A HYPERVELOCITY MICROPARTICLE LINEAR ACCELERATOR FOR USE IN MICROMETEORIC SIMULATION

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Summary

Various means have been developed to simulate micrometeorites in the laboratory. A system is described here which is based on the Wideroe heavy ion accelerator principle. Conductive charged particles in the 0.1 to 5 micron diameter size range are accelerated in much the same manner as are heavy ions. The final velocities so far obtained have been 10.8 kilometers/sec.

This accelerator has been used to study the damage effects of hypervelocity particles to optical surfaces. The system provides a good simulation of the lower velocity type of cosmic dust most frequently encountered in space.

The microparticle linear accelerator offers some advantages over the electrostatic type. However, all types of electric field accelerators used for hypervelocity work are limited to the smaller microparticle sizes due to the very large charge the particle must support.

Introduction

Most spacecraft skin is sufficiently thick to withstand long term micrometeoric bombardment. Two exceptions to this are optical surfaces and surfaces where emissivity-absorptivity balances are critically adjusted. As meteors of a size sufficient to penetrate 30 mil skin are believed to be relatively rare at earth's orbit it is the smaller sizes, 1 to 500 micron diameter, which due to their number will be of most concern. In this size range meteor bumpers would not be necessary. However, it is possible that thin wall heat radiator tubes could be penetrated by 100 micron diameter meteorites.

To study the effects of micrometeorites in the 1 to 5 micron size range a linear accelerator was constructed. This machine was designed along heavy ion linear accelerator concepts except for the particle injector and charger. As the particles are not a gas, it was necessary to provide continuous agitation of such nature as to insure relatively constant particle flow.

Accelerator Design

This microparticle RF linear accelerator is based on the principles of operation of the Wideroe heavy ion accelerator[1]. The particles that can be accelerated range from 0.1 to 5 microns in diameter and can be composed of any material that, in this size range, can support a charge-to-mass ratio of 30 coulombs per kilogram. A few examples are atomized aluminum, carbon, iron, and possibly conductive glass microspheres.

In operation, these particles are first positively charged by contact using a high electric field to produce charge-to-mass ratios of the needed magnitude. The charger (Fig. 1) is built into a rotary injector that in turn is located inside the head of a VandeGraaff generator operated at approximately 433 kv. If a particle of mass, m, kilograms and charge, q, coulombs falls through a potential of, v, volts, the energy equation gives a final particle velocity of

$$V = \sqrt{2\,\frac{q}{m}\,v} \qquad (1)$$

or with $q/m = 30$,

$$V = 7.75\sqrt{V} \text{ m/sec} \qquad (2)$$

The charged particles fall through a 4-ft-long pyrex drift tube 4 in. in diameter before arriving at the entrance port to the accelerator, which is at ground potential. Having fallen through this 433,000-v potential, the particles now have, by Eq A-2 , a velocity of:

$$V = 7.75\sqrt{443,000} = 5,100 \text{ m/sec} \qquad (3)$$

At any time, T, there will always be particles arriving at the head of the RF accelerator possessing a $q/m = 30$ and a velocity of 5.1 km/sec. These are the particles that are acceptable for acceleration by the system.

The accelerator (Fig. 2) consists of accelerating elements numbered 1 thru 10, with appropriate spacings to be described shortly. The elements themselves are aluminum with a doughnut configuration, 3-in. outside diameter, 1-in. inside diameter. No focusing grids are used. All the odd-numbered elements are tied together electrically and are connected to one side of a high-voltage transformer, and the even-numbered elements are similarly connected to the other side of the transformer, which is center-grounded and has a peak-to-peak maximum of over 3000,000 v. However, only 260,000 are required. The resonant frequency of the transformers when coupled to the accelerator elements is 36.62 KC. The power to the transformer is supplied by a 6000-v, RF amplifier having a 15-kw capability. The amplifier is driven at 36.62 KC. With these conditions, the accelerator elements have a voltage swing of 130,000 v, plus and minus, relative to ground.

