ELECTRODYNAMIC GENERATOR OF GRAVITY SENSATION

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ABSTRACT

Rotation is in the focus of all artificial-gravity research as centripetal acceleration generated by rotation can be substitute for gravity. A very effective way to spin an object in space is to use electrodynamic technologies and obtain controlled rotation of habitats for generating gravity sensation by means of guidance and velocity control by a unified trajectory control system made of propulsion and steering subsystems. Superconducting electrodynamic technologies are especially suitable to be optimized and applied in space. Deep space, as cold vacuum without gravity, offers significant advantages for application of electrodynamic technologies.

1 SUPERCONDUCTING ELECTRODYNAMIC TECHNOLOGY APPLIED IN SPACE

Electrodynamic technologies based on repulsive forces use powerful superconducting magnets to obtain gaps large enough to enable their use in circular paths. Electrodynamic systems are stable and there is no need for active electronic stabilization. Superconducting Japanese EDS (electrodynamic suspension) Maglev (magnetic levitation) trains technology in which vehicle is suspended, guided and propelled by magnetic forces and fields, is suitable to be optimized and applied to spin an object in space by contolled rotation.

1.1 Low Temperature

Generally accepted temperature in space is approximately 2.725 K, less then 3 K above absolute zero temperature at which molecules stop moving. Such a low temperature makes very interesting use of superconductor materials as superconductivity occurs in certain materials at very low temperatures followed by zero electrical resistance and the Meissner effect which excludes the interior magnetic field. Superconductors' electrical resistance decreases gradually when temperature decreases, and drops strongly when the material is cooled below its critical temperature. Electrodynamic systems don't need expensive cryogenic systems to cool superconducting magnets (SCMs) in frigid space environment. SCMs provide strong electromagnetic fields and repulsive forces for larger and safer operating gaps. They can conduct electricity even after the power supply is cut off. Use of SCMs in space will be highly economical and efficient.

1.2 Lack of Gravity

Levitation is natural condition in weightlessness deep space so, the target to achieve is to obtain controlled rotation. Electrodynamically propulsed system suited in space will need one and unified trajectory control system to achieve fully controlled rotation for deliberate acceleration for replacing natural gravity. The only clearances to be controlled are between propulsed rotating module and rotation generator. Once achieved fully controlled rotation, the weightlessness conditions will facilitate its maintenance making it highly efficient. In space, required propulsive power consumption will be reduced as well as a size of implemented SCMs and coils. Gravity sensation generated by rotation will be gradual, starting from zero in the axis of rotation and ending with designed values in rotating habitats.

1.3 Vacuum Conditions

Outer space is hard vacuum being the closest natural approximation of a perfect vacuum environment. No medium is required for propagation of electromagnetic waves as they are able to propagate in vacuum travelling at the speed of light which increase the efficiency of electromagnetic and electrodynamic technologies in space. Outer space has a very low density and pressure being effectively without friction. Electrodynamically propulsed contactless rotation in space would be completely loss-less and frictionless with highly improved overall power efficiency. Also, there is no corrosion problem in vacuum conditions.

1.4 Abundant Solar Energy

Energy supply for electrodynamically propulsed system in space can be obtained by photovoltaic solar panels in a reliable, renewable and highly efficient way.

2 ELECTRODYNAMIC ROTATION GENERATOR

The general theory of moments for electrodynamic magnetic levitation systems based upon the dynamic circuit principles and emphasized on the loop-shaped coil and the figure-eight-shaped null-flux coil suspension could be modified and fully applied in space. Cross-connected null-flux superconducting EDS concept applied in the Maglev trains technology in Japan is especially suitable to be modified and applied in space. It is characterized by very low magnetic drag at low speed, high suspension stiffness, high lift to drag ratio and high guidance to drag ratio. Propulsion of electrodynamic repulsive system can be described as "pull - neutral - push". Propelled module is able to remain centered thanks to a combination of attraction and repulsion forces. Null-flux and double-layered propulsion coils are suitable to be applied as they allow instantaneous adaptation to changes in the circular

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trajectory. Generation of controlled magnetic forces and rotating magnetic field between magnetic body (rotating module) and magnetized body (rotation generator) will obtain stable and contactless rotation.

