Developed a noiseless air inflator to increase the efficiency of testing robots in 2-dimensional zero gravity †

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Abstract: Space programs and space technology nowadays are important factors in Earth development, showing the complexity of creating and achieving objectives. Using Robotic Spacecraft as an exploration device for high-precision and mostly, astronaut's lifesaver. The challenge in developing a robot for low-gravity environment is about guidance, navigation, and control, making the robot tested countless times in a stable and durable low-gravity environment before the actual operation. One suitable testing method is air-bearing facilities in exchange for stability and precision problem, which is impossible to achieve correct test results. In this paper, we designed connecting hub to solve the time limitation problem from limited air in testing the robot's air-bearing facilities with the slightest disturbance using remote center compliance (RCC) model and fasten with electromagnets.

Keywords: low-gravity environment; remote center compliance; navigation and control robot

1. Introduction

Space programs and space technology are expensive but valuable in Earth development. Showing the complexity of creating and achieving objectives, especially in space exploration that was always operating in dangerous and unpredictable conditions. Nowadays, robotic spacecraft is one of the exploration methods for more precision and protect crews' life from the thread in hazardous biome. Thus, robots are important in space exploration and other space missions. However, the challenge of making a robot in space is the low-gravity environment that affects the robot's guidance, navigation, and control[1], leading to countless robot tests in a stable, durable low-gravity environment on Earth robot's efficiency[2].

One of the testing methods is using air-bearing facilities with advantages of high durability, stability, and precision by creating a stable air gap to the floor to reduce friction, making the two-dimension low-gravity condition that uses in several projects. European Space Agency's engineers build air-bearing facilities model named ACROBAT with the advantage of having an external inflating pipe that can be tested limitless and carry heavy objects used for European Robotic Arm motion test low-gravity environment[3]. Another one is Czech Technical University in Prague developing an air-bearing facilities model named ROOTLESS, another model with an external inflating pipe for limitless testing time with agility and weight problems[4]. One of the characteristics required for testing robot is duration, while both models of air-bearing facilities can achieve the goal in exchange of heaviness and errors from the external inflating pipe that compatible only specific project in ACROBAT and the lack of agility in ROOTLESS. When using air-bearing facilities model, obtain unlimited testing time while losing stability and precision—making air-bearing facilities development.

In this paper, we design an inflating hub to solve the time limitation problem from the air-bearing facilities' model with limited air with the least disturbance using remote center compliance (RCC) model and fasten between hubs electromagnets.

2. Effect of vertical collision on horizontal plane

We designed inflation method in the vertical plane, when connecting hub collides, (Figure A1.) and the effect from electromagnetic push or pull (Figure B1.) may affect air-bearing robot's momentum (Eq. 1) in the horizontal plane.

Momentum equation (Eq.1)

$$\Delta \mathrm{P} = mv$$

$$\Delta \mathrm{p_M} = \Delta \mathrm{F_f} \Delta \mathrm{t} = \mu \mathrm{F} \Delta \mathrm{t} = \mu \mathrm{m}\sqrt{2\mathrm{gh}}\ ;\ \mu = 0$$

Air-bearing robot's horizontal momentum changed (ΔP_M) is equal to changed friction in a unit of time ($\Delta F_f \Delta t$) that comes from the changing force in a unit of time combined with the coefficient of friction ($\mu F \Delta t$), which leads to changing the air-bearing robot's horizontal momentum change ($\mu m\sqrt{2gh}$). When coefficient of friction (μ) in horizontal plane of air-bearing system operating approach 0, receiving no effect from hub connection and other vertical forces, e.g., electromagnetic push and pull.

The hub collision model (Figure C1.) in a vertical plane is an inelastic collision, the effect from colliding remains, which may affect air-bearing robot operation. While post-impact speed (Eq. 2) comes from mass ratio between male and female hub (m_1:m_2) is 1:14.

Inelastic collision equation (Eq.2)

$$m_1 v_1 = (m_1 + m_2) v_2$$

$$v_2 = \frac{m_1 v_1}{m_1 + m_2}\ ;\ m_1 = 1, m_2 = 14$$

Showing relativity between male and female hub, the larger the male hub mass is lower than the female hub, the more post-collision speed (v_2) decreased. Making it another factor informs that air-bearing robot's momentum changed insubstantially.

