

故障诊断的神经网络多重模型 自适应方法

西北工业大学 王镛根* * 张学峰

【摘要】 将神经网络与故障诊断的多重模型自适应方法相结合, 提出了故障诊断的神经网络多重模型自适应方法, 并对某型航空发动机控制系统传感器故障进行诊断仿真。仿真表明, 该方法能够用来解决具有模型不确定性系统的故障诊断问题, 同时, 对未知的故障模态具有自学习能力。

主题词: 神经网络 模型法 故障诊断

分类号: TP277

故障诊断的 MMAF 方法具有如下重要的优点: (1) 不需要选择门限值; (2) 对于系统的非线性具有较好的鲁棒性; (3) 算法简单。该方法的主要缺点是不具有学习能力, 必须对所有传感器可能发生的故障情况要预先做全面了解, 否则会出现错判。同时, 该方法是一种基于模型的故障诊断方法, 要求获得系统精确的数学模型, 然而, 象航空发动机这样结构复杂、工作范围变化大、扰动因素多的大系统, 要获得其精确的数学模型是比较困难的。神经网络发展为解决这一类问题提供了新的思路。由于神经网络具有能充分逼近任意非线性函数的能力, 因此可应用神经网络的自学习代替滤波器设计过程中的解析计算, 获得残差信息, 同时, 使 MMAF 法具有学习功能, 对未知的故障模态具有自学习能力。

1 故障诊断的多重模型自适应法

对于如下非线性系统

$$x(t+1) = f[x(t), u(t)], \quad y(t) = h[x(t)] \quad (1)$$

其中 $f(\cdot)$ 和 $h(\cdot)$ 为非线性函数。根据系统的输入和输出, 在正常状态和 N 种潜在的故障状态下离线训练 $N+1$ 个神经网络, 确定神经网络的参数, 建立 $N+1$ 个状态估计器:

$$\hat{y}_i(t+1) = f[\Psi(t), \theta] \quad (i = 1, \cdots, N+1) \quad (2)$$

式中 $\Psi(t) = [y(t), \cdots, y(t-n_y+1), u(t-d), \cdots, u(t-d-n_m+1)]^T$ 。其中, 向量 $\Psi(t)$ 和 θ 分别为神经网络输入和神经网络的参数, $\hat{y}_i(t+1)$ 为神经网络的输出, 是 $y(t)$ 的一步预测值。 u 和 y 分别表示非线性系统的输入和输出, n_m 和 n_y 分别表示输入和输出的滞后步数。然后应用 $N+1$ 个状态估计器对系统进行状态估计, 则每个模型的预测误差为系统输出的测量值和一步预测值之差。 $\epsilon = \hat{y}_i(t) - y(t), (i = 1, \cdots, N+1)$ 。

通过以上过程, 即完成了故障新息的提取。将获得的 $N+1$ 个估计器的预测误差作为残

差,在此基础上对残差进行统计检验,进而实现故障诊断。最常用的方法是应用贝叶斯公式,通过残差计算第 i 个模型的条件概率

$$P(M_i | \epsilon) = P(M_i | \epsilon) P(M_i) \backslash \sum_{j=1}^{N+1} P(M_j | \epsilon) P(M_j) \quad (i = 1, \dots, N+1) \quad (3)$$

其中, $P(M_i)$ 为第 i 个模型出现的先验概率。

通过以上的条件概率,即可判断系统的运行状态,然后由以下的检测逻辑实现故障检测与定位。定义条件概率的下界 P_L 及上界 P_U , 则有: (1) 如果 $P(M_i | \epsilon) \geq P_U$ 并且 $P(M_j | \epsilon) \leq P_L$ ($j = 1, \dots, i-1, i+1, \dots, N+1$), 则说明系统运动于第 i 种模式下; (2) 如果 $P(M_i | \epsilon) \leq P_L$ ($i = 1, \dots, N+1$), 则说明系统运行于一种未知的模式下, 启动故障诊断系统的学习功能模块, 训练一个新的网络用来估计这种新的故障模式, 训练既可以在线实现, 又可以离线进行, 并将训练后的网络加入到状态估计器的集合中。进一步在此基础上实现状态重构及容错控制。

