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大型离心式风机变工况调节中噪声特性的实验研究

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摘 要: 目前大型电站使用的离心风机普遍存在噪声高的缺点, 降低噪声已成为环保要求的迫切问题。针对 G4-73No. 8D 大型离心式风机分别进行了出口节流调节、导流器调节和变速调节 3 种方式下的噪声特性实验研究, 得到了变工况下的噪声特性曲线。实验表明, 当流量减小时, 出口节流调节下的噪声总体有所升高; 导流器调节下的噪声总体呈小幅度的降低, 但在某些导流器开度下噪声反而有所提高; 变速调节下的噪声有大幅度的降低, 噪声得到有效控制。从降低噪声和经济性方面考虑, 变速调节的综合性能最优。

关 键 词: 离心风机; 噪声; 节流调节; 变速调节; 导流器调节
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引 言

风机是电厂烟风系统重要的动力源, 运行过程中产生的噪声将对环境产生噪声污染并影响操作人员的身心健康。选择高效低噪声的风机, 对于电厂具有重要的经济和现实意义。目前, 大、中型离心风机在设计工况下一般都具有高效低噪等综合优良性能。国际标准化组织推行 85 dB(A) 作为听觉损失标准, 我国规定, 新建电厂的噪声应控制在 85 dB(A) 以下, 老电厂允许噪声为 90 dB(A), 并逐步过渡到 85 dB(A)[1]。

受电力负荷调节的影响, 多数风机处于变工况运行, 风机的流量和压力需要根据管网的需要进行调节。目前, 风机的调节往往较注重各调节方法的经济性, 而对不同调节方法对风机噪声变化的影响, 尤其是实验研究报道较少[2~6]。本文针对电站普遍使用的 G4-73No. 8D 大型离心式风机分别进行出口节流调节、进口导流器调节和变速调节下的噪声特性实验研究, 分析和比较不同调节方式下的变工况噪声特性, 为同类型风机的实际运行和技术改造提供理论指导。

1 风机噪声成因分析

离心风机的噪声主要来源于气动噪声和机械噪声。气动噪声主要为旋涡噪声和旋转噪声。旋涡噪声是叶轮在旋转过程中, 叶轮叶片与气体相互作用、耦合所辐射的宽频带噪声, 包括来流紊流噪声、紊流边界层噪声、尾缘涡流脱落噪声和叶尖涡流噪声[2]。它是由于气体流经物体表面形成的紊流边界层及其脱体, 引起气流压力脉动造成的。离心风机产生旋涡噪声的主要原因是: 靠近叶片出口处的附面层分离, 气流在蜗壳内扩压流动时的分离, 叶片进口处的流动分离以及偏离设计工况时的流动恶化等[1]。该噪声与风机内部气流的流动状况密切相关, 设计制造良好的风机, 因其内部流动状态理想, 形成的边界层脱体较少, 则此类噪声较低; 反之, 则噪声较高。

旋转噪声是由于叶片周围不对称结构与叶片旋转所形成的周向不均流场相互作用而产生的噪声。对于离心式风机, 当蜗壳与叶片出口边缘间的间隙较小时, 将产生周期性的压力和速度脉动, 特别是在偏离设计工况时这种脉动将会大大增加[1], 突出表现在高速低负荷情况下, 这种噪声尤为明显。旋转噪声与叶片数和转速有关。旋转噪声的强度大致与圆周速度的 5~6 次方成比例; 当圆周速度增大一倍时, 声压级将增加 10~15 dB。

风机噪声的总功率级可表示为[4]:

$$L_W = L_{W0} + 10\log\left(\frac{1}{\eta}-1\right) + 70\log D_2 + 50\log n \tag{1}$$

式中: L_w—A 级声功率, dB; L_{w0}—基准声功率, dB; η—风机总压效率, %; D_2—风机叶轮外径, m; n—风机转速, r/min。

由式(1)可知, 风机的噪声与风机效率、叶轮外

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径和转速有关,且在最高效率点的噪声最低。风机噪声的产生及主要影响因素是风机变工况调节时控制噪声的依据。

2　不同调节方式下的风机噪声特性

风机常用的调节方式有节流调节、变速调节和进口导流器调节等。虽然这几种调节方式都可以满足运行要求,但调节效果对噪声的影响不同。为研究变工况调节下的风机噪声特性,本文对广泛用于 200 MW 及 300 MW 火力发电机组的锅炉送、引风机 G4-73No.8D 型离心式风机进行了以上 3 种调节方式下的噪声特性实验。

