

SPACE DEBRIS MITIGATION USING MAGNETO RHEOLOGICAL FLUID

- THE ASTRO-MAID

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Abstract-

I. Introduction

To solve the problem of debris size ranging from 1-10 cm, we have proposed an idea of a satellite named 'Astro-Maid', which can be used to clear space junk. The idea is to collect the debris from outer space, compress it to form a small cubical block and launch it towards earth with minimum trajectory.

Magneto Rheological fluid is used to capture the debris from outer space. The fluid is spilled on the honey comb mesh and is kept at a constant temperature to preserve its state. The magnetic arm carrying the mesh and the fluid is sent to outer space to capture the debris. The debris sticks to the fluid and are carried to and removed inside the machine. Debris is moved to a compression box where they are compressed and further launched.

All the debris are collected and compressed to form a small cubical block. The idea is to reduce the orbital velocity of the block by ejecting it in the opposite direction of revolution. It is launched at a speed by which it follows a minimum trajectory to enter the earth's atmosphere i.e. 100 km above the surface of earth. When the block enters the earth's atmosphere, it has to face density variation. Due to this, there is a formation of normal shock waves, as a result of which the temperature of the block rises. This launch of block also helps to regain the original orbital velocity that was decreased to capture the debris.

A study has estimated that dangerous space collisions will occur every five to nine years in the satellite and spacecraft orbit route, if the space junk is not effectively cleared.

Space junk is an accumulation of debris (mainly aluminium and silicon particles), anything from disused satellites to rocket parts discarded in-flight are orbiting the earth. Most of these are very small but with a very high orbital velocity, they are dangerous. However, according to NASA's Orbital Debris Office, the number of particles exceeding 10 cm is about 21,000 while 500,000 sized between one and 10 cm are bobbing around.

According to the first janitor satellite to be sent by EPFL, CleanSpace - One, the clean-up satellite will have to adjust its trajectory in order to match its target's orbital plane. When it gets within range of its target, which will be traveling at 28,000 km/h at an altitude of 630-750 km, CleanSpace One will grab and stabilize it. Finally, once it's coupled with the satellite, CleanSpace One will "de-orbit" the unwanted satellite by heading back into the Earth's atmosphere, where the two satellites will burn upon re-entry. But what if it doesn't destroy itself and repeats the whole process by itself.

The fundamental idea of the satellite 'Astro-Maid' is the same. The working altitude is 650km to 900 km. It captures the debris by making its relative velocity very less with respect to debris. There is no loss of machine as the compressed debris is ejected out to the earth. The machine can be used again and again.



II. Part Description

1. Header- The header contains sweeping piston, rack & pinion mechanism, motor, distance sensor (DS50), pipelines of MR fluid (perpendicular entry) towards MR fluid sprayer (or extruder).

Sweeping piston-The header contains the sweeping piston in rest state. In this part of Astro-maid, sweeping piston initiates its motion towards the debris clearing system. The seeping piston is moved with the help of rack and pinion mechanism, connected to the on board computer with a receiver on it. There is a sensor in the debris clearing system placed on the top wall. The function of this sensor is to sense the mechanical arm carrying debris from outside. As the arm is sensed, the sweeping piston is moved into debris clearing system, the rack and pinion mechanism comes into motion and the rack pushes the piston smoothly just above the honey comb mesh.

Distance sensor-The distance sensor placed on the outside of the header. The distance sensor is used for the maximum movement of arm to collect debris.



Design of the Astro-Maid

2. Opening door- The opening door is the one which gets opened to release the arm in space.

3. Bottom Solar panels- Bottom Solar panels are placed at the bottom of the Astro-maid. They are in folds, folded in a form of layer of 3 panels.

4.Top solar panels- Top solar panels are placed o the top of the Astro-maid. They are also in folds, folded in a form of layer of 3 panels.

