文章编号: 1001－2060(2010)01－0069－03

宝钢 N_2 炼钢煤气冷却高压水回流系统节能改造

余晓明[1], 申文军[1], 孔彪龙[2]
(1. 上海理工大学 能源与动力工程学院, 上海 200093; 2. 上海市通用机械技术研究所, 上海 200431)

摘　要: 以宝钢 N_2 炼钢煤气冷却高压水回流系统节能改造及自动回流装置性能检测系统为研究对象, 通过对高压水循环控制系统的自动回流阀组动态特性分析证明, 该装置将流量感应、止回、旁路控制及多级降压等控制功能集于一体, 使复杂的旁通回流系统得到合理简化, 且调节平缓, 有效保证泵的正常工作流程, 避免了大流量空排, 达到了节能与安全运行。经高压供水系统动态特性分析及多项节能改造的应用实践证明, 阀组完全达到了设计和现场运行工艺流程所要求的各项技术和经济性能指标。

关　键　词: 煤气冷却高压水; 自动回流阀组; 动态测试; 自力驱动; 控制循环

中图分类号: TH134　TP066.7　　文献标识码: B

引　言

宝钢二炼(上海宝山钢铁公司二炼钢厂)氧化转炉煤气冷却给水系统中, 氧化转炉产生的蒸气量随炼钢工艺过程变化而周期性波动, 汽包补水须随之周期性变化, 当转炉停止吹炼、汽包无需补水、系统给水量为零时, 为避免水泵空转须维持一个最小回流。以往曾采用将一个水循环控制阀串接在锅炉给水泵与止回阀之间的旁路中, 通过进口管中的感应孔板和传感器发出的反馈信号, 由电磁阀调节水循环控制阀的开度, 实现给水—回流过程的控制。这种控制方式在实际运行中的主要矛盾是[1], 由于控制回路的灵敏度问题影响系统的反应速度和精度, 反之则对干扰特别敏感而产生超补偿倾向, 易导致系统不稳定并发生振荡, 且总体结构复杂、组成设备多、相对成本较高。

为此, 研究中结合企业节能技术改造, 自行研制了自力式、多功能循环控制的自动回流阀组, 并通过系统的动态性能试验, 对高压供水空排止回自动回流阀组循环系统与常规系统运行特性进行了比较分析, 并实测了自动给水—回流过程中的压力控制、主流量、旁路流量及功率特性等。

试验研究和现场运行结果证明, 自力式组合型的自动回流阀组应用于锅炉、汽包供水设备及各类自动供回水控制等系统中, 能够大大简化系统的整体结构, 节省了常规系统中的流量监测和相应的各种伺服控制设备, 与旁路常开系统相比较, 能够在节能的前提下, 更经济、有效地保证系统的正常安全运行。

1　高压供水的回流控制

图 1(a)为锅炉高压给水常规控制系统, 该系统通过配置给水流量监测、止回、再循环伺服控制和多级降压等各种相应设备, 满足锅炉高压给水流量周期性变化时自动调节给水—回流的要求。

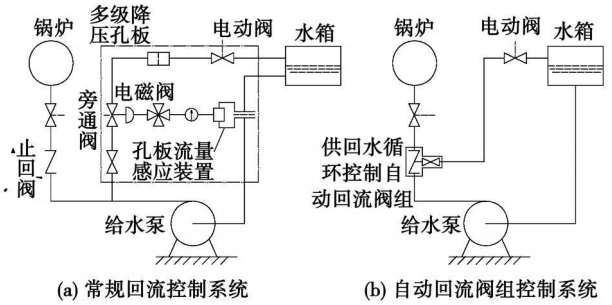

图 1　两种高压供回水循环控制系统

若为简化系统而采用人工控制, 即在止回阀和给水泵之间的旁路中设置手动阀, 省略信号反馈控制及相应设备, 无论汽包是否补水均保持恒定回流, 则会带来较大的能源浪费, 宝钢 N_2 炼钢和焦化工程等均需要采用这种自动供回水循环控制方式。

为满足企业节能技术改造和生产的发展, 以往曾从国外进口这种具有自动供回水循环控制功能的阀组设备, 它具有流量监测、止回、再循环伺服控制和多级降压等组合特性, 其旁路的开启是借助于泵输出的压力能, 关闭是依靠阀组内所储存的弹性势能, 调节控制是依靠管路内流介质的压力变化来实现的。考虑到价格、周期等实际因素需要立足于国内自行研制与开发这种自动供回水循环控制系统。当图 1(b)中

收稿日期: 2009－01－13　修订日期: 2009－06－01
作者简介: 余晓明 (1959－), 男, 江苏无锡人, 上海理工大学高级工程师.

