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基于仿真模型的对分式凝汽器故障样本知识提取研究

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摘　要:在热力设备实施故障诊断的过程中,由于设备、系统及故障本身的复杂性,常见的故障样本知识提取方法往往不能准确、完善地建立热力设备的故障诊断知识库。为此,结合仿真技术在电站热力设备和系统模型方面的优势,提出一种基于模型的热力设备故障样本知识提取新方法。运用该方法,通过建立对分式凝汽器的动态数学模型进行详细的故障仿真试验,结合现场运行经验和理论分析,总结、完善了对分式凝汽器的典型故障知识库。

关　键　词:对分式凝汽器;故障;样本知识提取;仿真模型

中图分类号:TK267;TP391.9　　　文献标识码:A

1　前言

在对电站热力设备进行故障诊断时,需准确、完善地建立设备的典型故障知识库。由于热力设备的结构、性能和热力系统构成较为复杂,机组运行方式多种多样,故障本身又具有动态时变特性且故障程度可大可小,常见的故障样本知识提取方法,诸如理论分析、向现场技术人员咨询、设备历史故障案例总结等,具有一定的局限性。

电站仿真技术在热力设备及过程模型方面有其独特的优势。仿真模型涵盖不同容量的各类型机组,并逐渐向用于设备性能校核、系统动态特性分析、热工过程试验的高精度分析型仿真模型发展[1]。将仿真模型技术运用于故障样本知识的提取具有良好的条件。

容量在300 MW及以上的大型火电机组大都采用对分、表面式凝汽器。现有文献的凝汽器故障诊断知识库大多属于半原理型知识库,没有详细考虑凝汽器的结构和系统实际情况,若应用于现场故障诊断需进一步修改和完善。

2　基于模型的故障样本知识提取方法

电站全仿真机不仅提供了具体热力设备的仿真模型,更重要的是提供了用系统工程的方法将热力设备融于整个热力系统进行性能全面分析的环境。用电站全仿真模型可对不同运行方式和运行工况下的故障进行模拟;可对不同程度故障的现象进行比较;可详细地观察故障动态过程的特征参数变化,因而作为故障样本知识提取方法是十分有效的。

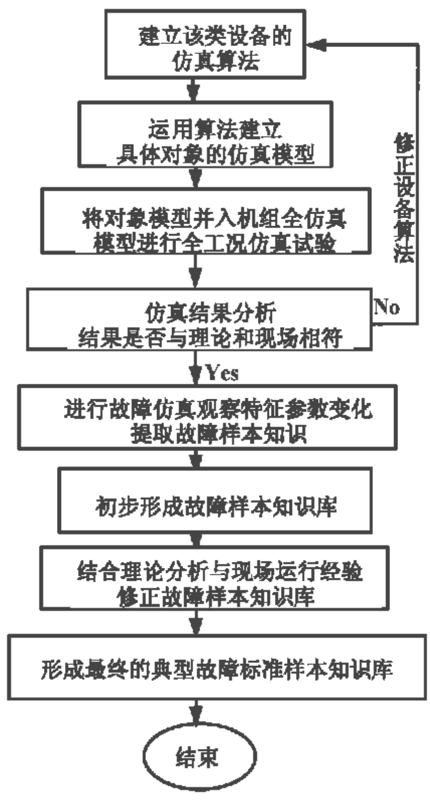

图1　基于模型的故障样本知识提取过程图

用仿真模型的方法实现故障样本知识提取的大致步骤如下(图1):

(1)建立该类热力设备的仿真算法,并通过具体对象的仿真模型,与整个机组的模型有机融合进行仿真试验。验证各种工况下模型静、动态特性的正确性。

(2)进行详细的故障仿真试验,观察不同故障程度下各特征参数变化的差异及故障的产生、发展的动态全过程,总结典型故障样本知识。

(3)结合理论分析和现场技术人员的经验,对典型故障样本知识进行修正和完善,形成最终的典型故障标准样本知识库。

现以某实际机组对分式凝汽器为例,详细阐述

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基于模型的对分式凝汽器典型故障样本知识的提取过程。

3　对分式凝汽器动态仿真模型的建立和验证

3.1　模型的建立[2~3]