5. M.R fluid storage tank- A tank containing MR fluid is kept behind the solar panels as shown in the diagram. The volume of the tank is 900 liters.

6. Ion Thrusters- They are the thrust generators of the Astro-maid. The Gridded Electrostatic Ion thrusters are used with Xenon (or cesium whichever possible) as a propellant .This gas has no charge and is ionized by bombarding it with energetic electrons.

7. Pipe guidelines for MR fluid- This pipelines carry fluid from the tank to the sprayer (extruder) passing perpendicularly through the header.

8. MR fluid sprayer (extruder)- It releases a thin layer of 2 cm on honey comb mesh.

8A. Debris clearing system – It removes the captured debris from mesh plate

10. Debris compressed gun- A piston powered by the pressurized air is used to fuse the debris before launch. (650-700 bar).

11. Compressed Helium gas container- The pressurized gas required to pressurize the piston to compress and launch is exhibited by the container. The gas is carried from the station on earth.

12. Orbital Maneuvering System (OMS) (X&Y shown in fig.) -The orbital maneuvering system in the OV is responsible for orbit changes after MECO. We use the LO_X /Ethanol engine currently used by the K-1. The Vacuum thrust is 3870 N. The OMS is sized to full fill the following requirements:

a) Circularization burn: needed to circularize from the elliptical transfer orbit into the desired circular orbit. The perigee altitude of the transfer orbit is 100km and the maximum apogee altitude is 1,200km.

b) De-orbit burn: after 24 hours in orbit the OMS of the OV will perform one or multiple burns to place it in an elliptical orbit with apogee no higher than 475 km, and perigee at 60 km. At 60 km the OV enters the appreciable atmosphere and begins its re-entry.

S. No	Name of the part	Size
		(length*breadth*height)
1.	Header	1.5m *3m
2.	Opening Door	1m*3m
3.	MR-fluid Tank	Radius= 0.306m,
		Height = 3m
4.	2*Pressurized helium	Radius =0.5m
	fluid tank	Height= 2m
5.	Total dimensions of	3m*3m*2m
	the Astro-Maid	

1. Dimension parameters

III.MR Fluid

A Magneto Rheological fluid (MR-336 AG) is a type of smart fluid in a carrier fluid, usually a type of oil. When subjected to a magnetic field, the fluid greatly increases its apparent viscosity, to the point of becoming a viscoelastic solid. Importantly, the yield stress of the fluid when in its active ("on") state can be controlled very accurately



by varying the magnetic field intensity. The upshot of this is that the fluid's ability to transmit force can be controlled with an electromagnet, which gives rise to its many possible control-based applications.

To understand and predict the behaviour of the MR fluid, it is necessary to model the fluid mathematically, a task slightly complicated by the varying material properties (such as yield stress). As mentioned above, the fluids are such that they have a low viscosity in the absence of an applied magnetic field, but become quasi-solid with the application of such a field. In the case of MR fluids (and ER), the fluid actually assumes properties comparable to a solid when in the activated ("on") state, up until a point of yield (the shear stress above which shearing occurs). This yield stress (commonly referred to as apparent yield stress) is dependent on the magnetic field applied to the fluid, but will reach a maximum point after which increases in magnetic flux density have no further effect, as the fluid is then magnetically saturated. The behaviour of a MR fluid can thus be considered similar to a Bingham plastic, a material model which has been well-investigated.

The MR Fluid (336-AG) being used here has a very high response time. It has a high dynamic yield stress. Low Plastic Viscosity and a broad operational temperature range.

How it works?



By the application of magnetic field-



Flow mode-



Shear Mode-



Squeeze-flow mode-



As the figures above show how the ferro- magnetic particles align themselves when magnetic field is applied. The flow direction and the shear mode is also shown in the figures. The alignment of particles increases the viscous effect of the fluid. As a result it becomes quasi- solid and the debris sticks to it.

