Active Space Debris Removal by Using Coil Gun Mechanism

Logesh Sadasivam, Akshai Sriram, and R.V.Subendran

Abstract**—** we are proposing idea to remove space debris from LEO (Low Earth Orbit) by using of coil gun mechanism, external robotic arm, and ablative laser propulsion. Once our satellite is in the designated into orbit, its inbuilt sensors sense debris on various magnitudes and process the debris. The sensors on board the satellite sense the debris and command the programmed arm to intercept it and load it into the coil gun. Most of space debris is Ferro magnetic substance hence our coil gun mechanism is very effective and efficient. Once the debris is in the coil gun bay, the debris in the coil gun is aimed towards earth's atmosphere. If the size of the debris is small, which it came near to earth atmosphere then it disintegrates the small piece of debris on the thermosphere region at 1500 °C. The movements and sensors of the coil gun are programmed to our requirements.

Keywords**—**Space Debris, Coil gun system, ablative laser propulsion, robotic arm, and LEO (low earth orbit**)**.

I. Introduction

THE increase of space debris is considered as one of the main threats for future sustainability of space activities and space access. The risk of debris collisions and the potential cascading effects could, due to their number and broad distribution, prohibit future human and robotic space missions.

Between 1957 and 2013, indeed, approximately 4800 launches have placed some 6000 satellites into orbit. Among these, about 400 were launched beyond Earth into interplanetary trajectories, but of the remaining ones only about 800 are nowadays still operational. This means that roughly 80% of space objects are uncontrolled debris. To these, launcher upper stages have to be added in order to have a rough idea of the large debris population. Furthermore, considering also smaller debris caused by explosions, fragmentations, collisions, accidental discharge and similar events, the whole debris population comprises millions of objects. Space debris are not uniformly distributed, but are concentrated in the most used and thus currently most useful orbits, in particular to the Low Earth Orbit (LEO) and in the Geostationary Earth Orbit (GEO).

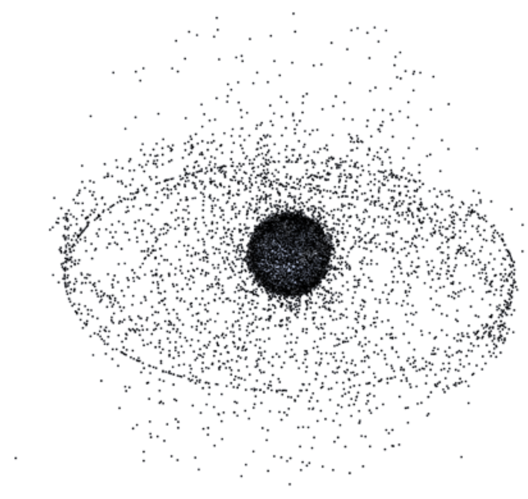

Fig. 1 Estimated Mapping of Debris around the Earth

In the recent years, space debris mitigation guidelines have been adopted at international level, though while necessary, indications are that even if fully implemented, these might not be sufficient to solve this problem in the long term. Active debris removal missions might, indeed, be necessary to clean up certain target space regions where the debris threat is more hazardous both for potential commercial or human mission and for the risk of further debris collisions.

II. Introduction Of Our Proposal

In our project the payload consists of robotic arm technology and electronic coil gun, which works, in the principle of electromagnetic. On the skin of robot there are sensors are connected, to detect the debris and onboard camera is also used to avoid the collision with working models. There are two robots used, one is having electromagnetic plate to capture metallic debris and other having electronic gun to capture non-metallic debris. After collecting the debris into the center, the coil gun- using electromagnetic principle gets charged by battery, which is powered and recharged by solar panels. Then, the coil gun accelerates the debris into deep space or earth's atmosphere according to the size of debris. The ablative laser propulsion is used for controlling magnetic box in the orbit.

