CONCEPTUAL DESIGN OF THE SEPARATION SYSTEM OF THE INTERNATIONAL BERTHING AND DOCKING MECHANISM

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ABSTRACT

This paper presents the conceptual design of the separation system of the International Berthing and Docking Mechanism (IBDM), more extensively described in [1]. This separation system is capable of:
- Safely deberthing and undocking vehicles weighing 5 to 80 ton
- Minimizing the angular velocity of the separation vehicle to result in a pure translation.

This paper contains the functional requirements of the separation system, the requirements for the separation mechanism and the conceptual design of the separation mechanism.

1. INTRODUCTION

The International Berthing and Docking Mechanism (IBDM) is an androgynous soft-docking mating interface between two vehicles (Fig. 1). It will be the first mating interface capable of docking, i.e. mating without the aid of a manipulator, and berthing, i.e. mating with the aid of a manipulator. To deberth a vehicle, the separation system has to disconnect the umbilical connectors between the two vehicles without giving the departure vehicle a separation velocity, whereas an initial velocity is required for undocking. The separation system has to allow regulation of the separation velocity to meet these requirements.

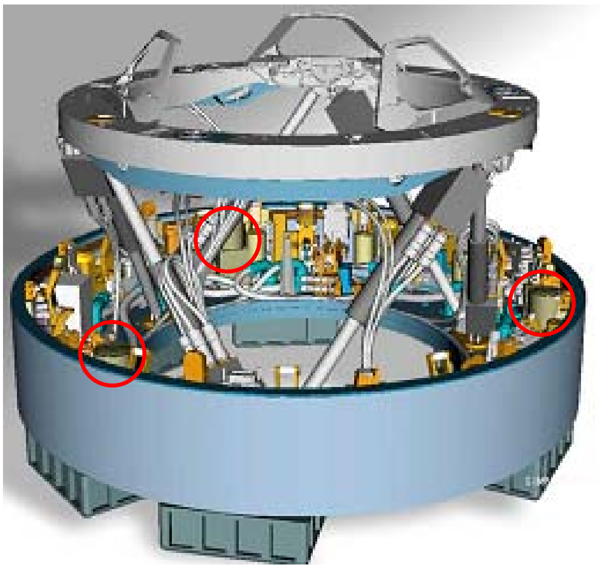

Figure 1: The International Berthing and Docking Mechanism: Separation mechanisms circled in red

The separation system consists of three separation mechanisms, one mechanism on each axis of symmetry of the IBDM. Each mechanism consists of a stack of disc springs which can be pretensioned by means of a DC motor and a spindle (Fig. 2 and Fig. 3). A load sensor and displacement sensors determine the stored potential energy in each spring stack.

The system design gives the possibility to regulate the stored potential energy in the three different mechanisms separately. Therefore, it is possible not only to account for different weights of vehicles at different velocities, but also to minimize vehicle rotation. If the mechanisms are not regulated separately and the centre of gravity of the separating vehicle is not positioned exactly in the centre of the three mechanisms, rotation velocities are introduced. Too large rotations could make communication between the two separating vehicles difficult and increase the chance of collisions.

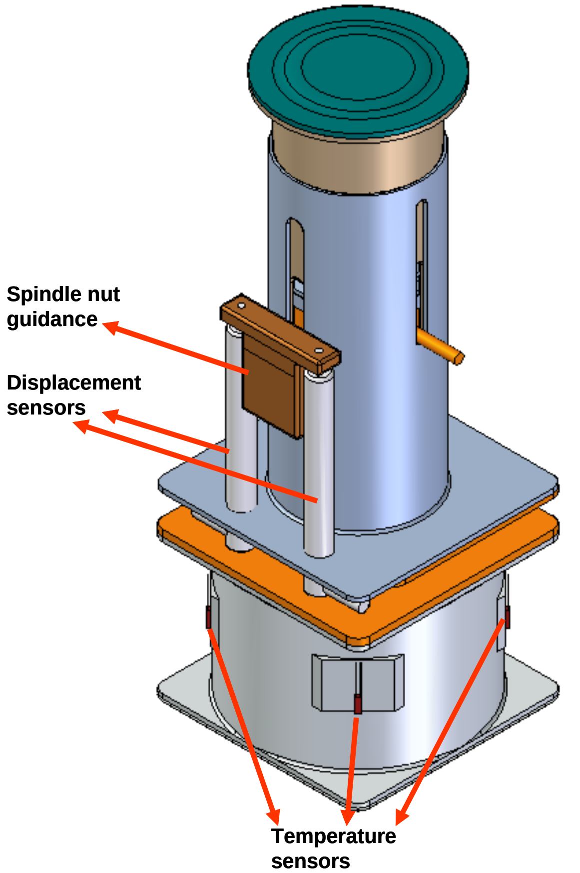

Figure 2: Separation mechanism

Proc. '13th European Space Mechanisms and Tribology Symposium – ESMATS 2009', Vienna, Austria 23–25 September 2009 (ESA SP-670, July 2009)

