THE POTENTIAL OF FLUIDISED POWDER TARGET TECHNOLOGY IN HIGH POWER ACCELERATOR FACILITIES

C.J.Densham, O.Caretta, P.Loveridge, STFC Rutherford Appleton Laboratory, Chilton, Didcot, OX11 0QX, UK
T.W.Davies, University of Exeter, UK
R.Woods, Gericke Ltd, Ashton-under-Lyne, OL6 7DJ, UK

Abstract

This paper describes the potential of fluidised powdered material for use as a particle production target in high power particle accelerator based facilities. In such facilities a multi-MW proton beam is required to interact with a dense target material in order to produce sub-atomic particles, e.g. neutrons for a neutron source or pions for a so-called conventional neutrino beam, a neutrino factory or a muon collider. Experience indicates that thermal transport, shock wave and radiation damage will limit the efficiency and reliability of facilities utilising solid targets at around 1 MW beam power. Consequently liquid mercury has been adopted as the target technology for the latest neutron facilities SNS and J-SNS at ORNL and Tokai respectively, and is the baseline for a neutrino factory and muon collider. However mercury introduces new technical challenges. This paper discusses how a fluidised powder target may combine many of the advantages of a liquid metal with those of a solid, and describes an experimental programme at RAL that is currently underway to implement this technology.

MOTIVATION FOR A FLOWING POWDER TARGET

A new generation of accelerator facilities requires target systems to dissipate powers in the MW range, with pulsed energy depositions of 100s of J/g and beyond. It is widely expected that difficulties of radiation damage, shock wave damage, thermal transport and the need to avoid unacceptable compromises to physics performance will preclude the use of solid targets in such facilities. Consequently liquid metal, namely mercury, has been adopted as the target technology for the latest neutron facilities SNS and J-SNS [1] at ORNL and Tokai respectively. An open mercury jet is the baseline for a neutrino factory and muon collider [2] where pulsed beam induced filamentation of the mercury jet [3] has been demonstrated to be controlled by a solenoidal magnetic field [4]. However implementation of a high velocity mercury jet in an accelerator facility presents considerable technical challenges and alternatives seem worth consideration.

In a neutrino Superbeam, i.e. a conventional neutrino facility beyond 1 MW beam power, a free liquid metal jet is not generally viable since it would need to be directed within the bore of a magnetic horn. Unlike for a solenoid, there is no magnetic field within the bore of a horn to damp out the high velocity jets generated by the pulsed proton beam.

It is in this context that a research programme has been initiated at the Rutherford Appleton Laboratory in the UK to explore the potential of fluidised powder targets [5]. The motivation is to investigate whether such a technology can combine some of the advantages of a solid target with those of a liquid while avoiding some of the disadvantages of either.

The attractions of a static granular target have been outlined before. A helium cooled granular target was investigated for a neutrino factory [6], however the static design had inherent cooling limits. A free-falling powder target has been subject to preliminary investigation [7] however was not considered worth further study.

The attractions foreseen for a flowing powder target include:

- Intrinsic resilience of individual grains to beam induced shock wave damage compared with macroscopic solid targets. In essence, a granular material is already broken and can only be subdivided into ever smaller grains [6].
- Pulsed beam induced stress waves are contained within each separate grain of material, and cannot generate splashing or jets in the bulk powder as can occur with liquid metals.
- The heat conduction path is very short in a powdered material compared with a lump solid. A flowing powder has excellent heat transfer characteristics both within the powder material itself and with container walls, raising the possibility that a flowing powder may be able to remove heat loads generated by secondary particle interactions with pipe walls.
- As for a liquid, a flowing powder can be pumped away from the interaction region and cooled externally using heat exchangers.
- Possibility for a flowing refractory metal powder (melting point ~3000°C) to withstand multiple beam pulses (ΔT ~100°C) interacting with the same material before cooling.
- No cavitation can occur in a powdered solid material within a carrier gas, since this is a phenomenon associated with liquids only.

