PRELIMINARY EXPERIMENTS ON A FLUIDISED POWDER TARGET

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Abstract

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.

This paper proposes a technology based on fluidized powder which could be employed as a high power target, for example in a future Neutrino Factory or Muon Collider. The fluidized powder is believed to bring together some advantages of both the solid and liquid phase whilst avoiding some of their drawbacks.

The article reports the results obtained from preliminary experiments on the pneumatic transport of tungsten powder. The experiments investigated the flowability of tungsten powder, its performance in a dense and lean phase conveying system and the possibility of generating a high density powder jet.

FLUIDISED POWDER TARGETS

The current Neutrino Factory and Muon Collider [1] proposals require the use of a high Z target material withstanding beam ionisation heating of around 1 MW. Liquid mercury is the baseline target material because it offers potential advantages in dealing with issues such as thermal cycling and dissipation of the heat load and shock waves.

The Merit experiment [2] investigated an open mercury jet travelling through a high field capture solenoid and simultaneously interacting with a pulsed proton beam. This experiment was successful in demonstrating the feasibility of the system, however a number of technical issues remain to be solved before it can be adopted in an actual facility. [3].

As an alternative to solid and liquid targets, this article discusses an alternative approach to the high power target issue which is based on a fluidised stream of powder. It is believed that a target solution based on moving powder offers some of the advantages of both the solid and liquid technologies whilst avoiding some of their drawbacks.

Like the mercury based target, a fluidised 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 rapidly any pressure fluctuation). Furthermore, a powder target is subject to less restrictive containment and disposal issues than those associated with mercury (e.g. powder can be vitrified or hot pressed before disposal and replenished if necessary).

In order to comply with the design criteria and geometry optimisation suggested by [1], some experiments were performed to evaluate the possibility of replacing the mercury jet with a tungsten powder jet. Tungsten is a suitable replacement for mercury, with the solid material able to survive the interaction with the beam (Z=74, ρsolid=19.25, Tmelt= 3695K) while maximising the muon yield [4, 5]. Unfortunately the literature on pneumatic conveying of powders does not contain any information on the handling of materials as dense as tungsten, the highest density material previously pneumatically conveyed as a powder being copper (density 8920 kg/m^3) [6, 7]. So a set of preliminary experiments were performed to determine whether tungsten powder is fluidisable in the lean and in the dense phase and whether the flowability of the powder is suitable for reliable pneumatic conveying. The experiments aimed also at determining whether it is possible to generate a dense horizontal free flowing jet of tungsten powder (i.e. not constrained in any duct, but free flowing in air) matching the baseline design suggested by [1]. Note that powder would more easily flow as dense phase constrained in conveying duct, but external cooling of the pipework around the beam interaction area of the Neutrino Factory would be required due to interactions with secondary particles.

The 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/m^3.

Figure 1: Micrograph of the tungsten powder used for the experiments.

During the experiments, the powder showed very little stickiness and seemed to behave like a dense fluid. The material was found to have excellent flowability and could be easily conveyed in the dense phase and in the lean phase using a vertical air lift, where the tungsten powder was levitated and conveyed by a high velocity (50m/s) ascending air stream. All experiments were performed using standard pneumatic conveying equipment available at the experimental facility at Gericke Ltd.

A stainless steel conical hopper of 20 litres capacity was used to hold the tungsten powder for the dense phase experiments. The hopper was pressurised by either air or helium in the range 1.5 barg to 3.9 barg which was used to drive the powder. The flow was produced propelling the powder from the storage hopper via a swept elbow and valve along a horizontal 1m long 2cm i.d. stainless steel tube (Figure 7 shows a similar layout).

Jets were created at the end of the horizontal tube as the powder entered into a co-flowing stream of air. Dense horizontal powder jets (less than the bulk porosity of 50%) with an initial diameter of 2cm and an initial horizontal velocity of around 10m/s were successfully generated using either pressurised air or helium as propellants. Figures 2 to 4 show images extracted from high speed recordings (6000fps) of different regimes of the powder jets encountered during the experiments.

