STAND FOR TESTING THE SATELLITES MOTION, IN LABORATORY CONDITIONS

Gheorghe Silviu Ionut[1], Negrea Catalin-Stefan[1,2], Angelescu Dorin[1], Tutoveanu Mihai[1,2], Istrițeanu Dan[3]
[1]National Institute of Research and Development of Mechatronics and Measurement Technique
[2]University POLITEHNICA of Bucharest, Industrial and Robotic Engineering, Department of Strength of Materials, 313 Splaiul Independenței, 060042, Bucharest, Romania
[3]RARTEL S.A, Bucharest, Romania
Emails: silviu1_silviu1@yahoo.com , catalin.negrea95@gmail.com , dorinnirod@yahoo.com

Abstract - As a result of the INCDMTM Bucharest experience in the field of testing and real-time measurement of the distance between satellites in formation and benefiting from a consultancy in the field offered by RARTEL S.A., we created together the base of a new space project. That's how the idea, of a laboratory stand for testing the movement of satellites, in order to stay in formation and/or to ensure accurate movement of new satellite engines, was born.
Two main possibilities were taken it into consideration: the displacement of the satellites on an air cushion and another one by using magnetic suspension. The magnetic suspension was eluded because of possible influences of the magnetic field over the other components of the satellites. Our experience of over 35 years in building guiding systems with hovering air cushion and combined with the space specific experience of RARTEL S.A generated the confidence of the possibility of executing such a project in our country. The paper contains the basic ideas and strategies for approaching such a complex project for the first time in Romania.
Feasibility studies have also shown the possibility of implementing such a system characterized by a clear and simple design, minimum preparatory adjustment requirements, clear visibility and direct interaction of all experiments, simple operation and high reliability. The start TRL is TRL 3 and final is at least TRL4. The proposed laboratory stand is a frictionless system able to sustain on an air cushion not only satellites but any other type of objects having more or less regulated shapes. So, it is possible to test, study and measure the dynamics of any device powered or not with a propulsion system, in frictionless conditions. Moreover, the system principle can be extrapolated and transformed in industrial environment into transportation systems for medium and small objects.

Keywords: Gazostatic testing stand, Satellite formation, Satellite engine, Gazostatic stand.

1. Introduction

The consortium made up of the Space Science Institute (ISS), ICPE Bucharest and INCDMTM Bucharest has completed an artificial scientific Nano-Satellite. The special driving engine of this satellite was made at ICPE and the measuring part dedicated to measure the distance between the satellites in formation was completed by INCDMTM.

The adjustment of the position between the satellites in formation flight must be realized automated in order to avoid collisions and to avoid that they depart too much from one another and get lost. Considering this project as a positive start of Romanian space activity, INCDMTM tried to get as involved as possible in this Romanian pioneering of space conquest. One of the problems identified was the laboratory testing of the movement of satellites in order to stay in formation and/or to ensure accurate movement of new satellite engines.

In order to test the adjustment of position under laboratory conditions, together with consultancy from RARTEL S.A., we have considered that a test stand is required to ensure the displacement of the satellites in space, in a free of friction conditions (similar to the ones existing in space). Two possibilities were taken it into consideration: the first of them is the displacement of the satellites on the air cushion and the second one is by using magnetic suspension. The testing variant based on magnetic suspension was eluded because of possible influences of the magnetic field over the other components of the satellites. So, the air cushion remains the only viable solution. The INCDMTM experience of over 35 years in building guiding systems with hovering air cushion and combined with the space specific experience of RARTEL S.A generated the confidence of the possibility of executing such a project in our country.

We have also analysed the variant to buy a table over a geostatic air cushion from a well-known producer. Geostatic air cushion tables made by producers in well-developed countries are dedicated to specific application and have certain characteristics (for example: for displacing mailing envelopes, moving glass plates, etc.) but none seems able to be adapted/modified for processes other than those for which they were created. The most important problem being that the operation mode of the table cannot ensure parameterization depending on the shape, weight and size of various satellites. After analysing the feasibility, we have considered adequate, at least for the actual conditions in our country, to propose as a TRL4 project the execution of a test stand for satellites of various shapes and sizes associated to the family of satellites CubeSat. So, the General objective of the project is developing a test system in laboratory conditions for a wide range of satellites, from Nano-Satellites to Micro-Satellites and for a wide range of sizes, shapes and weights of very different satellites. The system will consist of a geostatic table on top of which satellites will be able to travel in a frictionless fashion due to the air cushion. The test system must also have the ability to adjust the parameters of the cushion depending on the shape and weight of each satellite in order to ensure a good buoyancy and displacement without friction.

2. The Project Premises

An important role in the development of subsystems for flights is their characterization and validation under laboratory conditions by mimicking the operating conditions of space.

