Princeton/$\mu\mu$/98-10

Flowing Tungsten Powder for Possible Use as the Primary Target at a Muon Collider Source

C. Lu and K.T. McDonald
Joseph Henry Laboratories, Princeton University, Princeton, NJ 08544
(March 15, 1998)

1 Introduction

The use of a liquid metal jet [2] as the primary target at a Muon Collider source [1] is not yet an established technique. Among possible alternatives, we are investigating the use of a jet of tungsten powder.

We first considered metal-powder slurries, based on the example of a commercial zinc paint with density 3 g/cm^3. For a Muon Collider target, both high atomic number and high density are desirable. Both tungsten and tungsten carbide powders are readily, and are apparently used in slurries in some industrial applications.

After a somewhat negative experience with slurries, we investigated dry powder, following a suggestion by Colin Johnson at the Targetry Mini Workshop in Princeton, Feb. 28, 1998. Better success was achieved, as reported below, but much work is still needed before a powder target would be a viable option for the primary target

2 Materials

We purchased tungsten powder from Atlantic Equipment Engineers (Bergenfeld, NJ 07621, 201-384 5606) at about $40/pound in three granularities, 1-2 μm, 5-10 μm and 325 mesh (< 40 μm). Tungsten powder is primarily used as a getter in television sets. There is an indication that tungsten powder could be purchased in bulk for at little at $10/pound from sources in mainland China [3].

We also obtained samples of 1-μm tungsten carbide powder from Kennemetal (Pittsburgh, PA, 412-539-5079) and from Alfa Aesar (Ward Hill, MA, 800-843-0660)

The powders of less than 10-μm size exhibit agglomeration, the tendency for grains to fuse into larger clumps via rather strong chemical bonds.

3 Experience with Slurries

Our initial experience in making water slurries with these powders was not entirely satisfactory. While a flowable slurry could be made, the metal tends to separate from the water extremely quickly, leading to cesation of flow. Some kind of agitation of the slurry is likely required to maintain good flow characteristics.

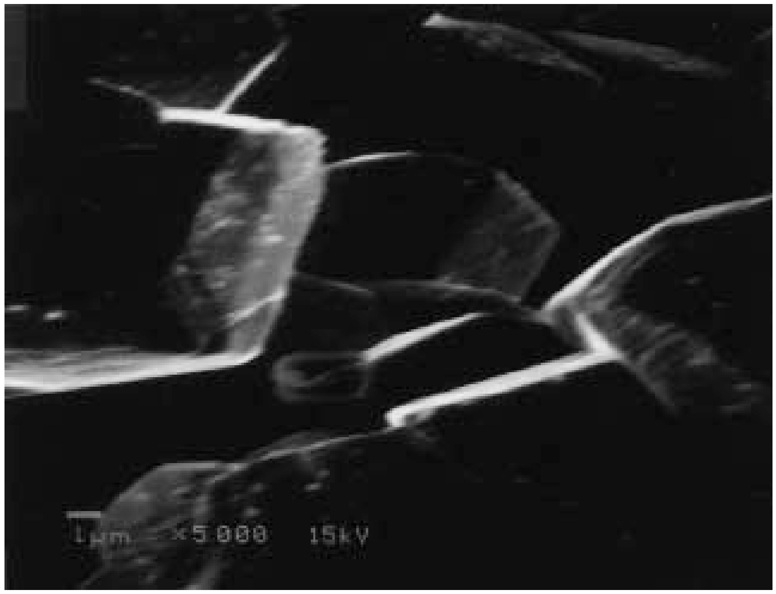

Figure 1: The grains of 325-mesh (40 μm) tungsten powder are relatively smooth, and this powder flows well.

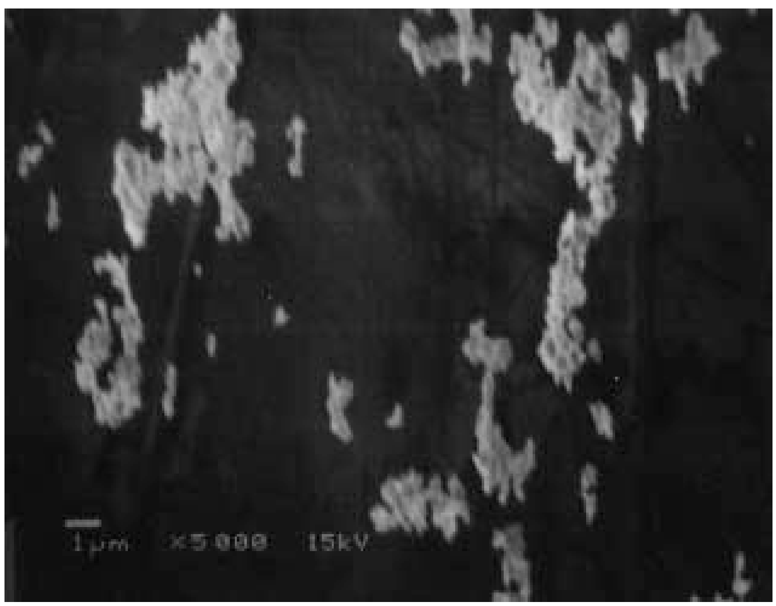

Figure 2: The grains of 1-μm tungsten powder exhibit agglomeration, so this powder does not flows well.

