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A simple and efficient levitation technique for noncontact coating of inertial confinement fusion targets

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Abstract. A simple and very efficient gas jet levitation technique for levitating inertial confinement fusion (ICF) targets has been developed. A low velocity gas jet through diverging nozzle generates precisely controlled low Reynolds number flow pattern, capable of levitating polymer microballoons up to 2500 μm diameter. Different shaped diverging nozzle are investigated, satisfactory levitation is achieved with simple conical shapes. With this setup microballoon can be levitated for hours with excellent stability, continuous rotation and at the desired height (reproducible with in less than 100 μm). The height of stabilization depends upon cone angle of diverging nozzle and velocity of levitating gas. This technique is very robust and highly insensitive to external disturbances like nonuniform temperature fields and vibrations.

This setup is very economical to fabricate, easy to operate and can be used efficiently in various spray coating application involving plastic and metallic layers on microballoons.

Keywords. Inertial confinement fusion targets; low Reynolds number levitation; fluid dynamics.

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1. Introduction

The laser fusion targets are very complex tiny objects, built around highly uniform hollow spherical submillimeter size shells, filled with cryogenics D-T fuels and coated with foams and metallic layers etc. For fusion application the original hollow shells are required to be extremely uniform in diameter ($>$99%), with very uniform wall thickness and ultra smooth inner and outer surfaces with roughness $<$10 nm rms. A typical high performance direct drive target which can compare in performance to the indirectly driven targets would have up to 100 μm thick foam over coat on the bare hollow sphere. The requirement of uniformity on diameter etc. remain similar to that of hollow sphere. It is obvious that any mechanical handling of these specified targets can cause damage beyond acceptable limit. We have developed in our lab various minimal contact techniques to handle these targets during routine operations. The gentle levitation technique fulfills the need during specialized operations like coating etc.

Previous papers have reported acoustic levitation techniques [1], gas levitation technique [2], multiple nozzle technique [3] and modified gas jet flow technique [4]. Acoustic levitation technique uses piezoelectric driver to generate the high intensity ultrasonic field required to levitate the microballoon. This technique suffers unsmooth and asymmetric coating on the microballoons, because it is very difficult to adjust the vibration or rotation of microballoons in acoustic field. Acoustic method is also very sensitive to temperature variation, air currents and acoustic reflection, which are not favorable to provide very good stability to levitate microballoon. In conventional gas levitation technique during coating, selected microballoon is supported by momentum transfer from gas molecules striking the microsphere underside. A major problem with conventional gas levitation technique is that since the gas flow spreads out as it moves away from the gas emitter nozzle, the side pressure decreases as the microsphere rises up, resulting in corresponding decrease in lateral stability.

This paper describes a special non-contact levitation technique to levitate a microballoon with exceptional stability and ease of manipulation. In this levitation technique microballoons are held floating by minimal drag force in a confined volume. We have been able to utilize very low velocity argon jet at normal atmospheric pressure to accomplish levitation of solid and hollow polystyrene spheres in diverging nozzle. This technique has large potential to be adopted for various coatings. This diverging nozzle helps in confining and shaping the flow appropriately around the microsphere. By adjusting the cone angle, length of diverging nozzle and velocity of gas, microsphere can be levitated at any height in axis of symmetry.

2. Principle

In classical gas levitation technique microballoon is floated on gas flow from straight nozzle. The levitation is unstable mainly due to imbalance in side pressure developed as gas flow spreads out around the microballoon. The side pressure however is seen to be regulated to a high degree by using confined volumes in shape of diverging nozzle.

When levitation force is equal to or greater than the weight of microsphere, the latter will be levitated. At low Reynolds number flow is mostly viscous and major contribution in levitation force is of skin frictional drag. As the Reynolds number increases, contribution of pressure drag increases which is due to pressure difference existing between the relatively high pressure on the upstream sphere surfaces and low pressure on the downstream surfaces. The total drag force F_{d} in a streamline flow is given as

$$F_{\mathrm{d}} = F_{\mathrm{f}} + F_{\mathrm{p}}$$

where F_{f} and F_{p} are frictional drag force and pressure drag force respectively.

In our setup Reynolds number is very low and levitation force can be given by Stokes law

$$F_{\mathrm{d}} = 3\pi\mu Dv, \tag{1}$$

where frictional drag force = $2/3^{*}F_{\mathrm{d}}$, pressure drag force = $1/3^{*}F_{\mathrm{d}}$, $D =$ diameter of the microsphere, $\mu =$ viscosity of the levitating gas, and $v =$ velocity of the gas.