The particles drift through the center of the first element, a field-free region, and arrive at the first gap. Since the element voltages are os-

cillating, only a portion of the particles will arrive at the first gap when the polarity and phase window are proper to accelerate them to the second element. Of those particles accelerated, only those with $q/m = 30$ will attain the proper velocity to cross the first gap, coast through the second element, and arrive at the start of the second gap precisely one-half cycle after entering the first gap so that the elements will reverse polarity completely, and the particle will undergo the same energy gain in the second gap as in the first. The energy gain is assumed to be 147,000 v per gap when the elements are run 260,000 v peak-to-peak. This is consistent with present accelerator theory.

In more detail, consider one particle entering the first gap at the proper time, possessing $V = 5.1$ km/sec and $q/m = 30$ coulombs/kg. Experience has shown that out of a 360-deg cycle (here requiring 1/36,000 sec), a particle should spend 72.5, 107.5, 72.5, and 107.5 deg inside a gap, element, gap, and element, respectively. If V_n denotes the coasting velocity inside the nth element, and $V_{n,n+1}$ denotes the average velocity in the gap following element n, then the length of the first gap is given by:

$V_{1,2}$ x (time spent in first gap)

$$= \frac{V_1 + V_2}{2} \times \frac{72.5}{360} \times \frac{1}{36,000} = S. \qquad (4)$$

On reaching the second element, the particle has so far undergone a total voltage gain of

$$433,000 + 147,000 = 580,000 \text{ v};$$

therefore,

$$V_2 = 7.75 \sqrt{580,000} = 5.9 \text{ km/sec} \qquad (5)$$

Hence, using Eq (3), (4), and (5),

$$S_1 = \frac{5.1 + 5.9}{2} \times \frac{72.5}{360} \times \frac{1}{36,000} \text{ m} = 3.07 \text{ cm.}$$

The length of the second element, l_2, is given by

V_2 x (time spent inside second element) =

$$5,900 \times \frac{107.5}{360} \times \frac{1}{36,000} = 4.89 \text{ cm.}$$

Experience has shown that

$$V_{n,n+1} = \frac{V_n + V_{n+1}}{2}$$

is a valid assumption for operation. This implies a constant acceleration in the gap.

Going further, the particle enters the second gap of length S_2, gains 147,000 v, and enters

the third element of length l_3. Using the techniques given to determining the velocities and lengths of elements and spaces along the accelerator, the following values have been determined and built into the accelerator.

n	Length of nth Element, l_n (cm)	Length of Space Following nth Element, S_n (cm)
1	4.22	3.07
2	4.89	3.49
3	5.47	2.87
4	6.00	4.21
5	6.49	4.53
6	6.94	4.82
7	7.36	5.10
8	7.76	5.37
9	8.14	5.62
10	8.51	

In addition, the following velocity values have been determined.

n	V_n (m/sec)	$V_{n,n+1}$ (m/sec)
1	5,100	5,500
2	5,900	6,250
3	6,600	6,920
4	7,240	7,520
5	7,810	8,100
6	8,370	8,610
7	8,870	9,110
8	9,350	9,600
9	9,810	9,600
10	10,260	10,040

Thus, the particles leave the accelerator at 10.26 km/sec to impinge on selected targets. The environment in the system is a vacuum of approximately 5×10^{-7} mm Hg pressure.

It has been noted during operation that as the vacuum falls toward 8×10^{-6} mm Hg pressure, the X-ray output rises sharply. A level of 0.1 r per minute at 10 ft from the accelerator chamber has been monitored at the above pressure with 260-kv peak-to-peak RF voltage impressed on the accelerator elements.

Particle velocity is measured by means of a double electrode probe which can sense particle passage by the particle charge (Fig. 3). As about 50 particles per second arrive at the target it is

necessary to mask off part of the probe aperture to insure sensing single particles.

Fig. 4 shows the VandeGraaff and high voltage end of the accelerator. Fig. 5 shows the accelerator elements. No focusing grids are used. Fig. 6 shows the RF power unit used to drive the accelerator. Fig. 7 shows the type of damage produced by the particles on a pyrex glass optical flat. The typical hypervelocity crater shape has been lost due to spallation of the glass. The scale is 10 micron per division.

Conclusions

This type accelerator has proved practical for accelerating charged microparticles. It is feasible to reach higher velocity with this machine by adding more elements with associated changes in transformer inductance and driving power. However, more attention to focusing and field fringing effects, due to the vacuum line wall, would be required. Practical considerations indicate that 40 kilometers/sec. may be about the upper limit unless a large investment of money is warranted.

