Projectile Hypervelocity Impact Simulation

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Summary: For the hypervelocity impact simulation of micrometeoroids on a space station, a plasma accelerator was constructed and tested to achieve projectile velocity of 10 km/s. Then the morphology of craters on an aluminum alloy target was investigated. The dual element shield structure consisting of aluminum alloy was tested up to 5 km/s impact. The morphology of impact area and the new technique of projectile emission was also reported.

1. INTRODUCTION

For the last 30 years, lots of communication satellites, weather ones and others have been launched into earth orbits. Now it has been planned to construct a space station where men can work for long duration. As the station should stay in space for extended duration, the occasion of micrometeoroid and man-made space debris impact will increase. Though the effect of debris impact at velocity of 10 km/s depends on the mass, the structural damage to the station will be caused by debris larger than about 3 mm. Smaller ones will cause surface pitting and erosion as cumulative effect, which must lead to some troubles for sensitive communication instruments, observation ones and others. At the impact of a 2024 aluminum alloy projectile on its target at velocity of 10 km/s, dynamic pressure will be induced up to 100 GPa and high temperature will cause melting the alloy. There will be a penetration or a crater with diameter several times larger or more than that of a projectile. At the debris population in 2010, the average number of impact per year on a space station of the general size, which has surface area of 5000 m^2, are predicted to be 4 or 200 for debris with diameter of 10 or 1 mm, respectively. It must be necessary to shield the station against impact.

It is easily remembered that the research satellite of the comet Halley, Giotto, approached to 600 km as far as the comet core and sent the observed data to earth. It was the shielding bumper that was set in Giotto to realize the observation. It protects the several kinds of instruments from innumerable dust impact at velocity of 50 km/s. Though the comet research is the unique case, it shows the ability of a shielding bumper. The development of protection method depends on the two kinds of researches, which are the developments of a hypervelocity impact simulator and a shielding bumper.

2. EXPERIMENT

The two-stage light gas gun has been used as a impact simulator. Very high pressure

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hydrogen or helium gas expands inside the gun and accelerates a projectile. However the velocity of a projectile is limited by the expansion velocity of high pressure gas. Then it is difficult to accelerate a projectile up to 10 km/s or more. Now a simulator with larger acceleration efficiency is needed. One promising technique is the electromagnetic acceleration utilizing intense magnetic field induced by large discharge current from a condenser bank. In this report, the abstracts of the performance test of a constructed plasma accelerator and the impact simulation of micrometeoroids are shown. Glass beads, 0.1~ 0.4 mm in diameter, as micrometeoroids were successfully accelerated up to 7~12 km/s by plasma flow with high density and high velocity induced by large discharge current. On the other hand, the morphology of craters produced by the impact on a 5052 aluminum alloy target were investigated. These are summarized in the references [*1*] and [*2*]. The advanced simulator, two-stage plasma accelerator, are summarized in the reference [*3*].

The dual element shield structure seems to be useful for the protection of a space stations. At the protection of single wall, its thickness must be several times larger or more than the size of a projectile. On the contrary, the dual element shield structure consists of inner and outer walls whose thickness are almost same as the size of a projectile. In this scheme, a projectile should be heated and melted together with the impact area of the outer wall. Then the inner wall shields these splashes. The weight of this structure can be effectively lighter than that of a single wall. Then the material should has lower density and lower melting temperature. Though the aluminum alloy seems to be suitable material, the optimum composition has not been found yet. In the future, some composit material consisting of ceramics would be developed. In this report, a dual element shield structure consisting of 5052 aluminum alloy was used for the impact simulation up to projectile velocity of 5 km/s. The morphology of the impacted area and the new technique of projectile emission are reported in the abstracts [*4*] and [*5*].

3. Results

1) Performance Test of Plasma Gun as Small Sphere Accelerator [*1*]

A plasma accelerator with capability of acceleration of glass beads to a velocity higher than 10 km/s has been developed and tested. This accelerator designed originally by one of the author, E.I., consists of a plasma gun with a compressor coil and a 300 kJ capacitor bank, whose maximum charging voltage is 10 kV. Velocities of glass beads having diameter of 150 ~ 450 μm increased linearly with the charging voltage up to 8 kV. High velocity impact test on to 5052 aluminum alloy was conducted. Crater diameter obtained at 10.8 km/s impact velocity was about 4.5 times of the glass bead diameter.

