Design and Additive Manufacturing of Soft Capture Docking System Using Magneto Rheological (MR) Fluid

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Abstract: ***This paper emphasizes the development of Satellite docking system using Magnetorheological fluid. Docking is a mechanism where a space craft tends to adhere with another space craft or an international space station maneuvering on its own. Magnetorheological fluid is a smart material that is controllable using magnetic field. When a magnetic field is applied to Magnetorheological fluid its viscosity increases and becomes viscoelastic and the liquid state changes to solid state, but as soon as the magnetic field is removed it will come back to its normal state. This property of the fluid helps in docking system of two satellites. The paper provides a unique perspective for developing and implementing a docking system using Magnetorheological fluid.***

Keywords: *IDSS* = International docking system standard**,** *IDD* =Interface definition document**,** *SCS* = Soft Capture System *HCS* = Hard Capture System, *MR* = Magnetorheological Fluid, *APAS* =Androgynous peripheral attachment System.

1. Introduction

Before man can truly call himself as master of space, he must be a master in orbital rendezvous", this saying helps in developing the skill of assembling huge space crafts , space stations and this can also help in interplanetary manned passage to Mars, Venus, and even to the Pluto. Rendezvous is done for transferring crew, refueling, repairing, resupply space craft and rescuing other astronauts from repaired space craft. There has been lot of development in joining of space vehicles and that is called Docking. Docking is a method of joining two space craft's or one space craft and a space station that comes closer through its own maneuvering. As the United States of America gets to be more reliant on satellites for interchanges, observation and protection, and the expense of sending people to administration them stays high, the Air Force and DARPA are searching for approaches to self-governing meet, dock, and repair space resources. The two mechanisms that undergo docking is the soft capture system (SCS) and the other is the hard capture system (HCS). Soft capture system bring the space craft closer to ISS followed by load reduction and hard capture helps in the controlling the stiffness of docking, it also helps in air tight of the structural connection between space craft's. Technically it's a capture process system that helps coarse alignment, fine alignment and a structural alignment. Now NASA is still civilizing the reasonableness of the future space flight programs like the Orion space craft program[1].

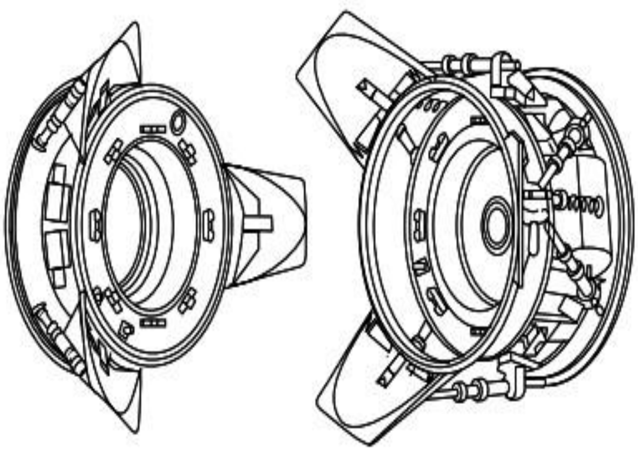


Figure 1: APAS Docking Unit [6]

2. History of Docking System

Russians were the first to enter into the space, but Americans were the first to dock using a space craft designed by the Boeing during Gemini program, Gemini VIII on March 16th 1966 were the first to dock. First Apollo space craft was introduced in the year 1964 and Apollo 9 was first Apollo space craft to get docked which occurred in March 3rd 1969. The Russians first docking was with Soyuz space craft with another Soyuz space craft on January 4th 1969; their method was a probe and drogue. The first Russian international space station was Salyut. The Russians launched the first module of the Salyut station on April 19 1971. The first Soyuz docking with Salyut was on June 30, 1971. This also used the Probe and Drogue mechanism. The Skylab was first American space station and this was first docked with Apollo. There were one another docking that held between USA Apollo and USSR Soyuz.[1] Soyuz was also had to dock with Skylab, which required the Apollo docking probe to fit to a Soyuz, but it couldn't be happened because of some circumstances that American faced and docking couldn't happen. [8]

