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激光微粒影象数字处理技术的探讨

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一、前 言

激光显微摄影和激光全息摄影测粒技术在工程中应用的最大障碍是微粒影象的处理，由于激光摄影测粒技术含有的信息量很大，人工判读既费时，结果还受检测者的视差、熟练程度、疲劳情况等诸多因素的影响。特别当微粒离焦时，人工判读只能将其舍掉，无法加以利用。然而，在激光摄影测粒中，存在着大量的离焦微粒影象，可以根据三维判读技术加以利用[1]。因此需要解决激光微粒影象的图象处理技术。

二、微粒影象处理中要解决的问题

激光显微摄影记录的微粒影象以及全息摄影再现的微粒影象统称为激光微粒影象后，影象的记录过程和特征详见文献 [2]。

微粒影象的处理过程是将摄影得到的光学图象经数字化器转化为数字图象后，利用计算机处理和提取微粒场分布的信息。

图象处理首先要解决的是噪音问题，获得清晰的光学图象是保证具有良好信噪比的一个重要因素。在激光摄影的记录或再现过程中，减小噪音的一个重要手段是使记录和再现光场均匀一致。由于激光束光强分布呈高斯特性，可以利用针孔滤波器滤波以获得均匀光场，一般针孔为 100μm 左右便能得到较好的滤波效果。有时采用数字滤波方法来进一步消除噪音。

图象处理的第二个问题是影象的判焦和离焦影象的处理。通常用影象边缘的光强阈值和光强变化率阈值来确定微粒的在焦性，并将离焦影象舍掉。这种处理中，光强阈值及其变化率阈值的选择很重要，将直接影响测量结果的准确度，一般通过实验确定这两个阈值。

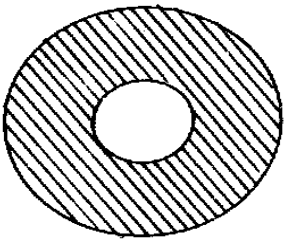

图 1 微粒影象示意图

图象处理要解决的最重要问题是影象边缘点的搜寻，这是其它问题，如影象的在焦性，微粒大小等的基础。

为了说明影象边缘的搜寻方法。首先看一下光学图象到数字图象的转化过程。图 1 是激光微粒影象典型特征的示意图，图中阴影线部分表示微粒影象，空心部分为中心亮斑。

微粒影象经数字化扫描后，生成一幅数字图象，即一组二维灰度级的数据。显然，影象的中心亮斑边缘及影象外径边缘(均以标准化光强为0.5确定[1])的灰度值同其它位置的灰

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度值具有明显的区别。理论上，二者灰度值应为介于最大和最小灰度值的 1/2，实际上是以某一灰度值范围确定的，否则会出现图象边缘的不连续情况，给图象处理带来麻烦。

处理微粒影象时，需要完成以下几个过程：(1) 判别哪些点是同一微粒的影象边缘？由于图象采集中粒子影象分布在各个区域。因此首先要将不同微粒的影象之中心亮斑和影象外边缘点逐个分开，使同一影象的中心亮斑边缘和影象外边缘点各为一点集。这便是影象边缘的搜寻；(2) 如何判别和处理微粒间的相互碰撞情况？(3) 当影象处于采样边界时怎样处理这种情况？(4) 根据某一小范围的灰度值搜寻影象的中心亮斑及外边缘点时可能会出现不连续情况，如何解决这一问题？上述这些问题是影象边缘的搜寻过程中同时考虑的问题。

三、微粒影象边缘的搜寻方法—边缘追踪法

边缘追踪法是搜寻微粒影象中心亮斑边缘及外边缘点的方法，以图 2 来说明，图中仅画出微粒影象的一部分。

假设找到某一微粒影象的一个边缘点 A，那么，可以逆时针单方向追踪与 A 点毗邻的点 B、C、D，判别哪一点满足边缘条件。当得到 D 点为边缘点时，又以 D 为新的搜寻中心点寻找下一个边缘点。如此反复进行，直至完成一个循环为止。如果存在粒子间相互碰撞情况，那么根据收集到的这组外边缘点求得的粒子非圆度将较大，这时，应将这组数据舍掉，以保证结果的可靠性。当出现影象边缘点不连续时，即在某点毗邻点中没有符合边缘条件的点时，应该将搜寻点加以扩充。以图 2 说明，如果图中点 A 的单方向三个毗邻点 B、C、D 不满足边缘条件，则以 B、C、D 为中心，以它们各自的相邻点 E、F、G、H、I 这五点作为搜寻点。发现满足边缘条件时，以所寻得的点为起点继续搜寻，有时还需要重新选定边缘点的灰度范围，以保证追踪法顺利进行。实际处理中，还可能出现影象处于采样边缘上，此时，应去掉当前搜寻的微粒影象。最后要解决的是中心亮斑边缘点的搜寻。当完成了某一微粒影象外边缘点的搜寻以后，也采用上述方法，以该影象边缘为界搜寻中心亮斑边缘点。

