Bolometric Measurement of Beam Intensity at Cryogenic Windows

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- Study of energy deposition in Al windows
- Mechanical deformation of windows
- Temperature modulation in windows
  - resistance measurements in special coatings
- Program at University of Chicago

• NB: these are very preliminary ideas!
Bolometer (from O.E.D.)

[f. Gr. beam of light + measure.]

An electrical instrument of great sensitiveness for measuring radiant heat. Hence bolometric (blmtrk), a.

1881 Nature XXV. 14 An instrument..capable of indicating a change of temperature as minute as 1-100,000th of a single Centigrade degree ..is termed by its discoverer, Professor S. P. Langley, the bolometer, or actinic balance.

1882 Athenæum 2 Sept.310/1
His ‘bolometer’, or radiation measureran instrument some twenty times more sensitive than the thermopile.

1881 C. A. YOUNG Sun 306 Shown by the bolometric measures described above.
Deformations of Windows

• Intense muon beam interactions in windows have been considered for secondary particle emission measurements

• However, we are now considering beams with energy deposition large enough to cause measurable mechanical deformation

• Additionally, the liquid hydrogen temperatures could permit novel use of resistance measurements in
  – Superconducting Edge Bolometers
  – other resistive films
Beam Properties

• Assume FNAL design
  – bursts of quadruple-bunches at 15 Hz
  – $2 \times 10^{12}$ muons in each group
  – roughly 100 ns duration of group

• Beam size
  – I use $\sigma = 5$ cm gaussian
  – but results extend to other profiles

• Windows
  – cryostat windows at 10 - 20 K
  – typically 200 - 400 $\mu$ thickness
    • I use 300 $\mu$
Properties of Al at 10K

- Density: 2.7 g cm\(^{-3}\)
- Minimum dE/dx: 6.9 \(10^{-13}\) J cm\(^{-1}\)
- Heat capacity: 0.0014 J g\(^{-1}\) K\(^{-1}\) (6061)
- Thermal diffusion constant:
  \[ \kappa = 21.7\text{ cm}^2\text{ s}^{-1} \]
- Speed of sound: 5000 m s\(^{-1}\)
- Expansion coefficient: 2 \(10^{-5}\)

- Thus, the relevant time constants are:
  \[ T_{\text{sound}} = 100\text{ ns} \]
  \[ T_{\text{thermal}} = 40\mu\text{s} \]
- Energy deposit per bunch-group: 0.166 J !!!
- Heating per bunch group: > 15K, average
  – same \(\Delta T\) for any thickness; for 30 micron film, get time constant of 1 \(\mu\text{s}\)
  – pulsed temperatures matching hi\(T_c\) mat.
Mechanical Deformation

• For uniform illumination of 100 cm$^2$ (a worst-case!) we obtain window expansions of:
  – 95 nm
• Not practical!
  – marginal magnitudes
  – expensive (?) optics
  – need space for optics

• But… are capacitative measurements feasible?

• On the brighter side:
  – not damaging to surface coatings
Bolometers

• Real calorimetry!
• We would be interested in materials with a high temperature-dependent resistance

• Can deposit on surface in any pattern

• Can get short time constants in thin films
  – easy to sputter onto cryostat windows
  – metal films would be very robust
    • resist mechanical cycling
    • radiation hard
  – exotic materials
    • can be well matched to cold LH temperature
    • can give large signals
Pro and Con

• Thermal time scale
  – no single bunch profiling
  – but might get single-turn profile

• No separation of X-rays
  – but dual layers of different materials might allow a subtraction

• Easy segmentation (sputter deposition)
  – strip or pixel readout
  – long time-scale resistance measurement should be robust to RF noise

• Radiation hardness varies
  – low amplitude materials are ok
  – … but are the high-sensitivity materials rad-hard?
A15 Materials

- For windows attached to a LnH thermal batch, get crossing of superconducting “Edge”
  - large class of so-called A15 materials
    - e.g., Nb-Al-Ge
  - can formulate compounds matched to any temperature edge in the 10-30K range
  - resistance goes linear above the edge, so you can measure intensity
  - electrical segmentation possible with deposition by sputtering
  - use insulating substrate … can choose optimal thermal insulation
- Relatively inexpensive
  - robust electronic signals
The General A15 Behavior

\[ \rho (\mu \Omega \cdot \text{cm}) \]

\[ T (\text{°K}) \]

\[ \text{Nb}_3\text{Sb} \]
\[ \text{Nb}_3\text{Sn} \]
Radiation Damage

- This remains an important question

- A15 materials may not survive our beam halo, but this needs to be studied
  - the materials are often “tuned” using ion doses
  - can we establish saturation?

- However, more conventional bolometric materials are radiation-hard
  - can we get enough signal from “simple” resistive strips?
Work In Progress at Chicago

• New postdoc (Kara Hoffman) and Oreglia are setting up a bolometry lab at the EFI
  – materials and sputtering methods under study
  – radiation damage studies
• Finite element model under construction
  – will have thermal diffusion
• Particle backgrounds will be studied
  – sure, the backgrounds are bad, but
    • perhaps dEdx, time constants, profiles can differentiate

• ANL has the world experts on sputter-deposition of A15 materials … talks underway!