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应用模糊辨识方法对 DMFC 电堆的温度特性建模

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摘　要: 从甲醇燃料电池(DMFC)电堆实际应用的角度出发, 利用模糊技术对 DMFC 电堆非线性系统进行模型辨识和预测。以阴阳极燃料的流速为的输入量, 电堆的工作温度为输出量, 利用 1000 组实验数据作为样本, 建立了不同燃料流速下电堆工作温度的动态响应模型。仿真结果证明采用模糊辨识建模的方法是有效的, 建立的模型精度较高, 从而为设计 DMFC 电堆实时控制系统奠定了基础。

关　键　词: 直接甲醇燃料电池; 模糊技术; 模型辨识

中图分类号: TM911; TP183　　文献标识码: A

1　引　言

直接甲醇燃料电池(DMFC)是将燃料(甲醇)和氧化剂(氧气或空气)的化学能直接转化为电能的一种发电装置。DMFC 不通过热机过程, 不受卡诺循环的限制, 能量转换效率高, 同时 DMFC 还具有甲醇燃料资源丰富、成本低廉、存储携带方便、结构简单、响应时间短和操作方便等许多优点, 由此可见在当今能源危机和环境污染日趋严重的情况下, 对 DMFC 的深入研究是十分有意义的[1~2]。自 20 世纪 60 年代以来, 美国的 Intel、Motorola, 日本的 Hitachi、Toshiba、Sony 和韩国的 Samsung 等国际化大公司纷纷加大了 DMFC 的研究力度, 加速了 DMFC 商业化的进程。而国内 DMFC 的研究始于 20 世纪 90 年代, 目前已有中科院大连物化所、中科院长春应化所和上海交通大学等院校及科研单位先后开展了这方面的工作, 并在电催化剂、电极材料、模型和控制系统等方面取得了一定的进展, 但是距 DMFC 的商品化还需要一段时间[3]。

文中所讨论的是利用模糊技术对 DMFC 电堆的工作温度进行模型辨识和预测。在建模过程中, 应用模糊 C 平均聚类划分系统的模糊空间, 得出合适的模糊规则数目和规则适用程度, 同时利用最小二乘法算法辨识后件参数, 然后根据实验的输入(甲醇、空气的流速)输出(温度)数据建立了 DMFC 电堆系统的温度模型。

2　DMFC 的工作原理

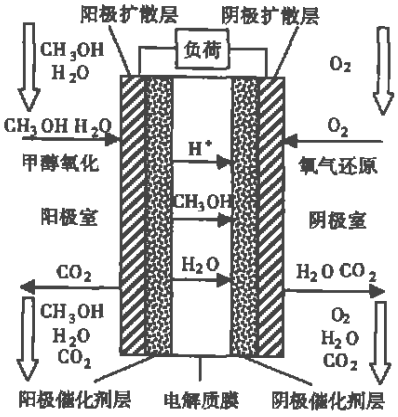

图 1　直接甲醇燃料电池结构原理图

图 1 为 DMFC 的结构原理图。DMFC 由阳极、电解质膜和阴极构成, 阳极和阴极分别由多孔结构的扩散层和催化剂层组成。甲醇(液相或者气相)和氧气或空气分别送入阳极和阴极室, 在阳极甲醇和水通过阳极扩散层扩散至催化剂层, 发生电化学氧化反应, 生成二氧化碳和质子。二氧化碳则通过阳极扩散层扩散回到阳极室中。而质子则在电场作用下通过电解质膜迁移到了阴极催化剂层, 并与由阴极室通过阴极扩散层扩散而至的氧气反应生成水。电子经过外电路也到达阴极。同时在这一过程中, 甲醇在扩散和电渗作用下, 从阳极渗漏到了阴极, 部分甲醇又在阴极催化剂层与氧气反应生成二氧化碳和水[4~6]。