本文在建立对分式凝汽器动态仿真模型过程中, 作如下假设和简化: (1)凝汽器汽侧压力均一, 可近似用集总参数法考虑; (2) 凝汽器壳侧划分为汽/气区和水区, 汽/气区按不凝结区和蒸汽区分别计算蒸汽和空气分压, 凝汽器总压力由蒸汽分压和空气分压代数求和; (3) 考虑对分式凝汽器结构上的对称性, 认为凝汽器有效冷却面积由两侧冷却水管道均摊, 当两侧冷却水管道工况(流量、管道清洁度等) 完全相同时两部分管道对蒸汽凝结的效果相同。

3.1.1　壳侧不凝结区

根据进出凝汽器的不凝结气体的质量平衡, 可计算凝汽器内不凝结气体的质量变化率 $dW_{air}/d\tau$ 和当前不凝结气体的储存量 W_{air}:

$$dW_{air}/d\tau = \Sigma F_{airi} - \Sigma F_{airo} \tag{1}$$

$$W_{air} = W'_{air} + \Delta\tau(\Sigma F_{airi} - \Sigma F_{airo}) \tag{2}$$

式(1)、(2) 中: ΣF_{airi} 为单位时间内进入凝汽器的不凝结气体总量; ΣF_{airo} 为单位时间内排出凝汽器的不凝结气体总量; W'_{air} 为前一计算时刻凝汽器内的不凝结气体量; $\Delta\tau$ 为时间计算步距。

将不凝结气体视为理想气体, 根据理想气体状态方程可得其动态基本方程:

$$\frac{d(P_{air}V)}{d\tau} = \frac{dP_{air}}{d\tau}V + \frac{dV}{d\tau}P_{air} = R_{air}(\frac{dW_{air}}{d\tau}T + \frac{dT}{d\tau}W_{air}) \tag{3}$$

式中: P_{air} 为凝汽器的空气分压; W_{air} 为凝汽器壳侧总的空气储量; R_{air} 为不凝结气体的平均气体常数; T 为凝汽器汽气混合物绝对温度; V 为凝汽器的有效汽/气空间容积, 可由凝汽器无水状态下的有效汽/气空间容积 V_0、凝汽器壳侧热井的存水质量 W_{hw11} 和凝结水密度 ρ 计算:

$$V = V_0 - W_{hw11}/\rho \tag{4}$$

在凝汽器正常运行时, 近似认为: $dV/d\tau \approx 0$, $dT/d\tau \approx 0$。则式(3) 可简化为:

$$VdP_{air}/d\tau = R_{air}TdW_{air}/d\tau \tag{5}$$

由式(5) 和式(1) 可得凝汽器当前时刻不凝结气体分压 P_{air} 的离散化迭代计算公式:

$$P_{air} = P'_{air} + \Delta\tau R_{air}T(\Sigma F_{airi} - \Sigma F_{airo})/V \tag{6}$$

式中: P'_{air} 为前一计算时刻凝汽器内的不凝结气体分压。

3.1.2　壳侧蒸汽区

对分式凝汽器壳侧蒸汽凝结总量 F_{cond} 为左侧循环水凝结蒸汽量 F_{condl} 和右侧循环水凝结蒸汽量 F_{condr} 之和。即

$$F_{cond} = F_{condl} + F_{condr} \tag{7}$$

根据传热学和凝汽器有关理论, 任一时刻的蒸汽凝结量 F_{condl} 和 F_{condr} 可用下式计算:

$$F_{condl} = \frac{K_L A_L \Delta T_{ml}}{H_{sav} - H_c} \tag{8}$$

$$F_{condr} = \frac{K_r A_r \Delta T_{mr}}{H_{sav} - H_c} \tag{9}$$

式(8)、(9) 中: K_L、K_r 分别为左、右侧冷却水管道各自的总传热系数, 可根据凝汽器结构、物性参数按照 HEI 公式计算, 或按照凝汽器额定负荷参数推算, 并按凝汽器内空气相对含量进行修正; A_L、A_r 分别为左、右侧冷却水管道对应冷却面积; ΔT_{mL}、ΔT_{mr} 分别为左、右侧对数平均温差; H_{sav} 为凝汽器内蒸汽的平均比焓, 由进入凝汽器的汽轮机排汽参数、进入凝汽器水的闪蒸参数等求平均值; H_c 为凝汽器蒸汽分压对应的饱和凝结水焓。