2) Belocity Dependencies of Glass Beads on the Impact Phenomena using a Plasma Gun [*2*]

A plasma accelerator has been constructed at Tokyo Institute of Technology (T.I.T) with cooperation of Technische Universitat Munchen. A glass bead with 325 μm in diameter having the mass 4.5×10^{-5} g can be accelerated up to 10 km/s by T.I.T. plasma accelerator. A transition from plastic top hydrodynamic regime on 5052 aluminum alloy target occurs at about 5 km/s for submillimeter-sized glass projectile. Craters are examined with scanning electron microscope and electron probe micro analyzer techniques and are discussed with a penetration formula which is based on energy model as proposed by Charters and Summers.

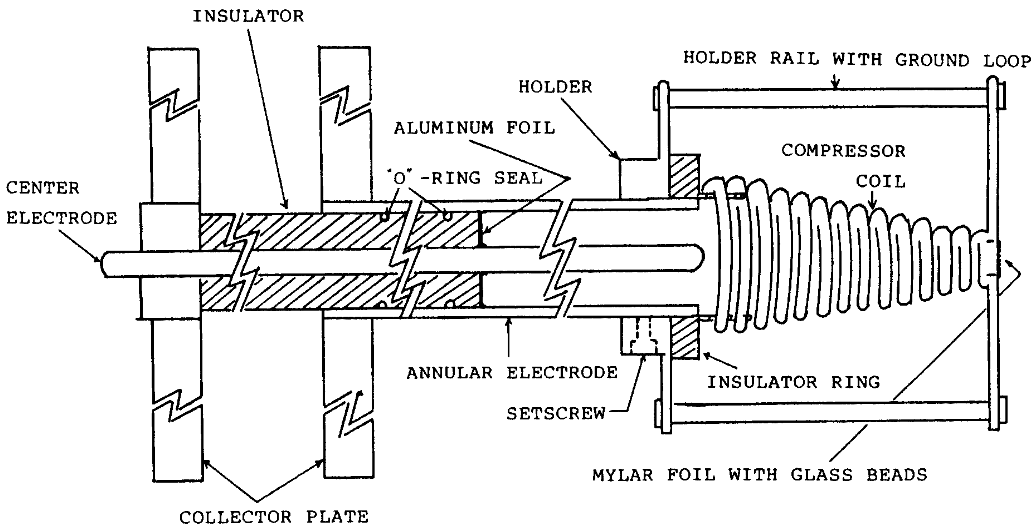


Fig. 1. Schematic representation of the plasma accelerator. The plasma accelerator consists of a coaxial accelerator and a compressor coil