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net

所示的电动阀开度随系统所需水量减少而关小，自动回流阀上端出口处压力随之上升至旁路开启压力的整定值时，主阀逐步关小直至闭合，旁路阀自动开启，图 2中所示的连接阀体与节流板之间的活动连杆机构（图略）在主阀前后压差和弹簧势能的共同作用下自动开大旁路阀的开度；反之，当电动阀开度随着系统所需水量增加而开大，自动回流阀上端出口处压力下降至旁路关闭压力的整定值时，主阀逐步开大，旁路阀的开度自动关小直至闭合。

随着系统阻力变化，高压泵的运行工况也不断变化，锅炉高压给水系统达到根据需水量的变化而自动控制供回水流量的目的。这类适用于高压供回水系统自动循环控制阀应用了内流介质压力变化的“自力驱动”原理[2~3]，实现了旁路阀启闭和开度调节的自动循环控制。

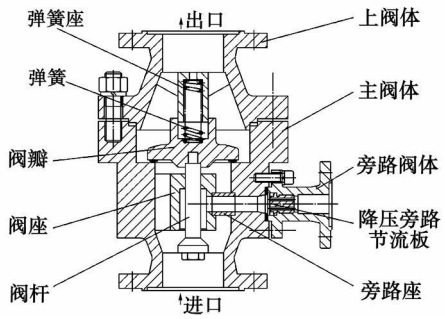

图 2 高压供水系统空排止回循环自动回流阀组结构示意图

通过现场长期运行使用证明，这种自力式、多功能自动循环回流阀组控制方式能够满足高压给水系统实际运行的各种特殊工况要求，与以往常规系统或电动控制方式比较[4]，更易获得系统最佳的稳定运行特性，并节省了各种相应仪表设备、简化结构、降低了系统的制造成本和运行费用。

2 泵阀管网特性试验研究

由于此类设备的研制在国内尚属首次，在试制过程中我们通过校企合作联合攻关、吸收和消化国外同类产品的先进技术[4]，并分别在试验室和有关企业实际系统中进行了模拟和实际运行试验，进行了不同类型的动态特性测试，根据试验结果分析验证技术改造方案的正确性。为更好地模拟系统的实际运行，联合建设了高压供水与回流并联式大型水力试验装置，在系统性能测试中，根据有关试验技术规范，分别采用标准孔板、压差传感器和电磁流量计测量主供水和旁路回水流量，同时监测各工况主阀前后和旁路压力，同步采集水泵转速、功率及进口真空度等。有关系统动态性能试验过程、试验条件和试验系统参考文献[5]。图 3与图 4分别给出了“泵阀管网系统运行特性曲线”和“主、旁路流量—压力特性曲线”。图 3中 R_1 为供水主管阻力特性曲线，R_2 为回水旁路阻力特性曲线，当主管阻力增大则 R_1 趋向 R_1'，这时主管流量下降压力上升，使旁路开度增大，因旁路阻力的减小使旁路阻力特性曲线 R_2 趋向 R_2'，回水流量增加。由于相对某一工况而言流动参量不随时间变化，根据流体流动连续性方程：

$$\iint \rho V_n \, dA = \text{const}$$

式中：ρ—工质密度；V_n—流速，dA—过流截面面积。

假设系统无泄漏，则：

$$\iint_{A_1} \rho V_n \, dA - \iint_{A_2} \rho V_n \, dA - \iint_{A_3} \rho V_n \, dA = 0$$

式中：A_1、A_2、A_3—主阀进、出口和旁路阀的过流截面的有效截面积。

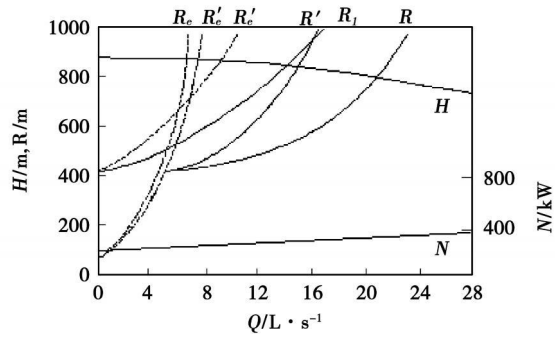

图 3 泵阀管网系统运行特性曲线

当 R_1、R_2 分别趋向 R_1'、R_2' 时，供水与回水并联特性曲线 R 必趋向 R'。系统的动态性能测试过程中，模拟汽包供水测得主阀供水流量从零至额定值，对应旁路则从某个回水流量（如额定值的 30% 至零。