The testing of systems and algorithms for control and ground verification of systems for operation of satellites under laboratory conditions implies the existence of a stand enabling the movement of the satellite in conditions similar to those of space that is with no friction, similar to those in space. For testing an autonomous satellite, we intend to make a platform on which to sit the satellites in order to test both the response of linear or rotational displacement actuation and controls verification and distance measuring sensors of satellites flying in formation of satellites. Given the experience of over 35 years of our institute in the design and execution of air-cushion guides for measuring machines such as robots for dimensional inspection in Cartesian coordinates, turntables and many other precision machinery provided with guides for displacement based on an air-cushion we propose using an hovering air cushion in the construction of the platform. The platform used for testing satellites will be fitted with a system that will enable satellites to travel on an air cushion, without friction. As such, a table with air cushion will be personalized in order to assess performance of various models of satellites. Such a table presents an opportunity to perform detailed experiments with 3 degrees of freedom (two translations and one rotation).

Because air-cushion tables existing in production cannot be used to test satellites in the laboratory, we proposed technological research on determining the theoretical and experimental geometric elements of the cushion, on how to perform the adjustment of the system's working regimes of the air cushions and the embodiment of modular systems for the execution of command-and-control functions.

Hovering on air cushions is produced and supported by air jets emitted continuously in one of the moving objects on the table surface.

This prevents any contact between the two objects. There is a thin cushion of air between them acting as a "lubricant", similar to the commonly used, film of oil. Due to the much lower viscosity, the air friction is reduced to a negligible level. Since in this case only some of the energy is transmitted, it is necessary to take additional measures to compensate for the loss of kinetic energy.

The principle of using the hovering air-cushion is characterized by a simple operation, high reliability, universal use, and excellent methodological quality. Some practical experiments cannot be obtained with other methods known at present. In the case of a hovering air-table the aim of adjustment of streamline transmitted through the air nozzles is being the key factor in designing this type of system for moving objects. To conserve air supply while providing optimum buoyancy the nozzles are based on a "check valve". These nozzles are mounted on the bearing surface, with a prominent spherical actuator above. The air flows only when the load is moving over the nozzle and presses the spherical actuator. The air flow is thus restricted to the area under the load. The task serves as its own "switch" to automatically start the air supply "ON" and "OFF". A "spherical actuator" nozzle is usually made of polycarbonate or stainless steel. The nozzles can be pressed or screwed and fit into the holes on the supporting surface. The best are screwed ones. These are more expensive but have virtually no leakage because they are sealed to the bearing surface with an "O" ring - which effectively saves air. They can be designed to operate at all pressures up to 100 psi (7 kg / cm2.). Such systems using precision nozzles have usually provided the required pressure air compressor air through a regulator. These systems are used when pressures are higher and need precise control of pressure. Pressure requirements vary, depending on the task involved and supporting surface flatness.

To demonstrate the feasibility, we propose the concept, development and experimentation of a stand that meets the requirements above and can demonstrate the fulfilment of requirements on satellites or models of satellites (mock-up satellites). The principle of using the air-cushion allows the displacement with almost zero friction between floating bodies. The system is characterized by a simple design possibilities adjustment of operating modes, clear visibility in all experiments, relatively simple operation and high reliability.

3. Air-Cushion Sustentation

Air-cushion sustentation is used for guiding movements and linear bearing of angular displacements across a broad range of measuring machines such as robot coordinate control systems, spatial positioning, rotary tables, specialized equipment in the microelectronics industry, video-inspector equipment and other systems for special applications.

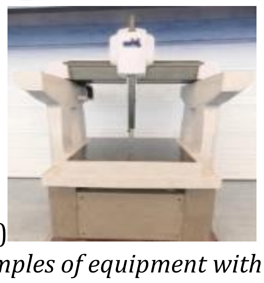
The applications of air-cushion sustentation in the construction of devices are known worldwide and many companies have applied air-cushion sustentation in the completion and continuous development of an impressive number of products in a diverse and varied range of different dimensions.

Overseas companies such as MITUTOYO - Japan WENZEL - Germany ABERLINK - UK, or from the group Hexagon Metrology companies TESA - Switzerland, LEITZ - Germany, DEA - Italy produce a wide range of measuring machines, robots for dimensional inspection in Cartesian coordinates, length measuring devices, etc.

In Romania, an air-cushion sustentation theoretical study was carried out in universities and the practical completion of air-cushion sustentation guides began in the 1978-1979 in INCDMTM Bucharest by making devices, measuring machines in Cartesian coordinates, 3D control robots and rotational turntables with air-cushion.

a)

b)



c)

Figure 1 - Examples of equipment with guides using the air-cushion sustentation made by INCDMTM (a- turntable; b- translational guide; c-3D measuring machine with air-cushion sustentation guides.