根据进出凝汽器汽空间的蒸汽质量平衡, 可计算汽/气空间蒸汽的质量变化率 $dW_{steam}/d\tau$ 和当前汽/气空间蒸汽的储存量 W_{steam}:

$$dW_{steam}/d\tau = \Sigma F_{steami} - \Sigma F_{steamo} \tag{10}$$

$$W_{steam} = W'_{steam} + \Delta\tau(\Sigma F_{steami} - \Sigma F_{steamo}) \tag{11}$$

式(10)、(11) 中: ΔF_{steami} 为单位时间内进入凝汽器汽/气空间的蒸汽总量; ΣF_{steamo} 为单位时间内自汽/气空间离开的蒸气量; W'_{steam} 为前一计算时刻凝汽器汽空间蒸汽储存量。

将凝汽器内的低压蒸汽视为理想气体, 由理想气体状态方程可得其动态基本方程:

$$\frac{d(P_{steam}V)}{d\tau} = \frac{dP_{steam}}{d\tau}V + \frac{dV}{d\tau}P_{steam} = R_{air}(\frac{dW_{steam}}{d\tau}T + \frac{dT}{d\tau}W_{steam}) \tag{12}$$

式中: P_{steam} 为凝汽器的蒸汽分压; R_{steam} 为蒸汽的平均气体常数。

采用 3.1.1 的同样方法, 可得凝汽器当前时刻蒸汽分压 P_{steam} 的离散化迭代计算公式:

$$P_{steam} = P'_{steam} + \Delta\tau R_{steam}T(\Sigma F_{steami} - \Sigma F_{steamo})$$

$$/ V \quad (13)$$

式中：P'_{steam} 为前一计算时刻凝汽器内的蒸汽分压。

则由道尔顿分压定律，凝汽器当前时刻总压力 P_{total} 为：

$$P_{total} = P_{steam} + P_{air} \quad (14)$$

3.1.3 壳侧水区

凝汽器热井水量 W_{hwll} 根据进、出凝汽器热井水量运用下面的离散化迭代公式计算：

$$W_{hwll} = W'_{hwll} + \Delta\tau(\Sigma W_{hwlli} - \Sigma W_{hwllo}) \quad (15)$$

式中：ΣW_{hwlli} 为单位时间内进入凝汽器热井的水量之和；ΔW_{hwllo} 为单位时间内离开凝汽器热井的水量。

热井水焓：

$$H_{hwll} = \frac{W'_{hwll}H'_{hwll} + \Delta\tau(\Sigma W_{hwlli}H_{hwlli} - \Sigma W_{hwllo}H_{hwllo} - Q_{loss})}{W_{hwll}} \quad (16)$$

式(16)中：Q_{loss} 为单位时间内热井向环境的散热损失。

热井水电导率的计算方法与热井水焓计算方法相似。

3.1.4 凝汽器冷却水侧

对于左侧冷却水，以凝汽器冷却水管路进、出口截面为界取控制体，可列出如下能量平衡方程：

$$\frac{d}{d\tau}(c_{cw}W_{cwl}T_{cwl}) = F_{condl}(H_{sav} - H_c) + F_{cwl}c_{cw}(T_{cwil} - T_{cwol}) = c_{cw}W_{cwl}\frac{dT_{cwl}}{d\tau} \quad (17)$$

式中：c_{cw} 为冷却水比热，W_{cwl} 为凝汽器左侧冷却管内的存水量，F_{cwl} 为左侧冷却水流量，T_{cwl} 为左侧冷却水进、出口温度 T_{cwil}、T_{cwol} 的算术平均值。

凝汽器正常运行时冷却水进口温度基本不变，因此：

$$dT_{cwl}/d\tau = dT_{cwol}/2d\tau \quad (18)$$

由式(17)、(18)可得凝汽器左侧冷却水出口水温 T_{cwol} 的离散化迭代计算公式：

$$T_{cwol} = T'_{cwol} + \frac{2\Delta\tau[F_{condl}(H_{sav} - H_c) + F_{cwl}c_{cw}(T_{cwil} - T'_{cwol})]}{c_{cw}W_{cwl}} \quad (19)$$