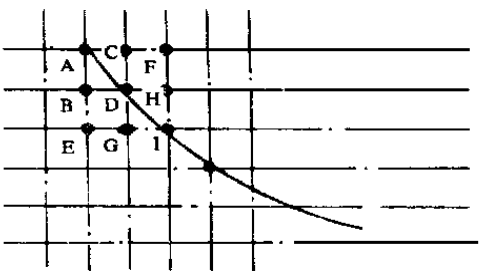

图 2　边缘追踪法示意图

四、激光微粒影象的处理过程

采用边缘追踪法搜寻微粒影象的内外边缘点，提取粒子场尺寸、分布等信息的步骤如下：

(1) 搜寻影象外边缘的一个完整点集，确定影象所包围的面积 S_1 和周长 l，由 S_1 及 l 确定非圆度，判断是否发生碰撞，(若发生碰撞、放弃当前的影象，重新搜寻新的影象边缘) 求出影象外径 $d'_{0.5}=2\sqrt{S_1/\pi}$；

(2) 搜寻中心亮斑的边缘点集，确定其占据面积 S_2 和中心亮斑直径 $d_{0.5}=2\sqrt{S_2/\pi}$，求出比值 $R_1=d_{0.5}/d'_{0.5}$；

(3) 根据 R_1 与 F 之关系曲线确定远场数 F[1]，如果 F 小于 0.3，则以对比度为 0.25 值确定微粒尺寸[2]；(4) 由 F 与比值 $R_2=d/d'_{0.5}$ (d 为待测粒径) 的关系确定 R_2，并求出微粒直径 $d=R_2/d'_{0.5}$[1]；确定粒子到焦面的距离 $Z=d^2/\lambda F$，其中 λ 为光波波长。

处理完一幅图象的所有微粒影象后，进行下一幅图象的处理，最后确定出粒子场的统计特性。

五、讨 论

根据上述方法，本文设计了微粒影象的图象处理程序，并在微机上调试运行。图象处理系统的采样象素为 256×256，灰度等级是 256。由于这套系统的摄象机镜头的空间分辨率较低，不能满足实际微粒影象处理的要求。为验证上述方案的可行性，本文暂不考虑实际微粒场的情况，人为地绘制激光微粒影象图进行处理。实验上，当具备高分辨的图象处理系统时，处理过程同这种模拟方法完全一样。

在绘制激光微粒影象时，选用直径为 746μm，记录距离为 0、100、200、400、800、1400、1800mm 情况的影象，放大 20 倍绘制而成。处理结果如表 1 所示，其中 $No.$ 1 到 $No.$ 7 分别表示上述记录距离的情况。

表 1 图象处理求出的粒径和位置

No.	1	2	3	4	5	6	7
d (μm)	733	703	737	754	765	759	774
误差 Δ_1 (μm)	13	43	9	8	19	13	28
Z (mm)	0	72	181	417	832	1457	1872
误差 Δ_2 (mm)	0	28	19	17	32	57	72

由上表看出，在记录距离较小时，由于中心亮斑较小，相对误差较大，因此求得的粒径和记录距离的相对误差也较大。这种情况下，如果采用在对比度为 0.25 位置直接判读，效果会有所改善[2]。

从上述对模拟微粒影象的处理结果看到，本文发展的边缘追踪法和拟定的处理方案是可行的。处理速度也较快，通常只需十几分钟便能完成一幅图象的处理，这与影象的密度等因素有关。

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[3] 郭业娅，“宝石轴承图象的自动检测方法和软件实现”，西北工业大学硕士论文，1987 年 3 月。

turbulence generator, in result the examinatorial pattern was successfully simulated. Practice of its applicalion proves that the simulation poles are simpler, less consumptive in energy and man-hour and more accurate in simulation than the traditional distortion screen.