2.1 Unified Propulsion & Guidance System

The aim of use of electrodynamic technologies is to obtain fully controlled rotation of habitat for generating gravity sensation by means of guidance and velocity control by a unified rotation and trajectory control system needed for uninterrupted and fully controlled propulsion and trajectory control. Unified rotation and trajectory control system is electro-magnetic guideway that consists of propulsion and guidance subsystems. The rotating module has to be in the same axis with the rotation generator being concentric and forming uniform radial gap. The path is completely circular and unique and it can not be changed nor modified. Radial and axial centering can be achieved by magnetic field generated by the radial set of null-flux figure-eight-shaped coils (red colored in Fig. 1 and Fig. 3) attached on the inside hull of the rotation generator and the radial set of SCMs (yellow colored in Fig. 1 and Fig. 3) attached on the external surface of the rotating module. SCM sets jointed in outer aluminum made vessels with incorporated electromagnetic shields that are radially inserted in the electro-magnetically propelled rotating module, will produce permanent magnetic field. The sets are not to be continually inserted but in facing pairs as it is shown in Fig. (3), (4) and (5). The other magnetic field is induced from the changes of the field that occur as the SCMs moves relative to the radial set of conductors located in the guideway. The relative motion between the rotating module and the rotation generator creates repulsive magnetic fields to hold the two objects apart. As the rotating module rotates, there is voltage induction in the coils due to the relative motion of the magnet-coil system. It creates current flow except at equilibrium position, resulting in a secondary magnetic field in opposition to the change in flux due to relative motion.

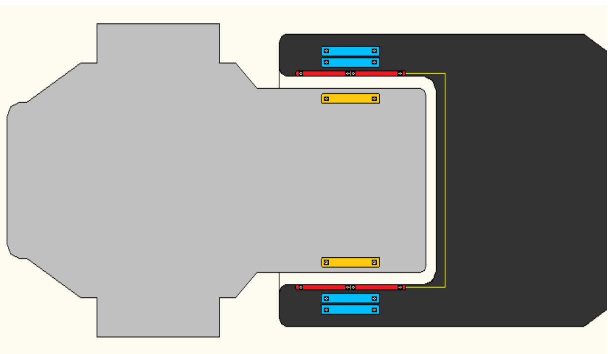

Figure 1. Electrodynamic radial thrust rotation generator.

So-called figure-eight-shaped null-flux coils similar to those applied in the Japanese EDS Maglev trains could be applied in space for trajectory and guidance control. They are to be installed on the inner surface of the circular rotation generator guideway and covered with aluminum curved-shaped panels. Guidance null-flux coils are placed over the propulsion coils which are arranged in one or even two overlapping layers to reduce the external electromagnetic disturbances influencing the SCMs mounted sequentially around the outer surface of the rotating module. Each pair of facing eight-shaped coils can be cross-connected by null-flux cable under the guideway constituting a loop as it is shown in Fig. 2. This concept includes high guidance-to-drag ratios and very low magnetic drag at low speed. The null flux decreases a lot power losses in the guideway provoked by the induced currents in metal loops. The null flux coils enable strong and fast acting trajectory control forces being inherently and passively stable. They must have high mechanical strength to bear magnetic forces and to be made of wound aluminium conductors molded out of unsaturated polyester resin reinforced with glass fiber and be electrical insulated.

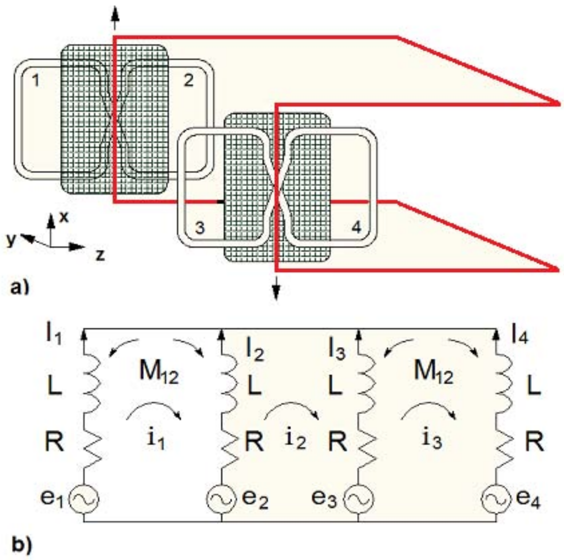

Figure 2. Cross-connected null-flux coils. a)Facing pair of figure-eight-shaped coils cross-connected by null-flux cable constituting a loop. b)Equivalent electrical circuit.

