凝机组抽汽 3 t/h，同背压机组排汽一道供生产所需 1.0 MPa 蒸汽，总发电量 0.75 万 kW。

非采暖期、车间 1 停时，锅炉产生 3.5 MPa 的蒸汽 75.5 t/h，其中 26 t/h 供生产用，18 t/h 供背压机组，31.5 t/h 供抽凝机组；抽凝机组以纯凝工况运行，背压机组排汽供生产所需 1.0 MPa 蒸汽，总发电量 0.75 万 kW。

4 结论

（1） 蒸汽动力系统的可调节性是系统是否合理的重要指标之一，它直接影响着企业的能耗水平。采用抽汽凝汽式汽轮机组较之采用背压式汽轮机组，可以增加汽动力系统的可调节性，而且从整个生产运行过程考虑，能量利用率也得到提高。

（2） 过程总复合曲线是用来设计、改进蒸汽动力系统的有效工具，因为它清楚地描述了过程系统热量要求所处的温位。为了使蒸汽动力系统的可调节性高，必须作出各种情况下的总复合曲线，据此来设计蒸汽动力系统。

参考文献

〔1〕 姚平经主编. 全过程系统能量优化综合. 大连理工大学出版社，1995.

〔2〕 冯霄，李勤凌. 化工节能原理与技术. 化学工业出版社，1998.

〔3〕 Vikas R Dhole, Bodo Linnhoff. Total site targets for fuel, co—generation, emission and cooling. Comp. &Chem. Eng., 1993, 17, 101 ~ 109.

〔4〕 Bodo Linnhoff. Use pinch analysis to knock down capital costs and emissions. Ghemical Engineering Progress, 1994; 90(8): 32.

〔5〕 朱自强，徐汎. 化工热力学，（水蒸汽附表）. 化学工业出版社，1991.

〔6〕 沈士一，庄贺庆，康松，庞立云合编. 汽轮机原理. 水利电力出版社，1992.

（渠 源 编辑）

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Through the use of a finite element method and a substructure technology a dynamic model of technological base-frame system is set up for a GT25000 gas turbine test. Calculated in detail are the natural characteristics and the dynamic response of the above-cited system. Also discussed is the effect on the system vibrations of a damper and damping action. The results of an analysis show that the technological base-frame possesses relatively good dynamic characteristics and features a rational design. **Key words**: gas turbine test, technological base-frame, substructure, natural frequency, dynamic response

两相流动对流化床燃烧行为的影响=**The Effect of a Two-phase Gas-solid Flow on the Combustion Behavior of a Fluidized Bed** [刊, 汉] / Lu Junfu, Jin Xiaozhong, Zhang Jiansheng, *et al* (Department of Thermal Engineering, Qinghua University, Beijing, China, Post Code 100084) //Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —217 ~219, 238

The measurement along a circulating fluidized-bed boiler height of the gas concentration and the combustion fraction distribution has demonstrated that the major difference between a bubbling fluidized bed and a circulating fluidized one consists in their radically different combustion behavior in a dense-phase zone. Due to a relatively low average particle diameter of the bed material the dense-phase zone flow of the circulating fluidized bed is different from that of the bubbling bed. This will lead to an increase in mass transfer resistance between the gas and solid phase, thus affecting the combustion reaction. The combustion behavior in the dense-phase zone is characterized by a shortage or lack of oxygen. The combustion reaction exists along the height of the circulating fluidized bed boiler and even in a cyclone separator. A combustion model for the fluidized bed dense-phase zone is set up, which takes into account the mass transfer resistance between the gas and solid phase. A comparison with the measured data obtained on an actual circulating fluidized bed boiler indicate that the calculated results are in relatively good agreement with the measured ones. **Key words**: circulating fluidized bed, bubbling bed, dense-phase zone, combustion behavior

非流线型体的滞止浓缩与弥散过程=**Stagnation Concentration Process and Diffusion Process of a Bluff Body** [刊, 汉] / Jin Yan, Wei Yonghua, Xiong Fanfan (Department of Thermal Engineering, Qinghua University, Beijing, China, Post Code 100084) //Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —220 ~222

The authors have come up with a new concept, proposing that both a stagnation concentration process and a diffusion process of particles constitute a basis for the concentrated pulverized-coal combustion technology. An analysis of the mechanism of the above-mentioned two processes is given in the present paper. With the help of a particle dynamic analyzer a study has been conducted of both the concentration process and the diffusion process of a bluff body which assumes the form of a damper, demonstrating for the first time the existence of the stagnant concentration process. The experimental test results show that through the use of the bluff body a concentration or enrichment of the pulverized coal can be readily attained. **Key words**: concentrated pulverized-coal combustion technology, pulverized coal burner, stagnation concentration process, diffusion process, bluff body