同理，可计算右侧冷却水出口温度。

3.2 模型的验证

对实际300 MW机组配置的N－16000－2型凝汽器，运用上述模型建立具体仿真模型，并将凝汽器模型与机组整个热力系统设备以及控制系统的模型有机融合，通过与现场经验丰富的技术人员合作，进行了包括机组启停、正常运行调整、凝汽器冷却水单侧运行、真空泵跳闸、循环水泵故障等多项仿真试验，对模型的静态精度、各种工况动态过程特性进行校核和验证，表明模型的静态精度能够满足仿真应用要求，正常启停和故障情况下模型的动态反映趋势正确。图2(a)、(b)、(c)分别为凝汽器冷却水一侧停运(关B侧冷却水出口门)、停掉一台循环水泵、凝汽器真空泵跳闸情况下，凝汽器真空及相关参数动态变化曲线。

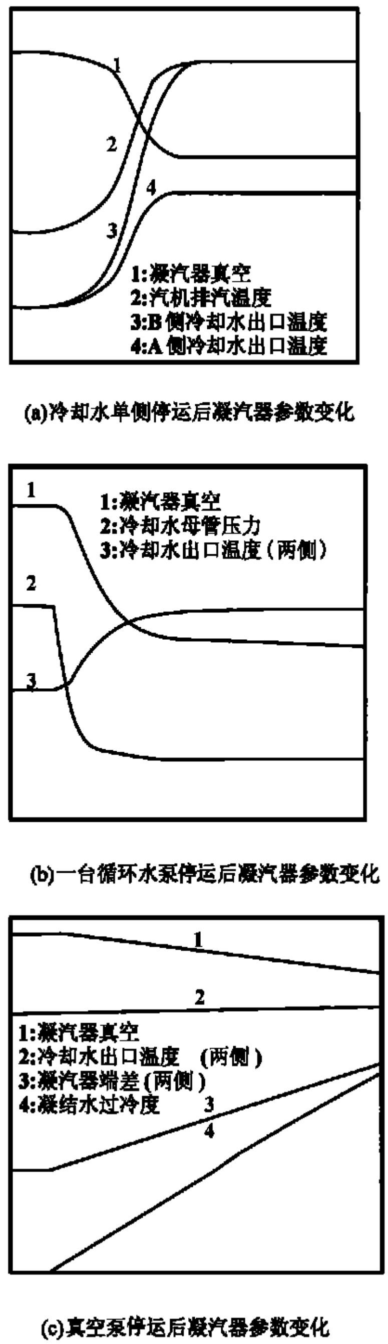

图2 凝汽器仿真模型动态过程特性示意图

4 基于模型的对分式凝汽器故障样本知识提取

4.1 对分式凝汽器典型故障集和征兆集

原有的凝汽器故障诊断知识库属于半原理型知识库[4~5]，应用于实际机组对分式凝汽器现场故障诊断还需根据对分式凝汽器结构特点、现场凝汽系统构成及测点实际布置对典型故障集和征兆集进行如下改进：

(1) 由于对分式凝汽器冷却管有左、右侧之分，因此相关故障细化为为左侧故障和右侧故障(必要

时还考虑两侧同时故障)。相应地, 征兆集参数也按左右侧分别考虑。

(2) 在故障征兆参数的选择上, 除考虑特征参数与具体故障的关联强度外, 还充分考虑现场的测点布置情况, 尽量应用 DAS 系统采集的参数(如凝汽器真空、水位等); 或者由上述参数经简单计算可得到的参数(如凝汽器左、右侧端差, 凝结水过冷度, 凝汽器水阻等)。

结合本文实际机组对分式凝汽器的特点和凝汽系统的构成, 总结出 19 个对分式凝汽器典型故障: u_1, u_2, …, u_{19}(见表 1), 相应地选取 42 个故障征兆参数: x_1, x_2, …, x_{42}(见表 2)。x_i (i = 1, 2, …42) 根据征兆存在与否取 1 或 0。

表 1　对分式凝汽器典型故障表

u_1	运行循环水泵严重故障	u_{11}	凝汽器冷却管破裂使循环水内漏(A 侧)
u_2	凝汽器出口水室存有空气或凝汽器冷却管板脏污(A 侧)	u_{12}	凝汽器冷却管破裂使循环水内漏(B 侧)
u_3	凝汽器出口水室存有空气或凝汽器冷却管板脏污(B 侧)	u_{13}	凝汽器冷却管堵塞(A 侧)
u_4	凝汽器出口水室存有空气或凝汽器冷却管板脏污(A、B 侧程度基本相同)	u_{14}	凝汽器冷却管堵塞(B 侧)
u_5	冷却管出口闸门未全开或出口管道堵塞(A 侧)	u_{15}	凝汽器冷却管脏污(A 侧)
u_6	冷却管出口闸门未全开或出口管道堵塞(B 侧)	u_{16}	凝汽器冷却管脏污(B 侧)
u_7	冷却管出口闸门未全开或出口管道堵塞(A、B 侧程度基本相同)	u_{17}	凝汽器冷却管脏污(A、B 侧程度基本相同)
u_8	后轴封供汽中断或轴封供汽压力太低	u_{18}	运行真空泵严重故障
u_9	真空系统或小机真空系统不严密空气轻微漏入	u_{19}	真空系统管路破裂空气严重漏入
u_{10}	运行凝结水泵工作不正常		

