

凝汽器管板强度的矩阵位移分析法

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摘要: 采用力学中的矩阵位移法, 将 HEI 标准中所提出的管板梁条力学模型进行了单元离散分析和整体解析, 以矩阵位移法为内核算法, 在 VS2010 环境中使用 VB.NET 语言编写了专用计算软件, 并对 HEI 中的实例进行计算。计算表明: 软件计算输出的最大弯矩、最大应力及最大挠度数据与 HEI 算例中给出的结果相比, 相对误差在 1% 以内; 与采用 ANSYS-APDL 计算的弯矩值相比, 自编软件计算的弯矩结果误差在 1% 以内; 在凝汽器管板强度分析计算中采用矩阵位移法对管板梁条力学模型进行求解是可行的。

关键词: 凝汽器; 管板; 梁条; 矩阵位移法

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引言

凝汽器是凝汽式汽轮机的主要辅助设备, 是构成热电站的重要设备之一, 其可靠性将直接影响整个发电机组安全与经济运行^[1]。凝汽器管板是凝汽器最重要的部件之一, 管板的强度直接关系到凝汽器冷却管与管板间胀焊连接的严密性, 关系到冷却水向汽侧的泄漏问题、影响汽轮机组的正常运行, 因此对管板进行强度计算是十分必要的。

长期以来对凝汽器管板强度进行计算多是单靠设计生产经验, 这使凝汽器在使用过程中可能存在不小的安全隐患。为了避免安全事故的发生, 提高管板设计生产水平, 在最近的十几年里国内针对管板强度计算的研究主要参照 HEI 标准中的“表面式凝汽器标准”^[2]。HEI 标准中对管板的力学模型进行了简化, 所采用的梁条模型分析计算方法虽给出算例, 但并未提及详尽的分析求解方法和步骤, 在应用过程中还存在缺陷。

本研究采用力学中的矩阵位移法, 将 HEI 标准中所提出的管板梁条力学模型进行了单元离散分析和整体解析, 并以矩阵位移法为内核算法在 VS2010

环境中使用 VB.NET 语言编写了专用计算软件, 可以实现对凝汽器管板强度的有效求解, 并为管板规范化生产奠定一定的基础。

1 管板的梁条力学模型

大型电站凝汽器管板是被冷却管支承的多孔矩形板, 冷却管起弹性基础作用。如果避开直接考虑水室并且把管板分成适当数目的窄条, 同时把这些窄条及其支承冷却管看作弹性基础上的梁, 便可以得到管板刚强度计算的近似解法。管板梁条模型的选取有一定的规则^[3-4], 梁条模型应在水室法兰与外缘冷却管之间的距离最小处选取, 且应当把重复出现一次冷却管排列形式的宽度选定为梁条的宽度。选取后的梁条其结构力学模型可以看成是由分置弹簧支撑的杆件结构, 如图 1 所示。

分置弹簧的弹性常数 $k_1 = \frac{n E_1 A_m}{L/2}$, N/mm。其

中: n —沿梁条宽度一排的冷却管数, 根; E_1 —冷却管弹性模量, MPa; A_m —冷却管金属截面积, mm^2 ; L —冷却管有效长度, mm。

端部负荷 $P = VW$, N。其中: V —水压试验条件下水室全部负荷作用在梁条单位宽度上的负荷, N/mm。梁条非开孔区均布载荷 $W_1 = q_1 W$, N/mm。其中: q_1 —水压试验压力, MPa。开孔区均布载荷 $W_2 = \varphi W_1$, N/mm。其中: φ 是用于考虑因开孔而使梁条承受水压面积减小的系数, 针对 HEI 中所提供的算例, φ 按下式确定:

$$\varphi = \frac{3S \times S \cos 30^\circ - 2A_f}{3S \times S \cos 30^\circ}$$

式中: A_f —冷却管通流面积, mm^2 。

在已知端部负荷、非开孔区和开孔区均布载荷

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以及各几何参数的情况下,可采用力学中的矩阵位移法对图 1 所示力学模型进行求解。