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III. Launch Vehicle

- The satellite is launched using the Polar Satellite Launch Vehicle (PSLV)
- The PSLV has four stages using solid and liquid propulsion systems alternately, and each stage is to be dropped as its propellant is consumed.
- The first stage uses a single engine configuration and six strap-on boosters.
- The first stage produces 1,090,000 lbf and specific impulse of 269 seconds.
- The second stage employs Vikas engine and generates a maximum thrust of 180,000 lbf and has a specific impulse of 293 seconds.
- The third stage of PSLV produces a maximum thrust of 74,000 lbf with a specific impulse of 274 seconds in a single engine configuration
- The fourth and terminal stage of PSLV has a twin engine configuration using liquid propellant producing a thrust of 3,100 lbf with a specific impulse of 308 seconds.
- Inside the atmosphere, the payload is protected by an aerodynamic fairing.
- This is not needed when the rocket is in space, so it is jettisoned.
- The payload now has enough speed to coast to 775 km altitude, the highest point of our flight.

IV. Satellite

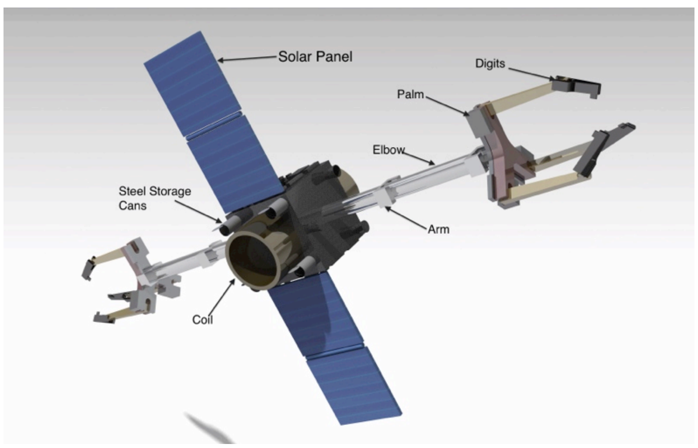

Fig. 2 The proposed satellite with its external parts

The payload section of the launch vehicle will carry five individual satellites, which are used for removal of debris in space.

Upon reaching our desired altitude, all five individual satellites are ejected and propelled into their respective orbit.

Each satellite consists of a robotic arm (with three individual digits), two solar panels, antenna, motion system, sensors, coil gun, battery, and solid metal propellant.

The basic idea of the satellite is to capture space debris of dimension up to 10 cm in the LEO. The debris is captured using the mechanical arm system, which is connected to the satellite. The satellite contains sensors, which detect the presence of debris.

The body of the satellite contains a storage area made up of layers of Steel, which is used to store debris of smaller size before deorbiting.

Upon debris detection, the satellite's velocity is accelerated or decelerated to come in relative to the speed of the debris and the mechanical arm moves towards the debris. Based on the size of the debris the mechanical arm attracts or captures the debris near the LEO.

Debris of size < 1 cm is captured and placed inside storage area made of thin layers of steel cans, when these cans are filled, the storage cans are sealed and shot out towards the earth atmosphere using coil gun mechanism. Debris of size >5 cm is captured and shot out towards the earth's atmosphere individually.

V. Propulsion System And Orbital Calculation

Our satellite, in earth orbit is controlled by using Ablative Laser Propulsion System as non-thermal process (plasma generation and acceleration) during debris capturing.

It is a form of beam-powered propulsion in which an external pulsed laser is used to burn off a plasma plume from a solid metal propellant, thus producing thrust.

The small ablative laser propulsion setup is very high at about 5000 seconds (49 KN sec/Kg)

The specific impulse is achieved by adjusting laser intensity on the target, by changing the focal-spot area and laser-pulse duration, which causes exhaust velocity to vary across the range from chemical reactions (approximately, specific impulse of 500 seconds to much higher values 3500–5000 seconds).

TABLE I
Ablation Laser Propulsion Performance Matrices

Parameters	Value
Thrust-to-mass ratio	High(15 N/kg)
Thrust	Scale linearly with laser power
Thrust Density	High (8E5 N/ m^2)
Electrical Efficiency	Very high (>100%)
Specific Impulse	Low to Very high (200 – 3100 sec)
Main benefit	Very high electrical efficiency

The ablation efficiency is calculated using

$$\eta_{AB} = \frac{W_E}{W} = \delta m \psi V_{E^2}/(2W) \quad (1)$$

The specific ablation energy is calculated using

$$Q^* = W/\delta m \quad (2)$$

For ablative laser propulsion, mission are of short duration on the scale of Sanger's dreams because ablation fuel lifetime of mass M with laser power P decreases quadratically with Cm

$$\tau_{AB} = \frac{2\eta_{AB}M}{PC_m^2} = 2\eta_{AB}M/(FC_m) \quad (3)$$

We choose orbit at an altitude of 775 km in LEO because of debris in the space more than 100 million is revolving around the earth's orbit.