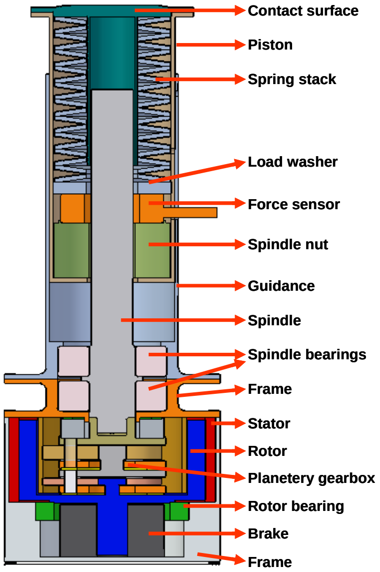

Figure 3: Separation mechanism: cutaway view

Safety and redundancy are very important in this system. The spring stacks have to be fail safe, as failure of the springs and piston during the separation can not be solved with a redundant spring stack due to the passive nature of the separation. Fail safe springs provide the opportunity to divide the spring stack between the two opposite mechanisms that are in contact due to the androgynous design of the IBDM. Each of the mechanisms can put pretension on the springs. This gives the necessary redundancy on system level while avoiding redundant elements on mechanism level. Each mechanism can be passive or active (Fig. 4 and Fig. 5). To ensure redundancy, all six mechanisms of the two IBDMs can be controlled from either vehicle, using the umbilical connectors.

2. REQUIREMENTS

2.1 Key system requirements

- The separation system shall be single fault tolerant.
- The separation system shall disconnect the umbilical connectors and deliver the initial separation velocity for undocking of vehicles.
- The minimal separation velocity for undocking shall be 67.2 mm/s.
- The separation system shall disconnect the umbilical connectors and minimize the initial separation velocity for deberthing of vehicles in order to avoid big loads on the manipulator. The initial separation velocity shall be generated by the departure vehicle, once placed at a safe distance by the manipulator arm.
- The separation system shall consist of three mechanisms.
- The separation mechanism shall be capable of safely separating vehicles weighing between 5000 kg and 80000 kg, but nominal vehicle weight shall be 21500 kg.
- The separation system shall minimize rotation velocities of the departing vehicle.

2.2 Key mechanism requirements

- Each mechanism shall be able to store 81J of energy which shall be released upon separation.
- The maximum force delivered by one mechanism shall not exceed 5350 N.
- The envelope of the mechanism shall not exceed 130 mm x 100 mm x 250 mm.
- The maximum mass of one mechanism shall not exceed 5 kg.
- The EMA voltage shall be 28V DC. The maximum current a motor can draw shall be 2A; 8A peak inrush. Powered operations shall be no more than 2 minutes per operation.
- The mechanism shall have an operational temperature range of -50°C – 50°C.
- The mechanism shall have a survival temperature range of -100°C – 100°C.

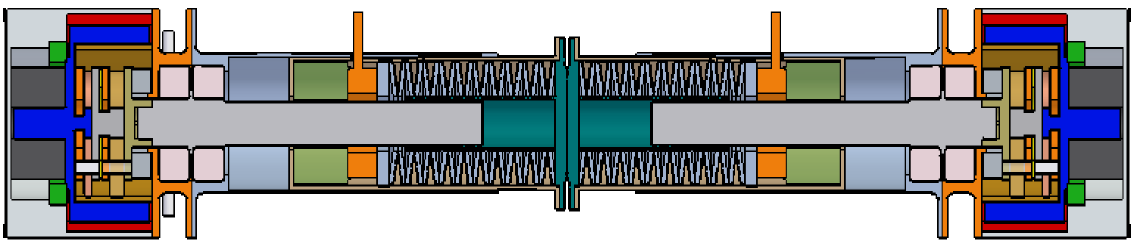
Figure 4: Two opposite mechanisms: Neutral position