噪声测量使用 ND_2 型精密声级计和倍频程滤波器,该声级计适用于各类瞬时噪声的精密测量及噪声频谱分析。风机性能实验遵循 GB/T1236—2000《工业通风机—用标准化风道进行性能试验》,噪声测量遵循 GB2888—1982《风机和罗茨风机噪声测量方法》,选用近场测声法进行。按照测量标准对额定工况下的风机近声场噪声声级与频谱进行了测量,测点布置如图 1 所示。

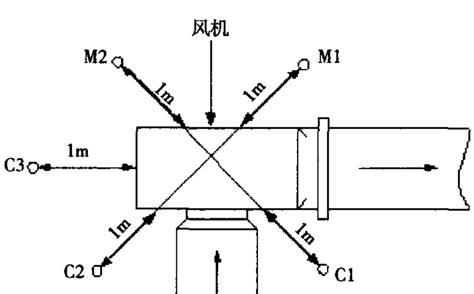
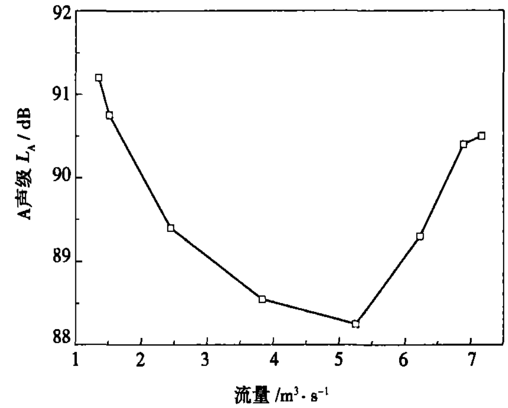


图 1　风机噪声测点布置

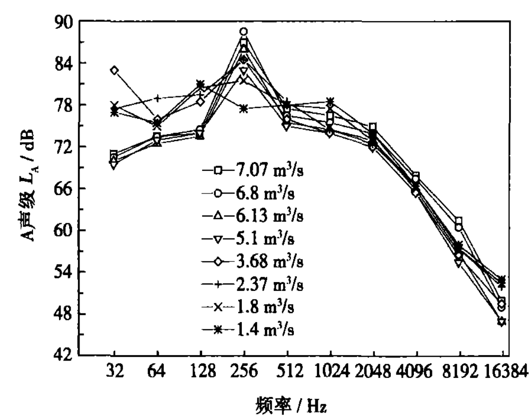
2.1　出口节流调节

节流调节是最简便的风机流量调节方法,通过调整进、出口处的闸门或挡板开度来改变风机流量。本实验采用出口节流锥来调节风机流量。在变工况下,A 声级噪声和倍频程声压级与风机流量间的关系如图 2 所示。

图 2(a)表明,风机噪声随流量的增加先降低后变大,当流量在 4.0~6.0 m^3/s(75%~110%额定流量)时,A 声级噪声较低。当流量减少时,噪声则明显增加。这是因为闸门开度关小,导致气流压力增高,从而引起涡流噪声增大。相对于最低点的噪声,当流量减小时,噪声增长幅度约为 1.0 dB/m^3。并且,当闸门开度很小时,风机工作点还可能进入不稳定工作区而出现喘振现象,导致噪声的进一步增大。



(a) 风机流量与声压曲线



(b) 风机倍频程声压级频谱

图 2　风机 A 声级噪声与频谱噪声

图 2(b)给出了不同流量下的噪声频谱图。噪声随频率的分布特性总体呈现出随频率的增加逐渐下降,但频率在 250~300 Hz 之间出现噪声峰值,该峰值是旋转噪声和旋涡噪声相互混杂的结果。其中,旋转噪声的频率为:

$$f_r = \frac{nZ}{60} i \tag{2}$$

式中:n—风机叶片轮转速,n=1 450 r/min;Z—叶片数,Z=12;i—谐波序号 1, 2, 3, ……。

i=1 为基频,从噪声强度看,基频最强;i=2, 3, 4, ……为高次谐音,其总趋势是逐渐减弱的。由式(2)可得该风机的旋转噪声基频频率为:f_r=290 Hz,因此,在 250~300 Hz 之间风机噪声以旋转噪声为主,总的噪声为旋转噪声、旋涡噪声及振动等噪声的叠加。