INCDMTM has an experience of over 35 years in the calculation and implementation of air-cushions guides for instrumentation and control and particularly air-cushions for ensuring displacements without friction on the 3 axes of modern measuring machine in three coordinates. In this area, in INCDMTM we have made and patented several guidance systems (Patent no. 81.876 / 1983 - Gasostatic skid; 87.492 / 1984 - Shift sleds mobile device to guide machine tools; 91.807 / 1996 Electro-mechanical gasostatic braking system; 98.273 / 1989 - Guiding device for machine tools, especially for coordinate measuring machines and similar ones; - Translational bearing 108.064; 113.586 / 2003 – Gasostatic couple). So, the starting TRL is considered to be TRL 3. Because the project will be finalized by laboratory tests aimed to evaluate the validity of the developed solution, TRL at the end of the project is estimated to be 4. The product will be made in the CERMISO department of INCDMTM institute which has the technical equipment for the development of the prototype or even low series.

4. The Testing Stand

The main steps in the project are the basic technological research and establishing the performance regarding the concept of the stand (TRL 2) and proof of concept and performance set by making and testing it (TRL 4).

The Partners together with RARTEL S.A. will use a step-by-step engineering approach. The first step is:

STAGE I - Basic technological research on the formulation of the concept and establish performances for the testing stand (TLR 3)

The stage is starting with a logic systematization of the existing and obtainable CubeSat models, type, forms and characteristics. Once defined the complete list of satellites there will be necessary to design accessories (for satellites having unregulated surfaces) and mock-up satellites for the models that cannot be obtained. It will be taken into account to possibility to make some thrust modules adaptable to real satellites or to the adapters in order to simulate rotation and translation of the satellite/mock-up.

The most important part will be the issue of the active elements that conduct the air flow. Once the final form of the active elements is defined, the rest of the stand it will not generate any technical problems despite the vast amount of work necessary to obtain the first prototype.

In parallel the partners will approach in the same manner the execution of the Test Stand. That will generate the second step which is:

STAGE II - Proof of concept and performance set by making and testing the testing stand (TLR 4)

Finally of the project will consist in effective tests on the testing stand, and development of it. The engineering approach is defined by a series of working plans well defined and divided between the partners. The work plans will be divided between the two entities according to each other capability and experience in order to maximize the efficiency of the project.

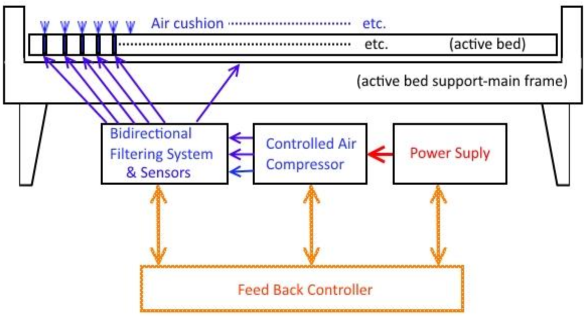


Figure 2 - General diagram of the Testing Stand

The most complex part of the Test Stand is for sure the active bed. It implies lots of hi-tech mini mechatronic valves needing high accuracy execution and perfect repeatability of the individual parameters. The execution of the valves implies the optimal functionality of the testing stand. It assures thru the Feed Back Controller the optimal energy consumption, in order to obtain perfect air floatability for heavy loads with minimal consumption. The air fittings system must be flexible, easy to replace, and to maintain in case of any damage for any part of the system. It must assure the perfect leak-proof. Filters must assure clean air jet without impurities and humidity. The Feed Back Controller will maintain in optimal parameters all the testing stand parameters and must be provided with a user friendly interface with the operator. The air cushion must be active only under the load despite the movement, improving the total consumption of the system. The valves are self-trigger able systems itself, maintaining the air stream open as long as the load surface is over it and closing as long as no load is above. All elements will be executed in the CERMISO centre of INCDMTM under the supervision of designer's team and direct assistance with the executor's team. All elements are to be inspected to assure (especially for the valves) the perfect repeatability correlated with functional parameters. All fittings and couplings will be mounted, including Bidirectional filtering system and sensors, Controlled Air Compressor and Power Supply.

After tests and simulations, the highest performance and most versatile solution will be chosen for the final type of active element studied and tested. All active elements will be the same type, form and shape so the execution to be standardized. This is necessary for optimization of the production process of the elements because the final number of such element can be around 2-3000 pieces depending of the final dimensions of the active testing stand surface.