The rotating module is guided and driven by superconducting coils (blue colored in Fig. 1 and Fig. 3) mounted sequentially around the inner surface of the rotating generator characterized by a strong magnetic field which enable larger gap between the rotating module and the rotation generator. The choice of operating gap in space is a design decision. Larger gaps improve safety. The dynamic circuit theory could be extended for nonflat and curved SCMs and coils. Although the null-flux coils and SCMs are usually flat, taking in account the circular path, use of slightly curved gradient coils would allow instantaneous adaptation to changes in the circular trajectory to benefit the electromagnetic fields interactions and the rotation itself. SCMs are not complicated to construct nor operate. They can conduct electricity even after the power supply has been shut off. Magnetic fields induced by SCMs are strong and with serious effects on humans.

Their penetration into interior of a habitat must be limited with electromagnetic shields. The guidance subsystem enables stable radial and axial centering, being high-precision and self-aligning system. Variations from centered position will push the rotating module back to the designed optimal position without any active electronic stabilization.

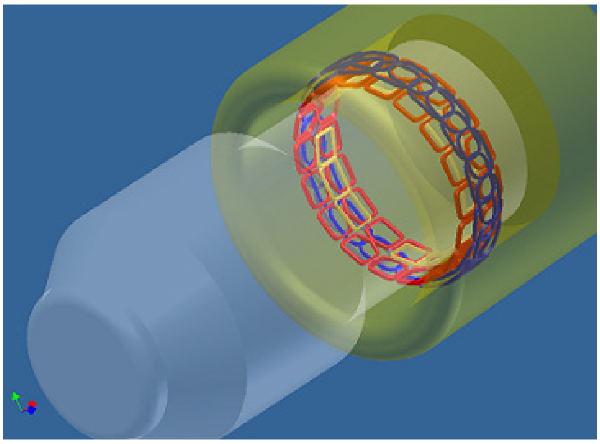

Figure 3. Arrangement of the coils and SCMs in the unified rotation & trajectory control system.

2.2 Propulsion

The SCMs suited on the propelled module will spin in a field created by ring of propulsion magnets suited on the rotation generator guideway, made of superconducting coils and energized by a three phase alternating current creating a shifting magnetic field. Alternating current is generating a traveling magnetic field which moves the rotating module without any contact. The on-board SCMs are attracted and pushed by the shifting field, propelling the rotating module. They are direct current magnets and their fields do not vary with time. Propulsion is achieved when the two magnetic fields are synchronized and locked among themselves. As a result, rotation rate is proportional to the input frequency of the alternating current. A force that pulls the rotation forward is produced by the excitation current in the SCMs and the magnetic field induced by the propulsion magnets. Propulsion forces can be controlled by changing the magnitude and the phase angle of armature. Magnetic polarity (magnetic field direction) of the SCMs alternates along the module. The guideway loops experience an alternating wave of magnetic flux as the rotating module moves. Downwards magnetic flux is followed by upwards flux, then by downwards flux, etc. Propulsion can be described as "pull-neutral-push". The only clearances to be controlled are between the rotating module and the rotation generator.

The propulsion coils are wound aluminium conductors molded out of epoxy resin being electrically insulated and mechanically strong as they have to persist simultaneously the reaction force of propulsion and high voltage. Undesirable vibrations of the SCMs caused by the magnetic field's change from propulsion coils and the magnetic drag, can be reduced by implantation of high voltage double-layered propulsion coils. The front and the back coils are different because their distances from the SCMs are different and it is necessary to adjust their numbers of windings. SCMs have been very improved recently making possible adoption of single layered propulsion coil structure with shorter coil length, simpler structure and easier installation being more cost-effective. Terminals along the rotation generator guideway and one-touch connectors can simplified the cable connecting.