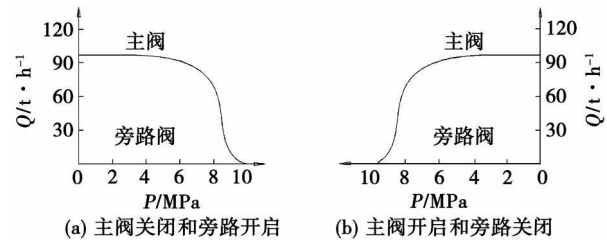

图 4 主、旁路流量—压力特性曲线

图 4中试验曲线分别表示主供水流量和旁路回水流量之间的变化与系统压力的关系。从主、旁路流量—压力特性曲线可以看出，当系统处于向汽包供水状态时旁路阀自动关闭，而汽包停止供水时旁路阀自动打开，将泵流量控制在额定值至 30%左右，避免了水泵闷车、过热或大功率电机的频繁启动等不良工

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

况，有效地保证了高压泵及其配套设备的稳定、安全运行和使用寿命。同时，在汽包停、供水间隙内，能够使高压泵处于小流量回流的运行工况下，高压泵的电机负荷大大下降，有效地节约了系统的运行费用。

3　应用分析

在此类自力式、多功能供水循环控制自动回流阀组未投入使用前，宝钢 N2炼钢煤气冷却系统为保护设备曾采用固定回水的人工控制方式，即无论水泵向汽包供水与否，始终以 30 t/h的流量通过止回阀与高压泵之间的手动阀回流至水箱，泵的实际运行工况为额定流量的 30% ~130%之间。图 5(a)和图 5(b)分别表示人工方式与自动供回水循环控制方式的水泵负荷周期变化特性曲线。

根据负荷曲线所表示的工艺流程，可计算单套自动供回水循环控制自动回流阀组使用前后的年节电额：

$$W = t\times\gamma\times H\times Q/1\,000 = t\times g\times H\times Q/1\,000 = 2\,640\times1\,000\times9.81\times(550\times30/3\,600\times1\,000)$$
$$= 118\,700\ \text{kW}\cdot\text{h/y}$$

式中：t—水泵年平均运行时数，h/y；$\gamma=\rho_g$—水的重度，N/m³；Q—水泵流量，m³/h；H—水泵扬程，m。

可见仅单套设备的节电额就非常大，N2炼钢两台转炉共计配备 4套供回水循环控制自动回流阀组(两备两用)，可节电费 20万元/y。宝钢焦化工程原设计为 3台高压泵并联，正常运行启动两台、一台备用。以往采用旁路常开回流，运行中由于 30%流量的浪费造成主供水系统的供水不足，不得不将 3台高压泵同时启动。而系统改造后充分利用原来所浪费的 30%流量，功率为 360 kW的给水系统节约电费 360万元/y。

该系统经过多年应用，宝钢炼钢厂 LT系统锅炉供水循环控制系统运行至今未发生过任何故障，能够维持水泵的最小流量，保证水泵的安全运行，单泵可节电费 10万元/y。同时还应用于宝钢炼焦分厂三期 CDQ和宝钢 135 t/h锅炉工程，自投入使用至今，性能良好，一方面能够保护泵的安全运行，满足了自动供回水循环控制系统的需要，同时能够减少耗电，节能效果显著。仅宝钢焦化工程项目技改一项，设备检修和节电就达 360万元/y。宝钢数套类似系统全部改造后每年可节约电费达上千万元。此外，还应用于上海石化股份有限公司炼化部乙烯装置，原系统采用的 3台国外进口阀门，由于年久失修，旁通阀无法自动关闭，并丧失旁通降压的功能，应用该项技术后也取得了良好的循环控制和节能效果，即单泵可节电费 200万元/y。

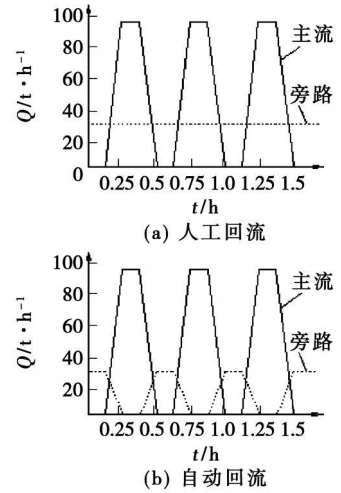

图 5　两种供回水循环控制方式负荷变化特性

4　结　论

(1) 应用小流量自动回流技术，通过在水泵出口设置自动回流阀维持泵的最小回流，使以往常规的复杂旁通回流或电动控制回流系统得到了合理的简化。

(2) 由于自动回流阀组具有平缓的调节性能，减少了压力突降造成的洞穴汽蚀，有效地保证了高压水泵的正常工作流程，避免了各种特殊工况转换过程中的大流量空排，达到了设备的节能和安全运行。