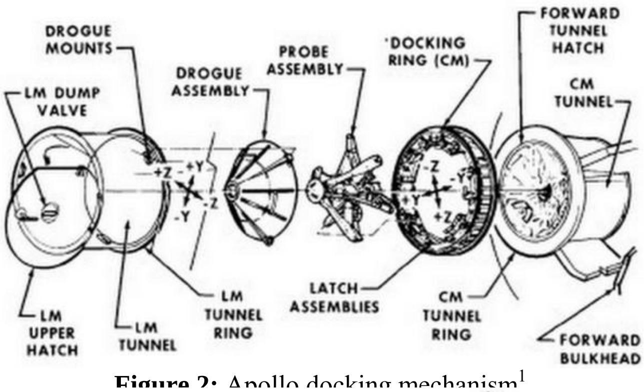


Figure 2: Apollo docking mechanism[1]

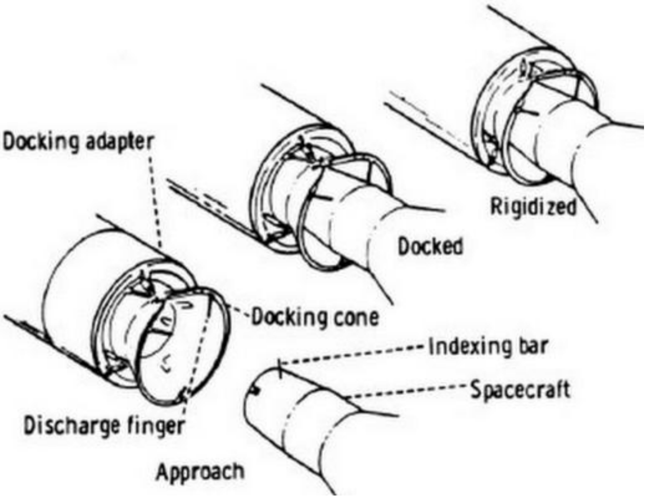


Figure 3: Gemini docking mechanism [1]

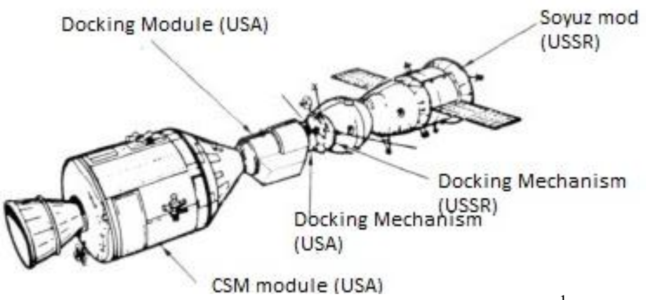


Figure 4: Apollo Soyuz docking mechanism [1]

3. Working of Docking System

According to IDSS IDD, the working mechanism of docking undergoes two phases i.e. Soft capture system and hard capture system. When the space craft comes closer to international space station (ISS), the SCS catches the docking vehicles. It adjusts to and hooks to the in active docking component, then balances out the recently joined space apparatus in respect to one another. The SCS then pulls the docking space craft tools so as to launch the second phase which is performed by hard capture system (HCS).This performs structural locking and fixing at the docking. It helps exchanging structural loads between the rockets and to make transfer tunnel which is used to be pressurized for crew and payload exchange for joint mission operations. After this mechanism the guides of the SCS will lock with the ISS guides and helps in docking of two space vehicles.[1]

4. Magnetorheological Fluid

Magnetorheological fluid is a new smart material and it is easy to control, under the action of an external magnetic field, it can achieve the transition between high yield stress viscoelastic colloid and Newtonian fluid in milliseconds and this transition is irreversible, continuous and controllable, so it has broad application prospects.[2] Usually magnetorheological fluids are the suspensions of micron sized, magnetizable particles (mainly iron) suspended in an appropriate carrier liquid such as mineral oil, synthetic oil, water or ethylene glycol. The diameter of the magnetizable particles range from 3 to 5 microns and materials can achieve yield strengths up to 50–100KPa at magnetic field strength of about 150–250 KA/m.[4] The following tables explains the properties and performance parameters of MR Fluid.

Table 1: Summary of the properties of MR fluids [3]

Energy Consumption [J/cm3]	0.1
Max Field Intensity [KA/m]	250
Max Shear Stress [KPa]	50-100
Apparent Viscosity [Pa.s]	0.2-1.0
Suitable Temperature [℃]	-50 to +50
Impurities Sensitivity	Insensitive
Density [g/cm3]	3-4
Input Voltage [V]	2-25

Table 2 .The main performance parameters of MR Fluid [3]
To calculate the shear stress between the MR Fluid and the model, the following equation is used

$$\tau_{y(H)} = \tau_o + \sigma_n \tan \varphi \qquad (1)$$

Where, $\tau_{y(H)}$=shear stress

τ_o=yield stress

σ_n=stress

φ=angle of internal friction

The shear stress specifies viscosity of the fluid. The increase in the value of the shear stress represents the high viscosity of the fluid. The value of viscosity of fluid specifies the thickness of the fluid. This directly implies the more the shear stress the high the fluid is viscous in nature. The shear stress will increase with the magnetic field.[4] the following table represents the shear stress of the MR fluid of different proportions of carbonyl iron powder and oil .These are the main carrier fluids of MR Fluid.

