Real time monitoring of coating status for microsphere target with digital image difference method

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Digital image difference method monitorring coating status of microsphere targets automatically is suggested. A CCD micro-imaging system is developed for monitoring the status of bouncing and adherence between microspheres and the bouncing pan. A new bouncing pan with multiple holes is adopted for microsphere coating to enhance the microsphere coating efficiency.

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The success of the laser fusion will provide endless energe resource for the human being. One of the important technique in the laser fusion is the fabrication of microsphere target with diameters of $0.1 - 0.3$ mm. In order to absorb laser energy efficiently, a low z organic film is needed on the surface of the microsphere. The plasma polymerization method is generally adopted with deposit rate of about 1 μm/h and deposit time of over 100 hours. The microspheres must be in levitation and rotate with the change of barycenter in order to get a uniform and glossy surface. An advanced bouncing pan coating technique in which microspheres are bouncing constantly in a bouncing pan has been adopted widely[1]. Nevertheless, because of static electricity incurred by plasma cloud in the plasma coating chamber adherence between the microsphere and the bouncing pan or among microspheres appears occasionally, which destroys the condition of uniform coating. Hence it is necessary to monitor the coating status incessantly and get rid of the adherence in time.

Digital image difference method for monitoring the coating status has been suggested. At the same time a multi-hole bouncing pan and a set of optical installation[2] which can perform real-time monitoring of coating status by means of CCD micro-imaging system and computer digital image processing system have been developed.

As shown in Fig. 1, microspheres are placed in the bouncing pan at the center of vacuum chamber. There

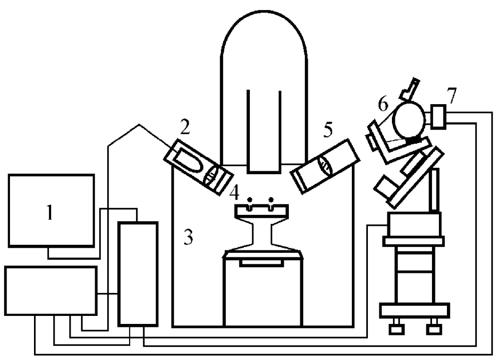

Fig. 1. The monitoring system used for microsphere coating. 1: PC; 2: Illuminator; 3: Vacuum chamber; 4: Bouncing pan; 5: Image converting objective; 6: Zoom microscope; 7: CCD.

are two rows of hemispherical holes on the center of the bouncing pan surface. Altogether there are 20 holes, and each hole holds one microsphere so as to avoid adherence microspheres. The digital images of microspheres are obtained by CCD micro-imaging system and computer digital image storage and processing system. The CCD micro-imaging system is composed of an image converting objective and a zoom microscope objective. Firstly, the entire view of the two rows of hemispherical holes together with the microspheres is imaged outside the vacuum chamber and near the chamber window by the image converting objective. Then the first image is re-imaged at the CCD receiver by the zoom microscope objective which circularly scans the holes on the first imaging surface one by one, so each hole with microsphere in it can be monitored respectively. The period of scanning the whole field is within 2 minutes. The analog images received by CCD are converted into digital images through video a blaster. These digital signals are divided into two sections. One for displaying real-time images transmits to the computer monitor and the other is stored in memory or hard disk of the computer finally.

Comparing with other recognition technitques, the digital image difference method, in which the background noise can be diminished effectively is used to monitor and control the coating status automatically. At the same time, the regular algorithm of average square difference[3] is replaced by a non-linear stretching algorithm of average cube difference in order to enlarge the difference between bouncing and adherence status of microspheres. The non-linear stretching algorithm of average cube difference is shown as follows

$$D_i = \frac{1}{N_1 N_2} \sum_{j=1}^{N_1} \sum_{k=1}^{N_2} |X_{jk} - Y_{jk}|^3 \quad i = 1, 2, \cdots. \qquad (1)$$

A real-time image is represented as $N_1 N_1 \times 1$ dimensional vector. X_{jk} and Y_{jk} represent values of the ikth pixels of two images respectively. The key of recognition is to analyze and confirm D_i's matching probability between bouncing and adherence status. The shell of microspheres can be made of either polymer or glass, i.e. polymer microspheres or glass microspheres. According to experiments, when placed in a favorable position, such as the center of bouncing pan, either polymer microsphere or glass microsphere can get nice illumination, and the D_i distributions of bouncing and adherence status have extensive deviation. Thereby it is easy to determine a judging threshold.

But for positions which cannot get well illumination, such as the edge of bouncing pan, the D_i distributions are greatly influenced by the decreasing of image contrast. For polymer microspheres, the D_i distributions of the two statuses still have enough deviation, so a reasonable judging threshold can be determined. But for glass microspheres, the most part of images shows dark background color because of the transparent material of microspheres. When the bouncing height of a microsphere is quite low, difference of the pixel values between adherence and bouncing is small, even without difference. Therefore the two D_i distributions overlap. In order to ensure recognition of microsphere status, average square difference S_j of 4 continuous D_i is calculated. That is

$$S_j = \frac{1}{4}\sum_i \left| D_i - \frac{\sum D_i}{4} \right|^2 . \quad (2)$$

Comparing S_j with D_i, greater deviation can be found. Thus S_j can be used for determining a judging threshold for either polymer microspheres or glass microspheres. Futhermore the period of scanning 20 holes is still less than 2 minutes.