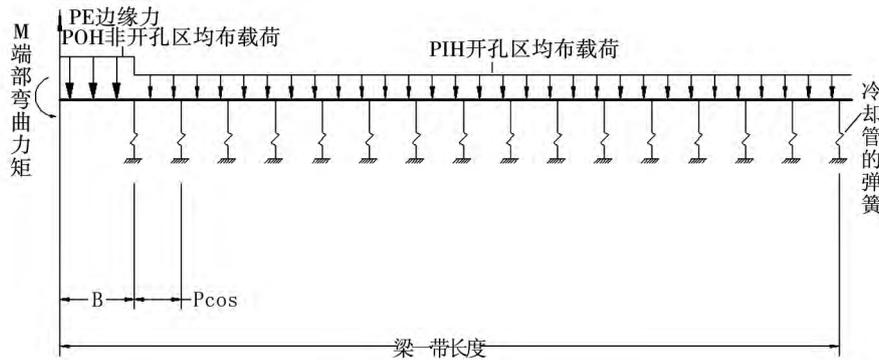


图 1 梁条结构的力学模型

Fig. 1 Mechanics model for beam structures

2 梁条模型的矩阵位移分析法

矩阵位移法的基本思路是将力学模型结构整体拆开,分解成若干个单元(一般将每个杆件取作一个单元),然后再将这些单元按一定的条件集成整体。其中包含了两个基本环节:单元分析和整体分析^[5-6]。

在矩阵位移法中,单元分析的任务是建立单元刚度方程,形成单元刚度矩阵;整体分析的主要任务

是将单元集成整体,由单元刚度矩阵按照刚度集成规则形成整体刚度矩阵,建立整体结构的位移法基本方程,从而求出方程的解。

2.1 梁条结构的离散

针对图 1 中所示梁条结构的力学模型,将梁条结构离散为若干单元,相应的每个杆件、弹簧对应一个单元,对梁单元和单元结点进行编码。离散后的梁条模型如图 2 所示,其中包含 16 个梁单元,16 个弹簧单元以及 17 个结点。

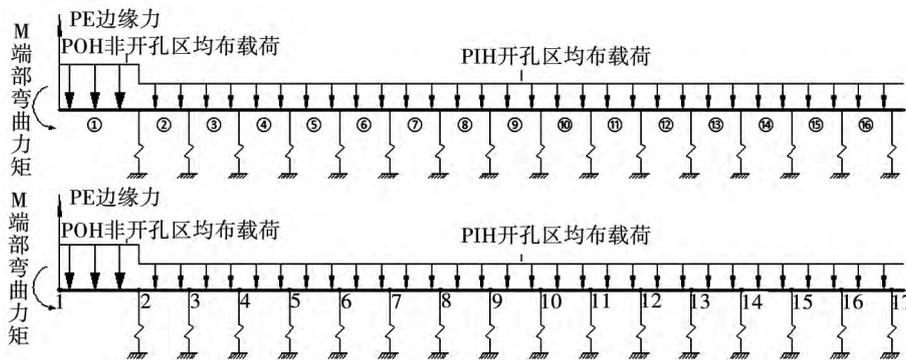


图 2 梁条离散模型

Fig. 2 Discrete model for beam-strip

2.2 单元分析

取某一梁单元进行分析,如图 3 所示,因所研究

对象为连续梁,忽略轴向变形,则: $\bar{u}_1 = \bar{u}_2 = 0$, $\bar{F}_{x1}, \bar{F}_{x2} = 0$ 。

杆端的未知位移向量为:

$$\bar{\Delta}^e = \{\bar{v}_1, \bar{\theta}_1, \bar{v}_2, \bar{\theta}_2\}$$

式中: \bar{u}_1, \bar{u}_2 为端部轴向位移; $\bar{\theta}_1, \bar{\theta}_2$ 一端部转角;