2 某型发动机控制系统传感器故障诊断

以某型发动机设计点 ($H = 0, Ma = 0$) 为对象, 用基于 RBF 神经网络的多重模型自适应诊断发动机控制系统传感器故障^[4]。

2.1 故障模式已知

在系统无故障以及 n_1 传感器发生阶跃故障 (30 r/min) 两种状态下分别训练 RBF 网络, 建立 2 个状态估计器 ANN0 和 ANN1, 然后利用它们对系统进行故障诊断。并假定正常状态和故障状态出现的先验概率 $P(M_i) = 0.5$, ($i = 1, 2$), 利用上节所述方法得到故障诊断结果如图 1 所示。由图可明显看出, 该方法

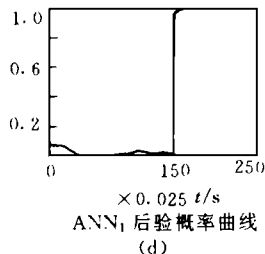
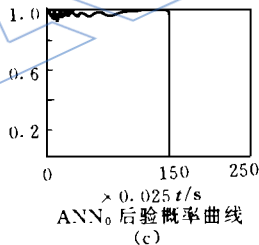
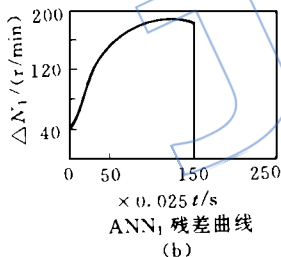
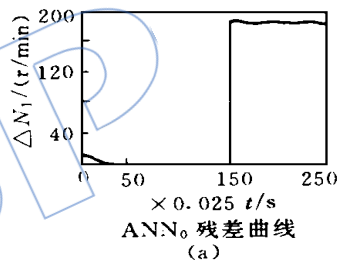


图 1 故障诊断结果

能准确检测出已知的传感器故障, 并且延迟时间很短。

2.2 故障模式未知

考虑一种新的故障模式, 假设系统运行到 $t = 150$ 时 T_4^* 传感器发生故障, 在这种情况下故障诊断系统的诊断结果表明, 在有新的故障模式出现时, 两个估计器均不能很好的逼近系统的真实输出、残差很大, 因而这两种模式出现的后验概率均接近于零, 由此可证明此故障为一未知故障模式, 需启动系统的学习功能, 应用获得的故障数据训练一新的状态估计器 ANN2。此时故障诊断系统即可诊断两种故障。假定系统运行在这 3 种模式下的先验概率均为 $1/3$, 仿真结果表明, 故障诊断系统经学习后可以准确地诊断出新的故障模式。说明基于 RBF 网络多重模型自适应故障诊断方法具有很强的学习能力, 更适用于实际应用。

3 结 论

通过应用神经网络多重模型自适应法,分别诊断了 n_l 传感器和 T^* 传感器的故障,证明了该方法的有效性。由设计、仿真过程可知,在整个过程均未应用发动机模型,故验证了该方法不需要系统的精确模型,只需在模型发生变化时启动学习功能,因而完全可用来解决具有模型不确定性系统的故障诊断问题。同时,证明了该方法对未知的故障模态具有自学习能力。

参 考 文 献

- 1 Maybek P S. Application of Multiple Model Adaptive Algorithms to Reconfigurable Flight Control and Dynamic Systems. Academic Press. Inc, 1992, 52: 155- 228
- 2 Chen S, Bilings S A, Crant P M. Recursive Hybrid Algorithm for Nonlinear System Identification Using Radia Basis Function Networks. Control, 1992, 55(5): 1051- 1070
- 3 Low X C, Willsky A S. Analytical Redundancy and the Design of Robust Failure Detection in Uncertain System. Automatica, 1986, 22(3): 333- 344
- 4 张学峰. 针对航空发动机模型不确定性的故障检测、隔离与调整: [学位论文]. 西北工业大学硕士论文, 1996

(责任编辑 王庆康)

stand larger unbalanced load than Squeezed Film Damper. As a kind of dry-friction damper, RMRD can work under very high or low temperature for a long period of time. It is especially suitable for High Pressure Liquid Hydrogen (Oxygen) Pumps of rocket engines working under very low temperature.

Key Words Rotors Dampers Absorbers

AN INVESTIGATION ON IGNITION PERFORMANCE OF A CATALYTIC IGNITER AT HIGH ALTITUDE

Dong Kang

(Qingling Company, AVIC, Xiping 7131017)

He Xiaoming, Han Qixiang, Tan Haoyuan

(2nd Dept. Nanjing University of Aeronautics and Astronautics, Nanjing 210016)

ABSTRACT An experimental investigation on performance of a catalytic igniter made of platinum/rhodium catalyst has been conducted in a turbofan engine afterburner. Its ignition delay was measured under the conditions: the static pressure of 0.04–0.115 MPa; the inlet total temperature of 673–773 K; the velocity at the lip of igniter cone $\lambda = 0.20$ –0.36. The investigation simulates the operation of the engine's afterburner when aircraft flies at an altitude of 18000 m and the Mach number of 1.0. The experiments on performance of the igniter for igniting of 1100 runs at normal pressure were also conducted to verify the longevity of the catalytic igniter.