采用优化算法分析燃烧火焰辐射光谱求取火焰温度=**Determination of a Flame Temperature from the Analysis of a Combustion Flame Radiation Spectrum through the Use of an Optimized Algorithm** [刊, 汉] / Zhou Jie (Institute of Thermal Power Engineering under the Zhejiang University, Hangzhou, Zhejiang, China, Post Code 310027) //Journal of Engineering for Thermal Energy & Power. —2000, 15(3). —223 ~225

A flame temperature can be determined from an analysis of the radiation spectrum emitted by a gas-burning flame in conjunction with the use of an optimized algorithm. This approach simplifies the calibration of the absolute radiation intensity of a flame as demanded by the conventional two-color method. Meanwhile, it is conducive to a better understanding of the variation relationship of the flame radiation emissivity versus wavelength. The measured temperature values are in good agreement with those obtained by a thermocouple, demonstrating the fairly high precision of the method. Moreover, this also makes it possible to conduct the on-line monitoring of a combustion flame temperature. **Key words**: flame temperature, optimization, radiation intensity

蒸汽动力系统可调节性分析=**An Analysis of the Regulation Possibility of Steam Power Systems** [刊, 汉] / He

Ate, Feng Xiao (Department of Chemical Engineering, Xi' an Jiaotong University, Xi' an, Shaanxi, China, Post Code 710049), Sui Xinha, Gao Wuxia (Shandong Provincial Dongying Shenli Petrtoleum Management Bureau, Dongying, Shandong, China) // Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —226 ~ 228

A constant change of situations in a factory demands that a steam power system should lend itself to be readily regulated within certain limits. With general composite curves serving as a tool this paper makes an analytical comparison of the steam power systems using respectively a back-pressure steam turbine unit and an extraction condensing steam turbine unit. Furthermore, a specific example is used to explain how to design a steam power system featuring a good regulation possibility with the help of the general composite curves. **Key words**: steam power system, regulation possibility, general composite curves, steam turbine

湿化器的传热传质机理和性能分析＝**Heat and Mass Transfer Mechanism and Performance Analysis of a Humidifier** [刊, 汉] / Shang Demin, Wang Yongqing, Chen Anbin, *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). —229 ~ 231, 209

Proceeding from the basic principles of heat transfer and mass transfer, the authors have set up a mathematical model for a humidifier, a major component of a humid air turbine (HAT) cycle. The humidifier performance is studied with the irrationality of some current treatment methods being identified. **Key words**: humid air turbine cycle, humidifier, heat transfer and mass transfer, work performance

有限时间内不可逆卡诺热机的最少循环时间和熵产的关系＝**The Relation Between the Minimum Cycle Time and Entropy Generation of a Finite-time Endo-irreversible Carnot Engine** [刊, 汉] / Liu Shiqiang, Yang Yushun (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). —232 ~ 234

An exploratory study is conducted of the issue of finite-time thermodynamics time. Deduced in this paper is a simple decreasing relationship between the minimum cycle time and the irreversible entropy generation of a finite-time endo-irreversible Carnot engine. It is noted that the entropy can not only mark the time arrow but also calculate the quantity of time. **Key words**: finite time thermodynamics, time, entropy generation

三种催化剂对半焦燃烧特性的影响＝**The Effect of Three Kinds of Catalyst on Semicoke Combustion Properties** [刊, 汉] / Zhu Tingyu, Wang Yang (Shanxi Provincial Institute of Coal Chemistry under the Chinese Academy of Sciences, Taiyuan, Shanxi, China, Post Code 030001) // Journal of Engineering for Thermal Energy &Power. —2000, 15(3). —235 ~ 238

The combustion properties of four types of semicoke were studied with the help of a thermobalance. The results of the study show that the semicoke prepared with the addition of a catalyst possesses a relatively small MI value and a fairly good reaction activity with a small oxygen absorption quantity needed prior to a coal combustion reaction. By way of combustion dynamics calculation it is found that the semicoke prepared with calcium oxide added has the highest combustion activation. In conclusion, the conception of an average activation energy is proposed to represent an index of the semicoke combustion activity, which is compared with other combustible comprehensive index S put forward by other researchers. **Key words**: thermobalance, semicoke, combustion kinetics, average activation energy

叶片弯曲对跨音速涡轮叶栅流场的影响＝**The Effect of Turbine Blade Positive Curving on the Flow Field of a Turbine Transonic Cascade** [刊, 汉] / Wang Songtao, Wu Meng, Feng Guotai, *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). —239 ~ 242

A numerical simulation was conducted on the flow field of a straight cascade composed of uniformly loaded blades and a bowed cascade composed of blades of different curved angles. A study was performed of the change under the curved blade action of the blade profile pressure distribution, Mach number contour lines and blade surface pressure distribution.