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TITLE A SEGMENTED CALORIMETER FOR LOW-ENERGY PARTICLE BEAMS IN SPACE

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A SEGMENTED CALORIMETER FOR LOW-ENERGY PARTICLE BEAMS IN SPACE

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Abstract

We describe a segmented calorimeter for determining the spatial intensity distribution of a neutral particle beam. Our instrument for a 1-MeV H^0 beam consists of a 5 x 5 array of boron nitride (BN) blocks, each block 0.975 cm by 0.975 cm by 0.051 cm thick, glued onto a polyimide printed circuit board. The temperature sensor behind each block is a special integrated circuit (AD590). The sensor data are multiplexed into an IBM AT computer for laboratory testing or into a telemetry system and a microVAX II computer for flight. Special features include protection against beam induced sparking and the launch and space environment.

Introduction

We have developed a segmented calorimeter for detecting and analyzing low energy neutral particle beams from accelerators in space. Energy that is deposited in an array of thin blocks in the calorimeter causes a temperature rise in each block. This temperature rise is directly related to the beam power (Eq. 1), and, therefore, related to the beam intensity if the beam energy is known. Segmentation into blocks allows the spatial distribution to be determined. More traditional instruments (such as a Faraday cup or other electrical devices) cannot be used without stripping of the electrons. The presence of secondary electrons and plasmas makes these instruments difficult to calibrate, especially if the beam is spatially large. Because this calorimeter measures the temperature rise by stopping the protons, it is insensitive to the presence of electrons. Our calorimeter is designed for a 1 MeV H^0 beam, 2.5 cm in diameter. However, it is also suitable for charged beams and higher energies.

Material Details

The calorimeter consists of a 5 x 5 array of boron nitride (BN) blocks, each block 0.975 cm by 0.975 cm by 0.051 cm thick, glued onto a polyimide printed circuit (PC) board (Fig. 1). Boron nitride is preferred over graphite because it fluoresces more than graphite when bombarded and, hence, is more easily positioned in the beam for testing. The adhesive is an epoxy custom designed for low outgassing, high temperatures, and flexibility under launch vibrations. Its curing temperature was limited to 195 °C, the maximum safe temperature for the sensors. The polyimide PC board chosen because it can tolerate high temperatures, contains one set of holes to minimize heat flow between adjacent blocks and another set for the sensors (Fig. 2). The glued PC boards successfully passed vibration tests and temperature cycling tests designed to simulate the rocket launch.

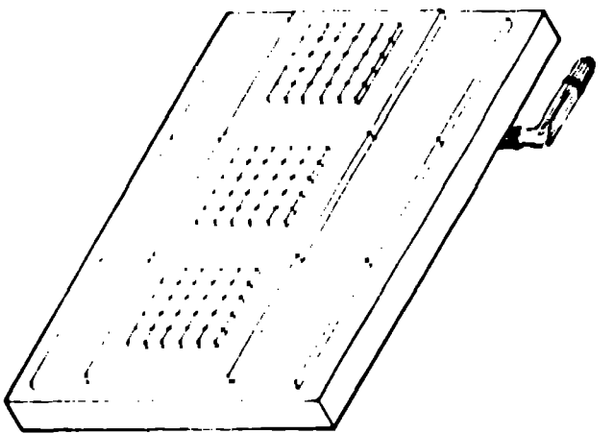


Fig. 1. Three calorimeters for the three beams, H^+, H^0, and H^- after separation by the magnet.

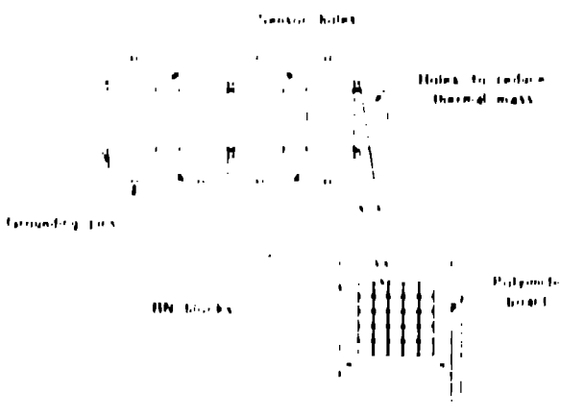


Fig. 2. Partial drawing of an array showing holes in the PC board for the sensors and grounding pins and holes to minimize heat flow between adjacent BN blocks.