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DMFC 中的电极反应如下：

阳极甲醇氧化的半反应：

$$CH_3OH + H_2O \rightarrow CO_2 + 6H^+ 6e^-$$

阴极氧还原的半反应：

$$3/2O_2 + 6H^+ + 6e^- \rightarrow 3H_2O$$

电池总反应：

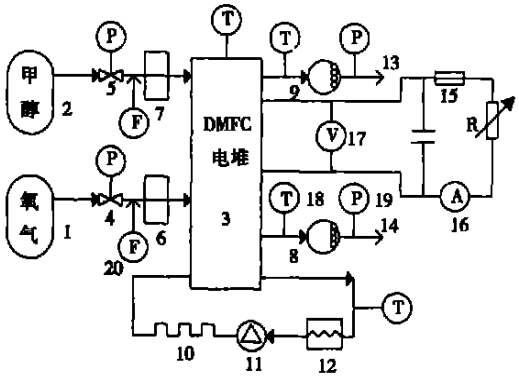
$$CH_3OH + 3/2O_2 + H_2O \rightarrow CO_2 + 3H_2O$$

3 DMFC 系统的描述和分析

根据对 DMFC 电堆系统的动态特性的分析，DMFC 的温度模型可描述为：

$$\frac{d\vec{\theta}(t)}{dt} = f[\vec{\theta}(t), \vec{V}(t)] \tag{1}$$

其中：$\vec{V}(t) = [v_a(t), v_c(t)]^T$ 为控制输入矢量，即甲醇(阳极)、空气(阴极)的流速；$\vec{\theta}(t) = [\theta_a(t), \theta_c(t), \theta_e(t), \theta_b(t)]^T$ 为输出矢量，即阳极、阴极、电解质板和隔板的温度。



1-压缩氧气瓶或氧气压缩机；2-氢气钢瓶；3-DMFC电堆；
4,5-减压阀；6,7-增湿罐；8,9-水-气分离器；10-散热器；
11-冷却水泵；12-冷却水箱；13-循环利用或排空；14-排空；
15-熔断器；16-电流计；17-电压计；18-温度传感器；
19-压力传感器；20-质量流量计

图 2 DMFC 电堆控制测试系统示意图

根据操作经验，电堆阳极、阴极、电解质板和双极板的工作温度与阴极气体和阳极甲醇流速有关。阴极空气、阳极甲醇的流速会影响电池的温度，当流速较小时，电化学反应充分，热量损失小，最终稳定温度高；而当流速较大时，反应不充分，并带走部分热量，最终稳定温度低。文中为了降低电堆的工作温度和保证燃料被完全消耗，假设阴极氧化剂燃料足够多，但是燃料的供应流速不能高于电堆的最大反应率[6~7]。另外，本文建模的目的为在给定控制输入情况下，动态模拟出电堆工作温度的变化曲线，完成输入到输出的动态非线性映像。DMFC 的温度模型的可以用一个非线性差分方程来描述：

$$\vec{\theta}(k+1) = f[\vec{\theta}(k), \vec{V}(k)] \tag{2}$$

从上述数学模型和操作经验来看，DMFC 电堆的燃料气、氧化气的压力和流量等控制参数对电堆工作温度会产生极大的影响。本文所采用的 DMFC 电堆试验控制测试系统示意图如图 2 所示。控制系统输入为甲醇、空气的流速，输出为电堆工作温度(即阴阳极中心的工作温度)。

