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改进的畸变极值预测法

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一、参数估计中的二阶导数修正

1. 极值预测基本方程 根据文献[1]，在已知动态压力畸变指数D的概率分布P(y)时，预测时间为T内的最大瞬时压力畸变由下式给出

$$D_{max} = P^{-1}\left\{[N/(N+1)]^{\frac{1}{m}}\right\} \quad (1)$$

其中$N = T/\Delta T$为预测时间的分段数，ΔT为单位时间段，m则为ΔT内对D的采样次数。

当D的概率分布未知时，最大瞬时压力畸变则由(2)或(3)式给出

$$D_{max} = a_2 + t/a_1 \quad (2)$$

$$D_{max} = \alpha/\beta - [\alpha/\beta - \gamma]e^{-\beta t} \quad (3)$$

$$t = -\ln[-\ln F(D_{max})] = -\ln\{-\ln[N/(N+1)]\}$$

其中F(y)为对应于(2)或(3)式的Ⅰ、Ⅲ型极值渐进函数[2]。至此，预测最大瞬时压力畸变的核心问题转为用实验数据对a_1、a_2或α、β、γ的估计。本文着重讨论较难的三参数估计问题。

2. 文献[1]参数估计法中的问题 文献[1]采用极大似然法对参数进行估计，求解过程为高斯——牛顿迭代计算。输入畸变指数的极大值序列y_1，y_2……，y_n，得到对数似然函数。

$$L = \ln\left[\prod_{j=1}^{n}\left(\frac{d}{dy}F(y_j,\ X)\right)\right] X = (\alpha,\ \beta,\ \gamma)' \quad (4)$$

极大似然参数估计方程与最小二乘问题则分别为(5)与(6)式

$$H = (H_1,\ H_2,\ H_3)' = \partial L/\partial\alpha,\ \partial L/\partial\beta,\ \partial L/\partial\gamma)' = 0 \quad (5)$$

$$\Phi = \sum_{j=1}^{3} H_j^2 = 0 \quad (6)$$

针对(6)的高斯一牛顿迭代计算则为

$$P_k = -[DH(X_k)'DH(X_k)]^{-1}DH(X_k)'H(X_k)$$

$$X_{k+1} = X_k + \omega_k P_k \qquad (k = 0,\ 1,\ 2,\ \cdots\cdots) \quad (7)$$

其中　$P_k = (\Delta\alpha,\ \Delta\beta,\ \Delta\gamma)'k$　　$DH(X_k) = \begin{pmatrix} \partial H_1/\partial\alpha & \partial H_1/\partial\beta & \partial H_1/\partial\gamma \\ \partial H_2/\partial\alpha & \partial H_2/\partial\beta & \partial H_2/\partial\gamma \\ \partial H_3/\partial\alpha & \partial H_3/\partial\beta & \partial H_3/\partial\gamma \end{pmatrix}_{X = X_k}$

而ω_k则满足　$\Phi(X_{k+1}) < \Phi(X_k)$　(8)

$$\omega_k = \min_{\omega} \Phi(X_k + \omega P_k) \quad (9)$$

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由文献〔3〕知，高斯—牛顿解（7）存在着类似于牛顿法的截断误差

$$R=\frac{1}{2!}\left(P_k^1\cdot\nabla\right)^2 H\left(X_k+\Lambda P_k\right) \tag{10}$$

$$\Lambda=\begin{pmatrix}\lambda_1 & 0 & 0\\ 0 & \lambda_2 & 0\\ 0 & 0 & \lambda_3\end{pmatrix} \qquad 0<\lambda_1,\ \lambda_2,\ \lambda_3<1$$

故当初值X_0偏离（7）式的收敛解X^*稍大时，R就有不可忽略的影响，虽加ω_k一维搜索，但敛速下降且仍有发散现象存在。

3. **二阶导数修正矩阵**　对（10）式中所有二阶导数均以前后二次迭代中相应的一阶偏导数的差分表示

$$\left(\frac{\partial^2 Hi}{\partial\alpha^2}\right)\Delta\alpha^2\cong\left[\left(\frac{\partial Hi}{\partial\alpha}\right)_{k+1}-\left(\frac{\partial Hi}{\partial\alpha}\right)_k\right]\Delta\alpha \quad i=1,\ 2,\ 3 \tag{11}$$

首先由（7）式计算出$\hat{P}_k=(\Delta\hat{\alpha},\ \Delta\hat{\beta},\ \Delta\hat{\gamma})$，利用（11）式，可得到对称的二阶导数修正矩阵

$$S_k=\frac{1}{2!}\begin{pmatrix}S_{\alpha\alpha} & S_{\alpha\beta} & S_{\alpha\gamma}\\ S_{\beta\alpha} & S_{\beta\beta} & S_{\beta\gamma}\\ S_{\gamma\alpha} & S_{\gamma\beta} & S_{\gamma\gamma}\end{pmatrix} \tag{12}$$