An example about determining threshold is given below. Figure 2 shows the dynamic images obtained by CCD. In Fig. 2(a), the hole (left) No. 5 which gets well illumination is at the center of the bouncing pan and the hole (right) No. 19 which gets poor llumination is at the edge of the pan, and in each hole there is a polymer microsphere. When glass microspheres take the place of polymer microspheres, the contrast of microsphere images decrease obviously as shown in Fig. 2(b). Figure 3 shows the D_i distribution of glass microsphere. When the glass microsphere placed in hole No. 5 is in bouncing status, the D_i distribution which includes 100 times of non-linear stretching calculation is shown as the upper curve in Fig. 3(a). When the glass microsphere placed in hole No.5 is in adherence status, the D_i distribution is shown as the lower curve in Fig. 3(a). There

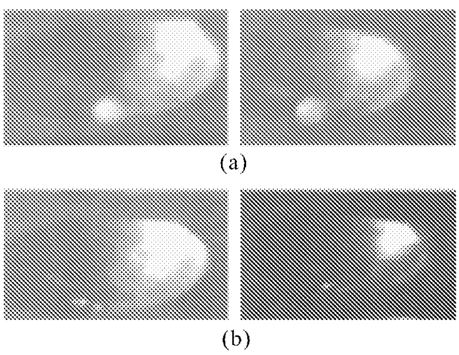

Fig. 2. Images of microspheres placed in different hole of bouncing pan obtained by CCD. (a) Hole No. 5 (left) at the center of bouncing pan and No. 19 (right) at the edge of bouncing pan. In each hole there is a polymer microsphere. (b) Hole No. 5 (left) at the center of bouncing pan and No. 19 (right) at the edge of bouncing pan. In each hole there is a glass microsphere.

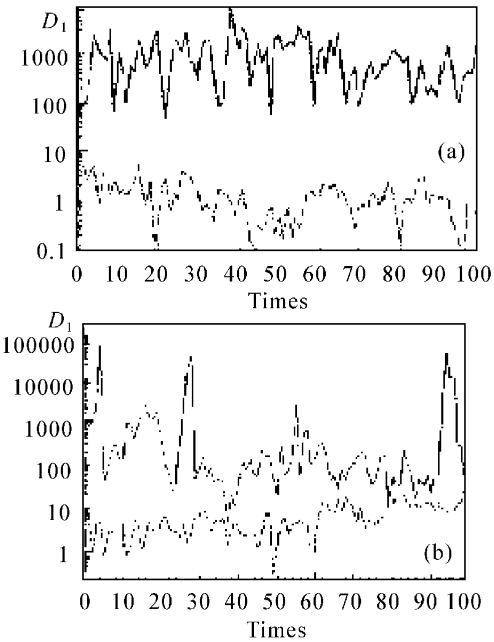

Fig. 3. D_i distributions of glass microspheres. (a) D_i distributions of glass microsphere placed in No. 5 hole. (b) D_i distributions of glass microsphere placed in No. 19 hole.

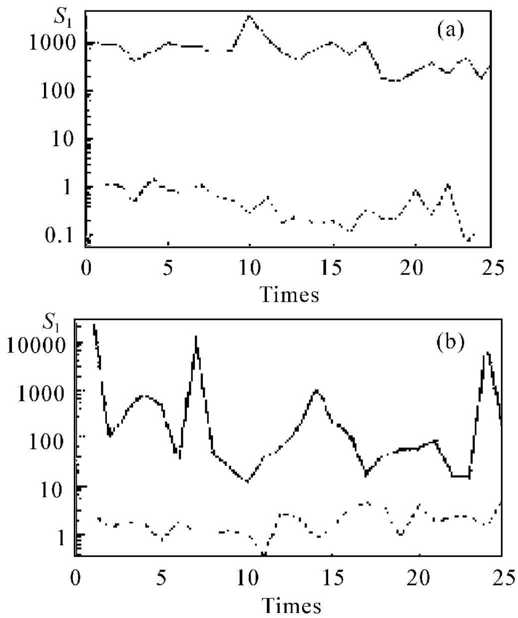

Fig. 4. S_j distributions of glass microspheres placed at different positions of the bouncing pan. (a) S_j distributions of glass microspheres placed in No. 5 hole. (b) S_j distributions of glass microsphere placed in No. 19 hole.

exists sufficient deviation between the two distributions of different statuses, and thus the judging threshold could be selected as between 5.58968 and 45.8949. When a glass microsphere is placed in hole No. 19, the D_i distributions of bouncing and adherence statuses are shown as the upper and lower curves in Fig. 3(b), respectively. Obviously, the two D_i distributions are overlapped. Corresponding S_j distributions are calculated as shown in

Fig. 4. Figure 4(a) shows the S_j distributions calculated from $100D_i$ values of the glass microsphere placed in hole No. 5. Similarly Fig. 4(b) shows the S_j distributions of the glass microsphere placed in hole No. 19. The deviations of the S_j distributions of bouncing and adherence in Fig. 4 are both enlarged markedly whether the glass microsphere can get well illuminance or not. Thereby it is easy to select a threshold. For glass No. 5 microsphere the S_j threshold can be selected between 1.4 and 154, and for No. 19 the S_j threshold can be selected between 4.6 and 11.5. We have selected value 7.3 as a threshold for recognising the coating status of glass microspheres.As for polymer microspheres, either D_i or S_j can be adopted since all the images have well contrast, and finally S_j has been selected. When S_j value 7.3 is used for either glass microspheres or polymer microspheres, the monitoring experiments show that the misjudgement of either glass microspheres or polymer microspheres is zero in 4 consecutive hours of monitoring.

Firstly, the real-time images of microsphere target in the coating process are processed by means of nonlinear stretching difference algorithm. the data are calculated by means of average square difference method group by group. Thus a judging threshold of bouncing and adherence statuses can be obtained easily. Since the S_j distributions obtained show large deviation between the two statuses, the misjudgment in the long period of the entire coating process can reach zero. Using the monitoring system the efficiency of laser fusion target microsphere coating has been greatly enhanced.

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