For equation (1), (2), and (3), η_{AB} might refer to ablation efficiency, W_E might refer exhaust kinetic energy, W might refer kinetic energy, δm might refer mass element, V_{E^2} might refers to square of exhaust velocity, Q^* might refers to specific ablation energy, τ_{AB} might refers to ablation fuel lifetime, M might refer to mass, P might refer to laser power, F might refer to force, C_m might refer to momentum coupling coefficient.

Calculation for implementing our satellite into an orbit

TABLE III
ORBIT CALCULATION

Parameters	Value
Altitude	775 Km
Velocity	7.4547 Km/s
Period	99.125 min
Mean Motion	14,4 (revs/day)

V. ROBOTIC ARM OPERATION

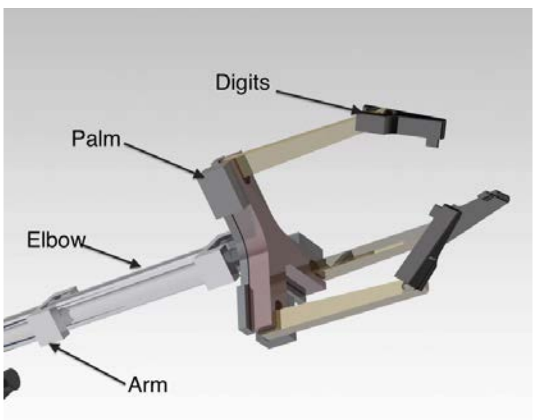

Fig. 3 Robotic Arm of the Debris cleaner

The Robotic Arm, which is equipped with instruments to sense and grab the debris is designed and installed on the two opposite sides of the satellite. It constitutes the (a) Arm, (b) Elbow, (c) palm and (d) Digits or fingers.

The palm region of the Robotic arm is equipped with cameras and sensors to sense the moving debris. Once a debris is located, the information from the palm is send to the main board in the satellite to process various information's, like the velocity of the debris, size and the material composition, as the velocity is found, The satellite accelerates to its speed and comes in relative to its position. When the satellite and the debris are at the same velocity, the Robotic arm using its digits catches the debris.

If the size of the debris is less than 5cm, the robotic arm stores the debris in the Steel storage cans. Once the steel storage cans are filled with the collected debris, it is take out from its position using the robotic arm and is placed in from of the coil arrangement for getting accelerated towards the earth's atmosphere

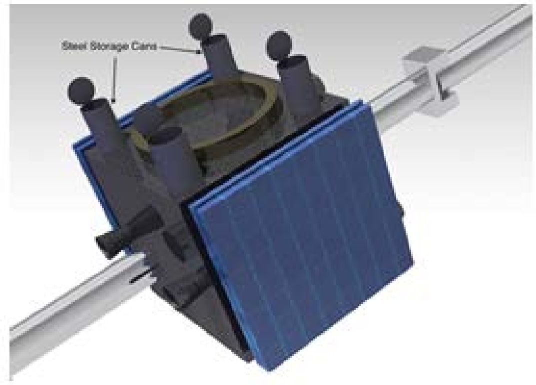

Fig. 4 Steel Storage cans in the payload region

If the captured debris is larger than 5cm, the robotic arm overrides the above procedure, and is directly placed in front of the coil gun.