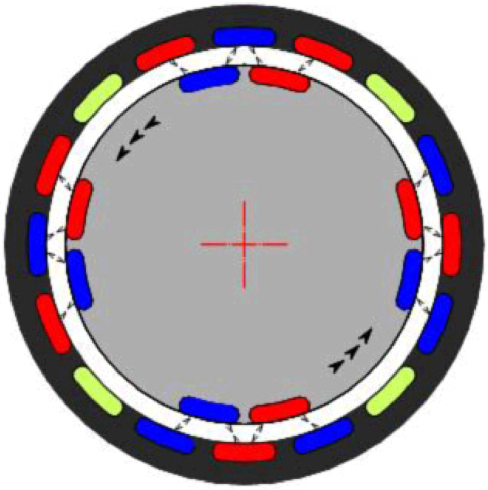

Figure 4. Rotating SCMs are attracted and pushed by the shifting field, propelling the rotating module.

2.3 Radial Centering

When the rotating module is displaced from the designed position and its rotation axis, the SCMs on the side that gets closer to the rotation generator guideway will have the same polarity as those on the top of the guideway. The repulsive forces between the two magnetic fields will push the rotating module from the guideway toward the designed position. The opposite set of the SCMs on the opposite side of the rotating module where the gap has increased, will have the opposite polarity then the facing ones on the top of the guideway. The attractive forces between the fields will pull the rotating module toward the designed position.

Electrodynamics employs magnets on the rotating module to induce currents in the guideway. As the rotating module moves over the coils, its SCMs create repulsive force forcing the module to float above the guideway. Resulting repulsive force produces inherently stable support and guidance because the magnetic repulsion increases as the gap between the rotating module and the rotation generator guideway decreases. At the same time will be induced attractive forces from the coils in corresponding loops. The farther the module moves from the projected rotation axis, the stronger will be the induced repulsive and attractive forces bringing it back, as it is shown in Fig. 5. Induced magnetic forces over the rotating SCMs are directed toward the center of the rotation tending to be completely equilibrated, generating radial centering of the rotating module in the same axis with the axis of the rotation generator. Mutual inductances between the null-flux coils and SCMs are time-dependent and space-dependent so equations can be developed on the basis of harmonic approximation for simplified analytical expressions. In a stable system, any variation from its stable position will push it back to the designed optimal position. The system is stable and it does not need active electronic stabilization. The radial gap between the rotating module and the rotation generator could reach 30 cm, much bigger then the maximum gaps on the Earth that are 15-18 cm large.

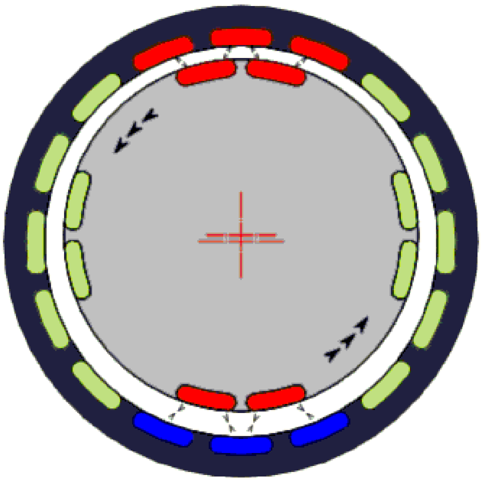

Figure 5. Repulsive and atractive forces between two magnetic fields keep the rotating module centered.

2.4 Axial Centering

Electro-magnetically propelled rotating module is able to remain centered over designed trajectory on the electro-magnetic guideway thanks to a combination of attraction and repulsion forces. Guidance or steering is possible thanks to the sideward forces that guide the rotating module to follow designed circular path. When the rotating module is in the straight position, no current flows. If it leaves the straight position, it creates a changing flux that generates a field that pushes it back into the line as it is shown in Fig. 6. When running SCM slightly displace laterally from the center of the eight-shaped null-flux coil, within the coil is induced electric current temporarily acting as electromagnet. Electric current induced in the loop results in repulsive forces acting on the coils on the nearer side and attractive forces acting on the coils on the side farther apart. The repulsive forces are pushing the SCM toward the straight position and the rotating module toward the desired path while attractive forces are pulling it toward at the same time. Current is induced by Lenz law to restore position of the moving SCM to nearly its midline position because the current that flows in that coil opposes or eliminates any flux change within the coil, also known as flux eliminating coil. This can be described as magnet spring constant that is equal to the slope so, the rotating module always keeps rotating over the path determined by the centers of the null-flux coils.

