

SOLID TARGET FOR A NEUTRINO FACTORY

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Abstract

The UK programme of high power target developments for a Neutrino Factory is centred on the study of high-Z materials (tungsten, tantalum). A description of lifetime shock tests on candidate materials is given as part of the research into a solid target solution. A fast high current pulse is applied to a thin wire of the sample material and the lifetime measured from the number of pulses before failure. It has been found that tantalum is too weak at these temperatures but a tungsten wire has reached over 26 million pulses, equivalent to more than ten years of operation at the Neutrino Factory.

1 Introduction

There are proposals [1] to build a Neutrino Factory in the US, Europe or Japan, in order to understand some of the basic properties of neutrinos. Extensive Neutrino Factory R&D is underway around the world on a number of fronts. Target R&D is particularly important because it could be a potential showstopper. The UK programme of high power target developments for a Neutrino Factory is centred on the study of high-Z solid materials (tungsten, tantalum).

The Neutrino Factory target is not a stopping target. It dissipates a mean power of about 700 kW in a 2–3 cm diameter bar of tungsten about 20 cm long. The remaining 3.3 MW of beam is absorbed in a beam dump and surrounding shielding. The energy density averaged over the target volume is ~ 300 J/cm³ per pulse (assuming a 2 cm diameter target). Tungsten and tantalum are candidate materials since they have high Z values, are refractory and are relatively strong. Also, these metals have been shown to be extremely resistant to radiation damage effects in the ISIS target [2] (up to 12 dpa), similar to the Neutrino Factory target after 10 years of operation. The magnitude of the thermal stress on the target, which is the main issue for solid targets, is governed by the magnitude and rate of change of the energy density. With the Neutrino Factory there is a requirement for short micro-pulses of 1-2 ns length within a macro-pulse of a few micro-seconds. MARS [3] calculations have been made of the beam hitting tantalum and tungsten targets to assess the distribution of energy deposition, and to calculate the corresponding temperature rise. The peak temperature rise is about 200 K, in which a parabolic transverse beam current distribution is assumed, where the beam radius and the target radius are equal. The temperature rises are then used in the commercial package LS-DYNA [4] to calculate the dynamic stresses in the target. As can be seen in Figure 1, the equivalent Von Mises stress can reach several hundred MPa, depending on the target diameter, the number of bunches (an odd number of bunches is preferred for the muon accelerator) and the pulse length. Also, we can see that by a clever choice of pulse length (assuming equally spaced bunches) we will be able to reduce the stress on the target by a factor of two or more.

When discussing a solid tungsten (or tantalum) bar as a choice for a Neutrino Factory target we do not mean to have a single bar. In our case, the individual bar concept assumes that we have hundreds of bars, and that a “new” bar would be presented for each beam pulse and then cooled by radiation until the next turn. A lot of work is still required to develop this idea into a full concept, for example to

examine the effect of eddy currents on the wheel, to estimate the forces that the support structure will need to withstand, etc. However, the first step in this direction is to determine the lifetime of tungsten and tantalum as potential Neutrino Factory targets.

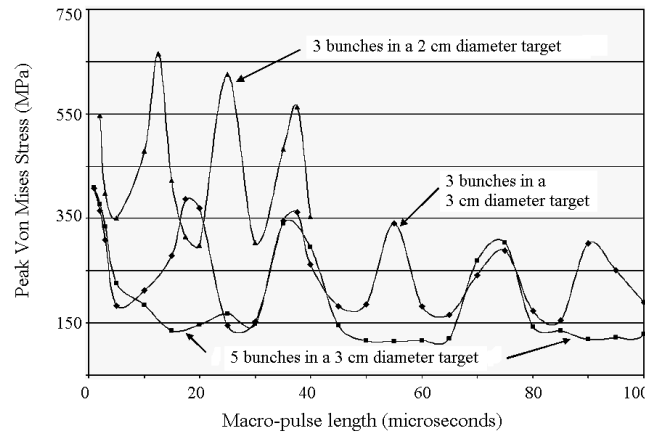


Fig. 1: Variation of the peak stress versus macro-pulse length in 2 and 3 cm diameter targets, with 3 and 5 equally spaced bunches (each 2 ns long).