2.2　变速调节

变速调节是一种较经济的调节方法,该调节方式对于调节范围大且经常处于低流量范围工作情况,其节能效果十分突出。由于变速调节并不改变管路特性曲线,而通过调节风机转速使风机压力特性改变来调节工况点,因而没有附加阻力引起的能量损耗,是一种理想的调节方式。

实验采用变频器调节风机转速,变速调节下的噪声特性如图 3 所示。当风机转速降低时,A 声级噪声大幅度下降。风机转速每减少 100 r/min 时,A 声级噪声降低 2.0~4.0 dB,平均降低 2.5 dB;而且,在小流量下,噪声降低更为明显。这是因为变速调节流量使叶轮出口气流与蜗舌作用的交变力及由于物面上涡旋脱落产生的交变力引起的气流密度的变化减少,因此,大大降低了风机的噪声。

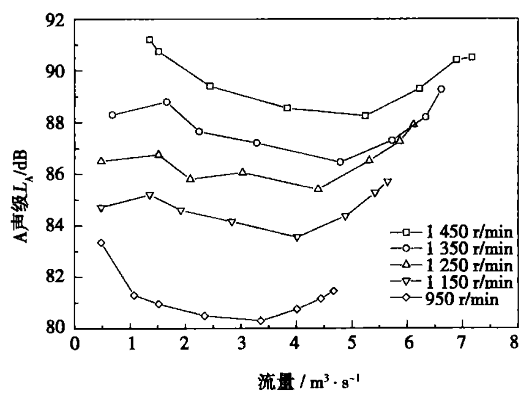


图 3　变转速下的风机流量与声压关系

与额定转速 1 450 r/min 下的出口节流调节相比,在相同风机流量下,采用变速调节的降噪效果非常显著。例如风量为 4 m^3/s(75%额定流量)时,采用出口节流调节,A 声级噪声为 88.5 dB;采用变速调节,在转速分别为 1350 r/min、1250 r/min、1150 r/min 和950 r/min时,其 A 声级噪声分别为 86.9 dB、85.5 dB、83.5 dB 和 80.7 dB,A 声级噪声分别降低 1.6 dB、3.0 dB、5.0 dB 和 7.8 dB;风量为 2.0 m^3/s(40%额定流量))时,节流调节下的噪声为 90.2 dB;采用变速调节,在以上转速下的噪声分别为 88.2 dB、86.0 dB、84.5 dB 和 80.6 dB,噪声分别降低 2.0 dB、4.2 dB、5.7 dB 和 9.6 dB。由此可见,采用变速调节,在满足相同的风机负荷下,噪声有大幅度的降低,而且,转速越低,噪声降低的效果则越为明显。

另外,从经济性角度说,出口节流调节因增加额外的压力损失而浪费了电能,是一种不经济的调节方式。而变速调节,其功率与转速的三次方成正比,转速降低越大,其节能效果越显著。因此,无论从经济性还是从降低噪声特性上,变速调节均优于出口节流调节。

2.3　进口导流器调节

导流器调节也是较广泛使用的一种调节方法,在离心风机前进气管道中装置导流器,通过改变导流器转角调节风机流量。该方式虽然要损耗一部分气流预旋能量而使风机经济性有所下降,但在设计工况附近的风机压力曲线接近平行,因此效率下降不多,也是一种较经济的调节手段。

进口导流器调节下的噪声特性如图 4 所示。该图表明:采用进口导流器调节时,A 声级噪声总体水平呈现下降趋势,但下降幅度不大。例如,当流量为 4.0 m^3/s(75%额定流量)时,100%开度时的 A 声级噪声为 88.5 dB;75%、60%和 45%开度时的 A 声级噪声分别为 88.0 dB、88.0 dB 和 87.3 dB,噪声分别降低了 0.5 dB、0.5 dB 和 0.8 dB;流量为 2.0 m^3/s(40%额定流量)时,100%开度的噪声为 89.7 dB;75%、30%和 15%开度时的噪声分别为 89.2 dB、89.5 dB 和 87.5 dB,噪声分别降低了 0.5 dB、0.2 dB 和 2.2 dB。