- Target material is continuously reformed and replenished as for a liquid target.
- Eddy current generation and consequent interaction forces of a conducting powder with a solenoid have been studied for the neutrino factory parameters using the Vector Fields code. The retarding force on a powder grain was shown to reduce as a function of radius to the power of 5, giving a negligible effect for the grain size <250 μm used in experiments thus far.
- Fluidised beds and powder jets are a mature technology developed for the conveyance of powders in the chemical, material and food processing industries. Such experience can be exploited with the design of various components in the development of a complete target system.
- Many of the questions relating to the implementation of a flowing powder target can be investigated experimentally and, crucially, off-line. Also, unlike mercury, powdered tungsten is non toxic. These factors mean that a productive experimental programme can be undertaken at a relatively modest cost.

IMPLEMENTATION OF A FLOWING POWDER TARGET

Figure 1 illustrates an outline concept for a flowing powder target contained within a pipe, passing through the bore of a magnetic horn as for a Superbeam. An intermediate tube could be introduced to provide a path for coaxial gas return from an air lift system as illustrated in Figure 2.

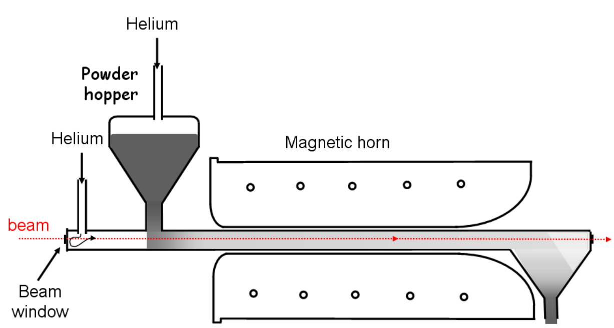

Figure 1: Illustration of contained flowing powder target.

The same concept could be used for a Spallation Neutron Source target or for a Neutrino factory. However the first configuration studied was that of an open jet of tungsten powder, as this was considered the most challenging arrangement and is also directly comparable with the open mercury jet baseline for a Neutrino Factory.

Figure 2 shows a schematic outline of a circuit that would provide continuous operation and recirculation via an external heat exchanger, in an open jet configuration.

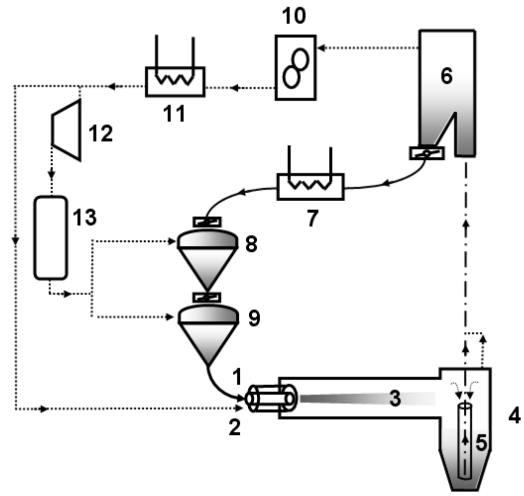

Figure 2: Schematic outline of a circuit for continuous powder target supply, with (1) powder discharge nozzle, (2) gas return line forming coaxial flow, (3) either open target jet (shown), or flow within pipe (4) receiver hopper, (5) suction nozzle for gas lift, (6) gas lift receiver vessel with filter, (7) powder heat exchanger, (8) and (9) pressurised powder hoppers, (10) Roots blower, (11) gas heat exchanger, (12) compressor, and (13) gas reservoir.

STATUS OF EXPERIMENTAL RESEARCH PROGRAMME

Numerical simulations are not generally useful in the study of the behaviour of bulk powders, and so a predominantly experimental research programme has been initiated at RAL. A test rig comprising most of the elements in the schematic of Figure 2 has been commissioned to investigate off-line key issues for flowing powders, namely (1) flow characteristics of candidate target materials in a dense phase, starting with tungsten as a prototype high-Z refractory metal target, (2) effectiveness and pressures required for both air and helium as a driver gas (helium would be used in an on-line facility for its favourable heat transfer properties and to minimise effects of gas activation and ionisation), (3) achievable material fraction, (4) vacuum recirculation, (5) erosion of pipe walls and methods of mitigation, (6) open jet and closed pipe configurations.