2 Lifetime shock tests

In order to make thermal shock measurements on tantalum and tungsten samples it would be best to do a lifetime test on a real size target in a beam over several years. However, beams of this power are not readily available for any length of time. Hence, it was decided to pass a fast, high current pulse through a thin wire made of the candidate materials. A thin wire is necessary to allow the current to diffuse into the centre of the wire in a sufficiently short time for the shock to be effective. For tantalum and tungsten the wire cannot be greater than ~ 0.5 mm in diameter. A power supply for the ISIS [5] kicker magnets is being used, supplying a maximum of 60 kV and 8000 A at up to 50 Hz in a pulse which rises in 100 ns and is 800 ns long. The wire is operated at temperatures of 600-2000 K by adjusting the pulse repetition rate.

The stress in the wire is calculated including both temperature and the Lorenz force from the magnetic field produced by the current passing through it. It was shown that Von Mises stress in the wire reaches similar values to the beam-target case, hence it is possible to relate the current in the wire that produces the same peak stress as the beam in the full sized target. We found that the tantalum was too weak at temperatures of 1400 K or more. The tungsten was much more robust and the wire only failed when operated at temperatures well over ~ 2000 K. In some cases the wire(s) survived tens of millions of pulses, for example 26.4 million pulses in the high temperature regime at the equivalent beam power of 4 MW in a 2 cm diameter target. This corresponds to the target lifetime at the Neutrino Factory of more than 10 years (more than 20 years for a 3 cm diameter target).

3 Laser Doppler Vibrometer measurements

In addition to the lifetime tests, we have started a set of measurements of the surface radial and longitudinal motion of the wire using a single point Laser Doppler Vibrometer (LDV) from POLYTEC [6]. The LDV employs a laser, which must be reflected off the wire, and measures the wire velocity via interferometry. Figure 2(top) shows the shape of the current pulse and the corresponding radial velocity of 0.5 mm diameter tungsten wire is shown in Figure 2(bottom). The current pulse is arriving at $t=0$ and we can see the clear difference between the LDV reading (red line) before and after the pulse. Black line

in Figure 2(bottom) shows result of LS-DYNA simulations which agrees very well with experimental result. Further work will be carried out, but these preliminary results fully confirm the modelling results and results of our lifetime tests.

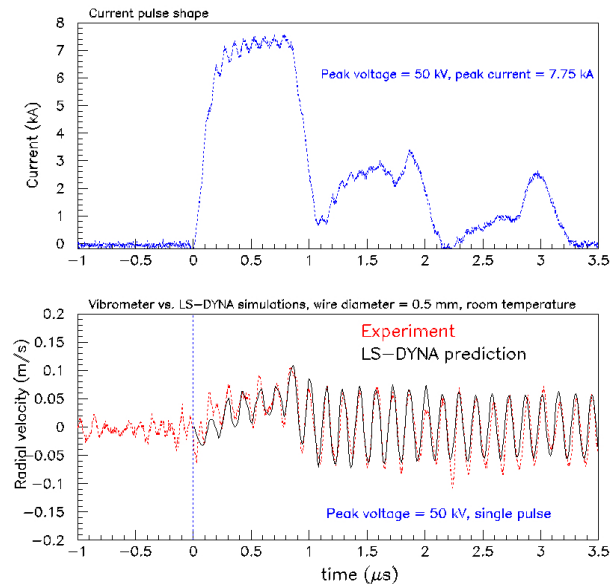


Fig. 2: The shape of the current pulse (top) and the corresponding measured (bottom, red) and simulated (bottom, black) radial velocity of 0.5 mm diameter tungsten wire.

4 Conclusions

Our lifetime shock tests demonstrated that tantalum is not strong enough at high temperatures, but a tungsten wire has reached over 26 million pulses, equivalent to more than ten years of operation at the Neutrino Factory. Measurements of the surface velocity of the wire using a Laser Doppler Vibrometer are in progress, and the first results fully confirm our modelling results. These measurements combined with LS-DYNA modelling will allow the evaluation of the constitutive equations of the material under conditions expected at the Neutrino Factory.

Acknowledgement

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References

- [1] See the proceedings of NuFact from 1999 to 2006, e.g. NuFact05; Nucl. Physics B (Proc. Suppl.) 155 (2006).
- [2] J. Chen et al., J. Nucl. Mater., 318 (2003) 56.
- [3] N. Mokhov, <http://www-ap.fnal.gov/MARS>.
- [4] Livermore Software Technology Corp., <http://www.lstc.com/>
- [5] See the ISIS web site: <http://www.isis.rl.ac.uk/>.
- [6] POLYTEC Webpage, <http://www.polytec.com>.