

航空发动机自适应建模技术研究

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【摘要】 本文介绍了航空发动机自适应建模方法,并根据某型发动机高空试验实测数据对该型发动机数学模型及其部件特性进行了自适应修正,修正后的发动机模型计算结果与实测结果十分吻合,证明利用本文所介绍的方法可获得更为准确的发动机数学模型。

主题词: 航空发动机 数学模型 自适应控制 建立模型

分类号: V233.791

1 加权函数自适应建模方法

航空发动机加权函数自适应建模方法是在已建立的发动机数学模型基础上来完成的。在模型中引入了一个加权函数和一系列修正因子,利用这些修正因子对发动机部件特性以及发动机数学模型进行修正;改变修正因子的取值使加权函数值最小,实现对发动机部件特性和模型的最优修正。在考虑模型的自适应过程时,作了如下假设:(1)给定的发动机实验数据能够准确地表示该发动机的工作状况;(2)给定的发动机初步的部件特性数据,可以作为发动机自适应建模的部件特性使用。

1.1 建模方法

发动机截面参数 Y_{out} 可用解析式或图表表示为部件特性数据、设计点参数和结构参数 Y_{in} 的函数关系 $f(Y_{in}, Y_{out}) = 0$, 由于发动机模型本身偏差以及部件特性不准确,使模型计算值与实测数据存在偏差 e 。用 X_{act} 表示发动机的真实特性, X_{cal} 表示模型使用的部件特性,定义修正因子: $MF = X_{act} / X_{cal}$ 。预选一系列修正因子 $MF_i (i = 1, 2, \dots, n)$, 假如实测参数值为 Q_{mi} , 模型计算出的参数值为 Q_{ci} , 求解发动机模型平衡方程产生的残量为 err_i , 建立加权函数 F_c 如下:

$$F_c = \sum_{i=1}^M a_i \times err_i^2 + \sum_{i=1}^N b_i \times (Q_{ci} - Q_{mi})^2$$

其中, M 是残量个数, N 是实测参数个数, a_i 和 b_i 是加权系数。

将修正后的特性 X_{act} 代入发动机模型中,则 F_c 的值是修正因子 MF_i 和发动机模型的独立变量 v 的函数,即: $F_c = F_c(v_1, v_2, \dots, v_M, MF_1, MF_2, \dots, MF_N)$

这是包含 $M + N$ 个独立变量的方程,通过发动机模型求解,可以得到 Y_{out} 。在理想状况下:

$$[Y_{out1}, Y_{out2}, \dots, Y_{outN}]^T = [(Y_{out1})_{act}, (Y_{out2})_{act}, \dots, (Y_{outN})_{act}]^T$$

在满足上述条件的基础上进行模型求解,可得到如下解:

表 1 地面状态($H = 0, M_a = 0$)的计算结果

	n_l	n_h	$m_a / (\text{kg/s})$	$m_f / (\text{kg/h})$	f_n / N	P_2 / Pa	T_2 / K	T_3 / K	T_y / K	P_y / Pa
试验数据	100.96	99.03	65.49	3706.00	39348.0	812191	602.73	1180.5	867.50	218907
	97.89	96.76	63.78	3366.40	36397.0	771529	587.22	1131.5	838.90	208662
	94.87	94.66	61.07	3035.10	32861.0	723859	573.00	1090.0	814.00	197782
	91.7	92.63	57.73	2706.00	29019.7	671251	558.27	1049.7	786.40	185024
	89.58	91.32	55.49	2499.40	26525.0	549478	548.00	1022.8	761.26	177825
	83.93	88.06	49.62	2036.33	20813.5	549478	524.50	962.50	723.15	160443
	77.52	81.35	39.21	1375.00	12318.0	403889	475.92	858.76	648.95	135172
自适应模型计算结果	100.96	99.12	65.43	3709.50	39312.0	811413	602.09	1181.6	868.29	218200
	97.89	96.88	63.75	3371.43	36346.0	770893	588.00	1132.6	839.74	208576
	94.87	94.6	61.02	3037.61	32827.0	723282	573.36	1091.5	813.17	197332
	91.70	92.53	57.68	2703.40	28979.0	670606	557.75	1048.8	785.81	185176
	89.58	91.26	55.45	2497.11	26491.0	550059	547.30	1021.9	760.30	177477
	83.93	87.96	49.56	2033.71	20794.0	549046	523.76	961.30	722.63	160155
	77.52	81.46	39.25	1376.50	12333.0	404187	476.43	860.00	649.79	135539
原模型计算结果	100.96	100.4	64.19	4140.00	39190.0	880297	589.00	1280.1	935.40	227216
	97.89	98.15	61.68	3980.00	35985.0	819517	575.79	1241.8	904.80	215262
	94.87	95.84	58.92	3672.00	32403.0	754685	561.45	1197.9	882.20	201992
	91.70	93.27	55.42	2977.00	27927.0	675671	542.90	1140.8	844.50	185480
	89.58	91.63	53.12	2664.00	25074.0	628060	530.60	1101.6	807.30	175249
	83.93	87.87	47.38	2232.00	19043.0	531825	504.24	1018.7	775.50	155191
	77.52	82.78	41.10	1656.00	13687.0	447746	477.88	941.00	712.00	138882