(3) 此项节能技术改造成果对宝钢、金山石化和国内各行业近年来引进技术和设备的消化吸收及国产化进程，减少进口、节约外汇等均起到了积极的促进作用。

(4) 经过高压供、回水系统的动态特性试验分析与专家技术鉴定，以及宝钢、金山石化等企业节能技术改造的应用实践证明，立足国内自行研制的自力式、多功能循环控制阀组完全达到了设计和现场运行使用工艺流程所要求的各项技术和经济性能指标。

参考文献：

[1] 莱昂斯. 阀门技术手册[M]. 北京：机械工业出版社，1991：466－473.
[2] 李著信. 输油管线自动开关阀研究//第三届全国工业流体力学学术会议论文集[C]. 上海：上海交通大学出版社，1993：143－146.
[3] 王小安. 三通式电动调节阀[J]. 阀门，1996(2)：2－4.
[4] 上海科学技术情报研究所. 上海市新产品水平查新报告(980896)[R]. 1998.
[5] 上海理工大学. LYHT型自动供回流阀组性能测试报告[R]. 上海：上海理工大学，1998.

(本文责任编辑　孙显辉)

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved.　http://www.cnki.net

of the primary air flow of the front and rear arch will exercise a notable influence on NO production. An increase of the primary air speed will lead to a reduction of the NO_x emissions concentration. Keywords: flame boiler; air distribution; numerical simulation; NO_x emission

涉外锅炉钢结构的风荷载计算及分析 = Wind Load Calculation and Analysis of a Foreign-related Boiler Steel Structure[刊, 汉] / CHENG Dong-mei, QIU Chang-hua (Electromechanical Engineering College, Harbin Engineering University, Harbin, China, Post Code: 150001), CHEN Ming (CSIC No. 703 Research Institute, Harbin, China, Post Code: 150036), QIAO Hong-bin (Huadian Energy Source Shareholding Co. Ltd., Harbin, China, Post Code: 150050) // Journal of Engineering for Thermal Energy & Power. — 2010, 25(1). — 61 ~ 64

In a boiler steel structure design, the basic wind speed or pressure is deemed as a basic condition for determining the design wind pressure. If the basic wind speed or pressure is chosen incorrectly, an unsafe or uneconomic design structure may result. How to convert the wind speed based on different national standards and how to choose the design wind pressure has currently become a key issue for calculating the wind pad in a foreign-related project. With Trinidad and Tobago waste heat recovery boiler project serving as an example, after a comparison of the meaning of the basic wind speed and the design wind pressure expression of the American UBC97 standard with that of the Chinese pad carrying standard, the calculation process of the wind speed conversion and design wind pressure was given under both load standards. The results show that the basic wind pressure calculated by using UBC97 standard is 1.44^2 times of that calculated by using the Chinese one while the design wind pressure is 1.5^2 times of that calculated by using the Chinese standard. Keywords: UBC97, basic wind speed, wind load, boiler steel structure, basic wind pressure, standard comparison, structural calculation

燃气轮机余热锅炉过渡烟道的优化设计 = Optimized Design of the Transition Flue Duct of a Gas Turbine-based Waste Heat Recovery Boiler[刊, 汉] / WANG Yong-tang, WU Shao-hua (College of Energy Source, Harbin Institute of Technology, Harbin, China, Post Code: 150001), CHEN Ming, WANG Yan-bin (CSIC No. 703 Research Institute, Harbin, China, Post Code: 150036) // Journal of Engineering for Thermal Energy & Power. — 2010, 25(1). — 65 ~ 68

In the light of the flow section shape of a transition flue duct of a waste heat recovery boiler, presented were two optimized design schemes, namely, 1. change the elevation angle of the top face plate of the flue duct and 2. install guide plates in the flue duct. Moreover, through a simulation calculation of the optimized design schemes, the flue gas velocity distribution on the cross section of the flue duct outlet was obtained. After an analysis and discussion of the simulated results, the best choice of the two optimized design schemes was determined. The calculation results show that to install guide plates can obviously improve the flue gas velocity distribution on the cross section of the flue duct outlet with the averaged velocity increasing from 11.13 m/s to 11.51 m/s, and the mean square deviation of the velocity decreasing from 12.33 m/s to 4.02 m/s. The application of the conclusions in the practical engineering projects has resulted in gaining satisfactory effectiveness. Keywords: gas turbine, waste heat boiler, transition flue duct, guide plate, flue gas velocity distribution