4.2　故障征兆具体表达方法的探讨

现有文献给出了凝汽器的典型故障征兆集, 但均没提及故障征兆如何具体表达。而征兆具体表达方法直接影响故障诊断的效果, 有必要对其进行探讨。

以表 2 所示的对分式凝汽器的故障征兆集为例。表中的故障征兆中分为以下几类: (a) 参数升高或降低(增加或减小); (b) 参数 A 大于参数 B; (c) 参数波动。

对于(a) 类征兆, 有以下两种表达方法: (1) 以参数单位时间变化率的正负和大小确定参数升高或降低及其变化快慢; (2) 用当前负荷实际参数运行值与应达目标值比较并考虑不同偏差阈值确定参数升高或降低及其程度。两种征兆表达方法各有优缺点: 第一种表达方法, 征兆在故障发生初期对故障的反映十分灵敏, 有利于及早发现故障, 但随故障的持续, 设备逐渐进入故障平衡态运行时, 参数变化率往往减小甚至不再变化, 从而导致征兆缺乏稳定的保持性; 第二种表达方法, 当考虑偏差阈值时征兆在故障发生一段时间后才能表现出来, 但征兆出现后能长久保持, 有利于诊断结果的可靠性, 这种方法的困难在于不同工况下参数应达值的准确确定较为繁琐, 要结合当前工况, 依据设计数据、运行规程, 必要时进行实时仿真计算确定[6]。本文综合运用了以上两种方法, 建立了通用的(a) 类征兆表达算法, 使诊断系统对故障的反映较为迅速同时又保证了诊断结果的可靠性。

表 2　对分式凝汽器故障征兆集

x_1	真空急剧或大幅下降	x_{22}	凝汽器 B 侧水阻高于 A 侧水阻
x_2	真空缓慢或小幅下降	x_{23}	转子胀差大幅减小或出现负胀差
x_3	运行循环水泵电机电流大幅波动或下降	x_{24}	凝结水泵出口母管压力增加
x_4	循泵出口母管压力大幅波动或下降	x_{25}	凝结水泵出口母管压力下降或波动
x_5	凝汽器冷却水进口压力降低(A 侧)	x_{26}	运行凝结水泵电机电流下降或波动
x_6	凝汽器冷却水进口压力降低(B 侧)	x_{27}	凝结水电导率增加
x_7	凝汽器冷却水进口压力升高(A 侧)	x_{28}	凝汽器冷却水温升增加(A 侧)
x_8	凝汽器冷却水进口压力升高(B 侧)	x_{29}	凝汽器冷却水温升增加(B 侧)
x_9	A 侧进水压力高于 B 侧进水压力	x_{30}	凝汽器冷却水温升减小(A 侧)
x_{10}	B 侧进水压力高于 A 侧进水压力	x_{31}	凝汽器冷却水温升减小(B 侧)
x_{11}	凝汽器冷却水出口压力降低(A 侧)	x_{32}	A 侧冷却水温升高于 B 侧冷却水温升
x_{12}	凝汽器冷却水出口压力降低(B 侧)	x_{33}	B 侧冷却水温升高于 A 侧冷却水温升
x_{13}	凝汽器冷却水出口压力升高(A 侧)	x_{34}	凝汽器端差增加(A 侧)
x_{14}	凝汽器冷却水出口压力升高(B 侧)	x_{35}	凝汽器端差增加(B 侧)
x_{15}	A 侧出口压力高于 B 侧出口压力	x_{36}	凝汽器 A 侧端差大于 B 侧端差
x_{16}	B 侧出口压力高于 A 侧出口压力	x_{37}	凝汽器 B 侧端差大于 A 侧端差
x_{17}	凝汽器水阻降低(A 侧)	x_{38}	凝结水过冷度增加
x_{18}	凝汽器水阻降低(B 侧)	x_{39}	汽水分离器排出空气温度与冷却水进口温度差增加
x_{19}	凝汽器水阻升高(A 侧)	x_{40}	凝汽器热井水位升高
x_{20}	凝汽器水阻升高(B 侧)	x_{41}	运行真空泵电机电流大幅下降或波动
x_{21}	凝汽器 A 侧水阻高于 B 侧水阻	x_{42}	轴封蒸汽母管压力下降