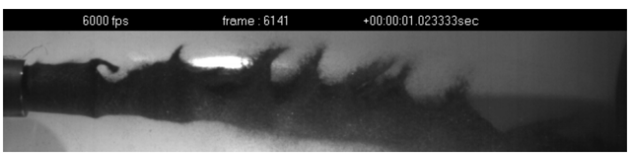

Figure 2: W powder pressurized through a 20mm ID cylindrical nozzle using a supply of 1.5bar He as a propellant

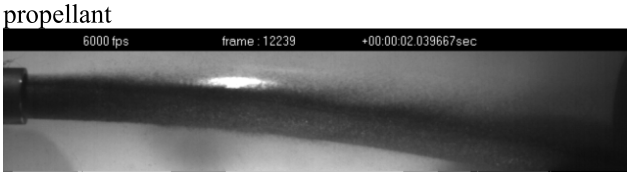

Figure 3: W powder pressurized through a 20mm ID cylindrical nozzle using a supply of 2.55bar He as a propellant.

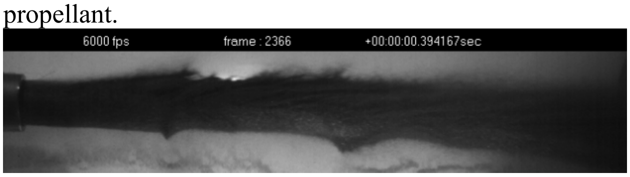

Figure 4: W powder pressurized through a 20mm ID cylindrical nozzle using a supply of 3.2bar He as a propellant.

From Figures 2 to 4 it appears that the powder flow is strongly influenced by the driving pressure (as well as by the geometry of the conveying pipework). The flow regime of the powder appears as pulsating at lower pressures (1.5bar in Fig 2, in jargon this is called dune flow), is smooth at medium pressures (2.5bar in Fig 3) and becomes turbulent at higher pressures (3.2 bar in Fig 4). The jets produced with a 2.5barg driver pressure were found to be quite coherent over an axial distance of about 30cm.

A possible plant layout for generating and recirculating a powder jet target in a Neutrino type facility is suggested in Figure 1. This layout is designed adapting the geometrical constrains proposed by [1] to the fluidised powder target concept.

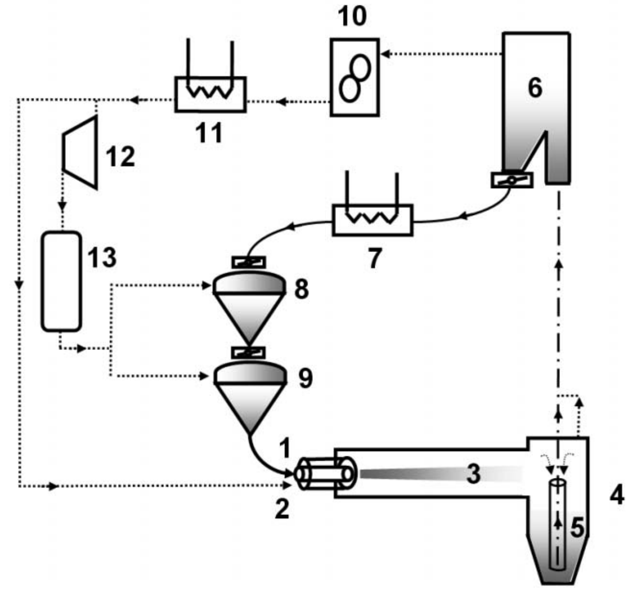

Figure 5: Plant layout for the production, treatment and recirculation of tungsten powder jets as target for a future Neutrino Factory.

In Figure 1, a dense powder jet is produced by pressurising tungsten powder through nozzle 1. The jet travels through the capture solenoid/interaction area 3 and is collected in a receiving vessel 4 (as in the mercury system, the capture solenoid would surround 3 and 4, and the receiving powder hopper 4 could act as a beam dump). The powder collecting at the bottom of the receiving hopper is fluidised in nozzle 5 and transported vertically in the lean phase (dot-dashed line) in an air lift to the vacuum separator vessel 6. At this point the dense phase powder (continuous line) is dropped into a cooler and then fed into the pressure hoppers 8 and 9. Batch feeding and cycling of the pressure in vessel 8 allows loading of vessel 9 while powder is continuously ejected from nozzle 1. Meanwhile the fluidising gas (dotted line) is recirculated by the blower 10, cooled in heat exchanger 11, pressurised by the compressor 12 and stored in the reserve volume 13. In order to improve and maintain the coherence of the powder jet, a fraction of the recirculated gas is injected at 2 in an annular coaxial flow surrounding the jet.