IV.HONEY-COMB MESH PLATE

This is a normal mesh, the purpose of it is to separate Magnetorheological fluid from the debris. It is basically metallic mesh with honeycomb holes. The diagonal length of the honey comb structure will be 1mm. The behavior of the honeycomb structures is orthotropic, hence the panels react differently depending on the orientation of the structure.



Fig: Honey comb mesh plate

V. ASTRO-MAID MECHANISM

PSLV is used to launch our machine in the lower earth orbit at the velocity of 7km/s, then ion thrusters are activated which take 5 months to reach the same velocity as that of debris. The ground station directs its path to debris belt.

When Astro-maid reaches position of debris, optical sensor place on the header locates debris then the on-board system aligns machine parallel to the path of the debris, as Astro-maid is moving with same velocity as that of debris the relative velocity is nearly zero. The extruding machine placed over the bay doors sprays a layer of MR-fluid (thickness 2cm) over the honey comb mesh plate. The robotic arm which holds the honey comb mesh plate starts moving out of the Astro-maid, plate will be very close to the extruding machine, once the mesh comes under the extruder the machine pumps out the MR-fluid with help of pressurized air which will be similar to the system used in the satellites to circulate fuel to the engine.



Fig 1: MR-fluid sprayed on the mesh plate

The arm moves to a position set by the on board computer which takes the data from on-board sensor. The position is set in such a way that no debris hit the robotic arm. Once the robotic arm is in position, it is rotated by 90 degrees and speed of the satellite is reduced by Orbital Maneuvering System placed at the sides of the Astro-maid. Then debris hit the fluid and gets stuck, the fluid is magnetized with the help of magnetic rods to which the mesh plate is attached, then the fluid particles due to its magnetic properties hold the debris.



Change of arm orientation

Then robotic arm rotates back to its original position and resizable arm [which can be seen in fig: 2] is used to reduce the height of the mesh plate by 10cm so that the debris which are attached to the mesh doesn't hit the extruding machine. Once the arm is back inside Astro-maid bay door gets closed and MR-fluid is de - magnetized.



Fig 2: resizable arm

Then a rubber stopper[which can be seen in fig: 3] is attached to the base of the honey comb plate structure and suction force is generated which separates the debris from the fluid, now the resizable arm is used to raise the height by 10cm, where debris will be separated from honey comb plate. Now, the debris is to be removed from the top the honey comb mesh plate. To remove them from the mesh plate certain steps are to be followed which requires the use of the following-



Fig 3: Internal structure



A. Suction pump:- To separate MR fluid and Debris there is a suction tube which is attached below the honey comb mesh plate . Once the suction tube is attached, air is released into the tube and suction mechanism is activated (as done in space toilets). MR-fluid which has been separated is moved back to the MR-fluid tank.



Fig 4: internal compression and ejection system

B.Sweeping Piston - The mesh plate moves up, from the suction tube. The plate is brought just beneath the surface of the sweeping piston. The sweeping piston is a slow moving piston over the honey comb mesh plate. The piston sweeps the area and all the debris are moved by the opening of the door of the compression box. The total mass of the debris is estimated by the mass flow sensor. Assuming the maximum amount of mass is of aluminium . Limited amount of mass flows into the compression box as shown-

Atomic radius of atom of a Al	= 118pm
Volume of 1 atom	$= (4/3)^* \pi^* r^3 = 6.9^* 10^{-30}$
Maximum volume of cube formed	$= 125 * 10^{-6} \text{ m}^3$
Number of atoms in maximum volume	$= 18.1 \times 10^{24}$
$6.023*10^{23}$ atoms are in	= 27 grams of Al
Mass of the cube	= 811 grams

As the mass of the debris reaches 811 grams (data got by mass flow sensor) the sweeping piston stops. The door to the compression box(8A in fig 3) gets closed by receiving the information from the on-board computer.

