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# EXPERIMENTAL STUDY ON PENETRATION CHARACTERISTICS OF METAL HARPOONS WITH VARIOUS TIP SHAPES FOR CAPTURING DEBRIS

**Abstract**

Active debris removal (ADR) using conductive tethers or propulsion systems has been studied by many researchers, and various methods have been proposed and studied to attach the removal system to debris. The authors also studied the method to attach a de-orbit system to the space debris with a metal harpoon. We conducted tests to shoot into a fixed target simulating a part of the large debris and unbound targets simulating a small debris which falls freely, as well as developing corresponding numerical simulation models. The shape of the metal harpoon tips is considered to have a great influence on the penetration behavior. However, the conical shape of the harpoon tip has been mainly studied and the other shapes of harpoon tips have not been studied sufficiently at present. If the harpoon has a conical shape tip, the harpoon will not penetrate to the debris if the tilt angle of the debris is bigger than the half of the harpoon tip angle. Therefore, it is necessary to design the shape of the harpoon tip appropriately to penetrate the debris at any angle. In addition, the debris in orbit are in various orientations, so the study on projection to rotating debris should be carried out. In this study, we investigated the effects of the shapes of harpoon tips on the penetration behavior in the fixed target with the oblique angle of 0, 30, and 45 degrees, and compared with the results of analysis. Four types of harpoon tips, conical, double-bladed, sphere, and flat were employed and their penetration behaviors were compared. When the harpoon was shooting into fixed targets in the experiment the penetration velocity of the double-bladed harpoon tip to targets was lower than those of the other head shapes with the any angles. However, the penetration hole was punched in a circle shape by the double-bladed harpoon tip, so it resulted in a creation of new debris. Conical harpoon tip was punched in the shape of petal, so it did not generate new debris. Sphere harpoon tip could not make suitable docking states with the 45 degrees. In the fixed target with the 30 degrees, the flat harpoon tip penetrated at lower velocity than when the target placed horizontally. The edge of the flat harpoon tip affected decreasing the penetration velocity, but with the 45 degrees, penetration velocity was still higher than that when the target placed horizontally.