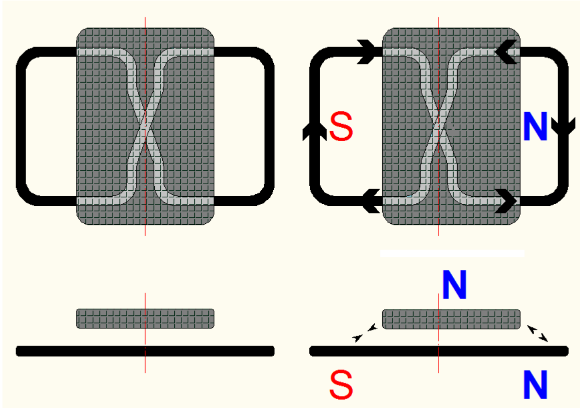

Figure 6. Rotating module remains centered over designed path due to attraction and repulsion forces between null-flux coils and displaced SCM.

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2.5 Design Varieties

It is possible to develop three different designs of the electrodynamic rotation generator. The described configuration shown in Fig. 1 and Fig. 3. is of the radial thrust rotation generator. Axial thrust rotation generator includes cross-connected eight-shaped null-flux coils and propulsion coils suited on the both circular walls of the rotation generator and SCMs suited on the both faces of the cylindrical-shaped rotating module as shown in Fig. 7. Combined axial-radial thrust rotation generator combines the both concepts.

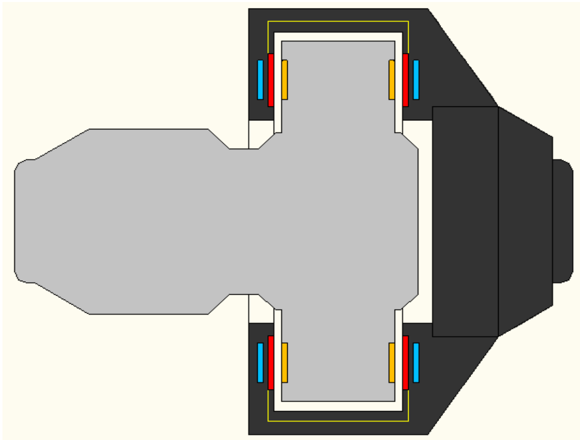

Figure 7. Electrodynamic axial thrust rotation generator.

All these concepts can be applied for ring-shaped rotating modules suited inside space habitats. Internal rotating modules would be suitable for a great variety of experiments and for greenhouse for space agriculture applying high pressure sodium (HPS) lights and humidifiers for indoor plant cultivation. Centripetal forces push the soil towards the inside hull of the module. HPS lights provide high photosynthetic efficiency during the entire life cycle of plants increasing their yield and vitality. Fig. 8 shows axial thrust rotating greenhouse with HPS lights which rotates inside the habitat without being obstacle for the crew.

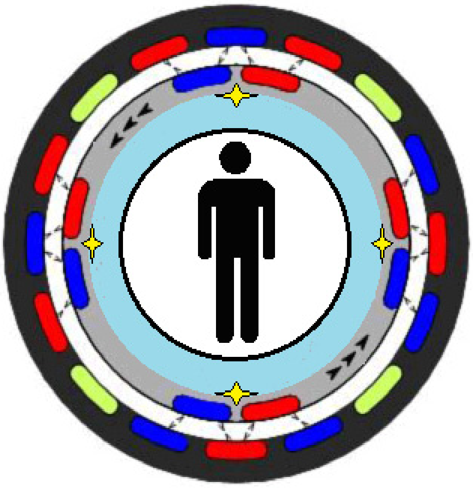

Figure 8. Inner axial thrust rotating greenhouse.