When drag force

$$F_{\mathrm{d}} \geq W \quad \text{or} \quad 3\pi\mu Dv \geq \pi D^3\rho/6 \tag{2}$$

the microsphere will be levitated. Therefore in a divergent flow there will exist a point of equilibrium where from eq. (2), velocity

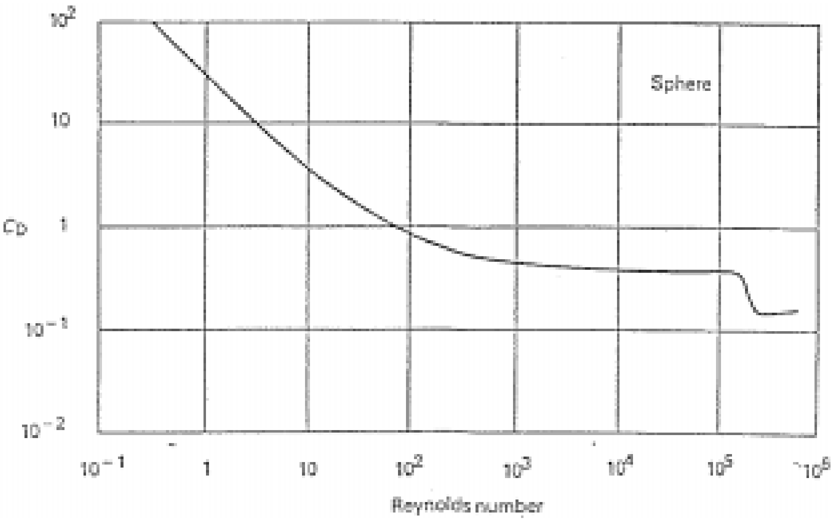

Figure 1.

$$v = (1/18\mu)^* \rho^* g^* D^2$$

exactly balances the mass of the microballoon. By choosing the angle of divergence and length of the diverging nozzle the point of equilibrium can be obtained at any height for a fixed diameter microsphere. As the Reynolds number increases (Re > 0.2) an attached toroidal vortex forms around rear of the sphere and it starts spinning. This vortex remains attached up to Reynolds number of 200 approximately, after which vortex rings are shed in random fashion and microballoon's vibrations are uncontrolled.

To levitate microballoons of 250–2500 μm diameter only viscous flow (Reynolds number $R_e < 0.2$) is needed for which drag coefficient is given by

$$\begin{aligned} C_D &= F_{\mathrm{d}}/(0.5\rho_0 v^2)^*(0.25\pi D^2) \\ &= 24/R_e. \end{aligned}$$

The flow having Reynolds number R_e greater than 0.2 is known as Allen flow and drag co-efficient is given by

$$C_D = 18.5/R_e^{0.6}.$$

Variation of drag coefficient with Reynolds number is shown in figure 1.

3. Experimental setup

The experimental setup is simple with arrangement of precision controlled gas inlet feeding argon gas in diverging nozzle. The behaviour of levitating particle is recorded using a CCD camera and a digitizer unit. The schematic diagram is given in figure 2.

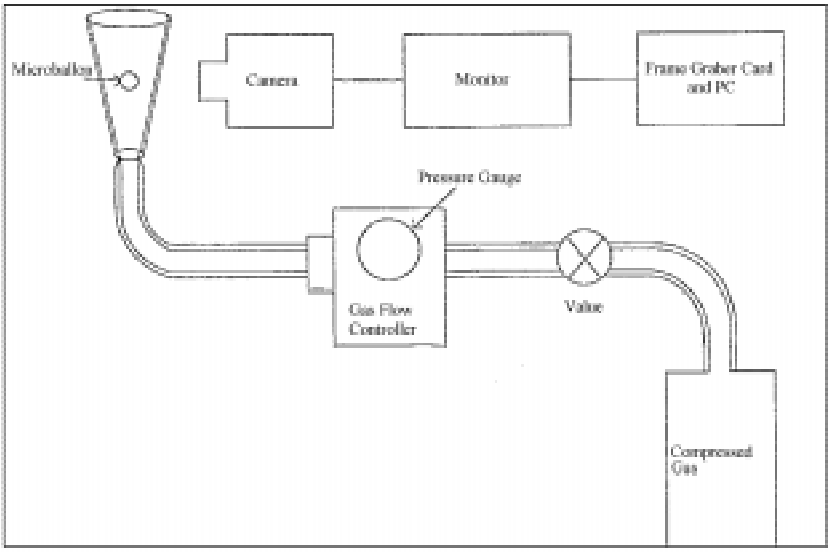

Figure 2.