References

1. John J. Livingood, "Principles of Cyclic Particle Accelerators", D. Van Nostrand Co., Inc., 1961. Chapter 14, pp 267-298. Bibliography pp 367-371.
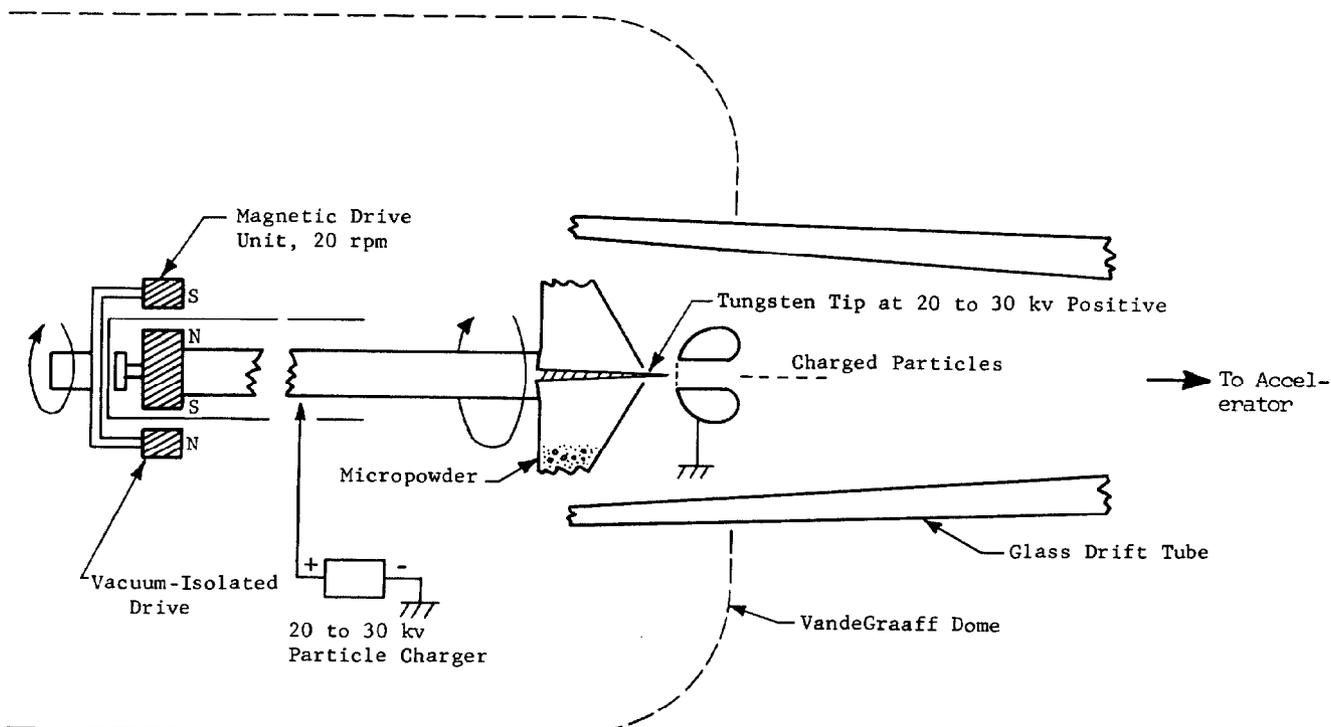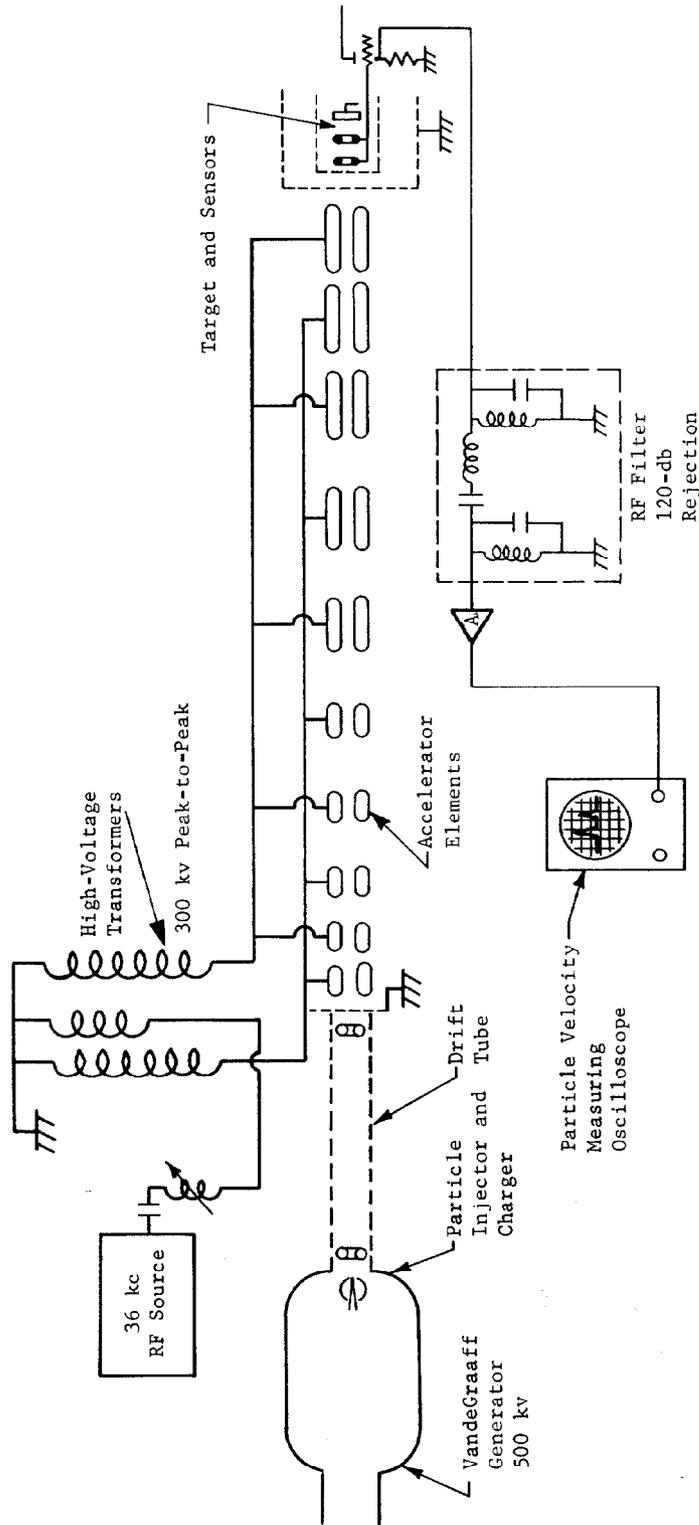
Fig. 1 - Particle charger and injector schematic