The critical stages of the plant shown in Figure 5 were tested during the preliminary experiments: i.e. dense phase powder conveying, powder fluidisation and the production of a dense powder jet. The experiments were performed in batch mode and with no heat transfer. Powder technology is a mature technology and so pneumatic components are standardised and readily available (e.g. various types of heat exchangers). Best practice knowledge is available for the optimal and reliable design of powder conveying systems. The plant layout presented in Figure 5 has few moving parts (none in proximity of the beam line) but is expected to experience some degrees of erosion of the components, the extent of which is currently unknown. In light of the successful preliminary experiments a new rig was designed and commissioned to understand and optimise the parameters affecting the powder jet and the performance of the main recirculation system. In order to validate the technology, the rig will be used to evaluate the life time and long term reliability of the components. Since erosion is strongly related to the characteristics of the conveyed material, the rig will be used to evaluate different target materials, including some potentially less abrasive than tungsten powder, e.g. graphite and different geometries of the interaction area.

Figure 6: Commissioning of the new powder rig.

Figure 6 shows a stage of commissioning of the new powder recirculation plant. In Figure on the left are the vacuum separator vessel (top) and the pressure hopper (bottom). The jet is created in the transparent section of tube in the middle and then the powder is collected and recirculated from the receiver on the right. The curved return elbow at the top was intentionally inserted into the circuit to assess abrasion.

Figure 7 shows a detail of the pressure hopper (on the left) which is used to drive the powder along the 1m long, 2cm i.d. tube into the transparent interaction/test section (on the right).

Figure 7: Pressure hopper, delivery tube and jet test section for the powder rig

CONCLUSIONS

A new solution based on fluidised powder technology is presented for application as a high power target. This technology is believed to have the potential to offer advantages to both solid and liquid targets, although it introduces new challenges. The preliminary experiments suggested that the technology could be directly applicable to the geometrical optimisation proposed by Design Study II, i.e. using a high Z recirculated material interacting with the beam as an unconstrained jet. 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. In order to validate the new technology, further work is required to evaluate/simulate the dynamic effect of the beam on the powder jet and the electro-magnetic interaction of the irradiated powder with the capture solenoid. Once the characteristics and boundary conditions of the powder jet system are known, re-optimisation of the geometry for optimal particle yield will also be necessary.

REFERENCES

[1] [26] S. Ozaki, R. Palmer, M. Zisman, and J. Gallardo, Feasibility Study-II of a Muon-Based Neutrino Source, ed., BNL-52623 (2001).

[2] H.G. Kirk, et al., A high-power target experiment at the cern PS, 2007 IEEE PARTICLE ACCELERATOR CONFERENCE, VOLS 1-11, Pages: 1216-1218

[3] P. Sievers and P. Pugnat, Response of solid and liquid targets to high power proton beams for neutrino factories, CERN LHC/2000-4, CERN-NuFACT note 035, 2000.

[4] C. Lu and K.T. McDonald, Flowing Tungsten Powder for Possible Use as the Primary Target at a Muon Collider Source, Princeton/μμ/98-10, 1998

[5] S. Ozaki, R. Palmer, M. Zisman, and J. Gallardo, Feasibility Study-II of a Muon-Based Neutrino Source, ed., BNL-52623 (2001)

[6] Pneumatic conveyors for bulk material, W.Gericke and K-E. Wirth, Powtek-Gericke Ltd., Ashton-under-Lyne, 1991.

[7] Handbook of pneumatic conveying engineering, D.Mills, M.G.Jones and V.K.Agarwal, Marcel Dekker, 2004. ISBN 0-8247-4790-9