

# Brushless non-steel HTS generator with combined excitation with trapped field plates on the rotor

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## Introduction

Currently, the world pays close attention to high-speed electric machines, which have high mass-dimensional parameters. These machines should consist of a high strength rotor rotating at high peripheral speed.

One type of such electrical machines is an inductor generator, which consists of a rotor, fixed on a shaft by a ferromagnetic sleeve, having explicit tooth surface. Main disadvantage of such generators is an enlarged section of the magnetic circuit both for the alternating and permanent components of the magnetic flux, and as a consequence, the low value of utilization factor  $K_{ut}=0,5 \times (1 - \Phi_{min} / \Phi_{max}) = 0,3 \dots 0,4$ . Here  $\Phi_{min}$  — is a minimum flux at rotor's slots,  $\Phi_{max}$  — is a maximum flux at rotor's teeth. The design of inductor generators with high temperature superconducting (HTS) at the rotor, which allows improving the use factor up to 0,5 due to the diamagnetic properties of the HTS materials between rotor teeth, was proposed by MAI. Experiments show that (in addition to diamagnetic properties) HTS materials can be magnetized ("capture" the magnetic fields, co-cooled "trapped-field" regime) up to 0,5 T at temperatures of liquid nitrogen.

## Design

This report is devoted to creation of new types of electrical machines: **semi-inductor non-steel HTS generators with combined excitation**. This type of electrical generator combines the advantage of inductor generator and generators with permanent magnets. Moreover, HTS-magnet instead of conventional rare earth permanent magnet will allow to increasing the range of magnetic flux density, which depends on the available cryogenic temperature.

Based on the analysis of possible variants, the authors propose a design of HTS generator with a round field coil on the stator, intended both to generate axial magnetic flux and to magnetize the composite HTS sheets or bulk HTS materials. This coil can be made from copper, aluminum, hyperconducting and superconducting wires. It depends on the contribution of trapped and excited fields. The armature winding can also be prepared from different types of wires. However, in recent time the use of superconducting wires is limited due to losses at high frequencies and also high permissible bending radii of the wires, which increase the sizes and reduces the allowable centrifugal stress.

The disk design was chosen for three reasons:

- 1) a lack of magnetization reversal of HTS materials.
- 2) an opportunity of the air gap adjustment.
- 3) a simplicity of production of the composite rotor and the round stator coil.