VI. COIL GUN MECHANISM

A. *Principle of Coil Gun*

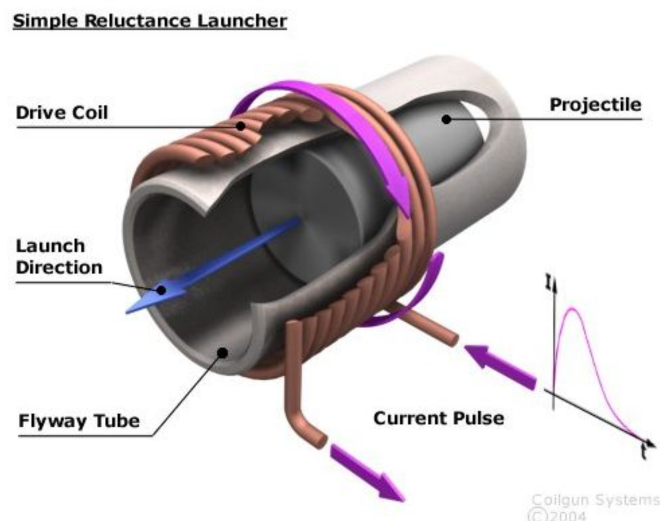

Fig. 5 Coil Gun Mechanism

The collected debris is ejected using the gun. The Coil Gun works on the principle of electromagnetic attraction, hence the projectile to be ejected should be of ferromagnetic nature. Upon receiving debris of non-ferromagnetic nature they are place in a ferromagnetic foiled storage area. When the robotic arm places the debris in the cylinder, the gun works by inducing a magnetic field in a coil of wire around the barrel using an extremely short, but high energy burst of electricity. This is usually accomplished by using capacitors and a high voltage charging circuit. The coil gun which is located at the center of the satellite contains two retractable cylinders, these cylinders comprise of the coil gun mechanism. The power for producing a very strong electromagnet field is produced by the rechargeable battery in the body of the satellite.

When fired, the electromagnet that is created pulls on the ferromagnetic projectile (able to be magnetized) with great

http://dx.doi.org/10.15242/IIE.E0314118

force, causing it to quickly accelerate towards the center of the coil. In the fraction of a second it takes for the projectile to reach the center of the coil all of the power supplied to it has been exhausted and the magnetic field has dissipated. This allows the projectile to continue out of the barrel with its own momentum towards the earth's atmosphere where it is incinerated.

B. Working

The projectile is loaded into the barrel and the capacitors charge. The capacitors are discharged into the coil, thus inducing a magnetic field that pulls the projectile towards the center of the coil. Before the projectile reaches the center of the coil the power from the capacitors is exhausted and the magnetic field dissipates. The projectile continues out of the barrel with its own momentum.

C. Factors Influencing Projectile Speed

Capacitor Voltage-The higher the capacitor voltage the higher the projectile velocity since the stored energy in a capacitor is equal to half the capacitance multiplied by the voltage squared as long as the switching capabilities are there then this is one of the more favorable variables to choose to increase as each extra volt makes a big difference.

Capacitor Capacitance-The higher the capacitance the larger the volume of stored energy in line with:
Energy stored in a capacitor=1/2 CV^2

D. Setbacks of Coil Gun Mechanism

This is the biggest disadvantage to coil guns, the current pulse length needs to be controlled in order to cut the power when the armature reaches the middle of the coil.

The second largest challenge to overcome with coil guns is delivering the electricity as quickly as possible. It stands to reason that the more energy you can put onto the coil gun, the more energy will be transferred into kinetic energy in the armature.

The main losses in this system are the eddy currents in the flyway tube and the projectile/armature, these can be minimized by slotting the flyway tube or using a non-conductive material. The projectile must be ferromagnetic thus this means that limiting eddy currents cannot be achieved by using a non-conductive material. The best solution to this is to use a powdered Iron in epoxy resin matrix. Although this improves initial efficiency it also removes the ability for the gun to be operated as an 'inductance coil gun'.

VII. Why Our Proposal Is Best

When compared to many proposed designs around the globe on cleaning space debris, there was and is a restriction to the number of debris it can deorbit and also its cost of production. Our design-Space Debris Removal using Coil Gun Mechanism with its highly efficient propulsion system, low cost production and compact in size, is considered as highly efficient mainly because of its capacity to deorbit n-number of debris during its lifetime and will reduce the potential dangers of space debris within few months of it launch, and our proposed design could pave the way for a cleaner and a safer space for the satellites and space shuttle launches into space.

VIII. Conclusion

As space debris is current upmost problem, here we proposed the method to capture the debris which is very efficient method by using fundamental of physics i.e. electric and coil gun. This is very cost effective method too. As a result of this activities, the realization of a new space debris removal system is becoming more feasible.

Acknowledgment

We take this opportunity to express our profound gratitude and deep regards to our Professors, Department of Aerospace Engineering and the Director of Research, SRM University for their valuable guidance, monitoring and encouragement throughout the course of this research paper report accomplishment.

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