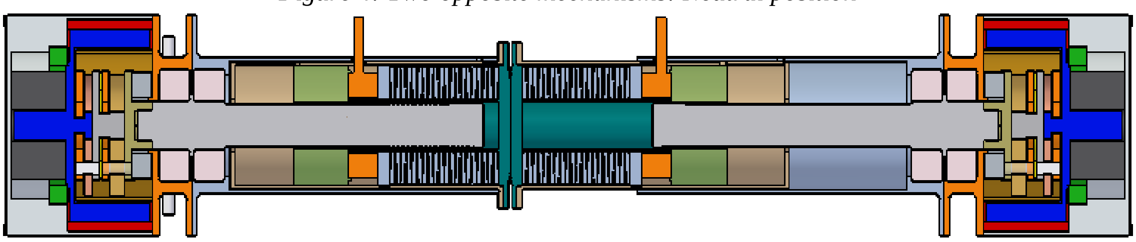
Figure 5: Two opposite mechanisms: Maximum pretension. Left: Passive mechanism. Right: Active mechanism

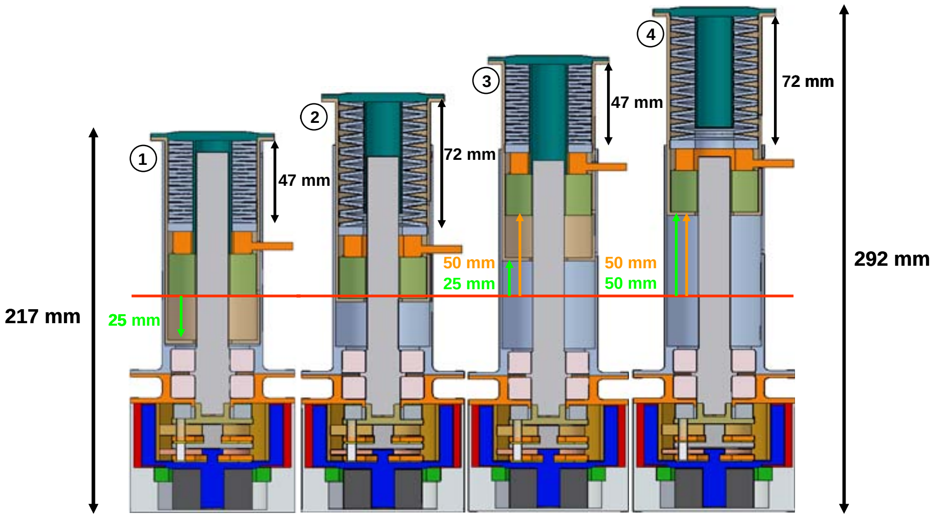

Figure 6: 1) Passive mechanism, fully compressed. 2) Neutral position or passive mechanism after separation. 3) Active mechanism, fully compressed. 4) Active mechanism after deployment.

3. DESIGN DESCRIPTION

3.1 Introduction

This chapter defines all parts of the separation mechanism concept to the extent that all requirements can be checked and all losses can be taken in account. It does not present a design ready for production.

The functionality of the separation mechanism is explained. This is necessary to give a broader view on the function of each of the separate components before all designs of the separate elements are described. One separation mechanism of the separation system itself can be divided by functionality into three subsystems:

- the push off system
- the spindle system
- the actuation system

The push off system deals with all components needed for the actual passive separation and the ones which are in direct contact with these components. The spindle system contains all elements needed for or related to building up and maintaining pretension in the springs. The actuation system consists of all components related to the actuator that drives the spindle system.

3.2 Separation mechanism function

Fig. 2 and fig. 3 show the separation mechanism and all of its components in its neutral position. Fig. 6 shows the four extreme positions of the mechanism.

When two IBDMs are mated, pretension can be built up in the separation mechanism spring stacks. Only one of the two opposite mechanisms is active; the actuator is used in only one mechanism. Number 2 in fig. 6 is the neutral position for both the active as the passive mechanism. Number 3 in fig. 6 is the active mechanism under full pretension. The spindle nut translates 50 mm outwards, the piston translates 25 mm outwards and the springs stack is compressed from an initial 72 mm to 47 mm. The piston of the passive mechanism, number 1 in fig. 6, translates 25 mm inwards; the spring stack is compressed. Fig. 4 shows two opposite mechanisms in neutral positions; fig. 5 shows two opposite mechanism with maximum pretension in the spring stacks. The right mechanism is the active mechanism.

After latch release, the springs push away the departure vehicle. The end position of the passive mechanism is the neutral position. The end position of the active mechanism is an extended position, number 4 in fig. 6. The spindle nut in the active mechanism has to be moved back to its original position, taking the piston with it, to restore the mechanism in its neutral position.

3.3 Push off subsystem

The push off system consists of the spring stack, the piston assembly and the force sensor.