与 HEI 中直接给出的结果之间相对误差都保证在 1% 以内。由挠度和弯矩曲线对比图可见 管板梁条模型的挠度与弯矩值均在端部达到最大 ,且两条对比曲线的变化趋势基本一致。

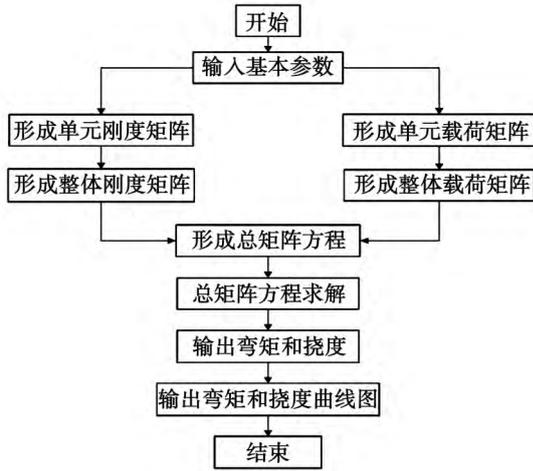


图 5 计算程序总框图

Fig. 5 General block diagram of the calculation program

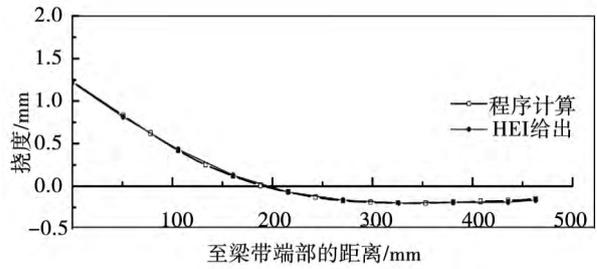


图 6 挠度对比图

Fig. 6 Chart showing a contrast of the deflection

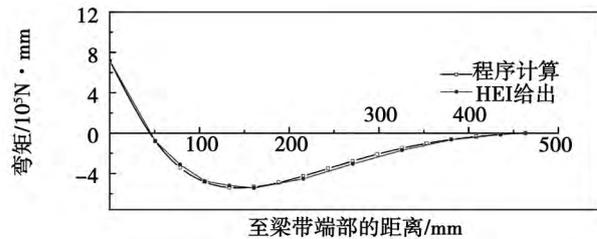


图 7 弯矩对比图

Fig. 7 Chart showing a contrast of the bending moment

表 1 与 HEI 的计算结果对比

Tab. 1 Contrast with HEI calculation results

参数	非开孔区			开孔区		
	HEI	软件计算	相对误差 / %	HEI	软件计算	相对误差 / %
最大弯矩 / N · mm	716 900	716 900	0	538 400	539 721.3	0.245
最大应力 / MPa	44.8	44.79	0.022	71.6	72.27	0.935
最大挠度 / mm	1.219	1.226	0.57	0.833	0.831	0.24

为进一步证明利用矩阵位移法对凝汽器管板梁条力学模型进行求解的有效性 ,采用 ANSYS - APDL 对图 2 中梁条离散结构中的前 13 个结点建立模型并计算各个结点的弯矩^[11] 模型如图 8 所示。