Given the known use of slurries in industry, it is probable that better performance could be obtained with greater effort than we have made thus far.

4 Experience with Dry Powders

The powders of less than 10-μm size exhibit agglomeration, the tendency for grains to fuse into larger clumps via rather strong chemical bonds.

Of the powder samples on hand, only the 325-mesh tungsten powder flows easily when dry, so it was used exclusively in the studies reported below.

This material has density about 8 g/cm^3 when freshly poured, but can be compacted to about 9 g/cm^3.

4.1 Vertical Motion of a Powder Jet

The 325-mesh powder forms a surprisingly good jet when poured vertically through a funnel, as shown in Fig. 3. The motion of the powder in the funnel imparts an inward transverse momentum, and the jet diameter decreased for about 1 m of fall. Beyond that distance there was evidence of scattering of the powder particles and the jet appeared to become slightly diffuse.

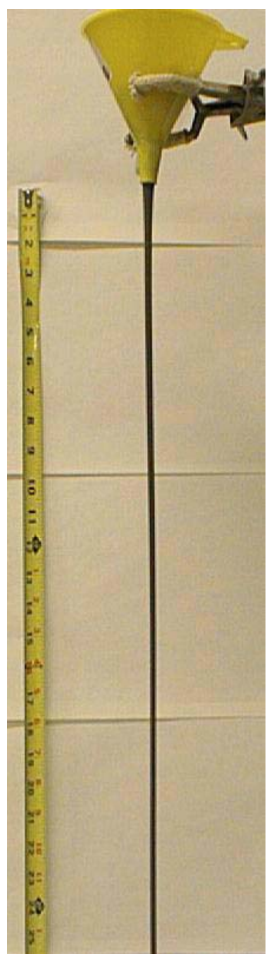

Figure 3: A vertical jet of 325-mesh tungsten powder as poured through a plastic funnel of 1-cm-diameter aperture.

This is a first indication of the importance of the shape of the nozzle through which the jet emerges. It is likely that a more optimal design would permit the jet to propagate a larger distance before the onset of disruptive scattering.

However, the density of the jet appears to be quite low. The 480-g sample took $t = 5.2$ s to flow out of the funnel. At 90 cm below the funnel, the jet diameter was observed to be $d = 0.5$ cm (compared to 1.0 cm at the exit of the funnel. After 90 cm fall, the jet velocity is $v = \sqrt{2gh} = 420$ m/s, so the equivalent volume is $V = \pi d^2 vt/4 = 1700$ cm^2, corresponding to a density of only 0.3 g/cm^3.

A much more carefully designed funnel will be required to achieve jet densities approaching the static powder density.

If the density of the jet is to remain constant, the cross sectional area $A = \pi r^2$ of the jet must decreases as the velocity v increases, so as to keep Av constant. Since $v = \sqrt{2gh}$ for a jet falling under gravity, the jet radius would need to obey,

$$r \propto \frac{1}{\sqrt[4]{2\pi^2 gh}}. \tag{1}$$

If this expression holds for $h > h_0$, where h_0 is a characteristic height over which the flow is established at the top of the funnel, then,

$$\frac{r}{r_0} = \sqrt[4]{\frac{h_0}{h}}. \tag{2}$$

For example, if $h_0 \approx 1$ cm and $h = 100$ cm, then $r/r_0 \approx 0.3$. In our studies we saw $r/r_0 \approx 0.5$ over a fall of 90 cm.

In a liquid, surface tension provides the inward forces needed for eq. (1) to hold. There is no surface tension in a powder jet. As long as the jet is inside the funnel, the wall of the latter imparts the inward velocity needed for the jet radius to shrink according to (1). Once the jet leaves the funnel, the inward velocity of a powder granule remains constant until it scatters off another grain. Since eq. (1) requires the inward velocity to decrease with increasing time, the jet will appear to coalesce for a while after leaving the funnel, but eventually scattering will occur and the density will decrease.

A funnel or horn could and should be manufactured with a profile given by eq. (1). It must then be determined whether friction would prohibit the powder from accelerating at g within the funnel, and what densities can be obtained in the jet.