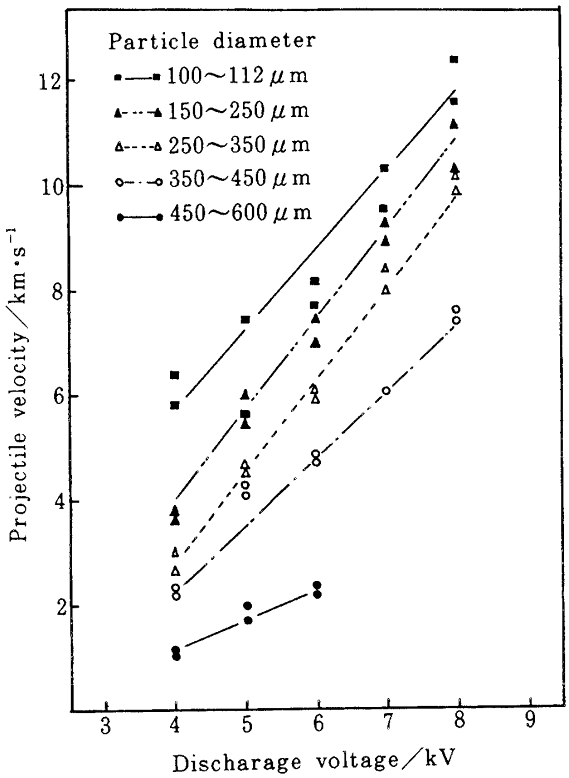
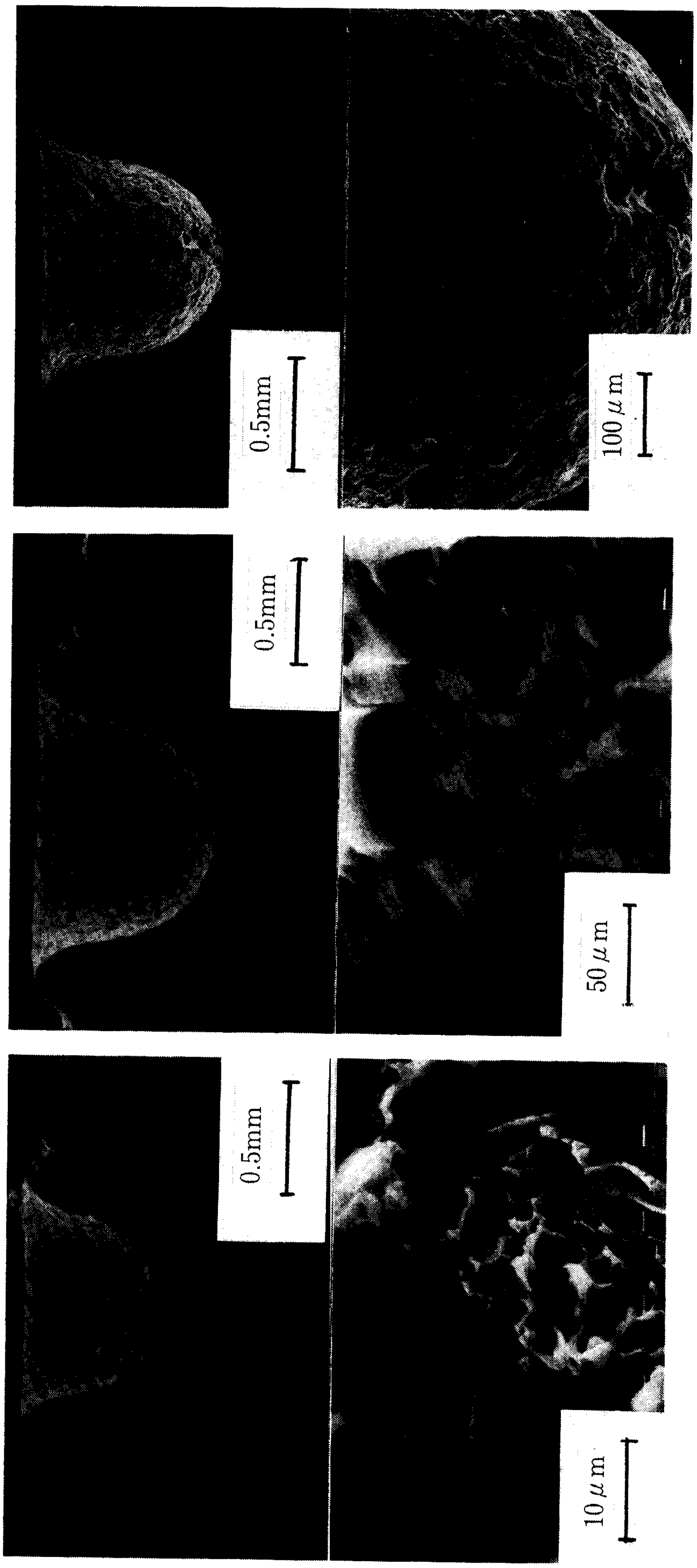


Fig. 2. Projectile velocity as a function of the capacitor bank discharging voltage with different projectile diameters.



(a) Impact at 9.3±0.7km/s (b) Impact at 10.0±0.8km/s (c) Impact at 10.8±0.9km/s

Fig. 3. Craters produced by 300 – 350 μm glass bead impactring upon 5052 Al target at 9.33, 10.00 and 10.77 km/s.

Table 1. Electrical characteristics of capacitor bank./Maxwell Lab. MLR-1504

Characteristics	Description
Maximum voltage	10 kV
Capacitance	6 mF
Maximum energy	300 kJ
Inductance*	57 nH
Resistance*	3.3 nΩ
Peak current (short circuit)	1.7 mA

*These values are included capacitor, ignitron and 8 m coaxial output cables.