3 ELECTRODYNAMIC GENERATOR OF GRAVITY SENSATION

Electrodynamic gravity generator (EDGG) consists of: rotation generator, rotating module, docking module, rotating habitats, columns, energy supply system and command & control systems. Electrodynamic rotation generator is unified propulsion and guidance subsystem that consists of the rotation generator and the rotating module. They generate travelling electromagnetic fields which spin the rotating module that transmits generated rotation to a rotating habitats on which inside hulls is to be generated general gravity sensation.

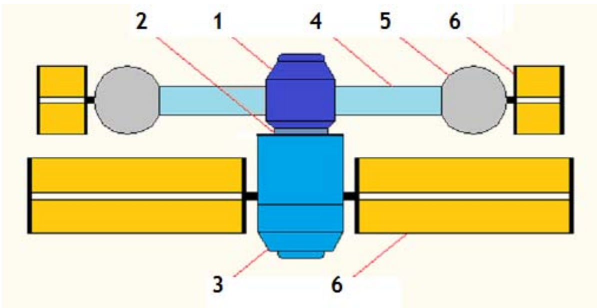

Figure 9. Radial thrust EDGG basic structure: 1 – Docking module. 2 – Rotating module. 3 – Rotation generator. 4 – Column. 5 – Habitat. 6 – Solar panels.

3.1 Design Considerations

Gravity generation in a wheel-shaped artificial gravity generator is gradual, starting from zero and ending with designed gravity levels which can be easily adjustable by change of rotation speed by change of AC frequency. Centripetal acceleration depends only on the angular velocity of the rotating object and the radial distance between the rotation axis and the rotating habitats. EDGG is light and low-speed electrodynamic system. Rotation induced by traveling magnetic fields will be completely contactless and frictionless. Magnetic drag is very low at low speed. It will not produce oscillations in the non-rotating parts nor there will be internal frictions nor energy dissipations. It will be high-precision system able to provide stable rotation. Continious rotation will complicate extra-vehicular activities and docking requiring de-spinning and provoking lost of generated gravitation. This can be avoided by integration of the docking module and the propulsed rotating module. The docking module carries the columns with habitat modules on their ends communicated by electrical elevator suited in inner space of a columns made as lattice structures or hollow compact structures. Longer columns improve gravity sensation at the same rotation rate, removing the habitats away from the electromagnetic fields. Being complex and massive, EDGG must be modular, made of highly integrated lightweight modules. Aluminium, fiber reinforced plastics, titanium and its alloys are appropriate to be applied. Rotating habitats would be fixed on the ends of the columns or jointed to form wheel-shaped structure, being aluminium-can type or inflatable modules.

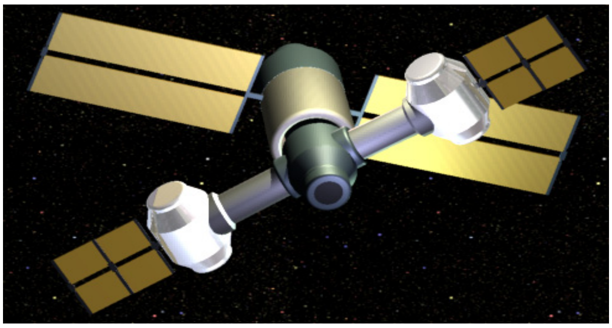

Figure 10. Simplified EDGG configuration.

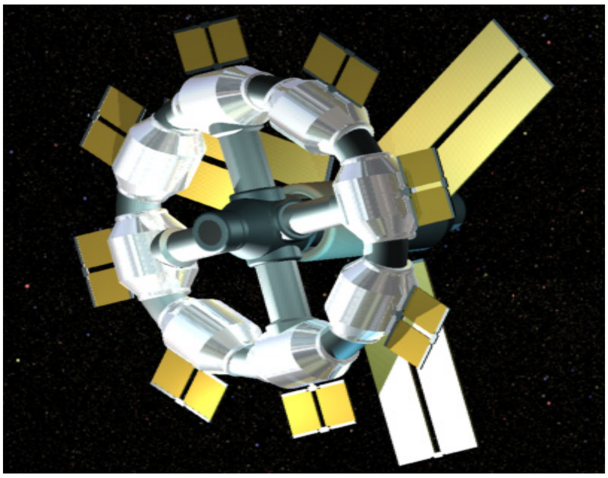

Figure 11. Wheel-shaped EDGG configuration.