Sensors

Each sensor is a special temperature sensitive integrated circuit (IC), Analog Devices Model AD590, touching the back of a block. The sensitivity is 1 μA/K, and the output is linear to ± 0.3 °C over the operating range -55 °C to +150 °C. In preliminary testing we tried thermocouples, which are less sensitive but more rugged. The AD590 ICs have relatively high-level outputs and can be multiplexed on the PC board, which reduces the number of wires in the vacuum. However, the sensor has several disadvantages: (1) a slow response time of 5 to 10 ms, (2) it requires power, and (3) it generates 1 mW, which raises the sensor's temperature above the ambient.

The AD590 ICs are susceptible to damage from sparking caused by the beam. To drain away charge and protect the ICs, we evaporated a thin metallic coating on the edges of each block and inserted 0.0-1 cm diam copper pins (Fig. 2) into holes through the PC board to connect the edges to the ground plane on the back of the board. When the beam was allowed to strike the board outside the array, we observed surface discharges to ground, which damaged the ICs. We eliminated this problem by masking the bare PC board with grounded metallic foil and connecting all grounds to the vacuum chamber, which is the accelerator ground.

Electronics

In the space experiment, the electronics are required to accurately sample 75 sensors in less than 200 ms. Seventy-five sensors are necessary because the accelerator beam passes through a magnet, which separates it into three beams (H^-, H^0, and H^+), each of which requires a 25-block calorimeter array. Less than 200 ms is available to sample all 75 sensors, because the sampling time must be shorter than the sensor response time (approximately one second), and the sampling must be done between beam pulses to minimize interference. Since the space accelerator pulses at 50-μs-wide pulses at 5 Hz, the available interval between pulses is less than 200 ms. The desired accuracy is 1.5% at the maximum expected temperature rise of 100 °C, the desired repeatability and resolution are both 0.5%.

Figure 3 shows a block diagram of our system which meets the above-mentioned requirements. We chose an architecture that combines multiplexing and filtering for low power, fewer components, and the ability to sample 75 sensors in less than 200 ms. The system includes a microprocessor, chosen over handwired logic for flexibility of design, ease of interfacing and fewer components, and other electronics of the high speed CMOS (HC/HCT) family, chosen for microprocessor compatibility and low power. The electronics system weighs 2.25 lbs., occupies 122 cubic in., and requires 3 at W at 28 Vdc.

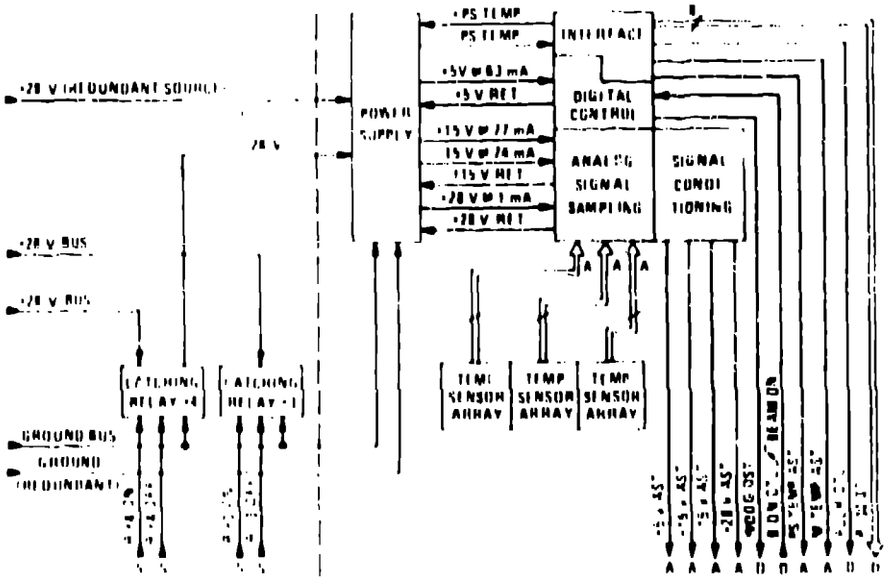
Figure 4 shows a timing diagram. Data from the twelve bit ADC are packed into the 150 eight bit bytes. Two header bytes and two trailer bytes delimit the record. Bytes three and four (labeled SN) provide a sequence number.

An IBM AT computer connected to one of the arrays recorded most of the test data. The temperature of each block and the time were read and stored on hard disk at 5 Hz. All 25 temperatures were displayed at about 1 Hz. A computer system based on a microVAX II, which can be interfaced to a telemetry system, has been developed for collection and reduction of space flight data.