Table 3: Represents the proportions used in MR fluid [7]

sample	Carbonyl iron powder		Oil (carrier fluid)		Weight ratio of iron powder to oil	Shear stress (KPa)
	Weight (gram)	Particle size (mu)	Weight (gram)	Viscosity (centi-stokes)		
1	76.5	5-Feb	22.25	30	3.4	27
2	80	5-Feb	9.18	350	9	-
3	80	5-Feb	11.44	350	7	-
4	80	5-Feb	16.16	350	4	35
5	80	7-Apr	20.04	350	5	38
6	80	5-Feb	15.84	1000	4	40

5. Working Principle of Magnetorheological Fluid

MR fluids have the ability to reversibly change from viscous liquids to semi-solids in milliseconds when being exposed to a magnetic field. This feature enables a rapid response interface between electronic controls and mechanical systems.[10] This principle can be used for damping or locking a device.

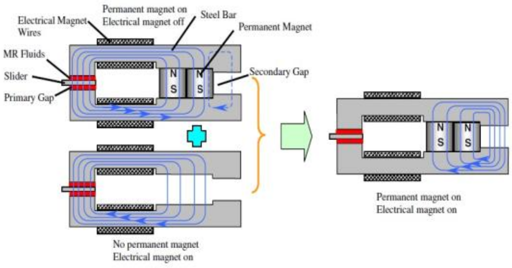


Figure 5: MR Fluid lock working principle[5]

The working principle mentioned here is used for damping or locking of model adaptive nozzle fan design.[5] The dampers used here are a new MR damper employing thin- film MR fluid. As the MR fluids are inherently semi-solid liquid, they can stay on the surface of the device with the attraction of permanent magnets. In addition, the carrier liquid, oil, is a good lubricant. This thin-film MR damper can function as both a damper and a lock. Using the permanent magnets, the MR fluid is trapped and the device is always in the locked position. When the device is powered on, the flux of the electrical magnets partially cancels and re-directs the rest of the flux from the permanent magnets, and then the slider is free to move. In this design, the MR fluid reduces the air gap and increases the locking force when it is powered off.[5]This locking principle gave an idea for implementing for the satellite docking system.

The soft capture system of satellite is designed according to the MR fluid damper working system principle. According to International docking system measurements, soft capture system[1] is designed in CATIA.[9] The design to the soft capture system is slightly changed by removing the guide. Two different soft capture systems are designed, one refers to space station soft capture system which is a circle with six hollow holes and the other refers to satellite which a circle with six vertically grooved cylindrical tubes (can be taken as cylindrical tube shape). The following CATIA[9] design explains the docking mechanism.

Figure 6: Soft capture system with hollow holes and vertically grooved cylindrical tubes.

Figure 7: The figure represents the docking system of two soft capture systems when brought together and docked

6. Experiment

In the experiment that has been conducted on the working principle of docking system, is explained by considering only the cylindrical tube section. The model is given for 3D-Printing and experiment is conducted on it.

Figure 8: Hollow cylindrical tube and vertically grooved cylindrical tube.

The hollow cylindrical tube is half filled with MR fluid. The cylindrical tube which is designed with vertical grooves is slowly inserted into the hollow cylindrical tube.

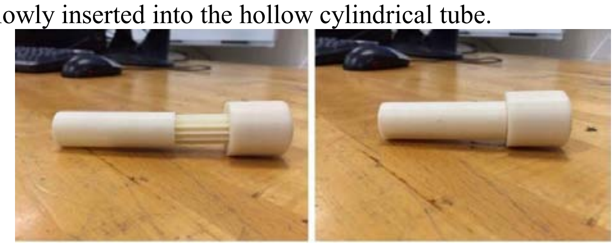


Figure 9: Inserting the vertically grooved cylindrical tube into hollow cylindrical tube

The MR Fluid will rise slowly through the gap in between the grooves. When the cylindrical tubes are closed, the magnetic field is applied to the model using magnets. The magnets used here are permanent magnets and the magnetic flux is generated inside the cylindrical tube.

