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A powder jet as a target for the Neutrino Factory

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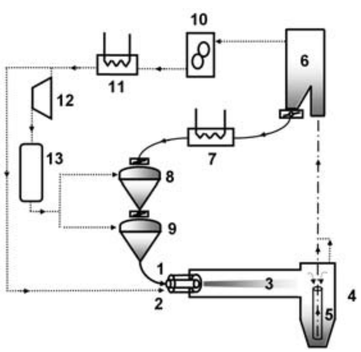
Rationale

A new generation of accelerator based facilities is under development with beam intensities an order of magnitude higher than those delivered by existing technology. The interaction of a high power ion beam with a high Z target material is a common critical issue and raises concerns over the reliability and lifespan of the facility itself. As the beam power delivered reaches the 1 MW level, there is a general assumption that liquid metal technology will be required. Targets have to survive extreme conditions such as shock phenomena, thermal fatigue, cavitation, water hammer and often present chemical and radiological problems.
A new technology based on fluidized powder is proposed which could be employed as a high power target, for example in a future Neutrino Factory or Muon Collider. Fluidized powder is believed to bring together some advantages of both the solid and liquid phase whilst avoiding some of their drawbacks.
Preliminary experiments were performed on the pneumatic transport of tungsten powder in order to investigate the potential of tungsten powder as the material for a fluidized powder target station. The experiments investigated the flowability of tungsten powder, its performance in dense and lean phase conveying systems and the possibility of generating a high density powder jet.

Production, processing and recirculation of a powder jet target

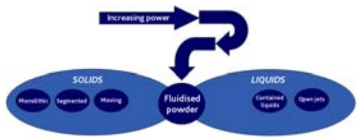
Tungsten powder could be a suitable replacement for mercury, with the solid material able to survive the interaction with the beam (Z=74, psolid=19.3, Tmelt= 3695K) while maximizing the muon yield. A possible plant layout for generating and recirculating a powder jet target in a Neutrino type facility is shown. This layout is designed adapting the geometrical constrains proposed by the "Feasibility Study-II of a Muon-Based Neutrino Source" to the fluidised powder target concept.



1. Powder injection
2. Coaxial gas stream
3. Jet/interaction point
4. Receiving hopper
5. Suction nozzle
6. Powder separation volume
7. Powder cooler
8.9. Pressure hoppers
10. Gas blower
11. Gas cooler
12. Gas compressor
13. Gas storage

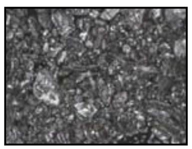
New powder based target system

A dense powder slug could be used as a high power target material. Like the mercury based target, a fluidized powder target allows recirculation of a batch of target material so that the cooling can be carried out off-line. Like solid materials, a powder target constrains most of the thermal shock in the solid fraction (a light carrier gas such as helium would absorb little ionisation energy during the interaction with the beam and would dissipate any pressure fluctuation rapidly).



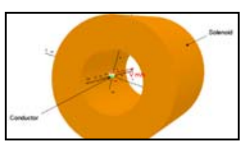
Experiments with tungsten powder

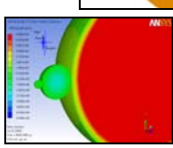
The preliminary experiments were performed using a batch of tungsten powder of 60 mesh (i.e. of grains smaller than 250um) having resting bulk density of 8600 kg/m3

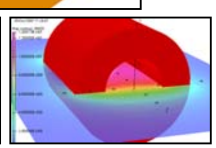


Simulations

An explicit non linear dynamics code has been used to simulate the stress induced in a spherical particle as a result of energy deposition from the particle beam. Results indicate that the stress reduces as the particle size reduces and peak stresses are well within the endurance limit.
Eddy currents generated in a tungsten particle travelling through a solenoid have been analysed to determine the relationship between particle size and induced forces on the particles. The axial retarding force was found to be proportional to the particle radius to the power 5 and as such the retarding forces on particles of the proposed size was found to be negligible. Assuming distinct current loops set up in each particle a collection of adjacent particles passing through the solenoid were modelled and in this case radial forces due to the eddy currents formed were also found to be negligible.