C.Compression box- The required amount (as discussed above) of debris is collected in this box. By maintaining the compression piston at an optimum pressure and a high temperature in the compression box of about 300° C the aluminium particles are softened. The helium gas is used to produce required pressure for compression. This type of fusing is known as thermo-compression. The aluminium particles

along with other debris particles are heterogeneously fused and are further sent to the debris gun.

D.Debris gun- The fused cubical block of aluminium reaches the debris gun box. The debris gun launches the block towards the earth with a minimum trajectory. The speed given to the block is provided by the expansion of the gas behind the piston. The block is launched in the opposite direction as a result its velocity is decreased. But due to lack of enough speed for the orbit to counter balance gravitational force, it is pulled down by the gravity of earth.

Energy stored in the cube g= (G M_e / (Re + h)²) Mass of earth (M_e) =5.97 *1024 Kg Radius of earth (R_e) = 6400 Km g₇₅₀ = 7.79 m/sec² g₁₀₀ =9.51 m/sec² Energy at 750 km = mg₁h₁ + (mv₁²)/2------(1) Energy at 100 km = mg₂h₂ + (mv₂²)/2------(2) Equating (1) & (2) V₂ = **5.08 Km/sec**

There is an increase in the speed, but this speed is not enough for the block to revolve in any other orbit, so it is pulled by the earth's gravity, following minimum trajectory.

Launching speed

= 4 km/sec

To reach earth the block has to follow minimum trajectory. By approaching this speed it can have a minimum trajectory

Mass of the block	= 0.8	311 Kg		
Impact Force required	= 08	11* 4000 =3244N		
Pressure created behind the piston= $F/a = 3244/(25*10^{-4}) = 12.9$ bar				
No. of moles	= 3.2	23 moles		
Number of moles	=	$PV/R_{He}T = 19.39$ moles		
Density of helium	=	P/RT = 25859 Kg/m ³		
Change in momentum along the pipe is given by-				

= 31.07 m/sec
= 0.5 cm
= pAu ₂ =60.07 Kg/sec

Thus the time for which the knob is opened = 14.5 sec



VII. Materials Used

The inner and outer parts of the satellite are being insulated by MLI (multi layered insulation) material which consists of light weight reflective films assembled in many thin layers. These layers are typically made up of polyimide or polyester films (according to design could be from 5 to 50 sheets) that are vapor deposited with 99.99% alumunium, on one or both sides. For sweeping piston carbon-carbon piston are to be used because of its more reliability and high resistance to structural damage caused by overheating. The internal structure of the compression system will be made up of carbon-carbon material because of its more reliability from structural deformation and high resistance to structural damage caused by overheating (this compression system consists of both the compression box and the compression piston. The helium tank will be insulated with MLI (multi layered insulation) for maintaining its temperature at 4K.

Mesh plate material would be a composite with high thermal conductivity for maintaining the working temperature of the MR fluid and must get magnetized on application of magnetic field(TBC).

VIII. Mass of MR-liquid carried

Amount of MR-liquid used once= volume* 1000[convert m³ to liters.] Volume = 1.5m*1.5m*0.02m [length of mesh*breath of mesh*thickness of fluid] = 0.045m^3 Amount of MR-liquid used once = 45 litters.

As on repeated use MR-liquid starts to lose its properties it can only be used 5 times hence to capture debris 100 times amount of liquid required are 900 litters.

Conclusion

The mechanism used in Astro-maid is one of it kinds, it uses themocompression-bonding to fuse debris. Astro-maid uses MR-fluid which can be used 5 times at most. It can clean 1mm-100mm size debris. OMS system is used for easy maneuverability Astro-maid uses earth's gravitation field to remove debris. Astro-maid uses impulse created by debris gun to regain its orbital velocity which was reduced to capture debris. Minimum debris mass that can be removed is 81.1 kg in one time i.e. without changing MR- fluid which gets spoiled with 5 times usage. As a result the space debris are removed from space.

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