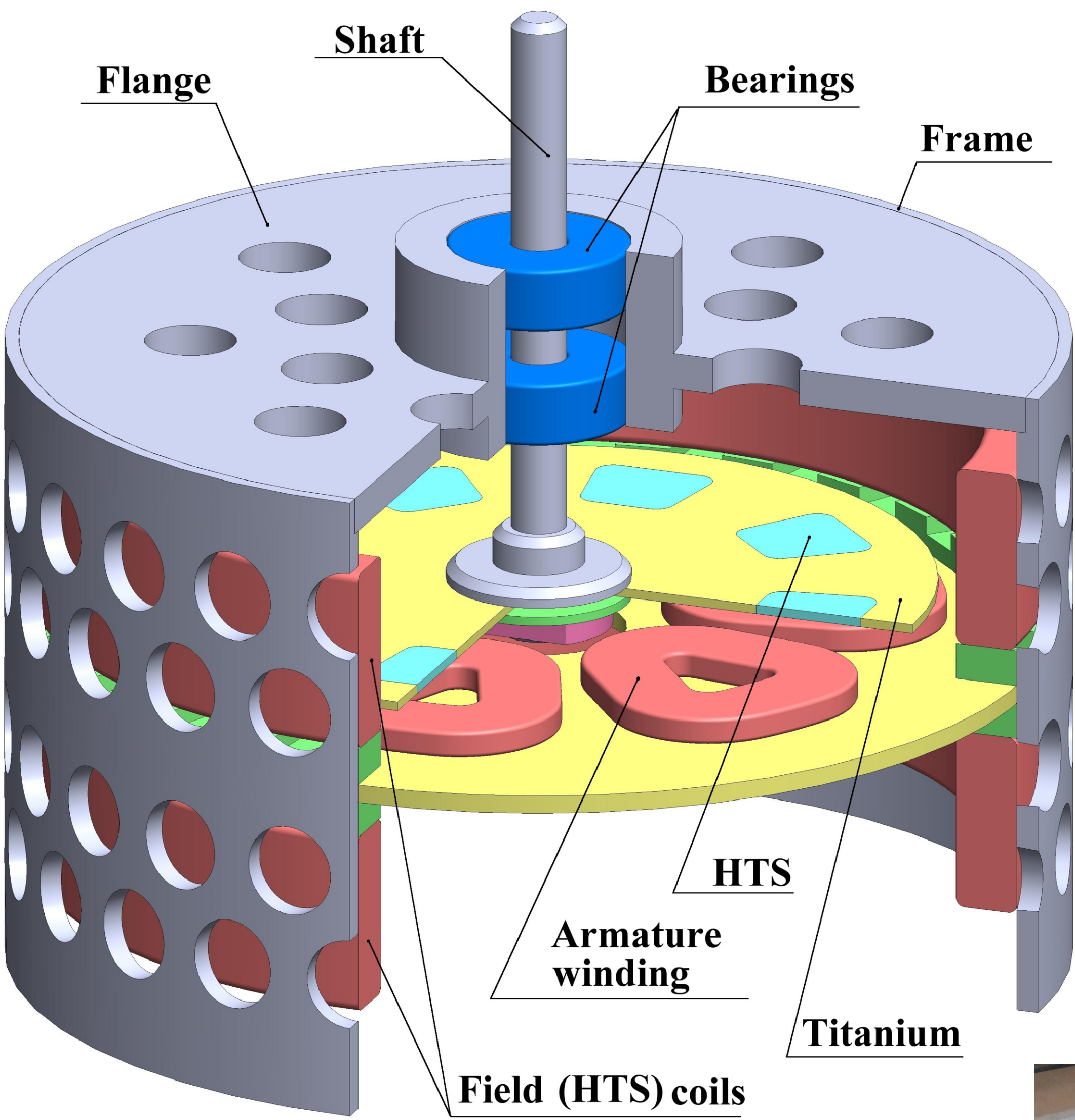
In addition, the disk design allows to significantly increasing the mechanical strength of the rotor, since the bandage is outside of the air gap.

Distinctive features of this machine are: a lack of ferromagnetic materials in the active zone of the machine and a location all of the windings on the stator. Such design allows increasing the flux linearly, depending on the current in the exciting coil. Moreover, the thick bandage may have a better ratio strength/density. For example: titanium or carbon instead of usual steel.

The proposed HTS machine can be operated in motor regime. Besides, the starting mode is possible without a frequency converter, since the rotor will accelerate due to the hysteresis torque up to synchronous speed.

The future application for multi-disk design of the proposed construction are discussed.