其中

$$S_{\alpha j}=(\hat{H}_{1j})_{k+1}+(\hat{H}_{1j})_{\Delta\hat{\beta}}+(\hat{H}_{1j})_{\Delta\hat{\gamma}}-3(H_{1j})_k$$

$$S_{\beta j}=(\hat{H}_{2j})_{k+1}+(\hat{H}_{2j})_{\Delta\hat{\alpha}}+(\hat{H}_{2j})_{\Delta\hat{\gamma}}-3(H_{2j})_k$$

$$S_{\gamma j}=(\hat{H}_{3j})_{k+1}+(\hat{H}_{3j})_{\Delta\hat{\alpha}}+(\hat{H}_{3j})_{\Delta\hat{\beta}}-3(H_{3j})_k$$

$$j=\alpha,\ \beta,\ \gamma$$

下标j表示H分别对α、β、γ的偏导数，而$\Delta\hat{\alpha}$、$\Delta\hat{\beta}$、$\Delta\hat{\gamma}$则分别表示$(\hat{H}_{ij})$中只增加相应的单增量

$$(\hat{H}_{ij})_{\Delta\hat{\alpha}}=H_{ij}(\alpha_k+\Delta\hat{\alpha},\ \beta_k,\ \gamma_k) \qquad i=1,\ 2,\ 3$$

则

$$R\cong S_k\cdot P_k \tag{13}$$

代入（7）式得到改进后的高斯—牛顿迭代计算

$$\hat{P}_k=-[DH(X_k)'DH(X_k)]^{-1}DH(X_k)'H(X_k)$$

$$\hat{X}_{k+1}=X_k+\hat{P}_k$$

$$P_k=-[(DH(X_k)+S_k)'(DH(X_k)+S_k)]^{-1}(DH(X_k)+S_k)'H(X_k) \tag{14}$$

$$X_{k+1}=X_k+\omega_k P_k$$

二、预测与实验结果分析

1. **算例**　结合最大瞬时压力畸变的预测，根据六组实验数据对两种算法进行了比较。采用修正算法(14)，当$\|P_K\|$较小时就不再修正。图 1 表明改进了的修正算法(14)式较高斯—牛顿法（7）收敛速度有很大提高。虽按(14)式进行的每步迭代计算量较（7）式增加，但由于总收敛次数减少，计算机时（CPU）仍减少约30%。

2. **已知畸变指数分布P(y)时的预测**　输入预测时间T、发动机截止频率f_c及分析采样频率f_s，将所需预测时间长度T分成N段，每段长$\Delta T=T/N$，含m个数据

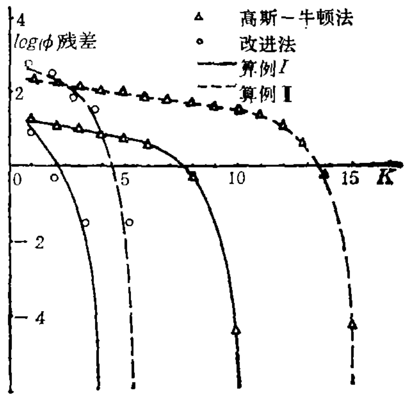

图 1　两种迭代方法收敛速度比较

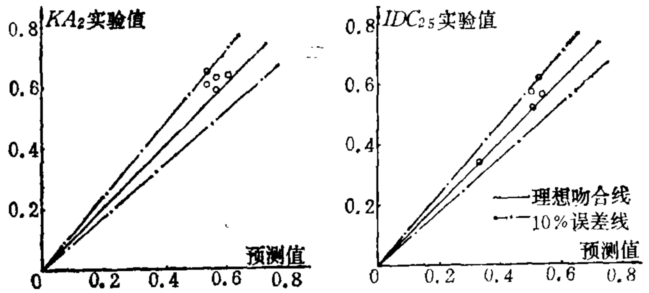

图 2　已知畸变指数分布的预测与实验结果

$$m = T \cdot fs/N \tag{15}$$

采用文献〔4〕方法输入畸变极值小样本，据此判定分布属性及参数，然后由(1)式预测出 T时间内的最大瞬时压力畸变D_{max}。

由于预测时T、fc、fs为定值，可供选择的唯一参数是N，由(1)式右端及(15)式可知，当N增大时，m按(15)式关系减小，故(1)的右端变化不大，因此N的选择比较任意。

图 2 为采用IDC_{25}与KA_2畸变指数（权数为1.0)时实验与已知分布预测对比，预测同实验符合较好。图上预测值低于实验值，主要受到文献〔4〕方法的一些影响，此外，样本不一定独立以及分布判断误差也有一定影响。采用已知分布的预测公式(1)所需机时甚少。