注: 表中符号: n_l 和 n_h 为高、低压转子转速; m_a 和 f_n 为压气机出口空气流量、净推力; m_f 为主燃烧室耗油率; P_2 和 T_2 为压气机出口总压、总温; T_3 为燃烧室出口总温 P_y 和 T_y 为低压涡轮出口总压、总温。

在现有条件下, 一种较好的近似修正方法是利用发动机共同工作点的修正值修正部件特性线上其它各点。

图 2 表征了该建模方法对低压压气机压比特性的修正结果。本文还对不同高度和马赫数的模型进行了自适应修正, 修正结果仍然是满意的, 限于文章篇幅, 本文省略。

从上述仿真结果可以看出, 自适应建模方法可以明显提高原模型的计算精度, 与试验数据相比, 未修正的原模型最大误差达 3.5%, 自适应模型的最大误差 < 0.3%。

用 C 语言编制程序, 在 PENTIUE133 微机上修正出一个工作点, 耗时约 15 ms, 满足实时性要求。

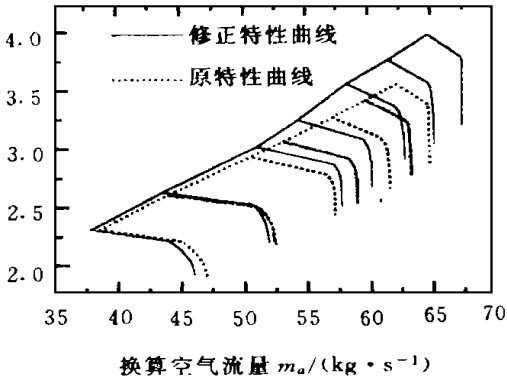


图 2 压气机特性修正曲线示意图

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ANALYTICAL REDUNDANCY BASED ON AUTOASSOCIATIVE NEURAL NETWORK FOR AEROENGINE SENSORS

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ABSTRACT

Analytical redundancy technology based on autoassociative neural network is presented for aeroengine sensors. It doesn't depend on model and needs only the sample net of measurement data without sensor fault to train the network. Then it can work on-line. Estimation Feedback Scheme is developed and can meet the real-time requirements. If there has been performance degeneration of aeroengines, a compensation algorithm can be used automatically. Sensor fault analytical redundancy is accomplished by integrating the network estimation and fault detection logic. The results of theoretical analysis and simulation show that the provided scheme has the ability of distinguishing performance degeneration and sensor faults, and it also can detect soft faults of sensors.

Key Words Aeroengine Neural network Redundancy techniques

TECHNICAL NOTES

ROBUST INTEGRATED FLIGHT/PROPULSION CONTROL DESIGN FOR A STOL AIRCRAFT

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ABSTRACT

An application of robust LQG/LTR control design methodology to a centralized integrated flight/propulsion control (IFPC) system design for STOL/MTD aircraft is presented. The emphasis is put on formulating the Robust Servo LQR (RSLQR) control synthesis problem. A conversion parameter is introduced in controller design to improve the comparability of the system parameters. A detailed evaluation is completed for a controller obtained from RSLQR control design. The results indicate that a RSLQR control design meets the IFPC control system with thrust vectoring.

Key Words Aeroengines Vector control Nozzles

ADAPTIVE MODELLING TECHNIQUE FOR AEROENGINE

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ABSTRACT

An adaptive method for aeroengine modelling is introduced on the

basis of an established original model. A weighing function and a series of correction factors are adopted. The value of the weighing function will be minimized when the correction factors are optimized so that the adaptive correction of the model and the part characteristics is accomplished. In order to validate the feasibility of this method, the test data of a given engine are used to revise its mathematical model and the part characteristics with the method.

Key Words Aeroengines Mathematics model Adaptive control Modelling

BISTABLE STATE OCCURRENCE OF SYMMETRIC SFD—FLEXIBLE ROTOR SYSTEM

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ABSTRACT

The bistable state occurrence has been investigated theoretically for squeeze film damper(SFD) supported flexible rotor system. The bistable state calculation method of the system is presented in detail. The bearing parameter B , stiffness ratio f and unbalance U are chosen to analyze the bistable state performance, and a domain of U (B , f) is obtained. The results show that the bistable state phenomenon can be avoided as long as the value of U beyond the above mentioned domain. This makes it convenient to optimize the SFD design parameters.

Key Words Squeeze film damper Bistable state Rotor system

DIGITAL SIMULATION OF POST- STALL BEHAVIORS OF A COMPRESSION SYSTEM

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ABSTRACT

The post-stall behaviors, such as surge and rotating stall, of a three-stage compressor are simulated based on an one-dimensional unsteady model for the dynamic response of compression system. The variations of the annular average parameters, i. e. velocity, pressure, temperature and flow coefficient, can be obtained from the simulation. The stall types can be identified by these parameters vs. time. In addition, the effect of parameter "B", proposed by E. M. Greitzer, is analyzed.

Key Words Axial compressors Stall Digital simulation