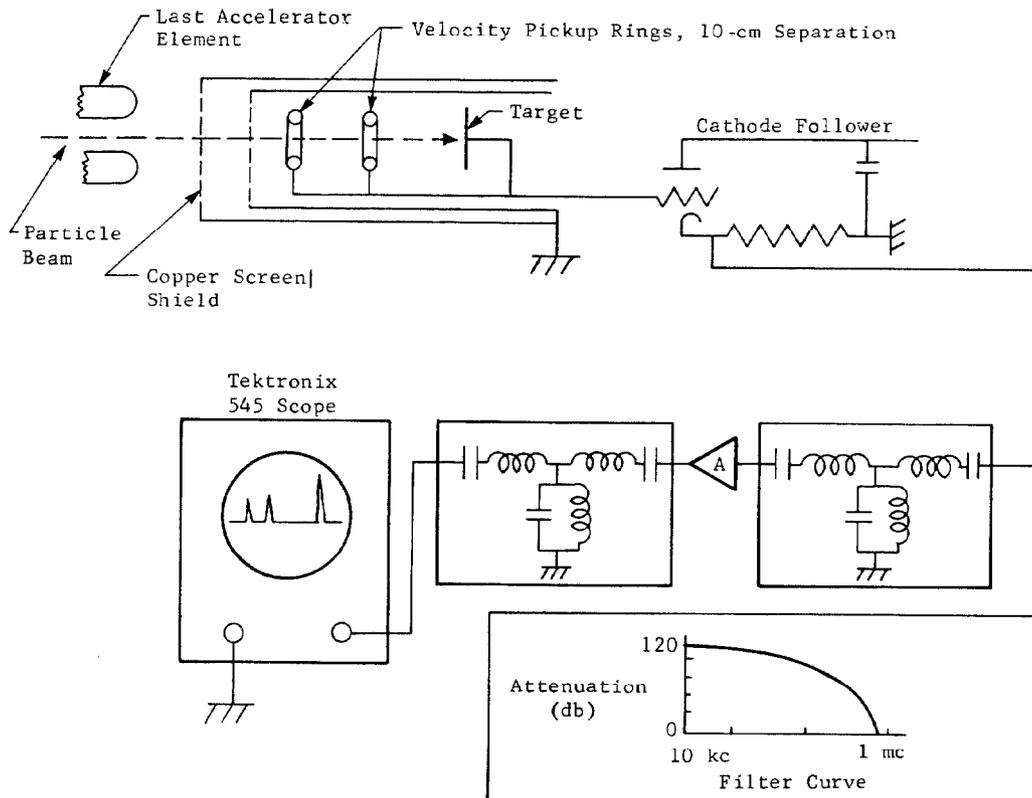Fig. 2 — Accelerator system schematic

Fig. 3 - Particle velocity measurement system schematic
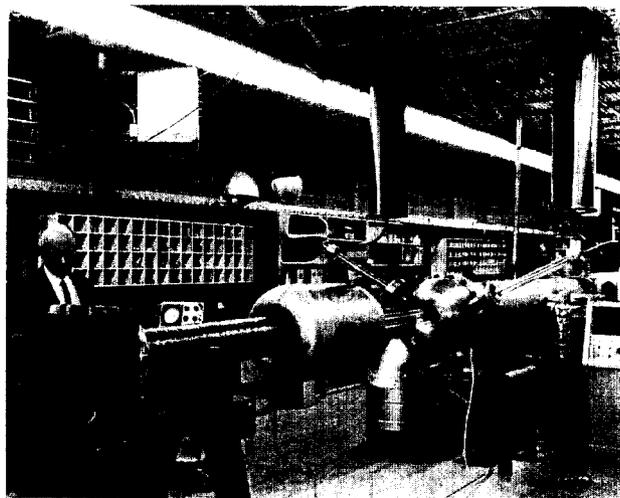
Fig. 4 - Accelerator VandeGraaff and High Voltage System
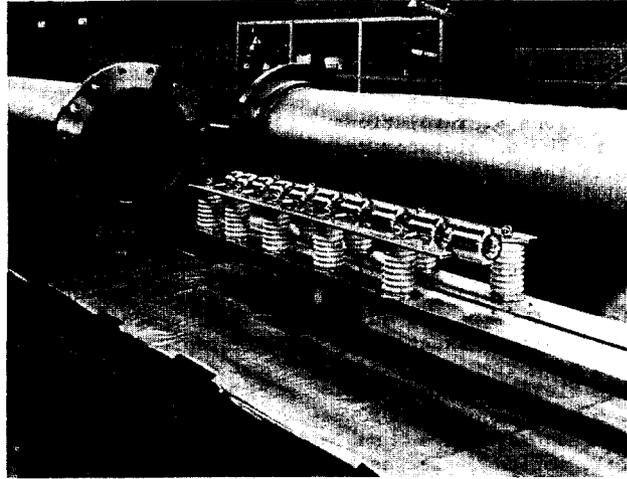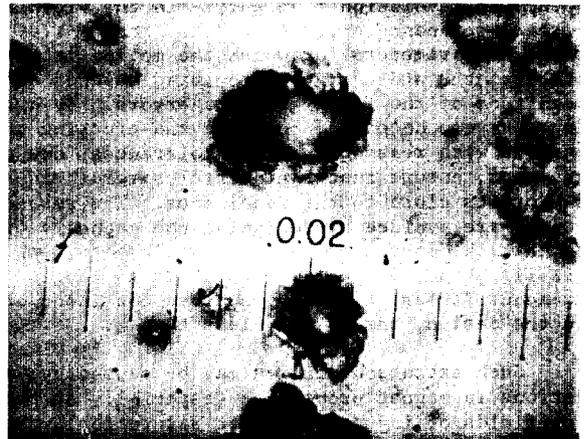
Fig. 5 - Accelerator Elements

Fig. 6 - Low frequency RF generator

Fig. 7 - Pyrex target damage craters.