(b) 类征兆的表达较为简单, 由 A、B 大小值比较即可得到, 当然应考虑不同参数正常随机波动和测量仪表误差因素设定合适的比较死区。对于(c) 类征兆, 参数的波动必然导致参数变化率忽正忽负, 可根据单位时间变化率正负交互的次数确定是否有此征兆。

4.3　用故障仿真方法实现对分式凝汽器故障样本知识提取

对于表 1 所示对分式凝汽器的典型故障集, 运用基于模型的故障样本知识提取方法, 总结出对分

式凝汽器典型故障样本知识库。图 3 为运用故障仿真方法提取“A 侧冷却管出口闸门未全开或出口管道堵塞”故障样本知识示意图。表 3 为对分式凝汽器典型故障样本知识库。需说明，对于不同机组、不同型号对分式凝汽器，应结合设备和系统的现场情况修正该知识库，使之更符合实际。

图 3 运用模型法提取“A 侧冷却管出口闸门未全开或出口管道堵塞”故障样本知识

5 结论

（1）结合仿真技术的优势，提出一种基于模型的故障样本知识提取方法。运用该方法可系统地、全面地、动态地考察故障发生后各特征参数的变化，有利于故障样本知识库的完善，与常规的故障样本知识提取方法相比具有独到的优点。

（2）运用凝汽器有关原理，建立了对分式凝汽器的动态数学模型，并对模型在各种工况下动态反映的正确性进行了验证。

（3）运用基于模型的故障仿真方法，结合理论分析和现场运行经验，较完善地总结了对分式凝汽器的典型故障样本知识库。该对分式凝汽器故障样本知识库比现有文献更为细化且更易应用于现场诊断。

表 3 对分式凝汽器典型故障样本知识库

	u_1	u_2	u_3	u_4	u_5	u_6	u_7	u_8	u_9	u_{10}	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	u_{16}	u_{17}	u_{18}	u_{19}
x_1	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	1
x_2	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0
x_3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
x_4	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
x_5	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
x_6	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
x_7	0	1	1	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0
x_8	0	1	1	1	1	1	1	0	0	0	0	0	1	1	0	0	0	0	0
x_9	0	1	0	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0
x_{10}	0	0	1	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0

表 3（续）

	u_1	u_2	u_3	u_4	u_5	u_6	u_7	u_8	u_9	u_{10}	u_{11}	u_{12}	u_{13}	u_{14}	u_{15}	u_{16}	u_{17}	u_{18}	u_{19}
x_{11}	1	1	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0
x_{12}	1	0	1	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0
x_{13}	0	0	0	0	1	1	1	0	0	0	0	0	0	1	0	0	0	0	0
x_{14}	0	0	0	0	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0
x_{15}	0	0	1	0	1	0	0	0	0	0	0	1	0	1	0	0	0	0	0
x_{16}	0	1	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0
x_{17}	1	0	0	0	1	0	1	0	0	0	1	1	0	0	0	0	0	0	0
x_{18}	1	0	0	0	0	1	1	0	0	0	1	1	0	0	0	0	0	0	0
x_{19}	0	1	1	1	0	1	0	0	0	0	0	0	1	1	0	0	0	0	0
x_{20}	0	1	1	1	1	0	0	0	0	0	0	0	1	1	0	0	0	0	0
x_{21}	0	1	0	0	0	1	0	0	0	0	0	1	1	0	0	0	0	0	0
x_{22}	0	0	1	0	1	0	0	0	0	0	1	0	0	1	0	0	0	0	0
x_{23}	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
x_{24}	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
x_{25}	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
x_{26}	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
x_{27}	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0
x_{28}	1	0	1	1	1	1	1	0	0	1	1	1	1	1	0	1	0	0	1
x_{29}	1	1	0	1	1	1	1	1	0	1	1	1	1	1	1	0	0	0	1
x_{30}	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0
x_{31}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
x_{32}	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0
x_{33}	0	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0
x_{34}	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1	1
x_{35}	1	1	1	1	1	0	1	1	1	1	1	1	1	0	1	1	1	1	1
x_{36}	0	1	0	0	0	1	0	0	0	0	0	1	0	1	1	0	0	0	0
x_{37}	0	0	1	0	1	0	0	0	0	0	1	0	1	0	0	1	0	0	0
x_{38}	0	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1
x_{39}	1	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0
x_{40}	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
x_{41}	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
x_{42}	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

