A New Containerless Image Furnace with Electro-static Positioning Device

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ABSTRACT

A new containerless image furnace with a microwave discharge plasma lamp and electro-static positioning device is developed for the use of the microgravity experiment on the Japanese experimental module (JEM).

The electrostatic positioning system was tested under the reduced gravity environment in the MU-300 aircraft. Solid specimens (maximum weight is 1.3 gr and 10 mm in diameter) and water drops (maximum weight is 0.11 gr and 6 mm in diameter) were successfully controlled under the 0.02G environment.

Rotation control of the dielectric specimen was also possible by means of supplying a rotating electric field while the specimen is levitating. The measured rotation speed of the glass shell specimen (0.08 gr, 10 mm) was up to 110 rpm, when the rotating field frequency was 6 Hz.

INTRODUCTION

A fuzzy reasoning electrostatic positioning system of the containerless image furnace is developed. The electrostatic positioning is first developed at JPL[1] and many types of electrode configurations have been studied. One of the features of the electrostatic positioning is its potential for the low level acceleration control. The acceleration level of the specimen can be easily adjusted depending on the feed back control rules. To isolate the specimen from the vibration of the positioning chamber, a free floating region concept is suggested by JPL[1]. Another feature lies on its capability of handling various materials.

This system is tested under the reduced gravity environment and various specimens are successfully controlled. The free floating concept is also tested adjusting the membership functions used in the fuzzy reasoning.

ELECTRO-STATIC POSITIONING SYSTEM

Outline of the Positioning System

Figure 1 shows the configuration of the positioning system[2]. From the requirement for the configuration with the imaging mirror, a ring type electrode is chosen for our positioning system. The ring type electrodes are used to control the vertical and the radial components of the electric field. The electric potential between the electrodes is derived as follows:

$$\phi = a_1 z + a_2\left(z^2 - \frac{1}{2}r^2\right) + C \tag{1}$$

where the first term is the dipole component, the second term is the quadruple component, and C is the other high order components.

The electric field can be obtained from $E = \mathrm{grad}\,\phi$, thus,

$$E_z = -\frac{\partial\phi}{\partial z} = a_1 - 2a_2 z \tag{2}$$

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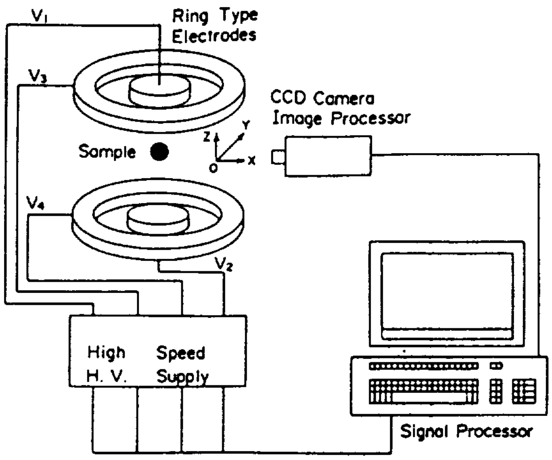

Fig. 1 Configuration of the electrostatic positioning system

$$E_r = -\frac{\partial \phi}{\partial r} = a_2 r \qquad (3)$$

$$E_\theta = -\frac{1}{r}\frac{\partial \phi}{\partial \theta} = 0 \qquad (4)$$

The motion equation of the charged specimen on the flame of the control system is given by

$$m\frac{d^2x}{dt^2} = qE + F \qquad (5)$$

where m is the mass of the particle and F is the external force such as residual gravity.

When the quadruple component (a2) appeared in eq. (2) and (3) is a negative value, a feedback system of the electric field is necessary for the position control in the z direction.

A CCD camera (120 Hz) is set on the horizontal plane to monitor the position of the specimen and a fast high voltage power source with high resolution (1kV/1ms, 12 bit, 4 ch) is used as a voltage supply of the electrodes.