Figure 3 shows a photograph of the test rig. An automated control system with a graphical user interface was written to operate the rig through the following stages and to log all instrumentation data. Operating in batches of c.100 kg, the tungsten powder is conveyed from a pressurised hopper through a horizontal 1 m long pipe with a 20 mm diameter bore, opening into a 200 mm diameter transparent tube to simulate entry of the jet into a pion capture solenoid. Air is drawn through this by means of an 18 kW roots blower drawing a vacuum of -400 mbar (gauge) on the receiver hopper. A coaxial flow of air around the jet is achieved by introducing an annular return from the blower at entry of the discharge pipe into the transparent tube. The powder is lifted from the receiver hopper with a specially designed nozzle which uses coaxial air flow to fluidise then lift the powder to a high level receiver vessel connected to the roots blower via a filter. Two sliding valves open to drop the powder into the pressure hopper which is then ready to be pressurised for the next batch. Automatic control of the circuit is achieved using a combination of timed processes and feedback from sensors e.g. a load cell to measure the mass of powder in the pressure hopper.

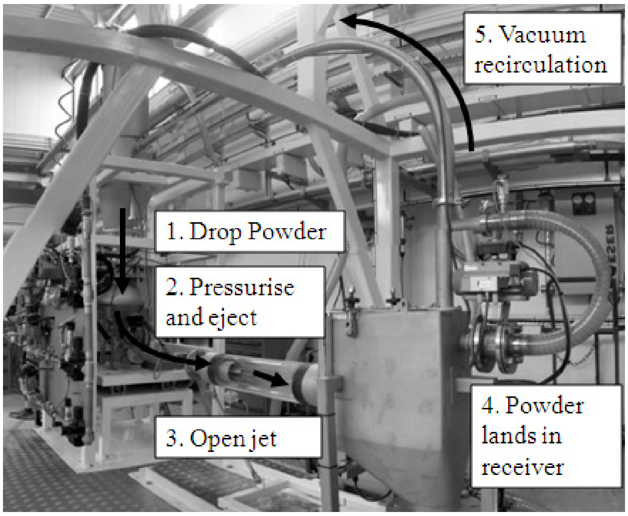

Figure 3: Powder handling test rig at RAL.

The jet was filmed using a Vision Research PHANTOM 7.1 high speed video camera from the EPSRC Instrument Loan Pool. This was set to 5000 frames per second, enabling estimates of the jet velocity to be obtained. During March 2009 a total of 31 cycles conveyed 3000 kg powder in the study of the effects of varying flow geometry, conveying pressure over the range 2 – 5 bar and coaxial flow velocity over the range 10 – 30 m/s.

A driving pressure of 2.0 bar generated a uniform jet velocity of 3.7 m/s and a mass flow rate of 7.9 kg/s. From this it was possible to estimate a jet material fraction of 42% ±5%. This is close to the maximum achievable value of around 50%. Figure 4 shows a still image from the high speed camera.


Figure 4: Tungsten powder jet of c.42% material fraction.

OUTSTANDING ISSUES FOR POWDER TARGET TECHNOLOGY

Flowing powder target technology naturally poses new challenges and limitations that do not exist for either solids or liquids. Erosion is almost certainly the key technical issue, for example at pipe bends, nozzles, valves and in receiver vessels/hoppers, and this is the focus of the current experimental programme. If this can be satisfactorily resolved, then other issues that would require study include:

- Secondary particle interactions with a pipe wall for a contained flowing powder target, including beam heating, shock wave damage and radiation damage all of which will be most significant for high Z targets. It is planned to carry out off-line measurements of the heat transfer between the pipe wall and the flowing powder to determine whether this will be a sufficient cooling mechanism.
- Demonstration that pulsed beam effects on powder in a carrier gas are negligible, with a few intense proton beam pulses impinging a thimble of powder in a helium atmosphere. The result would be directly comparable with a similar experiment carried out for a thimble of mercury [8].
- Licensing of a facility and strategies for handling highly activated powder, however radiological and safety issues are not expected to be any more severe than for mercury, and could be more benign.

SUMMARY

It has been demonstrated that tungsten powder can be readily fluidised within a pipe in dense phase and can form a dense, stable and coherent jet. Both these configurations have the potential to form the basis of a multi-MW target for future accelerator based facilities. An experimental programme is underway to explore the implementation and limits of such a system.

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