FUZZY CLUSTERING ANALYSIS OF GAS TURBINE ENGINE MISSION PROFILES

Cheng Dejing (*Chinese Flight Test Establishment*)

ABSTRACT In order obtain engine mission profiles from a vast amount of flight test, the fuzzy matrix of the membership function of engine mission profile samples is established according to the theory of fuzzy sets and boolean algebra behaviours. The fuzzy matrix is examined by using sqaure method for meeting the equivalent conditions. When it meets equivalent conditions, the dynamic clustering is carried out by selecting various threshold values. The clustering analysis of the mission profiles for an actual engine has been completed by the complicated and enormous fuzzy caleulation based on statistical data of the engine loads measured in fiight test. The clustering method of three parameters (flight altitude, Mach number and angle of throttle lever) is first employed in the clustering analysis and the results abtained are satisfactory.

AN ACOUSTIC METHOD FOR MEASURING CHARACTERISTICS OF ROTATING STALL IN A COMPRESSOR

Sun Xiaofeng, Hu Xongan, Feng Yucheng, Zhou Sheng
(*Beijing University of Aeronautics and Astronautics*)

ABSTRACT According to analysis of the characteristics of frequency and propagation of the sound generated by the rotating stall, an acoustic measuring method is developed, in which the characteristic parameters, such as the number and propagation speed of stall cells, are measured. Compared with existing methods, this method is a untouched measurement so as to avoid not disturb ance of the flow field . The primary experimental results obtained on a transonic axial-flow compressor facility demostrate the feasibility of this method.

EXPERIMENTAL INVESTIGATION ON JET NOISE

Zheng Keyang and Gui Xingmin (*Beijing University of Aeronautics and Astronautics*)

ABSTRACT The correlation of sound power with jet velocity is studied in this paper. It is indicated that Both Lighthill's and Lilley's formulas fit experimental data very well when Mach number of jet Maj> 0.4, but the diviation between the results obtained from the formulas and experimental data is not so negligible as Maj< 0.4. The authors propose substituting sixth power of the jet velocity instead its eighth power in the formulas. The direction sensitiveness and the frequency spectrum of jet noise have been investigated enperimentally.

TECHNIQUE FOR DIGITAL PROCESSING OF COHERENT IMAGES OF PARTICLES

Fang Jinyan, Yan Chuanjun and Wang Hongji (*Northwestern Polytechnical University*)

ABSTRACT An approach, known as Edge Tracking Method, has been developed in particular, which searches out the outer edge and the central spot edge of the coherent image of a particle. The processing procedure of the digital images and its program have been worked out in detail. Finally, the outer size and the central size a particle image are determined by means of the presented technique, then the particle size and its position are calculated by means of the Three-Dimensional Judgement Technique. The results obtained are reasonable.

A DISTRIBUTED FIVE-HOLE PROBE RAKE ON STATOR BLADES FOR ROTOR EXIT MEASUREMENT OFA COMPRESSOR

Lin Qixun, Shi Chunying, Pan Gengsen (*Northwestern Polytechnial University*)

ABSTRACT Each tube of five-holes probe will be placed at the same radius on five different blades of stator. The diameter of the probe and the wall proximity effect are decreased. The distributed five-hole probe rake has been verified experimentally. Its dynamical frequency response is enhanced seven times. Its characteristics are improved. The parameter measurement of each rotor exit in a multistage compressor becomes practicable.

EFFECTS OF ASPECT RATIO ON CASCADE PERFORMANCES

Li Ly and Yan Ruqun (*Norhwestern Polytechnical University*)

ABSTRACT An experimental research of compressor cascade performances has been completed in the conditions of varing aspect ratios (AR). The results show that AR has a significant influence on cascade losses, pressure ratios and blade loads. Furthermore, the correlations of cascade performance parameters with AR, cascade geometric and aerodynamic parameters are derived. The comparative analysis between the calculated results and the experimental data show that the correlation reveals the rules of variation of cascade performance parameters with the aspect ratio.

EFFECT OF ABRUPT INLET DISTORTION ON ENGINE STABILITY

Wang Xiaofeng (*Chinese Flight Test Extablishment*)
Wang Naixing (*Northwestern Polytechnical University*)

ABSTRACT The unsteady response of a compressor to abrupt change of inlet temperature has been calculated by numerical integration with the "actuator-volume" and the second order delay models. The calculated results are compared with flight test data favourably. The unsteady response of the compressor to abrupt change of inlet pressure (or combined with inlet temperature) has also been calculated in the same manner. The calculated results show that the effects of the abrupt inlet pressure on compressor stability cannot be ignored.