## Model of iron-free rotating machine with all of winding on stator

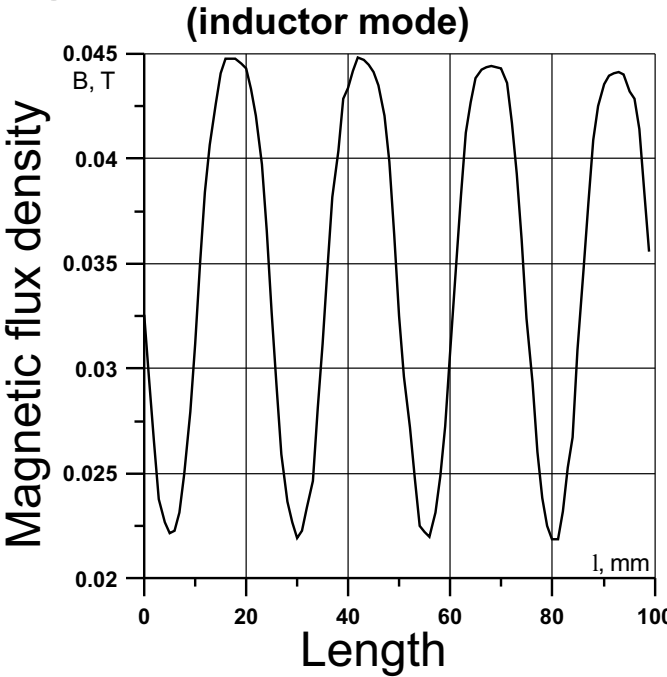


## How does it work?

The principle of operation is based on Faraday's law. The magnetic field modulation is formed by regular alternation of non-magnetic and diamagnetic HTS elements. EMF depends on both different permeability of rotor's elements and magnetization of HTS plates.

- There are 3 regimes:
- 1) inductor mode (with current in the field coil);
  - 2) "trapped-field" mode (without current);
  - 3) combined mode (with low current).