High speed videos of tungsten powder jets

Three different regimes for the powder jet were identified during the experiments.
It appears that the powder flow is strongly influenced by the driving pressure as well as by the geometry and pressure drop along the conveying pipework. The flow regime of the powder is pulsating at lower pressures (1.5bar in Fig 1, in jargon this is called dune flow), is smooth at medium pressures (2.5bar in Fig 2) and becomes turbulent at higher pressures (3.2 bar in Fig 3).

Fig 1

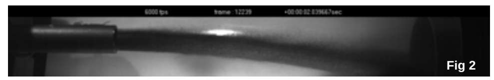


Fig 2

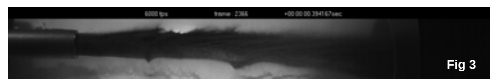
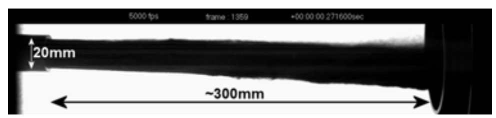


Fig 3

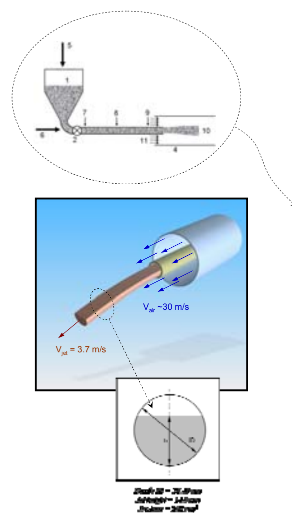


Jets at 2 bar

Jets produced with 2 bar driver pressure were found to be quite coherent over an axial distance of about 40 cm, and the driver pressure, jet velocity and geometrical characteristics of the jet appeared stable throughout the ejection. In this configuration the jet was surrounded by a 30 m/s coaxial air flow and the powder filled only part of the cylindrical conveying pipe (see figures on the right).
A bulk jet velocity of 3.7 m/s was measured by analysis of the high speed video data. The rate of powder ejection, measured using a load cell on the ejection hopper, was 7.9 kg/s. A jet density of 42 (±5) %v/v was estimated by dividing the mass flowrate by the volume flowrate:

$$\text{Density} = \frac{\text{Mass Flowrate}}{\text{Volume Flowrate}}$$

Note that the density of solid tungsten is 19300 kg/m^3 and that the powder used for the experiments had a density at rest of roughly 50% v/v of the solid density.

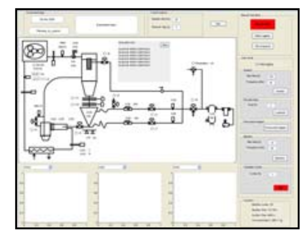


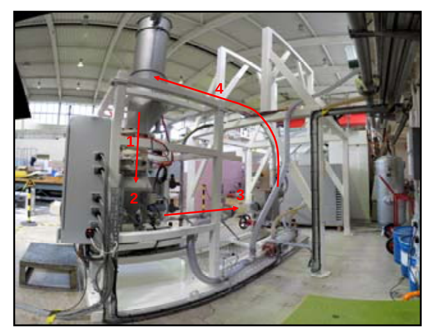
A new rig to study a future powder based target station

Although powder conveying is a mature standardised technology the proposed tungsten jet system introduces elements of novelty (e.g. dense powder jet, conveying of very heavy and hard powder, etc.) so the durability and reliability of such a powder based target station is unknown a priori. A new rig was recently commissioned which will allow evaluation of the performance and long term reliability of the proposed powder system. The rig will be used also to study different target layouts and different powdered target materials.

A batch experimental rig

The experiments were performed conveying the powder in a "batch" mode. The rig holds ~100 kg of tungsten powder which is conveyed to produce a jet lasting around 10 seconds. The rig is operated using an automated control system (see the graphical user interface in the figure on the right) which sequences the operation of the valves, the compressed air supply and the blower. The control system is also responsible for logging the data acquired from the instruments during the experiments.





Batch Powder Process

1. Hopper loading
2. Hopper pressurization
3. Powder jet observation
4. Suction / Recirculation

High Power Targets
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