Disc springs are most suitable for this application. The maximum allowed spring force for one spring stack is 5350 N. The selected spring delivers a force of 5350 N at about 75% of its deflection. The most appropriate spring is the 50x22.4x2.0 spring of Mubea [2]. A stack of 40 discs delivers the required stroke of 50 mm. The spring stack is split over the two opposite mechanisms. Each spring stack can provide 91 J, which is sufficient to guarantee the minimum separation velocity of 67.2 mm/s and to disconnect the umbilical connectors. The complete spring stack of one mechanism has a weight of 492.8 g and a length of 72 mm.

The piston assembly consists of two different parts, the piston itself and the contact plate. It contains the force sensor, the load washer and the spring stack. The two parts of the assembly serve five purposes. The piston itself acts as the support for the springs, as a piston and as a hard stop. The contact plate is the interface between the two opposite mechanisms. The cylinder serves as a hard stop.

The force sensor, necessary to control the pretension in the springs, is placed inside the piston, as close as possible to the springs. The force sensor is a through-hole load cell. Futek [3] can deliver the appropriate load cell, the LLW460. The load cell can handle forces of ten times the maximum possible load in the separation mechanism. This sensor has primarily been chosen because of its geometrical dimensions and because it can handle the wide temperature range.

3.4 Spindle subsystem

The spindle system consists of the spindle, the spindle nut, the spindle bearings and the displacement sensors.

The spindle has to operate within the spring stack and partially within the hard stop attached to the contact surface. This constrains the maximal outer diameter of the spindle to 19.6 mm. The outer diameter or thread diameter of the spring is chosen 18 mm. The spindle material is 15-5 PH. A trapezoidal thread is preferred to a rectangular thread, because the spindle nut will be aligned in radial direction due to the trapezoidal thread.

Bronze is used as material for the spindle nut and chosen because of its high surface pressure. This results in a spindle nut width of 24 mm.

The spindle bearings withstand small radial loads on the spindle and larger axial loads on the spindle if the spindle nut runs into a hard stop. Two identical single direction angular contact thrust ball bearings have been selected. They are assembled in opposite direction. Each bearing withstands an axial load in a different direction.

Two displacement sensors monitor the spindle nut displacement. LVDTs from Active Sensors [4] have been selected. These are the smallest sensors available with a stroke of 50 mm.

3.5 Actuation subsystem

The actuation system consists of the electromagnetic actuator, gearbox, gearbox bearing and brake. The dimensions of these elements are the result of an iterative process, which is not presented in this paper.

The chosen EMA-gearbox combination needs a nominal torque higher than 19.37 Nm and a peak torque higher than 35.33 Nm. The EMA of choice is the Aeroflex Z-0350-100-2-204 [5]. The EMA is capable of putting the spring under pretension and of releasing the spindle nut from its hard stop position. It is in line with all the necessary ECSS norms.

A dual stage planetary gearbox is selected for the separation mechanism. This type of gearbox has been selected because it can be built inside the inner diameter of the EMA. The gear ratio of 36 requires two stages, each with a gear ratio of six. For assembly and production purposes, the ring gear of the two stages is the same element.

The rotor of the DC motor has to be attached to a bearing to make sure the rotor is positioned exactly in the middle of the stator. The main driver in the selection of the bearing is the feasibility of its assembly into the separation mechanism. The chosen bearing is a Kaydon Reali-Slim [6] four point contact bearing.

The selected brake is a permanent magnet single disc brake for DC operation and dry running. The peak torque of the motor is 1.17 Nm. The torque margin is sufficient. The brake secures all driveline components during launch. The brake prevents the pretension load in the springs from driving the spindle back.

4. CONCLUSION

The IBDM design of the separation system is the first separation system capable of both undocking and deberthing. Force and displacement sensors are used to determine the potential energy. The ability to separately adjust the stored energy in the different mechanisms allows for a new functionality of the separation system. Rotation of the separating vehicle can theoretically be reduced to zero, leaving the vehicle in a pure translation.

The androgynous character of the IBDM allows each mechanism capable to fulfill the passive and the active roll in separation. The springs need to be designed failsafe as no redundant springs can be activated if failure should occur during separation. This design therefore uses the springs of both the active and passive mechanism to provide the energy for separation. Each mechanism fits in the predetermined envelope and weighs approximately 4.5 kg.

5. REFERENCES

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6. REMARK & ACKNOWLEDGEMENTS

All the technical work has been performed in the frame of Geert Smet’s master thesis at K.U.Leuven in cooperation with Verhaert Space.

The authors gratefully acknowledge the support of the Verhaert Space IBDM team.