Fuzzy reasoning is performed as the feedback calculation at a fuzzy processor in the control computer. The positioning error and the velocity of the specimen are chosen as the fuzzy inputs and control voltages of 4 electrodes are obtained as the reasoning result. The calculation time of the reasoning is no more than 1 ms (4 inputs, 4 outputs with 17 rules), and is enough shorter than the control cycle which is restricted by the transport rate of the position data from the CCD camera (8.3 ms). Parameters of the positioning system are listed in the table 1.

Table 1. Parameters of the positioning system

Electrode	gap width inner electrode dim. outer electrode dim.	20 mm ~ 40 mm 40 mm 80 mm
Voltage source of positioning	max. output rise time outputs accuracy	10 kV 4 ms 4 ch ~1%
Voltage source of rotation	max. output frequency	3 kV 0 ~ 100 Hz
CCD Camera	frequency accuracy	120 Hz 10 mm/95dot
Control System	sampling Fuzzy reasoning	8.3 ms 4 inputs/4 outputs

Positioning of a Solid Specimen

The positioning system was tested under the reduced gravity environment in MU-300 aircraft. During the 20 sec parabolic flight, the reduced gravity environment which has the amplitude of ~10^{-2}G and frequency of few Hz is obtained.

Figure 2 shows the results of the positioning in the z direction when the specimen is a 1.3 gr

(10 mm in diameter) spherical aluminum. In the figure the membership functions of the position error in the z direction are shown with the positioning results.

In the run–1 the membership functions defining negative and positive small position error (NM, PM) include the center position, although the membership function used in the run–2 does not include the center.

As the result, the specimen in the run–1 is controlled near by the center position, while the specimen in the run–2 is not controlled during the positioning error is small (±2 mm).

In the result of run–2, the freely floating specimen is isolated from the oscillatory disturbances of the aircraft. This free floating time is very short (less than a second) in this experiment because the residual acceleration of the aircraft is still strong in the low frequency region. However, in the spacecraft, the low frequency component of the acceleration is much less than the aircraft ($\sim 10^{-6}$G), the floating time will become much longer.

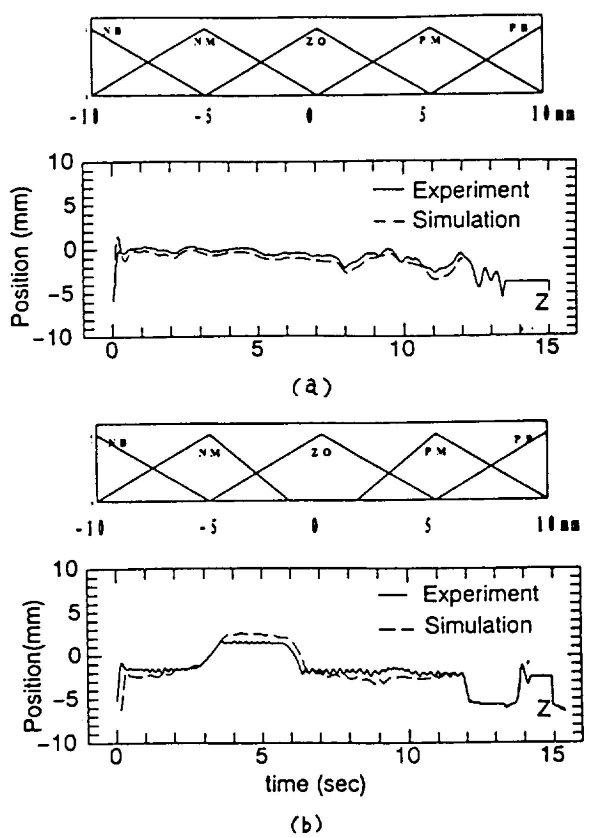

Fig. 2. Experimental results of the positioning in the z direction and used membership functions. (Aluminum 1.3 gr, 10 mm in diameter) (a) run–1, (b) run–2.