3) Improvement of Projectile Velocity and Impact Rate on a Target by Two-Stage Plasma Accelerator [*3*]

A new two-stage plasma accelerator was tested to conduct the hypervelocity acceleration of microprojectiles. The accelerator consisted of a gas gun as the first stage and a plasma accelerator as the second stage. It was confirmed that the two-stage operation performed well at any timing started by the laser trigger system. It was found that the velocity of projectiles was increased in the two-stage operation and that the velocity greatly depended on the position at the beginning of acceleration. The impact rate of projectiles on a target was also markedly increased.

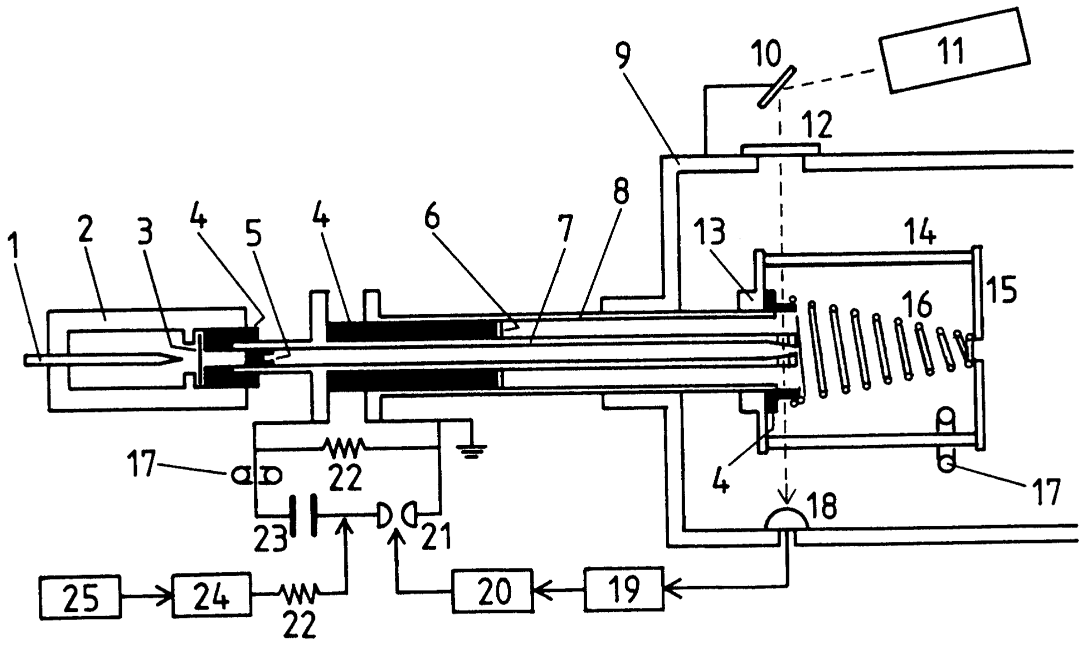


Fig. 4. Schematic diagram of the experimental setup. No. 1: Needle, 2: Gas reservoir, 3: Diaphragm, 4: Insulator, 5: Sabot and projectiles, 6: Aluminum foil, 7: Center electrode, 8: Outer electrode, 9: Vacuum chamber, 10: Mirror, 11: He-Ne laser, 12: Window, 13: Holder for ground loop, 14: Holder rail, 15: Coil spacer plate, 16: Compressor coil, 17: Rogowski coil, 18: Photodetector, 19: Delay pulser, 20: Ignitor, 21: Ignitron, 22: Resistor, 23: Capacitor bank, 24: Charging unit, 25: Controller.

4) Experimental Studies for a Dual Element Meteoroid Shield Structure (1st Report) [4]

The methods of multiwall meteoroid protection for spacecraft have been developed through the Apollo Program. The bumper is shown to be the most important element because it remarkably reduces the damage from the debris impact on the mainwall. The fundamental impact test was carried out to obtain the design data for a dual element meteoroid shield structure using 4 mm sphere pellets at velocity 4.1~ 4.8 km/s. In all cases, thickness of the A1 alloy (2024-T3) bumper and mainwall are 2 mm and the distance between them is 170 mm. As the first report, one method to separate the pellet of manganesezink polycrystalline ferrite from the sabot at hypervelocity and its velocity measuring method which modifies a conventional magnetoflyer method are described in this paper.