The details of each component are as follows:

1) *Diverging nozzle*: This is a very important part of gas levitation system since the stability of the microsphere is highly dependent on the divergence angle and total length. The effect of pressure gradient is very important in establishing the flow in diverging nozzle. The diverging nozzle or diffuser has positive pressure gradient, hence boundary layer grows rapidly. If diverging nozzle is too large then separation of flow will occur and if divergence angle is too small, then excessive length is required to obtain a require pressure. The design of the diverging nozzle is one of optimization between length and cone angle. Both cone angle and length have been optimized in designing diverging nozzle for levitation of different size microspheres. Height of stabilization is strong function of cone angle and diameter of the microsphere. Figure 3 shows dependency of stabilization height to cone angle.

2) *Gas regulator and flow controller*: These are also important parts of the system under study. It is very necessary to keep pressure constant before the adjustment of flow velocity of the gas. To avoid the potential pressure variation in the gas line, a gas is used which helps in reducing the pressure of the gas from reservoir. Pressure required for levitation is dependent upon the diameter of the microsphere and height of stabilization. Since microspheres are very light weight objects, required pressure for levitation is less than 5 psi.

Accurate control of flow velocity is also required since microsphere stabilization is very sensitive to the gas velocity. Since size of the diverging nozzle is fixed for a given experiment so only way to obtain the stabilization of microballoon is by varying the gas velocity which is achieved through flow controller in present setup.

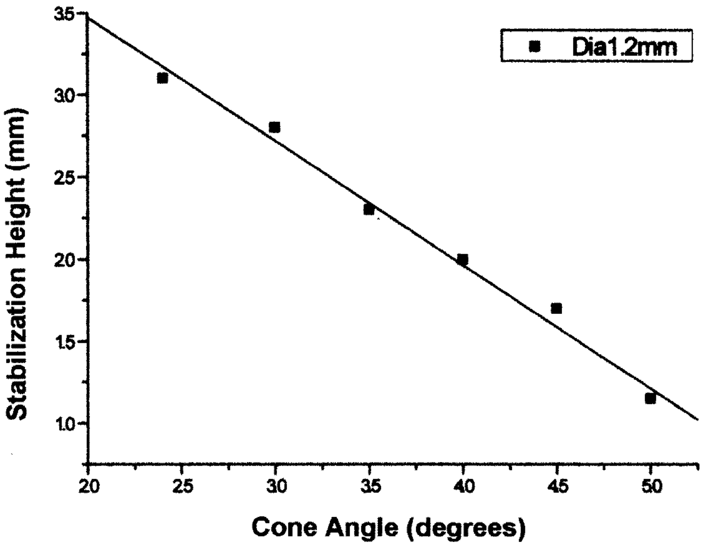

Figure 3.

3) *On-line monitoring system*: A CCD camera with resolution of 516 × 516 and pixel size 11 × 9 μm is used to make observations. The overall magnification of the monitoring system is 20. The images taken by CCD camera are captured in a computer using frame grabber card and image processing software for further processing.

Images of non-levitated and levitated microballoon, taken by CCD camera are shown in figures 4 and 5 respectively.

4. Results and discussion

Different sizes (ranging from 250 to 2500 μm) of solid and hollow polystyrene microspheres have been levitated very successfully with present setup. It is possible to levitate these microspheres very stably for several hours. When the velocity is just sufficient only to balance the weight of the microsphere, it is levitated without any spin or rotation. As the velocity of the gas flow is increased the immediate effect is increase in height of stabilization with little rotation. On increasing the velocity further microsphere starts rotating at high frequency at same height with random change in direction of rotation. The dependency of stabilization height to the flow rate (velocity) is shown in figure 6.

The effect of temperature variation on stability of the microballoons was also studied. The temperature was varied externally from ambient to 200 °C by hot blower, change in stabilization height was less than 0.1 mm, which is insignificant. The insensitivity of stabilization height to temperature and other external parameters achieved in our setup is of prime importance for coating of microballoon targets. During coating process of microballoons uncontrolled variation in height leads to unacceptable nonuniformity in coating.