（4）故障征兆的具体表达方法应兼顾征兆对故障反映的快速性和稳定保持性，使诊断过程对故障的反映较为迅速，并保证诊断结果的可靠性。

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（复 编辑）

turbine plant, wet compression

对单相换热器集总参数模型动态初始负偏移的机理分析＝**An Analysis of the Mechanism Governing the Dynamic and Initial Negative Deviation of a Lumped Parameter Model for a Single-phase Heat Exchanger** [刊,汉] / LENG Wei, FANG De-shan, XU Zhi-gau (Power Engineering Department, Southeastern University, Nanjing, China, Post Code: 210096), ZHANG Zhi-lun (Harbin Boiler Co. Ltd., Harbin, China, Post Code: 150046)//Journal of Engineering for Thermal Energy & Power. —2001, 16(3). —287～289

On the basis of the heat transfer equation and energy balance equation of a single-phase heat exchanger an analysis was conducted of the mechanism concerning the difference of dynamic response of various types of lumped-parameter models, especially the initial negative deviation of outlet temperatures in the dynamic process. It is noted that the use of outlet-inlet weighted mean lumped-parameter model will in a full range of operating conditions very likely lead to a negative deviation in the outlet temperature. By contrast, in the case of using an outlet parameter to serve as the lumped parameter it can be assured that no negative deviation will emerge. However, it is necessary to adopt a rational stage-by-stage model building, enabling the model to obtain an adequate heat-transfer temperature difference. **Key words**: single-phase heat exchanger, lumped parameter, mathematical model

评价电站制粉系统效率的模糊综合评判方法＝**A Fuzzy Comprehensive Method for Evaluating the Efficiency of the Pulverized Coal Preparation System of a Power Plant** [刊,汉] / WANG Dong-feng, LI Zun-ji (North China Electric Power University, Baoding, Hebei Province, China, Post Code: 071003), SONG Zhi-ping (North China Electric Power University, Beijing, China, Post Code: 100085)//Journal of Engineering for Thermal Energy & Power. —2001, 16(3). —290～293, 307

The prevalent conventional method under which the power consumption of a pulverized coal preparation system is calculated based on the electric power consumed in the grinding of each ton of coal has its shortcomings. The authors have come up with a more objective and comprehensive evaluation method, the so-called fuzzy comprehensive evaluation method. Moreover, also given is a fuzzy comprehensive evaluation model. The latter takes into account not only the power consumption of the pulverized coal preparation system but also the quality aspects of pulverized coal being ground and prepared. Such quality aspects include: pulverized coal fineness liable to influence ignition and burn-off characteristics as well as heat loss due to incomplete combustion, ball mill outlet temperature which denotes the capacity to dry pulverized-coal, rank and properties of raw coal received, the metal consumption of the pulverized coal system, quantity of material consumed and amount of other sundry expenses. The new evaluation method allows to make a unified assessment of the efficiency of a pulverized-coal system. **Key words**: pulverized coal system, efficiency, fuzzy evaluation, comprehensive evaluation

基于 DBMS 集成的工业炉参数化 CAD 方法＝**CAD Method of Industrial Furnace Parameterization Based on DBMS (Data Base Management System) Integration** [刊,汉] / LU Jia-hua, ZHANG Zhi-ying (Shanghai University of Science & Engineering, Shanghai, China, Post Code: 200336)//Journal of Engineering for Thermal Energy & Power. —2001, 16(3). —294～297

With Autocad serving as a drawing platform, Autolisp as a graphic development language and Fortran and Foxpro as programming tools for scientific computation, introduced in this paper is a CAD method of industrial furnace parameterization based on DBMS (Data Base Management System) integration. With the help of specific examples of industrial furnace design a detailed explanation is given of the integration procedures and main development philosophy. Engineering practice indicates that the proposed method has incorporated the merits of many kinds of software and languages, contributing to the achievement of an optimized design of industrial furnaces. Furthermore, with the adoption of this method it is possible to shorten design cycle and provide a feasible means for enhancing the competitive edge of industrial furnaces. **Key words**: industrial furnace, parameterization, CAD, data base management system (DBMS), integration