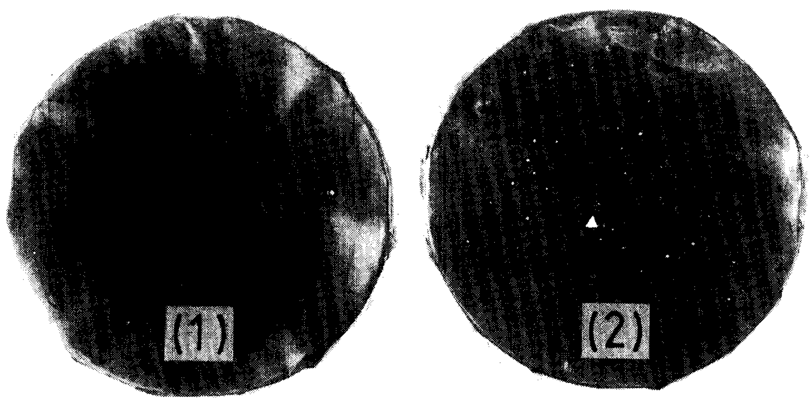


Fig. 5. Perforations on the thin plates in the single-stage operation (1) and the two-stage operation (2). Each perforation is indicated by a white point.

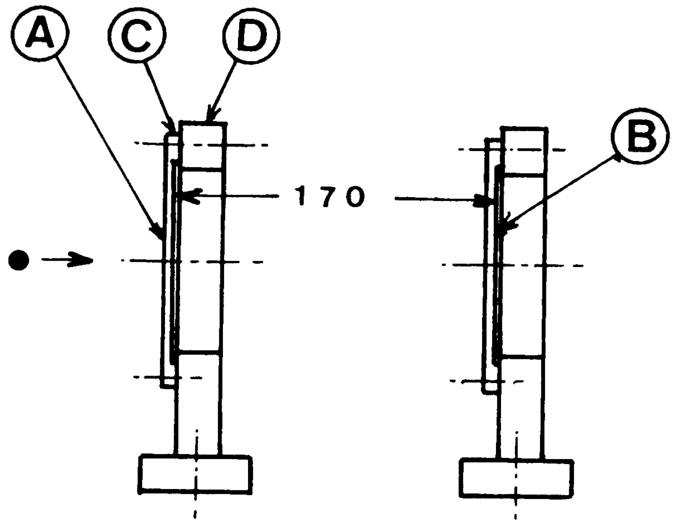


Fig. 6. Experimental arrangement for dual element meteoroid shield structure. (A): Bumper sheet, (b): Main wall, (C): Specimen holder, (D): Supporting frame.

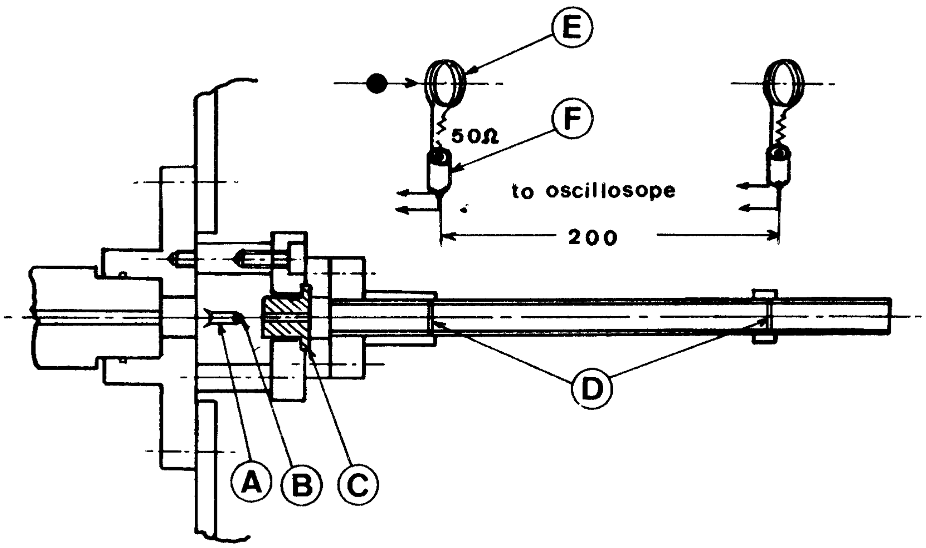


Fig. 7. Experimental assemblies for impact tests and pellet velocity measurement.
(A): Sabot, (B): 4 mm ferrite sphere pellet, (C): Sabot cather, (D): Permanent magnet, (E): Pickup coil, (F): Coaxial cable.