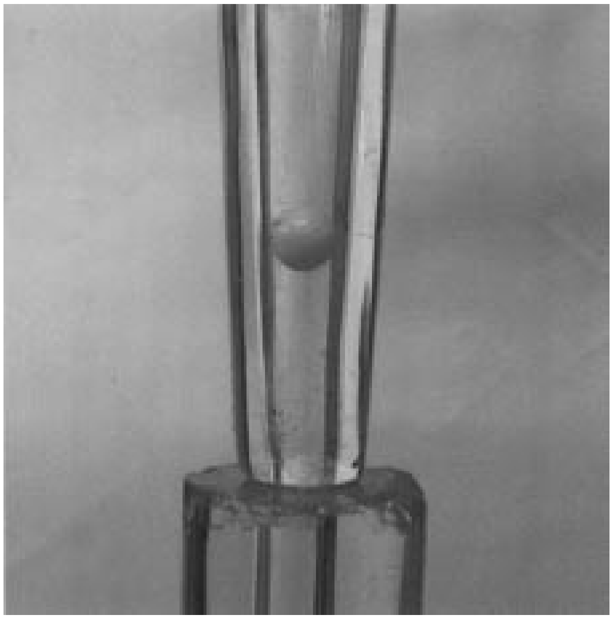

Figure 4. Image of non-levitated microballoon.

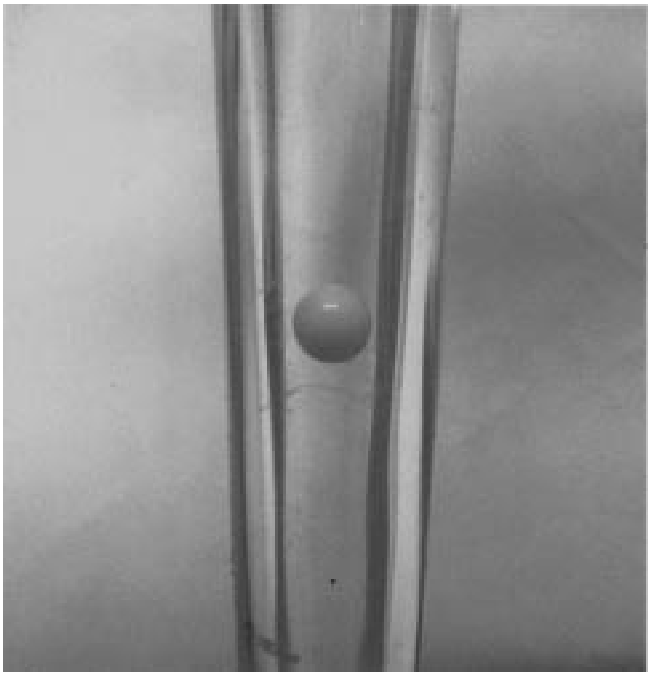

Figure 5. Image of levitated microballoon.

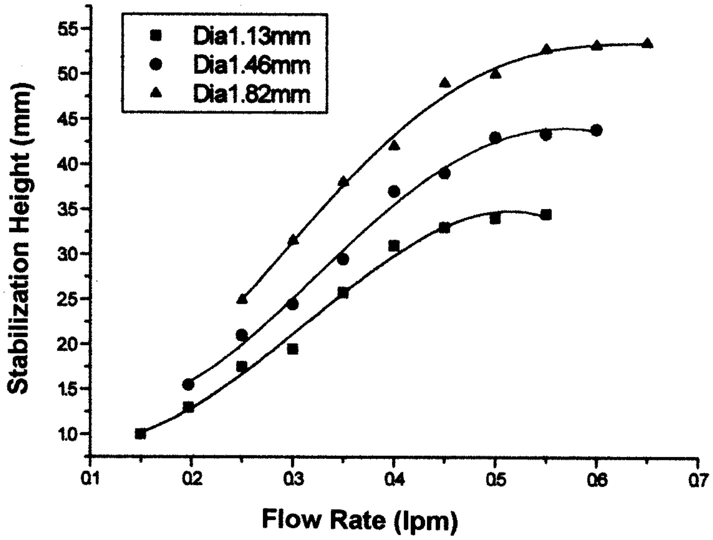

Figure 6. Density of stabilization height on flow rate.

The important conclusion is that we are able to stabilize microballoon in a gentle and controlled fashion with diverging nozzle. The microballoon is suspended in nozzle with no physical contact with glass enclosure. The flow past microballoon in fact acts as a stiff spring and helps in positional stability. Moreover as flow velocity is very small coating process is not interrupted. The technique is very robust and highly insensitive to temperature variation, unlike acoustic levitation techniques, and up to certain extent it is also insensitive to external vibrations. It is very convenient to fabricate and use the setup. Various sizes of microspheres can be levitated from the same setup without making many changes.

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