Comparison With Theory

We tested the calorimeter using a 1 MeV Van de Graaff beam of either H^- or H^+. The temperature of each block increased rapidly when struck by the beam and decreased rapidly when the beam was removed. Figure 5 graphs a typical heating and cooling sequence. The curves are described by

$$C_p \frac{dT}{dt} = P - \sigma A (T^4 - T_E^4) \qquad (1)$$



NOTE: POWER SUPPLY CAPACITY MARGIN IS NOT INCLUDED IN THE CURRENT NUMBERS GIVEN FOR EACH SUPPLY VOLTAGE

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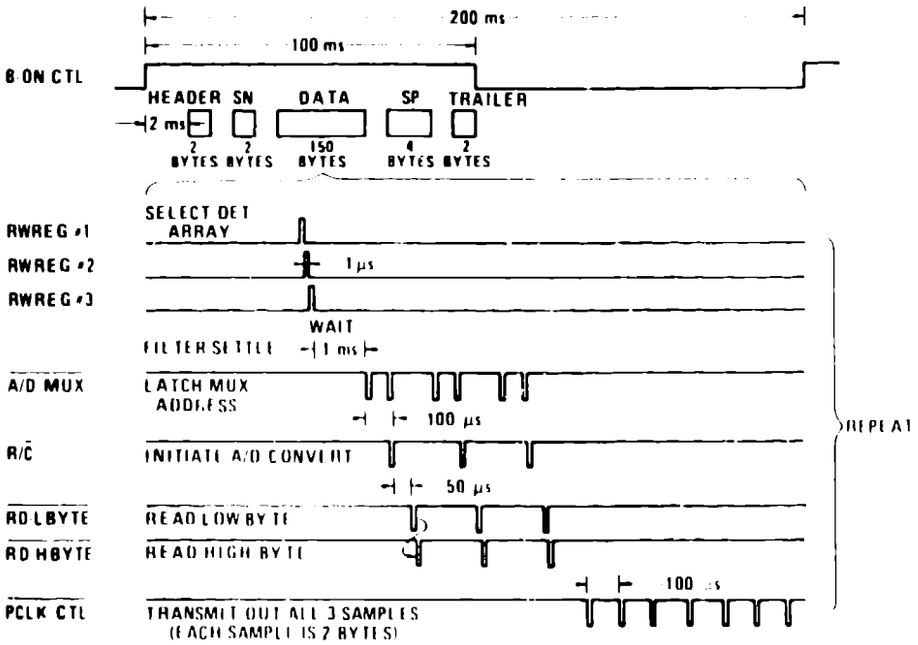

Fig. 4 Timing diagram

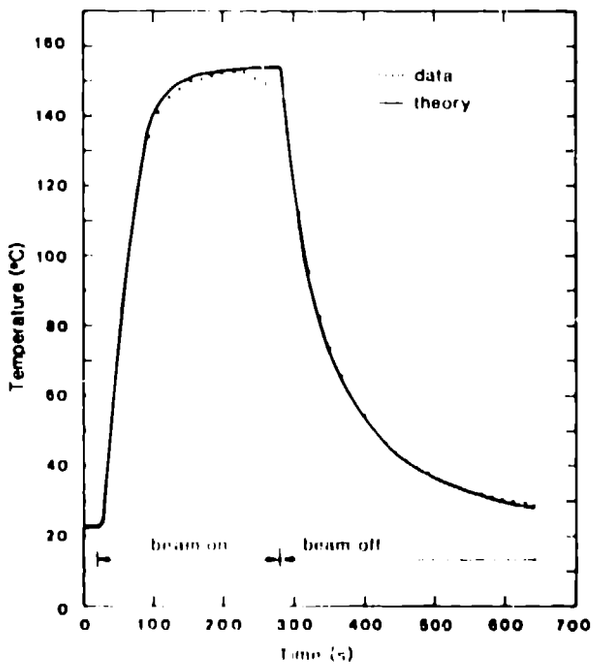

Fig. 5 Heating and cooling curves for a single BN block

where

C_p = thermal conductivity of the boron nitride
T = block absolute temperature
t = time
P = input power from the beam
σ = Stefan-Boltzmann constant
A = effective block surface area
T_p = ambient absolute temperature

The sensitivity is 3 °C/J near ambient temperature, and the operating range (limited by the AD590 IC) −55 °C to +150 °C.

If equation (1) is solved for P, then the beam current intensity can be calculated with

$$I = \frac{P}{V} \qquad (2)$$

where

I = beam current
P = input power from the beam
V = accelerator voltage

The beam current intensity is a function of dT/dt and T.

Conclusion

We designed and tested a segmented calorimeter for studying low energy particle beams. Our instrument is designed specifically for space application. However, it might have advantages in other applications where a neutral beam is used or where there are electrons or a plasma present.

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