宝钢 N_2 炼钢煤气冷却高压水回流系统节能改造 = Energy-saving Modification of a High-pressure Water Return Flow System Cooled by Baogang N_2 Steelmaking Coal-gas[刊, 汉] / YU Xiao-ming, SHEN Wen-jun (College of Energy Source and Power Engineering, Shanghai University of Science and Technology, Shanghai, China, Post Code: 200093), KONG Biao-long (Shanghai General-purpose Machine Technology Research Institute, Shanghai, China, Post Code: 200431) // Journal of Engineering for Thermal Energy & Power. — 2010, 25(1). — 69 ~ 71

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net

With the energy-saving modification of a high-pressure water return flow system cooled by Baogang N, steelmaking coal-gas and automatic return flow device performance testing system serving as the objects of study, through analysis of the dynamic characteristics of the automatic return flow valve group of the high-pressure water circulating control system, it has been verified that the device combines a variety of control functions such as flow rate induction, non-return, bypass control and multi-stage pressure reduction etc. into an integrated whole. This makes it possible to rationally simplify the complicated bypass return flow system and achieve a slow and smooth regulation. As a result, the normal operation flow path of the pumps is effectively guaranteeed, avoiding a fluid evacuation at a large flow rate and securing the aim of energy-saving and safe operation. It has been proven by an analysis of the dynamic characteristics of the high pressure water supply system and the practical application in several energy-saving modification projects that the valve group in question has fully met various technical and economic performance indexes required by the design and on-site operation technological process. Key words: coal gas cooling; high pressure water; automatic return flow valve group; dynamic testing; self-force driving; control cycle

中间再热机组一次调频特性研究 = Study of the Primary Frequency-modulation Characteristics of an Intermediate Reheat Unit[刊, 汉] / MA Su-xia(College of Electrical and Power Engineering, Taiyuan University of Science and Technology, Taiyuan, China, Post Code: 030024), MA Qing-zhong, ZHANG Long-ying (Shanxi Provincial Electric Power Corp., Academy of Electric Power Sciences, Taiyuan, China, Post Code: 030001) // Journal of Engineering for Thermal Energy & Power. — 2010, 25(1). —72 ~76

In the light of the great change in power grid frequency and the poor performance of primary frequency-modulation of the on-line units, the regulating system of an intermediate reheat steam turbine unit was redesigned to superimpose the frequency difference signal to the instructions for HP and IP regulating valve in the form of a feedforward signal, to let the HP (High Pressure) and IP (Intermediate Pressure) regulating valve take part in the primary frequency modulation simultaneously. This makes it possible to fully use the heat stored in the intermediate reheat volume. The simulation results show that after the feedforward signals have been provided for the HP and IP regulating valve, the primary frequency modulation performance of the reheat steam turbine unit has been greatly improved with the load response ability being enhanced remarkably, retaining at the same time the stable performance of the regulation system. However, to realize feedforward signal control mode of the IP regulating valve still necessitates the completion of relevant research. Key words: primary frequency modulation; high pressure regulating valve feedforward; intermediate pressure regulating valve feedforward; intermediate reheat unit

一种余热利用相变石蜡储热过程的数值模拟 = Numerical Simulation of the Heat Storage Process of a Waste Heat Utilization-oriented Phase-change Paraffin[刊, 汉] / ZOU De-qiu(Postgraduate School, Chinese Academy of Sciences, Beijing, China, Post Code: 100039), XIAO Rui, SONG Wen-ji, FENG Zi-ping(Key Laboratory on Renewable Energy and Natural Gas Hydrate, Guangzhou Energy Source Research Institute, Chinese Academy of Sciences, Guangzhou, China, Post Code: 510640) // Journal of Engineering for Thermal Energy & Power. — 2010, 25(1). —77 ~81

Based on a kind of phase-change heat storage paraffin and with its liquid phase natural convection during its melting process being taken into consideration, a mathematical model for the paraffin melting process inside a rectangular cavity was established and used to perform a numerical simulation. In addition, the change of the temperature and flow field and the shift of the interphase boundary during the paraffin melting process was analyzed. The heat transfer was intensified by utilizing an aluminium-made fins and the influence of the fin location on the paraffin melting time was also analyzed. The simulation results show that when the location of the fins y=0.1 mm, y=5 mm, y=10 mm and y=15 mm, the heat storage time was shortened by 43.1%, 52.0%, 38.3% and 22.2% respectively as compared with the case when the fins are not used. The research results are of definite significance to

?1994-2018 China Academic Journal Electronic Publishing House. All rights reserved. http://www.cnki.net