计算得到的弯矩随距离的变化情况如图 9 所示。

在 ANSYS - APDL 中提取每个结点处的弯矩值 ,并将各结点处的弯矩值与采用自编软件计算得到的弯矩值进行比较 结果如表 2 所示。

从表 2 弯矩的计算结果来看 ,采用 ANSYS - APDL 计算所得的结果与采用自编软件计算的结果相对误差也能保证在 1% 以内。

通过自编软件的计算结果与 HEI 算例及 ANSYS - APDL 计算结果的两组对比充分证明了利用

矩阵位移法对凝汽器管板梁条力学模型进行求解的合理性。

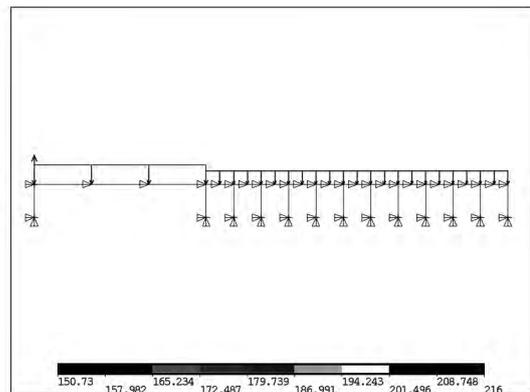


图 8 管板梁条离散模型

Fig. 8 Discrete model for tubesheet beams

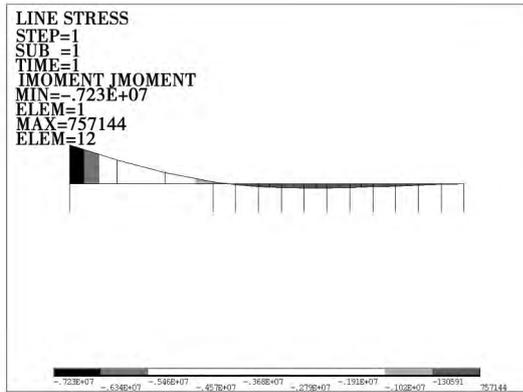


图 9 梁条弯矩计算结果

Fig.9 Bending moment calculation results of the beams

表 2 与 ANSYS-APDL 的计算结果对比

Tab.2 Contrast with ANSYS-APDL calculation results

结点编号	ANSYS - APDL	自编软件	相对误差 / %
1	-6507118.4	-6507188.4	0
2	255649.5	255417.8	0.09
3	762755.0	762492.5	0.03
4	1082276.4	1082015.4	0.02
5	1248194.1	1247957.8	0.02
6	1282285.1	1282092.0	0.02
7	1212084.6	1211946.6	0.01
8	1061713.2	1061636.9	0.01
9	852565.7	852448.9	0.01
10	610776.0	610691.8	0.01
11	365825.3	365775.5	0.01
12	150284.0	150246.2	0.02
13	0	0	0%

4 结 论

通过软件计算数据与 HEI 计算实例及 ANSYS - APDL 计算数据对比可见最大弯矩、应力、挠度值的相对误差均小于 1% ,软件输出的挠度和弯矩曲线的变化规律与 HEI 给出的基本一致 ,离散结构中各个结点的弯矩值的相对误差也小于 1% ,说明在凝汽器管板强度分析计算的分析中采用矩阵位移法对管板梁条力学模型进行求解是可行的。以矩阵位移法为内核算法所编写的软件已达到较高精度 ,且具有较高的计算效率 ,可用于凝汽器管板实际设计生产中的配套计算。

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(姜雪梅 编辑)

电站锅炉补给水处理流程全工况故障检测方法研究 = **Study of the Method for Detecting Faults in the Makeup Water and Feedwater Treatment Flow Path of a Utility Boiler Under All Operating Conditions**

[刊, 汉] ZHU Wei, ZHANG Shi-rong, LIN Yu (Automation Department, College of Power and Mechanical Engineering, Wuhan University, Wuhan, China, Post Code: 430072) // Journal of Engineering for Thermal Energy & Power. -2015, 30(1). -66-71

There exists a multi-steady-state operating condition switching-over and their transient process in a complex industrial flow path, causing the traditional principal component analysis and fault detection method easily to mistakenly alarm a fault. As a result, the authors proposed a transient process identification method based on the steady-state factors and an operating condition self-adaptive matching method based on the similarity factors and incorporated them into the principal component analytic method to form a new fault detection method. The method in question was used for detecting faults in the makeup and feedwater treatment flow path of a utility boiler and verified by using the operating data of the flow path under all operating conditions. It has been found that the method under discussion can effectively eliminate the influence of the transient process and enhance the fault detection performance and reduce the number of faults mistakenly alarmed through a matching of the operating conditions, thus accomplishing the fault detection of the water treatment flow path under all operating conditions. **Key Words:** boiler makeup water and feedwater treatment flow path, full-load operating condition, principal component analytic method, transient process, operating condition matching