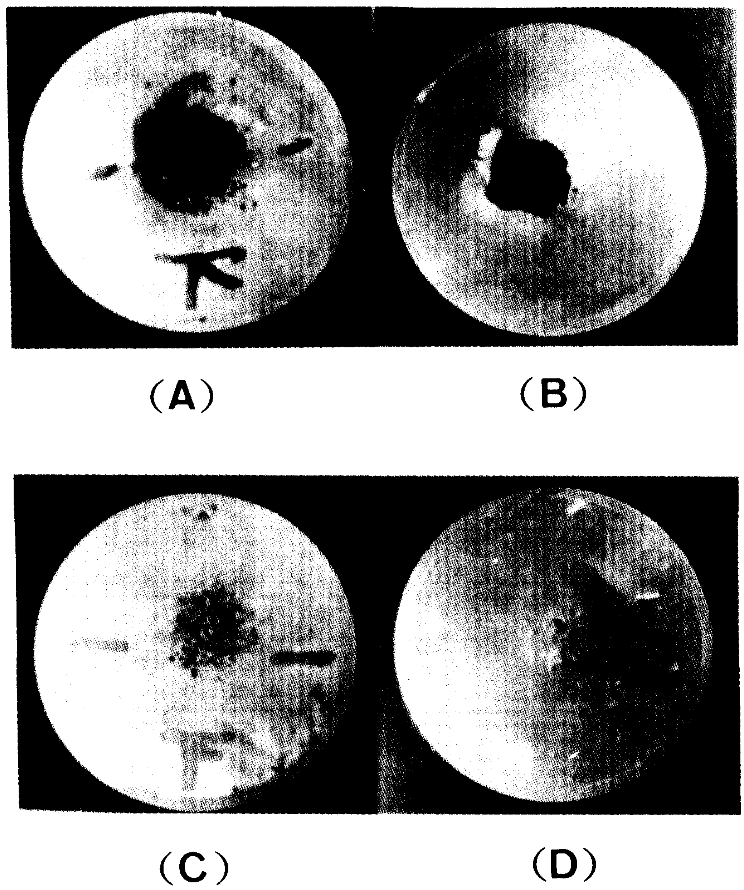


Fig. 8. Impact damage to a dual element meteoroid shield structure. (A): Front, (B): Rear view of a bumper, (C): Front, (D): Rear view of a main wall. Bumper: 2 mm thick 2024-T3 Al, Pellet: 0.172 g Mn-Zn polycrystalline ferrite, Impact velocity: 4.4 km/s, Spacing between bumper and main wall: 170 mm.