Both, the central rotating module and the rotation generator are to be equipped with propulsion units for maneuvering, especially needed for high-precision maneuvers in the assembly phase. It is necessary to design an emergency system for a case of total power cut off or a deliberate rotation abort, in order to prevent separation of the rotating module and the rotation generator. This can be managed by a set of swing or linear arms delimiters made of permanent magnets, radially suited in the entrance of the rotation generator module and manipulated by power packs with autonomous batteries. As there is no way to fix the non-rotating rotation generator in free space, there are going to occur phase angles between it and the rotating module caused by relative motion among them induced by magnetic forces and traveling magnetic fields. This can be controlled by a kind of compensator of induced phase angle or by simple adjustment of frequency of alternating current to recuperate and harmonize the rotation in accordance with desired rates of rotation.

Comfortable artificial gravity sensation environment is determined by four parameters:
- Centripetal acceleration: 0,3•g - 1,0•g.
- Min. radius: 12 m.
- Maximum rotation rate: 3 - 6 rpm.
- Min. tangential velocity: 10 m/s equal to 36 km/h.

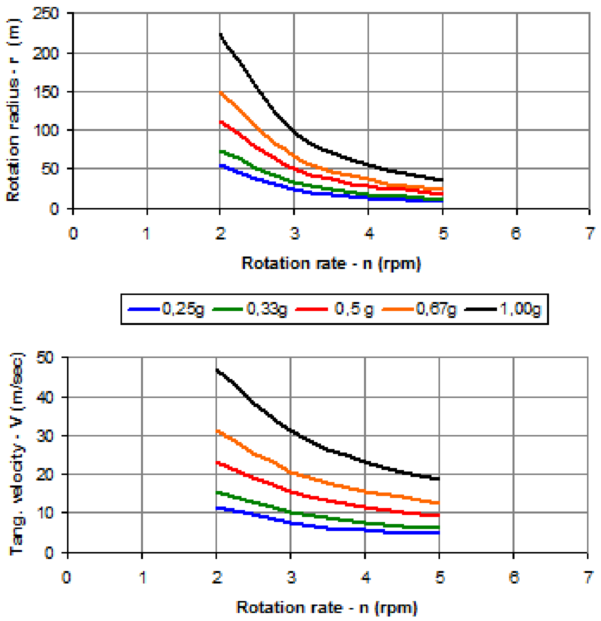

Figure 12. Tangential velocity and rotation radius in function of rotation rate.

3.2 Energy Requirments and Supply

Photovoltaic solar panels and arrays can generate electricity for propulsion, acceleration and stabilization of EDGG as well as for: communication and telemetry systems, air condition system, sensors, heat system, light and others systems. EDGG will have reduced power consumption and increased efficiency in the space conditions. Gravity sensation will be generated by low speed uniform rotation. Power supply system consists of: solar panels and arrays, batteries and charge controllers, DC/AC inverters, DC/DC converters, electrical transformers and rectifiers, mountings, trackers and wiring. Solar panels can be attached to the rotating module and the rotation generator, separately. Also, rotating module can be wireless powered by power transmission through magnetic resonance between primary resonator of transmitter located in the rotation generator and secondary resonator of receiver located in the rotating module. Uninterrupted power supply can be achieved by rechargeable batteries and inverters. Hydrogen fuel cells can be used as complementary energy source. Liquid hydrogen and oxygen don't require cryogenic storage in space.

4 CONCLUSIONS

Employing electrodynamic technologies in the space favourable conditions could result in development of new critical technologies for design of space habitats. First, although small steps, could be made by making smaller and cost-effective artificial gravity generators, at least for therapeutic dose of gravity. Well equipped with scientific equipment, artificial gravity generators could offer conditions for a big variety of experiments over behaviour of objects, liquids, humans, animals and plants. The emergence of space tourism could impulse realization of an orbital space settlement. Artificial gravity would enable food production, taking advantage of extraordinary conditions in space. Electrodynamic gravity sensation generators life support systems would enable exploration and colonization of deep space.

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