A special attention must be paid in order to obtain satellites or models of satellite as accurate as possible or as close as possible to the originals. It will be possible to be necessary to produce specials adapters even in the case we have originals satellites. The adapters will assure the floatability of the satellites in the case the real surface for buoyancy is creating problems due to irregularities of any type. It will be necessary to design and execute Universal Floating Adapters (UFA) and fake satellites (FS) as models for testing. These adapters/models will cover the whole range of CubeSat surfaces needed. The UFA will also be used in case of non-available satellites in order to simulate it (in that case the UFA will be loaded with an additional load up to the real weight of the original satellite or even an FS model). An interesting secondary application involving the UFA is the fact that using it you can test parts of the satellite (during the production of the satellite) even if it is not finalized (for example: testing only the propulsion system, testing only the telemetry system, etc.)

The control system assuring the correct functionality of the active elements must also be implemented. It must be taken into account the fact that the active elements must have a dynamic performance in order to optimize the air consumption per various type of loads. All operating modes will be taken into consideration including a friendly interface with the operator.

5. Risks Involved

Considering the vast experience of INCDMTM and RARTEL S.A. we consider that following problems regarding the technical aspects can arise:

The various sorts and type of satellites, having unregularly forms, and sensibility of the electro - magnetic field can generate some technical problems regarding floatability as well as interference between satellite and Test Stand. The solution to solve that problem is the issues of adaptors and the abandon of the magnetic field as a bearing vector and using instead the compressed air.

There are no other industrial producers of such stands despite the fact that various air hovering tables are in production in that moment in the world (basic application for industry transportation systems, entertainment, etc.). The solution for that is a new type of such an equipment conceived and dedicated to the specific fields of testing the movement of the satellites.

Another problem is the big number of air valves to be mounted on the active bed in correlation with big air consumption. To solve this, we are using special valves with normal closed function. The valves distribution being also the key of optimizing the air / energy consumption.

INCDMTM and RARTEL S.A. have paid special attention to assess how the realization of the project is technically feasible. Although INCDMTM has an experience of over 35 years in the making guides using air-cushion systems dedicated to equipment for measurement and control, the application in this case it is slightly different.

For the test stand modules that are not fully defined and there is no certainty from previous achievements or for components with the high degree of innovation it was provided a stage with special activities for basic technological research on the concept formulation and setting performance. In that stage are analysed from technical point of view others small uncertainties or parts with high degree of novelty.

6. Conclusions

The air-cushion principle as well as the use of magnetic forces allow nearly zero-friction motion of hovering bodies. The equipment system is characterized by a clear and simple design, minimum preparatory adjustment requirements, clear visibility and direct interaction of all experiments, simple operation and high reliability.

The Stand for testing the satellites motion is a very complex frictionless system able to sustain on an air cushion not only satellites but any other type of objects having more or less regulated shapes. So, it is possible to test, study and measure the dynamics of any device powered or not with a propulsion system, in frictionless conditions. The system principle can be extrapolated and transformed in industrial environment into transportation systems for medium and small objects (especially extremely fragile objects needed to pass thru a production line fabrication process), complex guides for mechanical systems that need less friction and great precision movement or special bearings using air instead of classical lubricants. So, despite the fact that the testing stand is extremely useful for its main purpose, which is related to space application and satellites studies, it can be foreseen a lot of other direct applications in industry, transport and even in board game industry. For this reason, the partners considered it feasible to submit an ESA project regarding the execution of such a test stand.

References

[1] Gheorghe I. Gheorghe, Mecatronica & Sistemele Cyber – Mecatronice, ISBN 978-606-8261-22-5, Ed. CEFIN, 2015;

[2] Mihaita Ardeleanu, Gheorghe Ion Gheorghe, Gheorghe Matei, Mecatronică aplicată, Ed. AGIR, 2007;

[3] Lewandowski, D.: Aerostatic bearing of high-speed spindle systems (in Polish), Scientific Papers of Technical University of Lodz, No 753, Lódź, Poland, 1996.

[4] F OryńskiS Kawczyński Oryński, F. and Kawczyński, S. - He choice of bearings for gas compressors, 14-19;

[5] F OryńskiS Kawczyński Oryński, F. and Kawczyński, S.: Gasostatic radial -axial borehole bearing. The patent application P398007, Polish patent application, 06.02.2012;

[6] Franciszek Oryński; Witold Pawłowski; Sławomir Kawczyński, New gasostatic borehole bearings - construction and research, Publication: Mechanics and Mechanical Engineering, Vol. 20, nr 1 (2016), s. 33-41

[7] Oryński, F., Pawłowski, W., Kawczyński, S. New Gasostatic Borehole Bearings - Construction and Research Mechanics and Mechanical Engineering, (2016), Vol. 20, nr 1, 33-41