Key Words Catalytic ignition Afterburners Aircraft engines

ANN-BASED OBSERVER FAILURE DETECTION

Zhang Xuefeng and Wang Yonggen

(7th Dept. Northwest Polytechnical University, Xi'an 710072)

ABSTRACT An Artificial Neural Network (ANN)-based observer failure detection method is presented, which uses ANN's self-learning ability instead of analytical computation of the observer design to get the redundancy relationship of the system. In order to deal with the failure detection of model uncertainty system, the failure detection of the control system sensor of a given aeroengine has been simulated with the presented method. The simulation shows that this method not only has the advantage of the observer failure detection method, but also has no need for the precise model of system. It is useful to the failure detection of the model uncertainty system.

Key Words Neural networks Failure Detection Observer

ANN-BASED MMAF FAILURE DETECTION

Wang Yonggen and Zhang Xuefeng

(7th Dept. Northwest Polytechnical University, Xi'an 710072)

ABSTRACT Artificial neural network (ANN) and Multiple Model Adaptive Filter (MMAF) are combined in a new failure detection method-ANN-based MMAF, which uses ANN's self-learning ability instead of analytical computation of the filter design. Numerical simulations of an aeroengine have been performed to detect the sensor failure of the control system. The results show that this method not only can detect the failure of the system with an uncertain model, but also has self-learning ability for the unknown failure pattern.

Key Words Neural networks Failure detection Modeling

MULTIPLE- SECTOR PARALLEL COMPRESSOR MODEL FOR FLOW FIELD CALCULATION UNDER DISTORTION

Song Wenyan, Li Ming, Fan Feida

(7th Dept. Northwestern Polytechnical University, Xi'an 710072)

ABSTRACT

This paper describes in some detail the method for computing an axial- flow compressor flow field under distortion. Based on the multiple- sector parallel compressor model and stream line curvature method, the stage distributions of the parameters of distorted flow field, such as total pressure, total temperature, static pressure, static temperature, air velocity and swirl angle, are obtained by solving the radial- equilibrium equation, then the details of compressor flow field under the given inlet distortion can be reached. As an example the flow field computation for a single stage compressor has been completed under the inlet circumferential distortion. The results demonstrate the practical value of the method.

Key Words Parallel compressors Distortion factors Flow field simulation

AN EXPERIMENTAL OBSERVATION ON STALL OSCILLATION AT LOW FLOWRATE IN A CENTRIFUGAL IMPELLER

Dai Ji and Chen Jingyi

(Institute of Engineering Thermophysics, CAS, Beijing 100080)

ABSTRACT

An experiment was conducted to investigate the self- excited flow oscillation in a centrifugal fan impeller. The unsteady dynamic pressures were measured around the periphery of the impeller outlet with 8 high- response transducers. The experimental observation shows the existence of a lower frequency, nonrotating oscillation in the low flowrate conditions. The measurements also indicate that the oscillation is unstable at a short duration and at a local position, and the peripheral distribution of oscillation strength is non- uniform. The analysis shows that there may be some relationship between the self excited flow oscillation and rotating stall, especially during inception behavior of rotating stall.

Key Words Centrifugal type Impeller Dynamic tests

EFFECTS OF SOLIDITY ON CHARACTERISTICS OF COMPRESSOR CASCADE WITH CURVED- BLADE

Zhong Jingjun, Wang Wei, Su Jiexian, Wang Zhongqi

(Energy Science and Engineering College, Harbin Institute of Technology, Harbin 150001)

ABSTRACT

The relationship between solidity and the characteristics of compressor cascades with curved blades is investigated. The experimental results show that with the increase of cascade solidity, the cascade loss increases at most incidences. The minimum loss incidence of the straight and positive curved blade cascade takes place at positive incidences, while the negative curved blade cascade appears at negative incidence. In order to reduce the loss, the solidity for the positive curved blade should be less than that of the straight blade. In the case of the same solidity, the secondary loss can be reduced and good incidence characteristics can be obtained with the negative curved blade, compared with the