基于仿真模型的对分式凝汽器故障样本知识提取研究＝**A Study on the Extraction of Sample Knowledge Con-**

cerning Faults and Malfunctions of a Dual-channel Steam Condenser on the Basis of a Simulation Model [刊, 汉] / MA Liang-yu, WANG Bing-shu, GAO Jian-qiang, MA Yong-guang, TONG Zhen-sheng (Research Institute of Simulation and Control Technology under the North China Electric Power University, Baoding, China, Post Code: 071003) //Journal of Engineering for Thermal Energy & Power. —2001, 16(3). —298~302

In performing a fault diagnosis of thermal equipment it is usually difficult to create accurately and adequately a fault diagnosis knowledge base for the concerned equipment. This comes about because of two reasons: 1. Complexity of equipment, system and faults themselves; 2. Improper method of extracting the sample knowledge of frequently encountered faults. To cope with this problem, a new method for extracting fault sample knowledge of thermal equipment has been proposed by taking advantage of the technical edge enjoyed by simulation technology in the modeling of power station equipment and systems. By the use of the proposed method and through the creation of a dynamic mathematical model for a double-channel condenser a detailed simulation test of the equipment faults was conducted. On the basis of summing up on-site operating experience and performing a related theoretical analysis a typical fault knowledge base has been finally consummated for the dual-channel steam condenser. **Key words**: dual-channel steam condenser, failure and fault, sample knowledge extraction, simulation model

机械驱动用单轴燃气轮机动态模型研究=**Dynamic Model Research of a Single-shaft Gas Turbine in Mechanical Drive Applications** [刊, 汉] / WEI Si-liang, LIU Shang-ming, NI Wei-dou (Tsinghua University, Beijing, China, Post Code: 100084) //Journal of Engineering for Thermal Energy & Power. —2001, 16(3). —303~307

With the continuous improvement in gas turbine performance its scope of applications is widening dramatically. Apart from its use in power generating units and combined cycle power plants there emerged ever more cases of its application as a variable-speed mechanical drive unit. Presented in this paper is a model of single-shaft gas turbine in mechanical drive service including its control system. The model has been simplified in light of specific conditions. Under a Matlab/Simulink environment a simulation was conducted of the process of load and speed increase-decrease as well as load rejection. The results of simulation agree quite well with actual physical processes. Hence, the proposed model can be employed for the study of a single-shaft gas turbine and its control system. **Key words**: gas turbine, simulation, dynamic model.

电站锅炉燃烧系统仿真模型的建立=**The Building of a Simulation Model for a Utility Boiler Combustion System** [刊, 汉] / CHEN Li-jia, WANG Zi-cai, ZHU Qun-yi (Harbin Institute of Technology, Harbin, China, Post Code: 150001) //Journal of Engineering for Thermal Energy & Power. —2001, 16(3). —308~310

In a real-time simulation system for a utility boiler it is common practice to adopt a zero-dimensional model for building a model of combustion system. This is understandable, because the aim of a simulation consists in simulating the dynamic behavior of an actual system in its full range of operation. However, the zero-dimensional model has oversimplified the complicated process of a combustion system. In view of this, when the operating load of a system fluctuates over a relatively large range, there will emerge a very large error or difference between a zero-dimensional model and an actual system. Under proper hypothetical conditions the authors have set up a one-dimensional model capable of reflecting the interior conditions of a combustion system and performed a simulation of the model. The results of simulation indicate that the recommended model features a very high precision. It has already been employed on the simulation of a 210 MW thermal power plant with its suitability for the intended purpose being verified. **Key words**: utility boiler, combustion system simulation, combustion model, real-time simulation

非线性时间序列的RBF神经网络预测方法及其应用=**A Method for Predicting Nonlinear Time Series Using RBF (Radial Base Function) Neural Network and Its Application** [刊, 汉] / ZHANG Chuan-bin, DENG Zheng-long (Astronautics Institute under the Harbin Institute of Technology, Harbin, China, Post Code: 150001) //Journal of Engineering for Thermal Energy & Power. —2001, 16(3). —311~312, 342

An innovative method involving the use of RBF (radial base function) neural network based on a training algorithm of au-