Positioning of the Liquid Drop

To obtain the performance of the liquid drop positioning, water drop was tested to levitate. A coaxial nozzle was inserted in the gap of the electrodes through a pin hole of the center electrode to supply the water drop. At first, water drop of 0.11 gr (6 mm in diameter) is made on the top of the inner nozzle, then is departed by means of the air jet come from the outer nozzle. Figure 3 shows the video view of the water drop positioning. The drop kept spherical shape during the levitation and successfully controlled.

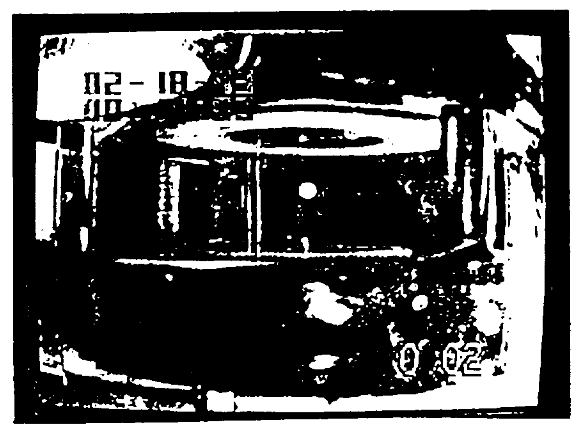

Fig. 3. Video view of the water drop positioning (0.09 gr, 6 mm in diameter)

Rotation Control of the Dielectric Specimen

Rotation control of the dielectric specimen is also possible by means of generating rotating electric field while the specimen is levitating. The ring electrode is divided in four electrodes along the theta direction.

External sine wave voltages of four phases (0 deg, 90 deg, 180 deg, 270 deg) are supplied to four electrodes in addition to the positioning control voltage of the ring electrode. As the induced charge on the surface of the dielectric specimens has the time delay to the rotating electric field, the specimen suffers the torque in the theta direction. Figure 4 shows the dependence of the rotating speed on the external voltage frequency and amplitudes when a grass shell of 0.09 gr (10 mm in diameter) is used as the specimen. The maximum rotating speed of 100 rpm is obtained when the frequency is 6 Hz and voltage amplitude is 3 kV.

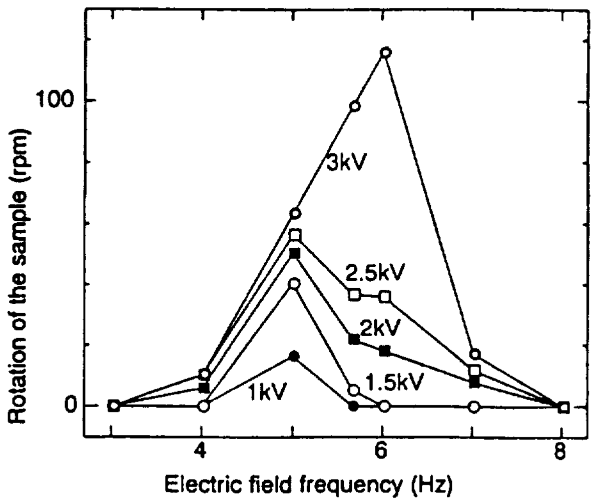

Fig. 4. Dependence of the rotating speed on the external voltage frequency and amplitudes (Glass shell, 0.09 gr, 10 mm in diameter)

Conclusion

A positioning system of the containerless image furnace is developed and tested in the reduced gravity environment. A Solid specimen (1.3 gr, 10 mm aluminum) and a water drop (0.11 gr 6 mm) are successfully position controlled. Rotation control of a dielectric specimens (0.08 gr 10 mm) is also possible while the specimen is levitating. The maximum rotating speed of 110 rpm is obtained when the rotating field frequency is 6 Hz.

REFERENCES

1. W. K. Rhim, M. Collender, M. T. Hyson, W. T. Simms and D. D. Elleman, "Development of an electrostatic positioner for space material processing," Rev. Sci. Inst. No. 56, 1985, pp 307-317.

2. K. Ikegami, C. Tsukishima and S. Okuda, "Control System of Electric Levitator," in the proc. of 17th International Symposium on Space Technology and Science, 1990, pp 2191-2196.