3. 畸变指数分布未知时的预测　确定T、fc、fs、N，用文献〔4〕方法输入小样本后产生40个极大值（每个极值对应一个ΔT),用(14)式估计出(2)或(3)式中参数，随即由(2)或(3)式预测T时间内的最大瞬时压力畸变。用文献〔4〕的方法避免了文献〔1〕中必须采用实验极值输入（需专用实时处理机）的缺点。

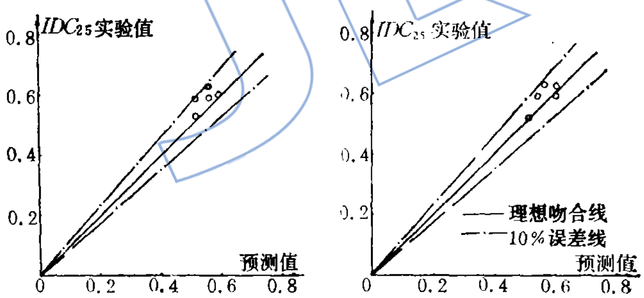

图 3　I 型和 III 型极值分布的预测与实验结果

图 3 分别给出了 I 型极值分布预测公式(2)与 III 型公式(3)的实验与预测结果比较。其中用(2)式预测的结果较(3)式预测的稍好，这进一步说明本实验中的畸变指数分布是属于指数函数类型的。图上的预测值亦低于实验值，这与文献〔4〕方法对畸变指数的实验随机特征进行了模拟有一定关系。对于其它各种复杂畸变情况，(2)、(3)式的适用性尚有待更多的验证。

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EXPERIMENTAL INVESTIGATION ON TEMPERATURE FIELDS IN THREE-DIMENSIONAL SWIRLING COMBUSTOR

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Abstract

This paper introduces the experimental results of temperature fields in a model combustor with a swirler and primary holes. Acetylene is used as gaseous fuel. Under several steady conditions the temperature distributions in primary combustion zone are measured by a pyrometer. The experimental results reveal the effects of air-fuel ratio, primary holes and secondary holes on the temperature distributions in the combustor.

PROBLEM OF FILTER POSITION IN THE PREDICTION OF MAXIMUM INSTANTANEOUS DISTORTION

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Abstract

Fluctuating pressure filtering in Motycka method of predicting maximum instantanneous distortion is modified by instantaneous distortion filtering. Comparison and analysis of the statistical properties of the instantaneous distortion and its maximum value with different filtering position are carried out. Relationships between the results obtained by the mentioned methods are established. It is shown that fluctuating pressure filtering in Motycka method can be modified by instantaneous distortion filtering to predict the maximum instantaneous distortion values and computing time can be greatly reduced.

AN IMPROVED METHOD FOR PREDICTION OF MAXIMUM TOTAL PRESSURE DISTORTION

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Abstract

Jacocks' method has been improved by deriving a difference correction matrix of second derivatives for Gauss-Newton iteration method. The numerical tests justify that the improved method enables the calculation to converge more rapidly and reduces the CPU time. The combination of the distortion prediction described in reference[4]with Jacocks' method avoids the necessity of experimental extreme values as input data for the Jacocks' method. The comparison of the distortion prediction results with the experimental data demonstrates better agreement.

APPLIED PROGRAM OF IDENTIFYING TRANSFER FUNCTION

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Abstract

The algorithm and the computer program TFIP used to identify the transfer function models from experimental freguency response data are presented. It is also considered how the selection of the model orders, the selections of the equation error and real error tolerance, and the modes for updating weight coefficients affect the convergent speed and identification results. The new term rejection criterion and the method for updating weight coefficients by variable mode are proposed, the former can simplify the program, and the latter may greatly accelerate the convergence of the weight coefficients.

A SCHEME OF CONDITION MONITORING AND MAIN FAULTS DIAGNOSING SYSTEM FOR A TURBOJET ENGINE

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Abstract

In order to enhance the ability of diagnosing faults and improve maintenance,we develop a condition monitoring and main faults diagnosing system for a turbojet engine. The whole system is divided into two sub-systems: the engine operation monitoring and the ground computer data processing. The former is used for analysing engine performance tendency and diagnosing some main faults in the engine, i.e., engine-surge, exceeding drop rpm, auto-flameout and so on. Inaddition, it can record the parameters at take-off or before and after fault occurs. When faults take place in the engine, it can also give pilots warning. The latter is used for analysing reasons of faults and estimating engine performance tendency.

MATHEMATICAL MODELLING AND DYNAMIC ANALYSIS OF A BOOSTER STATION DRIVEN BY WZ5G AEROENGINES

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Abstract