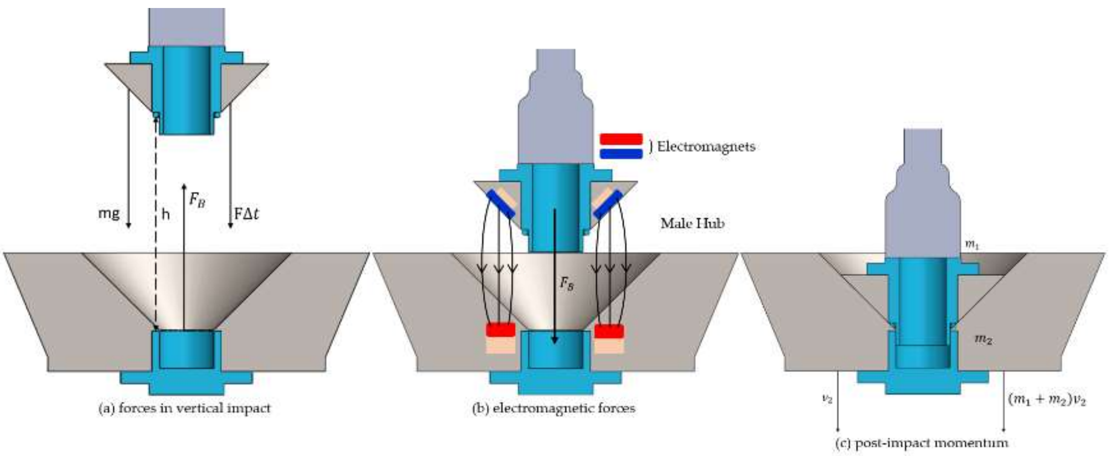

Figure 1. (a)forces in vertical impact; (b)electromagnetic forces; (c) post-impact momentum

3. Electromagnets in hub connection

Normally, male and female coupling have internal locking system such as, ball-lock and pin-lock couplings, when locking system above require mechanism to lock and unlock the coupling to prevent air leak while connecting. Causing force that disturb the test. Using Quick Connect Couplings for Multi-Port Connection (Automatic) MALC-01 Type that has no internal locking system, but complete air coupling connection requires locking system to prevent air leak and pressurize air from causing failed test and harming people as well as the project. By design connecting system and lock between male and female hub using electromagnets.

Electromagnet sealing is the primary method to seal that use commonly, e.g., keycard entry system. The main purpose of sealing is appropriate with the project, while our project using electromagnets to seal the inflator pipe. With particular electromagnetic force on certain pressure force in the inflator pipe (Eq. 3) when electromagnetic force (F_B) binding male and female hub together with certain force compare to inlet pressure (P_{in}) having the least force to bind male and female hub together securely (Table 1.) and inflating time (Eq. 4) in two 2.4 gallons tank that used in air-bearing facilities model named MANTIS. Calculate by compare air inlet volume (a_{in}) and inlet pressure. (Table 1.)

Magnetic force for tighten between hub (Eq.3)

$$F_B = P_{in} A_{pipe}\ ; A_{pipe} = 2.688 \times 10^{-4}\ m^3$$

Inflating time (Eq.4)

$$t_r = \frac{\left[\left(\frac{P_{max} v_{tank}}{a_{in}}\right) - v_{tank}\right] P_{max}}{a_{in} P_{in}}\ ; v_{tank} = 9.1L, P_{max} = 1.14\ MPa$$

Table 1. The result of the calculation electromagnetic force and time use

Input air(m³/min)	Electro magnetic force (N)	Time use (s)
0.8	70.69	28.64
1	94.08	13.06
1.2	117.47	6.87
1.4	140.85	3.97
1.6	164.24	2.44

4. Male female connector hub design

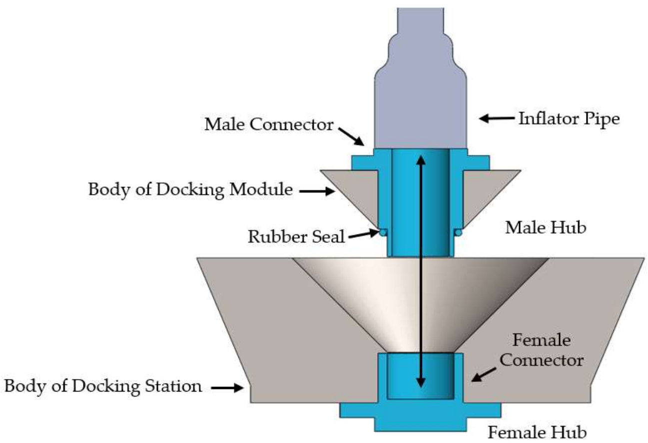

Figure 2. Hub design Docking module and docking station

A designed connecting system similar to the MULTI CUPLA system in factories with advantages in rapid connection and high agility means that the locking system is separate from couplings for controlling and status representing benefits. Connection using naked couplings is challenging to maintain high stability and precision, designing hub for making more contact surface for coupling with overall similar to Remote Center Compliance (RCC) motion model according to vertical connection. Our hub mechanical design is the same as Remote Center Compliance design, but not perfectly. Making a male inflator hub and a female receiver hub with a cone slope surrounded them. With these adaptations, the inflator hub will slide down the cone slope to a receiver hub in the same way the RCC does.

5. Conclusion

The collision impact force between male and female hub for inflation or other vertical-based forces will affect the horizontal plane. Theoretically, vertical forces affect horizontal plane negligibly in air-bearing condition. The coefficient of friction approaches 0, and inelastic collision from hub connecting relates with male and female hub mass ratio, making post-collision speed decrease significantly. The effect from connective collision to air-bearing robot is trivial, and the inflating time in the MANTIS model is short, making it worthwhile and compatible in actual use.

In the future, this connecting hub will build from the planned model. Attaching male hub on docking system at the mobile robot and female hub with the air-bearing robot. Connect the inflator pipe autonomously with the least effect to the system, inflates air, and detach perfectly.

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