4 DMFC 电堆的模糊辨识建模

4.1 基于模糊理论的 DMFC 电堆系统辨识结构和算法简述

DMFC 系统辨识的结构框图如图 3 所示，其中 TDL 为时分多路延时环节。

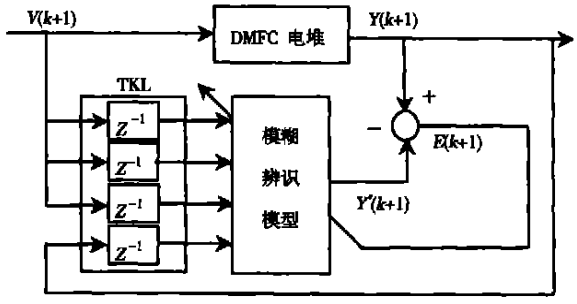


图 3 基于 T-S 模糊理论的 DMFC 电堆系统辨识框图

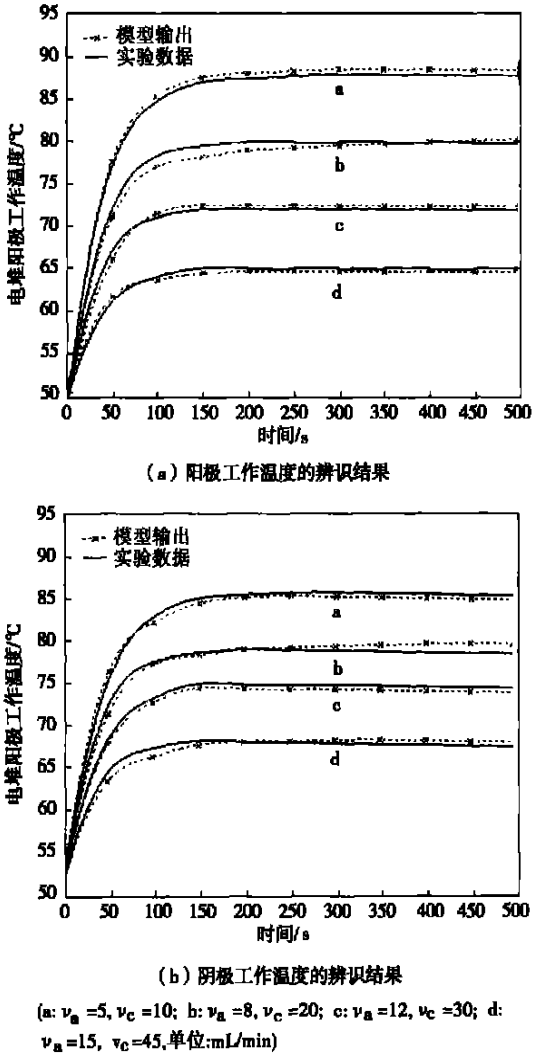
本文采用的 T-S 预测模型，该模型是由若干条如下形式的 if...then...条件语句构成的：

$$R_{l,i}: \text{if } x(k) \text{ is } A_{1,i} \text{ then}$$

$$y_{1,i}(k+1) = P^l_{i,0} + P^l_{i,0}x_1(k) + \cdots + P^l_{i,n}x_n(k) \qquad i = 1, \cdots, c \tag{3}$$

为了简化模型的辨识，提高模型的泛化能力，模糊模型的辨识分为前件参数辨识和后件参数辨识两部分。前件参数辨识，采用模糊 c 平均聚类的基本原理，进行在线模糊聚类[8~10]。后件参数辨识是采用传统的线性辨识方法：最小二乘法[11~12]。本文采用的模糊辨识建模的具体步骤参见文献[8, 12]，辨识后所确定的具体参数在 4.2 节仿真描述中已详细给出，在此不再累述。

4.2　DMFC 系统模糊辨识结果



(a) 阳极工作温度的辨识结果

(b) 阴极工作温度的辨识结果

(a: ν_a =5, ν_c =10; b: ν_a =8, ν_c =20; c: ν_a =12, ν_c =30; d: ν_a =15, ν_c =45, 单位: mL/min)