凝汽器管板强度的矩阵位移分析法 = **Matrix Displacement Method for Calculating the Strength of Tubesheets in a Condenser**

[刊, 汉] ZHOU Xiang, LAI Xi-de, CHEN Xiao-ming, LEI Ming-chuan (College of Energy Source and Environment, West China University, Chengdu, China, Post Code: 610039) // Journal of Engineering for Thermal Energy & Power. -2015, 30(1). -72-77

By using the matrix displacement method in mechanics, a unit discrete and overall analysis of the tubesheet beam mechanic model proposed in HEI standard were conducted and with the matrix displacement method serving as the core algorithm, the VB.NET language in the environment of VS2010 was used to prepare a special-purpose software and calculate the cases provided in the HEI standard. The calculation results show that compared with the results given in the calculation examples in the HEI standard, the maximum bending moment, stress and deflection have a relative error within 1%. Compared with the bending moment value calculated by using the software Anasys-Apdl, that calculated by using self-prepared software has an error within 1%. In the strength analysis and calculation of

tubesheets of a condenser it is reasonable and feasible to use the matrix displacement method to seek solutions to the mechanical model for tubesheets and beams. **Key Words:** condenser , tubesheet , beam , matrix displacement method

含 CO₂ 气流对 20 号碳钢冲蚀磨损性能影响的试验研究 = **Experimental Study of the Influence of a CO₂ contained Gas Flow on the Erosion and Wear Performance of 20 Carbon Steel** [刊 ,汉] ZHAO Xian-ping ,ZHU Chong-wu ,SUN Jian-rong ,PAN Wei-guo (College of Energy Source and Mechanical Engineering ,Shanghai University of Electric Power ,Shanghai ,China ,Post Code: 200090) //Journal of Engineering for Thermal Energy & Power. -2015 ,30(1) . -78 -80

Tube rupture of coal-fired boilers in thermal power plants arisen from the erosion and wear by flying ash is considered as a problem urgently to be solved in the sector. The authors studied the influence of a gas flow contained carbon dioxide on the erosion and wear performance of 20 carbon steel by using an experimental study method when the temperature is within a range from 250 °C to 450 °C and compared with the results of the test of the same kind previously made in the compressed air flow. The test results show that the wear and tear law of 20 carbon steel keeps unchanged after the carbon dioxide gas flow is added and the relative amount of steel worn and torn will first decrease and then increase with an increase of the temperature. At the same time ,due to the interaction of oxidized corrosion and erosion ,the erosion and wear amount of 20 carbon steel will conspicuously increase after an addition of carbon dioxide to the gas flow. **Key Words:** erosion and wear by flying ash ,CO₂ ,20 carbon steel ,coal-fired boiler

基于褐煤干燥技术的机炉热集成优化系统 = **Lignite Drying Technology-based Turbine-boiler Thermal Integrated System** [刊 ,汉] FANG Ya-xiong ,XU Cheng ,XU Gang ,ZHANG Chen-xu ,YANG Yong-ping(College of Energy Source and Mechanical Engineering ,Shanghai University of Electric Power ,Shanghai ,China ,Post Code: 200090) ,SONG Xiao-na (College of Energy Source and Mechanical Engineering ,Shanghai University of Electric Power ,Shanghai ,China ,Post Code: 200090) //Journal of Engineering for Thermal Energy & Power. -2015 ,30(1) . -81 -87

On the basis of the conventional steam extraction drying system for lignite-fired units ,proposed was a type of turbine-boiler thermal integration and optimization system in combination with the flue gas waste heat utilization technology for use in the tail portions of boilers. The steam exhausted from the drying of the lignite was utilized to pre-