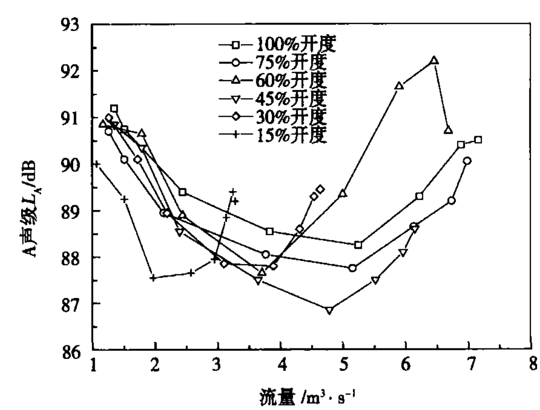


图 4　变导流器开度下的风机流量与声压关系

但是,该调节方式下的噪声并不是随导流器开度的减小总是降低的。例如,当调节流量处于 4.5 ~7 m^3/s(83%~130%额定流量)范围时,60%开度时的A 声级噪声高于 100%开度时的噪声;当流量处于 3.0 ~4.5 m^3/s(55% ~83%额定流量)附近时,15%和 30%开度时的噪声高于其它所有开度时的噪声;当流量处于 1.5 ~2 m^3/s(28% ~40%额定流量)范围时,60%和 45%开度时的噪声高于 100%和 75%开度时的噪声,而在此流量下,15%开度时的噪声有大幅度的下降。造成噪声的这种变化是多种影

响的综合结果。采用进口导流器调节时,气流的预旋所损耗的能量部分转化成声能而有增加噪声的趋势;当流量减小时,气流径向速度降低,对叶片冲击减弱而使旋涡噪声降低,因此噪声的变化不会很大。但由于改变导流器开度,使气流进入叶轮时容易产生预旋,造成叶轮出口气流失速,产生紊流,使风机产生声腔共鸣噪声,导致A 声级噪声突然上升。如导流器为 60%开度,流量大于 4.5 m^3/s(83%额定流量)时,噪声值突然上升,远高于其它开度下的噪声。

与出口节流调节相比,采用进口导流器调节,其噪声总体水平降低,但降低幅度较小,如流量为 2.0 m^3/s(40%额定流量)和 4.8 m^3/s(90%额定流量),15%和 45%开度时的噪声分别降低了 2.5 dB 和 1.8 dB;而在有些流量下,导流器开度的减小反而增大了噪声。与变速调节相比,采用导流器调节时的噪声明显偏高。采用变速调节时,风机噪声随转速的减小始终呈现降低趋势;当风机转速在1 250 r/min 及以下时,风机的噪声已低于 60%开度时的噪声水平,随着转速的进一步降低,在满足风机负荷的前提下,噪声将有更大幅度的降低;另外,变速调节的节能效果也优于导流器调节[1]。因此,总体比较变工况下的 3 种调节方式,无论从经济性还是从降低噪声特性方面,变速调节的综合性能最优,进口导流器调节次之;出口节流调节最差。

3 结　论

在分析离心式风机噪声成因的基础上,对电站中广泛使用 G4-73No.8D 型大型离心式风机进行了出口节流调节、进口导流器调节和变速调节 3 种方式下的噪声特性测试,得出:

(1) 采用出口节流调节,当流量从 5.3 m^3/s(接近额定流量)逐渐减小时,A 声级噪声明显升高;采用进口导流器调节,噪声降低幅度平均为 0.5 dB,最大为 2.0 dB,在某些流量范围内,导流器开度的减小反而导致噪声有所提高;采用变速调节时,噪声随转速的减小始终呈现降低趋势,噪声等级有了大幅度的降低,在满足风机出力的情况下,噪声最大可降低 7.8~9.6 dB,噪声得到有效明显的控制。

(2) 综合比较以上 3 种调节方式下的噪声特性和经济性能,变速调节最优,进口导流器调节次之;出口节流调节最差。本文的研究结果可为电厂离心风机的调节运行提供了一定的指导作用。

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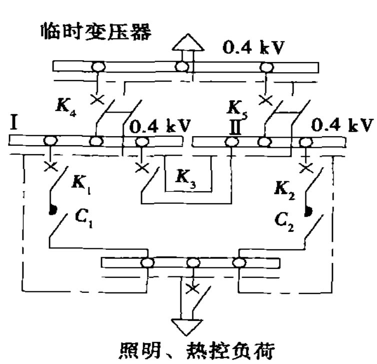

图 3　故障状态的工作原理图

4 结　论

核电站启动锅炉的电气设计方案和注意问题:

(1) 核电站启动锅炉的电气系统设计采用双电源进线、双母线供电的三相五线制方式;

(2) 小容量成组启动电动机通过进行自校验,可以进行直接起动;

(3) 为了避免零线共用形成环流的问题,电气回路中所有的断路器、接触器都要为四极。

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(辉　编辑)

某核电站启动锅炉的电气设计和调试中问题的解决= **Resolution of Problems Involved in the Electrical System Design and Commissioning Tests of Pre-operational Test Boilers for a Nuclear Power Plant**[刊,汉]/ZHANG Qing-jiang, SUN Shi-feng, DAI Yue, et al (Harbin No.703 Research Institute, Harbin, China, Post Code: 150036)// Journal of Engineering for Thermal Energy & Power. — 2007, 22(1). —73~74, 83

In accordance with the special requirements for the design of the electrical system of pre-operational test boilers for a nuclear power plant, proposed was a design scheme for the pertinent electrical system. The special requirements include the relevant technical conditions, safety and reliability of the boiler electrical system as well as the loading nature and capacity of the pre-operational test boilers. The design of the electrical system adopts a three-phase five-wire system of AC 380 V dual power source lead-in wires with each lead-in wire power source incorporating a section of busbar and a bus coupler being provided between any two sections of the busbar. Moreover, the motors in groups would undergo a check inspection through a self start-up. During the commissioning test, occasional trips occurred to the lead-in wire circuit-breakers. The causes of such problems were analyzed from the perspective of underlying principles. As regards the problems emerging in the commissioning test, proposed was a method to solve the problem through the formation of a ring current by the use of a common zero line in the three-phase five-wire electrical system. **Key wrods**: nuclear power station, start-up boiler, electrical equipment, three phase five wire system, four-pole switch, zero line

周向前弯轴流风扇转子叶顶泄漏流动研究= **Research Findings Concerning Blade-tip Leaking Flow in Circumferential Forward-skewed Axial-flow Fan Rotors**[刊,汉]/ LI Yang, OU Yang-hua, DU Zhao-hui (College of Mechanical and Power Engineering under the Shanghai Jiaotong University, Shanghai, China, Post Code: 200030)// Journal of Engineering for Thermal Energy & Power. — 2007, 22(1). —75~79

With a blade wheel of a low-pressure axial flow fan having three typical circumferential forward-skewed angles (forward-skewed angles of 1.27, 8.3 and 25 degrees) serving as an object of study, a numerical calculation was conducted of a three-dimensional viscous flow field along with a testing and measurement of the outlet loss. The calculation results are in comparatively good agreement with the measured ones. The results show that with an increase in the circumferential forward-skewed angle of blades, the starting location of the blade-tip leaking vortex will shift backward along the blade chord, gradually approaching the trailing edge of the blades. The vortex intensity will not increase all along but show a sign of weakening as influenced by the blade wake after a certain forward-skewed angle has been reached. The foregoing reflects that for a wheel with a big forward-skewed angle, the flow in the blade-tip area becomes more complicated, and meanwhile the factors influencing the top-end loss will multiply, including leaking vortex, secondary vortex, wake, and mutual mingling and dilution. **Key wrods**: low-pressure axial flow fan, circumferential forward-skew, blade-tip leaking flow, wake

大型离心式风机变工况调节中噪声特性的实验研究= **Experimental Study of Noise Characteristics of a Large-sized Centrifugal Fan During its Off-design Regulation Process**[刊,汉]/ LI Chun-xi, LEI Yong, WANG Song-ling, et al (Education Ministry Key Laboratory on Condition Monitoring and Control of Power Plant Equipment, North China University of Electric Power, Baoding, China, Post Code: 071003)// Journal of Engineering for Thermal Energy & Power. — 2007, 22(1). —80~83