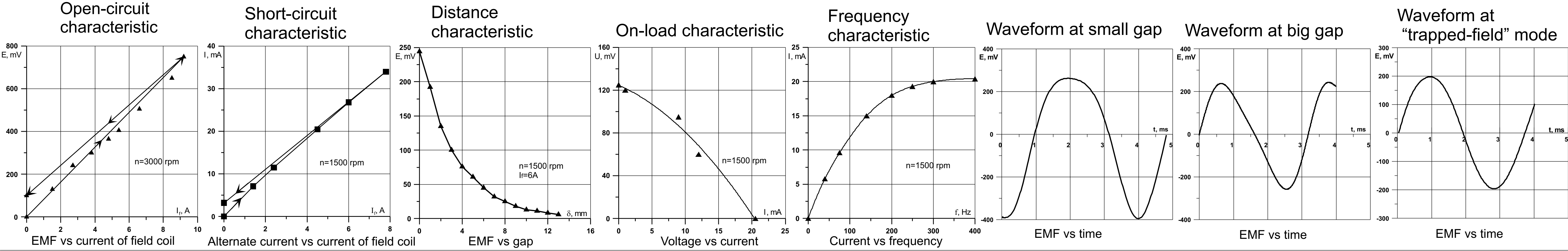
### Magnetic field simulation



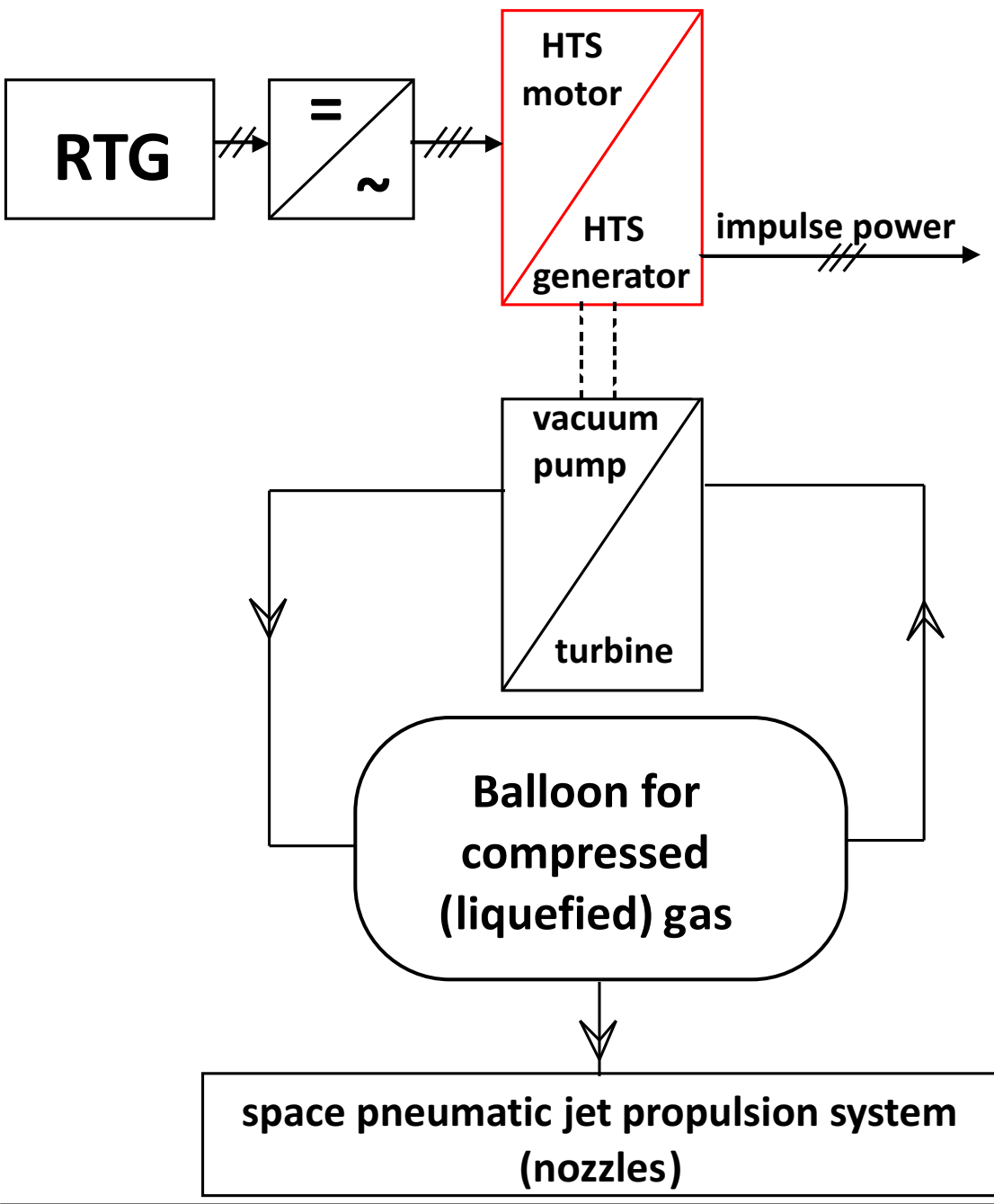
### Test bench



## Test results



## Space application



The main possible application is a power supply with high current frequency ( $f=4$  kHz at  $n=30000$  rpm) for cryogenic electrical systems and for energy storage devices, which have both mechanical and pneumatic type.

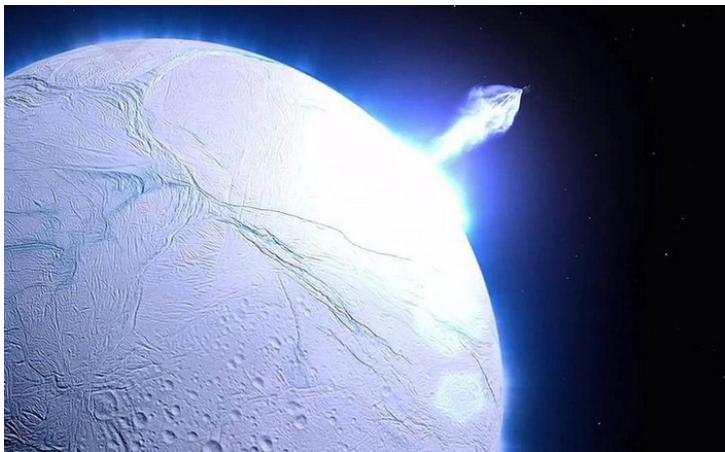
This type of electrical machine can work also in drive mode as a compressor or a vacuum turbomolecular pump in pneumatic systems on board of the spacecraft exploring remote space bodies with a rarefied cryogenic atmosphere, such as Triton ( $T_{av}=36K$ ), Pluto ( $R_{sur}=50K$ , on the surface of the planet) and Enceladus ( $T_{av}=75K$ ).

### Triton



( $T_{av}=36K$ )

### Enceladus



( $T_{av}=75K$ )

### Pluto



( $T_{av}=50K$ )



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