图 4　在不同燃料流速下的辨识结果

用 MATLAB 模糊逻辑工具箱进行模型训练与仿真。首先, 选用 DMFC 电堆在不同甲醇和空气流速下的 1 000 组工作温度响应值作为实验数据。其次, 将所得实验数据分为一个训练集和一个测试集, 前者用于模型训练过程, 后者用于测试所建立的模糊模型的有效性。训练数据(训练集) 是 500 组在不同流速下 DMFC 电堆温度动态响应数值, 这些数据存在一个数据文件中, 在训练过程将提供给模糊模型。选取模糊规则数 $c = 19$, 学习常数 $\eta = 0.8$, 重迭度 $\xi = 0.1$, 灵敏度 $\lambda = 12$, 得出辨识精度 $E = 1.608\,2e-003$。将上述训练好的模糊模型对 DMFC 电堆系统进行动态辨识仿真, 在预定的流速下, 将模糊模型计算得到的温度动态响应数值与实际 DMFC 电堆系统的实验中得到的温度动态响应数值比较, 得到仿真结果如图 4 所示。由仿真结果可知, 模糊模型能够动态地模拟 DMFC 电堆的实际工作温度, 最大误差不超过 2 ℃。

5　结语

本文根据实验测试数据, 利用模糊理论对 DMFC 电堆系统工作温度进行辨识建模, 从而避开了 DMFC 电堆系统机理的复杂性。由以上仿真结果可知, 模糊建模的方法有效, 建模精度较高, 同时为设计 DMFC 电堆系统的在线控制器奠定了基础。

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(渠　源　编辑)

words: coal, semi-char, ignition characteristics, combustion stability, pressurized combustion, pressurized fluidized bed

基于 BP 神经网络的煤粉锅炉飞灰含碳量研究=**The Investigation of Carbon Content in Fly Ash for a BP Neural Network-based Pulverized Coal-fired Boiler** [刊, 汉] / ZHAO Xin-mu, LU Jun-fu, YUE Guang-xi (Department of Thermal Energy Engineering, Tsinghua University, Beijing, China, Post Code: 100084), WANG Cheng-liang (Laicheng Power Plant, Laiwu, Shandong Province, China, Post Code: 271100) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(2). —158 ~ 162

Carbon content in fly ash is a major index, which reflects the combustion efficiency of a pulverized coal-fired utility boiler. On the basis of a BP (inverse propagation of error) neural network method set up was a 11-23-1 type BP neural network model. In accordance with the specific features of a four-corner tangentially fired pulverized-coal utility boiler 11 parameters which can influence combustion have been selected to serve as input factors of the neural network. The parameters include: pulverized coal fineness, burner tilting angle, oxygen content in flue gas, parameters of 5 ranks of coal, operation combination of burner spray nozzles, etc. A training course was conducted for the established model and model parameters were obtained. The error predicted by using the model is less than 6% when compared with actual values. On this basis the authors have also proposed a simplified method for analyzing the carbon content in fly ash, which may be affected by a single parameter. This makes it possible to attain under certain conditions a concise and intuitive reflection of multi-dimensional non-linear law contained in the network. The results of the calculation and analysis indicate that the model-based method can effectively identify the mechanism of various parameters in influencing the carbon content in fly ash and may be employed to conduct the analysis, prediction and optimized regulation of carbon content in boiler fly ash. **Key words**: pulverized coal-fired boiler, BP neural network, carbon content in fly ash, single-parameter analysis

基于典型样本数据融合方法的锅炉制粉系统故障诊断=**Fault Diagnosis of a Boiler Milling System on the Basis of a Typical-swatch Data Fusion Method** [刊, 汉] / TIAN Liang, CHANG Tai-hua, ZENG De-liang, et al (North China University of Electric Power, Baoding, China, Post Code: 071003) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(2). —163 ~ 166

It is difficult for the evidence in a D-S evidence theory application to determine the distribution of target-mode confidence function. In the light of this problem the authors have proposed a typical swatch-based method for the acquisition of confidence function distribution. This method utilizes the Hamming distance between the evidence and the typical swatch of each target mode to construct the distribution of confidence function, thus meeting the definition of confidence function distribution and reducing its subjectivity. By using this data-fusion method in the fault diagnosis of a boiler milling system it is feasible to identify such pulverizer malfunctions and faults as pulverized coal self-ignition, pulverizer being full of coal and empty of coal, etc. As verified by historical data, the method under discussion can effectively recognize various types of faults and make an early prediction and diagnosis of ensuing malfunctions. **Key words**: evidence theory, typical swatch, fault diagnosis, coal milling system