Nowadays, the centrifugal fans used in large-sized power plants universally suffer from a high noise level. Noise reduction has become a pressing task in environmental protection. An experimental study of noise characteristics of a Model G4-73No.8D large-sized centrifugal fan was conducted in three respects: outlet throttle regulation, flow-guide regulation and variable speed regulation. Noise characteristic curves under off-design conditions were obtained. The experiments show that when the flow rate falls, the noise level under the outlet throttle regulation mode will rise somewhat and that under the flow guide regulation mode fall slightly. But, by contrast, the noise level at certain opening degrees of the flow guide will somehow go up and that under the variable speed regulation mode will drop by a great margin, thus making it possible to effectively control the noise level. When viewed from the aspect of noise reduction and cost-effectiveness, the variable speed regulation offers an optimum overall performance. **Key wrods**: centrifugal fan, noise, throttle regulation,

variable speed regulation, flow guide regulation

HHT 与 RBF 神经网络在离心泵故障振动信号处理中的应用＝**The Application of HHT and RBF Neural Networks for Processing Fault-vibration Signals from Centrifugal Pumps**[刊, 汉] / ZHOU Yun-long, HONG Jun, ZHAO Peng (College of Energy Source and Mechanical Engineering under the Northeast University of Electric Power, Jilin, China, Post Code: 132012)// Journal of Engineering for Thermal Energy &Power. — 2007, 22 (1). —84 ~ 87

According to the specific features of fault-vibration signals of a centrifugal pump, presented is a new method for fault diagnosis of vibration signals of a centrifugal pump by employing a combination of Hilbert-Huang transformation (HHT) and a radial basis function (RBF) neural network. First, the time series data from the vibration signals of a centrifugal pump is subject to an empirical mode decomposition (EMD) followed by a Hilbert-Huang Transformation to obtain the energy of various intrinsic mode functions (IMF). Moreover, with "energy ratio" serving as an element, the eigenvector obtained from vibration signals of the centrifugal pump by utilizing the energy ratio can depict very well fault information for different vibrations. By using a RBF neural network, the mapping extending between the eigenvector and fault modes can be established to realize a fault diagnosis, thus achieving a high diagnostic rate for such conditions as normal state, mass imbalance, rotor misalignment and foundation loosening fault of a centrifugal pump. The experimental research results show that the method under discussion can effectively diagnose the vibration signals of a centrifugal pump. **Key wrods**: centrifugal pump, Hilbert-Huang transfomation, RBF (radial basis function) neural network, fault diagnosis

热力系统局部非线性模型辨识＝**Discrimination of the Local Nonlinear Model of a Thermodynamic System**[刊, 汉] / DONG Jun-hua, XU Xiang-dong (Department of Themal Energy Engineering, Tsinghua University, Beijing, China, Post Code: 100084)// Journal of Engineering for Themal Energy &Power. — 2007, 22 (1). —88 ~ 90, 95

In a multi-model control (MMC) version, a majority of local models are based on a linear model and their number and accuracy may influence the effectiveness of the multi-model control. An algorithm for the discrimination of nonlinear models is proposed based on a radial basis function (RBF) neural network. By adopting a nonlinear model structure proposed by G. B. Sentoni and others and utilizing the approximation ability of a radial basis function (RBF) neural network, realized was the discrimination of nonlinear models in a thermodynamic system. During the process of learning the RBF neural network, one can accelerate the converging process of learning by regulating the learning speed according to a performance function. Finally, a simulation verification was conducted. A multi-model control system based on two local linear models instead of five local nonlinear models can diminish the oscillation during a switching-over with the control accuracy being somewhat enhanced. The experimental results indicate that the discrimination algorithm under discussion can reduce the number of fixed models, thereby shortening model searching time and raising model prediction accuracy. **Key wrods**: themodynamic system, local model, non-linearity, RBF neural network

基于最小资源分配网络的热工对象辨识＝**Discrimination of a Thermodynamic Object Based on a Minimum Resource Allocation Network**[刊, 汉] / YANG Shi-zhong, LU Jian-hong (College of Energy Source and Environment under the Southeast University, Nanjing, China, Post Code: 210096)// Journal of Engineering for Thermal Energy & Power. — 2007, 22 (1). —91 ~95

The establishment of a comprehensive nonlinear model for a thermodynamic process serves as a basis for the overall optimization of a themodynamic control system. However, it is difficult for a static neural network to establish a model for nonlinear dynamic processes. A resource allocation network (RAN) lends itself to dynamically adjust the network parameters while an extension Kalman filter (EKF) algorithm can accelerate the converging speed. By organically combining the above-mentioned methods and adding on this basis pruning tactics and a sliding-window root-mean-square criterion, an improved minimum resource allocation network (MRAN) can be fomed. The improved MRAN has been applied to the nonlinear dynamic modeling of a typical thermodynamic process. The simulation results show that the MRAN features a compact network structure and high modeling accuracy, thus making it suitable for on-line applications. Finally, analyzed