4.2 Horizontal Motion of a Powder Jet

It is general preferably that the axis of the target be horizontal (or nearly so) at a muon collider source.

We made a simple test of the ability of a powder jet to be bent by 90°, by letting the jet fall about 1.5 m inside a 1/2-inch-diameter tube before encountering bends of radii 3, 5 or 10 cm. The powder did not flow around the 10-cm-radius bend; apparently the friction associated with the longer path was too great. The behavior observed with the 3- and 5-cm-radius bends was similar, as shown in Fig. 4.

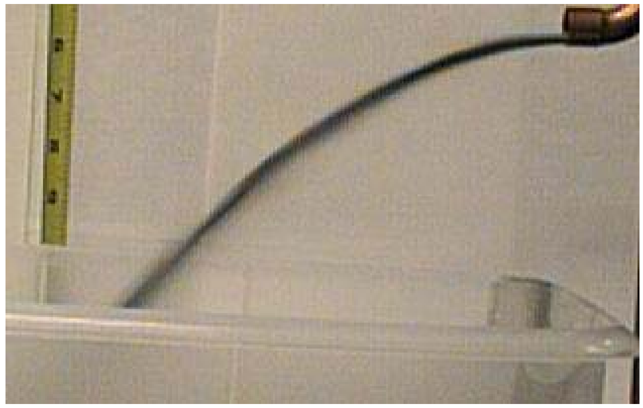

Figure 4: A horizontal jet of 325-mesh tungsten powder after falling 1.5 m inside a 1.25-cm-diameter tube with a 3-cm-radius bend of 90° at its bottom.

The jet can be seen to occupy only a small fraction of the area of the outlet of the 90° bend. A superior bend/nozzle can no doubt be designed.

We determined the horizontal velocity of the jet to be about 120 cm/s by observing its trajectory. However, the velocity would be 540 cm/s after a fall of 1.5 m. Hence, about 95% of the kinetic energy of the jet was lost in traversing the 90° bend.

Clearly, additional studies are needed to understand the limits of performance of powder jets. There is room for considerable finesse in such studies, as shown by the wonderful results of H. Swinney [4] (Fig. 5) obtained by controlled shaking of pans of powder in vacuum.

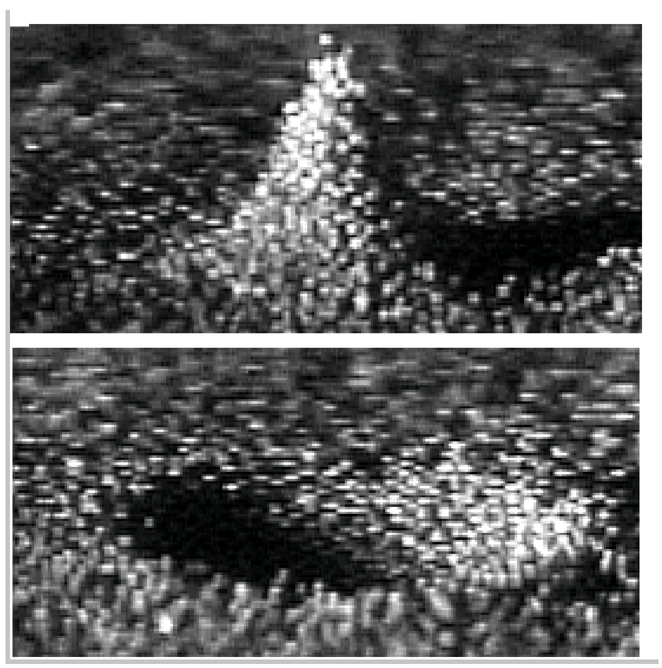

Figure 5: Localized, periodic structures generated by shaking a pan of sand in vacuum. From [4].

References

[1] R.B. Palmer *et al.*, *$\mu^+\mu^-$ Collider: A Feasibility Study*, BNL-52503 (1996),
http://physics.princeton.edu/~mcdonald/examples/accel/muon_collider96.pdf

[2] C. Lu and K.T. McDonald, *Low-Melting Temperatures Metals for Possible Use as Primary Targets at a Muon Collider Source*, Princeton/$\mu\mu$/97-3 (May 13, 1997),
http://physics.princeton.edu/~mcdonald/mumu/target/liquid.pdf

[3] http://www.metal-finishing.com/classifieds/metal/index.html

[4] P.B. Umbanhowar, F. Melo and H.R. Swinney, *Localized excitations in a vertically virated granular layer*, Nature **382**, 793 (1996),
http://physics.princeton.edu/~mcdonald/examples/fluids/umbanhowar_nature_382_793_96.pdf