应用模糊辨识方法对 DMFC 电堆的温度特性建模=**Temperature Characteristics-based Modeling of DMFC (Direct Methanol Fuel Cell) Stack by Using a Fuzzy Identification Method** [刊, 汉] / MIAO Qing, CAO Guang-yi, ZHU Xin-jian, et al (Fuel Cell Research Institute under the Shanghai Jiaotong University, Shanghai, China, Post Code: 200030) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(2). —167 ~ 169

From the viewpoint of a DMFC (direct methanol fuel cell) stack being put to a practical use fuzzy technology is utilized to carry out a model identification and prediction for the nonlinear system of a DMFC stack. With the fuel flow velocity at the cathode and anode serving as inputs and the working temperature of the stack as an output and 1000 groups of experimental data being taken as samples, a dynamic response model was set up for the DMFC stack working temperatures at different fuel-flow velocities. The results of a simulation have shown that the method of modeling by emplying the fuzzy identification is effective. The established model features relatively high precision, thus laying a foundation for the design of a DMFC stack real-time control system. **Key words**: direct methanol fuel cell, fuzzy technology, model identification

电热冷联产的新压缩空气蓄能系统= **A New Type of Compressed Air Energy-storage System for the Cogeneration of Electricity, Heat and Cooling Energy** [刊, 汉] / GUO Xin-sheng, FU Qin-sheng, ZHAO Zhi-xin, et al (Institute of Energy and Power Engineering under the Xi' an Jiaotong University, Xi' an, China, Post Code: 710049) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(2). — 170 ~ 173

A new type of compressed air energy-storage system is proposed, under which compressed air directly expands in an air turbine to do work and generate electricity, produce heat and cooling energy. The irreversible cycle of the system is analyzed and an equation given for calculating the energy-conversion utilization rate η of the energy storage system when only the flow resistance loss of all heat exchangers is neglected. By using the above-cited equation an analysis and a study are conducted of the influence of the following parameters on the system η value: isentropic efficiency of air turbine expansion machine and compressor, compressor discharged air heat energy, air turbine discharged air cooling energy, heat-transfer temperature difference of heat exchangers, air compression ratio, etc. It has been found that the increase in air turbine isentropic efficiency has a greater influence on η value than that of a same increase in compressor efficiency. With all the other parameters being fixed there exists an optimum pressure ratio, under which the system energy-conversion utilization rate attains a maximum value. The results of the analysis indicate that the compressed air energy-storage system under discussion can achieve an energy conversion rate of about 0.8. **Key words**: compressed air energy-storage for power generation, air turbine, heat supply, cooling energy supply station

主动平衡技术在带有尾透的离心压缩机上的应用研究(I 数值计算)= **Applied Research of Automatic Balance Technology for Centrifugal Compressors Fitted with a Tail (Part II: Numerical Calculation)** [刊, 汉] / SHEN Wei, HE Li-dong, ZHOU Wei-hua, et al (Research Center of Equipment Diagnostic Engineering under the Beijing University of Chemical Engineering, Beijing, China, Post Code: 100029) // Journal of Engineering for Thermal Energy & Power. — 2005, 20(2). — 174 ~ 177

A study was conducted concerning the use of automatic-balance technology for resolving the imbalance problem of the flexible rotor of a centrifugal compressor fitted with a tail. By using a finite element method the magnitude of shaft-journal vibration amplitude was calculated and compared in the presence of a shaft imbalance. As a result, an optimum location was identified for installing an automatic balance device on the shaft. A detailed analysis was performed of the relationship between the magnitude of counter weight and the reduction of initial vibration. This can provide a reference for selecting the maximum balancing capacity of an automatic balance device. In addition, by way of numerical simulation the vibration reduction effectiveness of a rotor system was verified. The results of the above study can offer a basis and reference for the installation of an automatic balance device on a rotor and for conducting automatic balancing tests. **Key words**: automatic balance technology, finite element method, centrifugal compressor, numerical simulation