Figure 10: Applying magnetic field to the model using permanent magnets

In the presence of applied magnetic field, the iron particles in the MR Fluid acquire a dipole moment aligned with the external field, which causes particles to form linear chains parallel to the field. This phenomenon will solidify the MR Fluid and restrict the fluid movement and hence the system is locked.

7. Results

By the experiment conducted the result obtained is that the docking using MR fluid between the two cylindrical tubes is very effective. The experiment is conducted with one cylindrical model but where as in a docking system six cylindrical models are implemented where the docking can be more .and the same can be applied for a satellite soft capture system

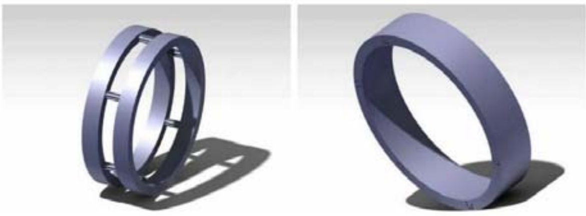
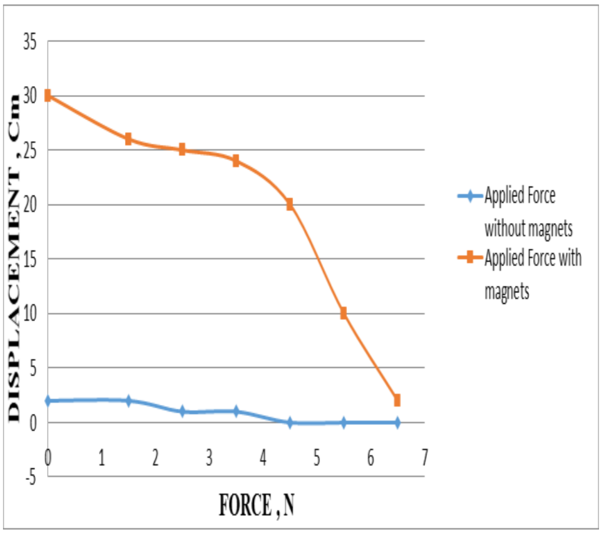


Figure 11: Six cylindrical tubes combining representing docking

A tensile test is also conducted that shows the required force to separate a model with a magnetic field applied on it. The below graph represents the tensile test results.

Table 4: Values obtained from tensile test

Displacement (cm)	Applied force without magnets(N)	Applied force with magnets (N)
0	2	30
1.5	2	26
2.5	1	25
3.5	1	24
4.5	0	20
5.5	0	10
6.5	0	2



Graph 1: Force vs. displacement showing the required force to separate two systems

By the tensile it is shown that when the systems are without magnetic field less force is required to separate them. But when the magnetic force is applied to the systems, a force of about 30N is required to separate the two systems. This experiment is for a small scale model, but when a heavy system is considered like satellite it requires even more force to get separated may be about 1000 times the 30 N which is a very large force. So this proposed model helps to dock effectively for the systems.

8. Conclusion

The paper presents the application of MR Fluid for the satellite docking system. Previously for the docking, guides were attached to the soft capture system. This paper proposed a model for satellite docking using MR Fluid. The experiment is conducted on proposed model and results are obtained. The main aim of the proposed model is to decrease the number of moving parts in docking the satellite system. With the application of MR Fluid the effort required to dock the satellite system can be reduced.

9. Future Work

Due to time constraint, experiment cannot be conducted on the grooved cylindrical tube. The research should be further continued to get better results.

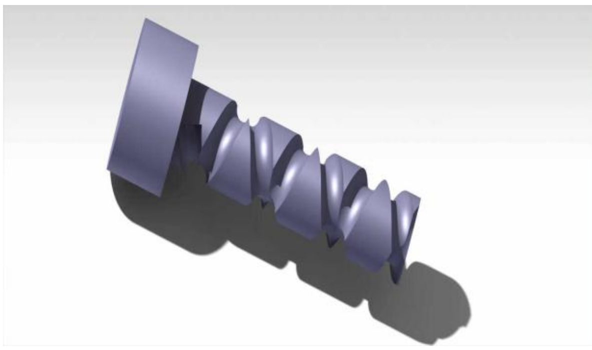


Figure 12: Cylindrical tube with grooves

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