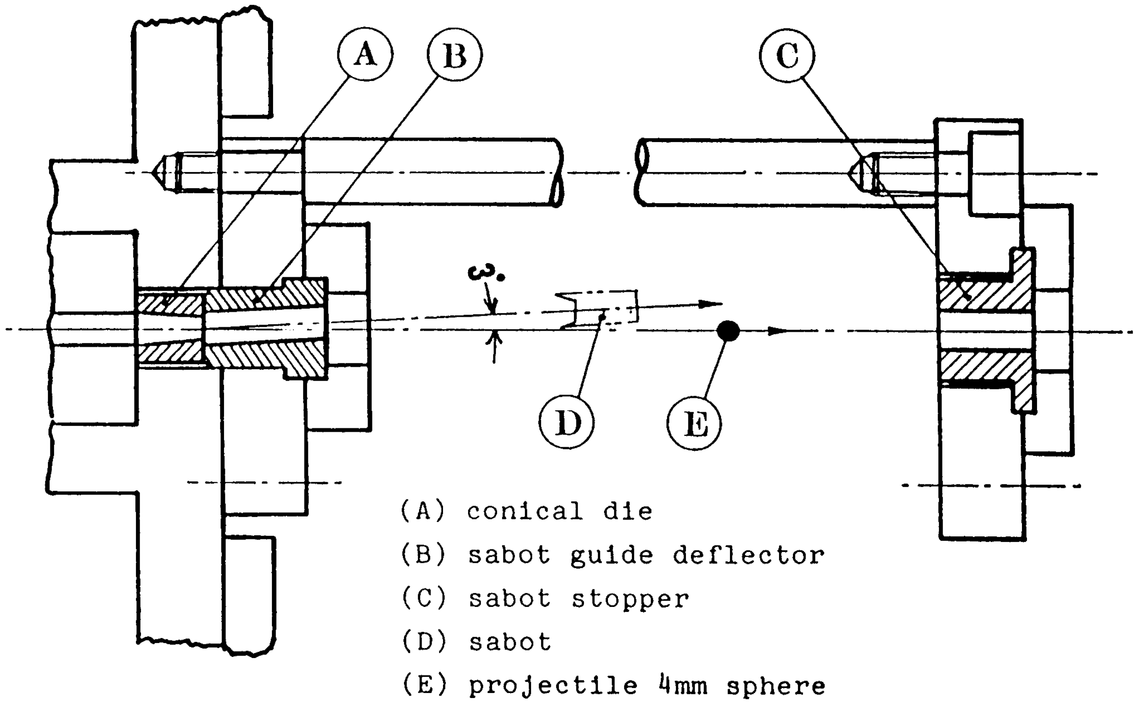


Fig. 9. Experimental arrangement for separation of sabot and projectile.

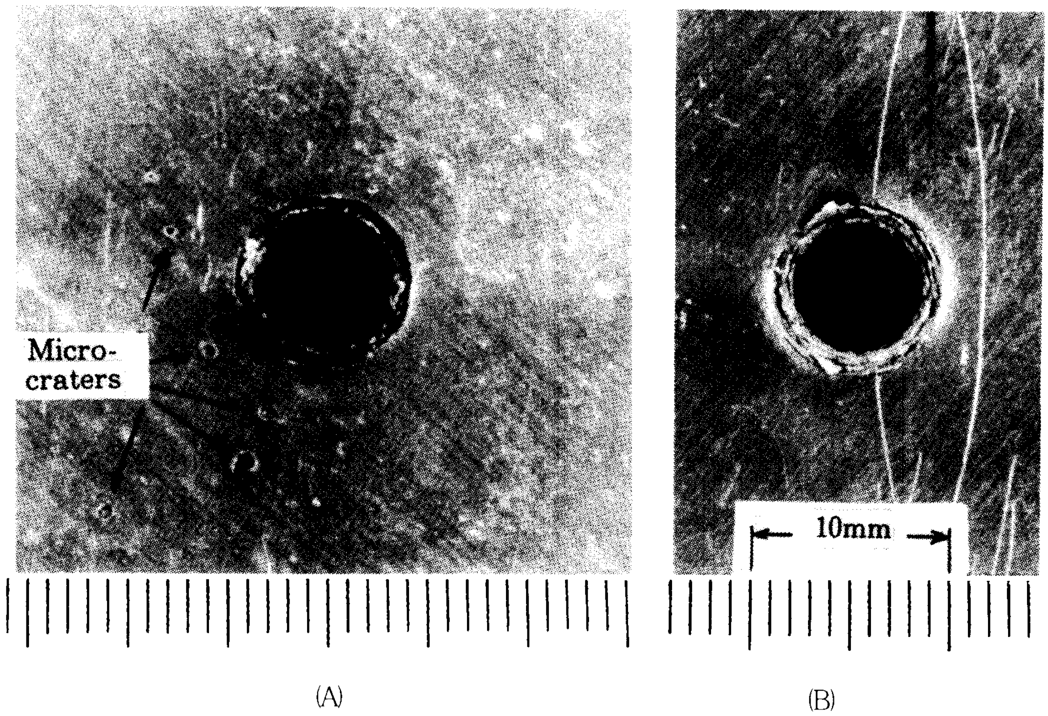


Fig. 10. Typical conditions of bumper plate applied to this separation method. (A) and (B) are detail diews of near impact point of front and rear, respectively. On the front side, some negligible micro-craters due to ejectar appear.

5) Separation Method of Projectile from Sabot at Hypervelocity (II) [5]

The paper describes a new separation method applicable for impact tests of a dual element meteoroid shield structure at hypervelocity. The method is characterized by a combination of conical die and sabot guide deflector. The first series of test was conducted to design a conical die and to determine a suitable material for sabot. Results showed that the conical die and sabot designed for appropriate deformation conditions minimized the damage potential of ejecta from the separation process at required impact velocities, and showed that the method was effective up to 4 km/s for a conical die with length of 16.5 mm, and half angle of 7^0.

References

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