



(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:  
**13.09.2023 Bulletin 2023/37**

(51) International Patent Classification (IPC):  
**H05H 1/54 (2006.01) F03H 1/00 (2006.01)**

(21) Application number: **23159635.4**

(52) Cooperative Patent Classification (CPC):  
**H05H 1/54; F03H 1/0012; F03H 1/0075**

(22) Date of filing: **02.03.2023**

(84) Designated Contracting States:  
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB  
GR HR HU IE IS IT LI LT LU LV MC ME MK MT NL  
NO PL PT RO RS SE SI SK SM TR**  
Designated Extension States:  
**BA**  
Designated Validation States:  
**KH MA MD TN**

- **Andrenucci, Mariano**  
**CARRARA (IT)**
- **Ferrato, Eugenio**  
**CECINA (IT)**
- **Piragino, Antonio**  
**MORMANNO (IT)**
- **Cifali, Gianluca**  
**CALCINAIA (IT)**
- **Leporini, Andrea**  
**PONTEDERA (IT)**
- **Paissoni, Christopher Andrea**  
**LIVORNO (IT)**
- **Kitaeva, Alena**  
**PISA (IT)**

(30) Priority: **08.03.2022 IT 202200004391**

(71) Applicant: **Sitael S.p.A.**  
**70042 Mola di Bari (BA) (IT)**

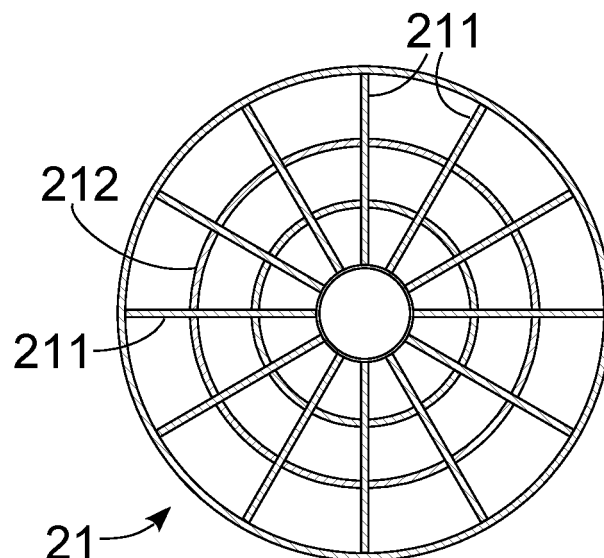
(72) Inventors:  
• **Andreussi, Tommaso**  
**PISA (IT)**  
• **Giannetti, Vittorio**  
**LIVORNO (IT)**

(74) Representative: **Lunati & Mazzoni S.r.L.**  
**Via Carlo Pisacane, 36**  
**20129 Milano (IT)**

(54) **ELECTRIC THRUSTER**

(57) It is presented an electric thruster (1) comprising an inlet conduit (2) defining an inlet section (1b) of atmospheric gas; an expulsion section (1c) of atmospheric gas from said electric thruster (1); an ioniser (3) configured to generate a first magnetic field and an accelerator

(4) configured to generate a second magnetic field; and an assembly (5) generating a stream of electrons which, by interacting with said magnetic fields, ionises and accelerates the atmospheric gas defining the thrust of said electric thruster.



**Fig. 2**

## Description

**[0001]** The present invention relates to an electric thruster of the type specified in the preamble to the first claim.

**[0002]** In particular, the invention introduces a thruster, or rather a propeller that uses atmospheric gas as a propellant and which, by means of ionised gaseous masses (plasma) accelerated by an electromagnetic field, defines a propulsive action usually used to keep a satellite, rocket or other vehicle in orbit at a given altitude (and in detail control its motion or advancement).

**[0003]** As is well known, low Earth orbit is populated by rockets and specialised propulsion vehicles such as scramjets and their combinations with rocket propeller. The conventional space vehicles must operate well above an altitude of 250 km to avoid re-entry induced by atmospheric drag, while at altitudes above 30 km, conventional aircraft cannot operate due to the lack of lift associated with low pressure and the shortage of oxygen at those altitudes, which is insufficient for classical combustion processes.

**[0004]** The vehicles travelling in low Earth orbit (250 to 2000 km altitude) typically use chemical (rockets) or electric propulsion systems, such as Hall-type plasma propellers, to generate the thrust required for on-orbit manoeuvres and repositioning. These endo-reactors use a propellant stored on board and thus have an operational life limited precisely by the amount of propellant.

**[0005]** A typical propulsion system based on a Hall endo-reactor of the Anterior Technique includes a propellant storage and supply system, an exhaust chamber, an external electron-emitting cathode, an anode inside the exhaust chamber that attracts electrons, a magnetic circuit to create a predominantly radial magnetic field, and an electric circuit that generates an axial electric field at the exit of the exhaust chamber. The magnetic field opposes the flow of electrons from the emitting cathode to the anode. The propellant particles, typically xenon, are introduced into the exhaust chamber and collide with these electrons, thus generating positive ions. These ions are accelerated and ejected from the exhaust chamber due to the axial electric field and generate thrust.

**[0006]** The known technique described includes some major drawbacks.

**[0007]** In particular, the well-known endo-reactors are difficult to apply in a vehicle, especially if it has to remain for long periods in a very low Earth orbit (below 250 km altitude) or in similar orbital regions of other celestial bodies due to the need to store a sufficient amount of propellant on board the vehicle to counter atmospheric resistance.

**[0008]** The need to provide an on-board propellant tank results in an increase in mass, volume and, consequently, the external surface area of the vehicle, causing greater resistance.

**[0009]** The increase in mass also means a heavier load for the launcher and an increase in consumption to per-

form orbital manoeuvres.

**[0010]** It shows how the need for propellant use and especially propellant management result in high costs for the well-known plasma endo-reactors, an increase in weight and an increase in frontal area, which causes them to be more resistant.

**[0011]** Other drawbacks are to be found in the high construction complexity and thus high costs of the well-known endo-reactors and on-board propellant management systems.

**[0012]** In this situation, the technical task at the heart of the present invention is to devise an electric thruster that can substantially obviate at least some of the aforementioned drawbacks.

**[0013]** In the context of this technical task, it is an important aim of the invention to obtain an electric thruster that is easily applicable to a vehicle operating in a very low orbit for long periods without imposing excessive costs and weight.

**[0014]** Another important aim of the invention is to obtain an electric thruster of simple construction and thus reduced costs.

**[0015]** The specified technical task and purposes are achieved by an electric thruster as claimed in the attached claim 1. Examples of preferred implementations are described in the dependent claims.

**[0016]** The features and advantages of the invention are clarified below by a detailed description of preferred embodiments of the invention, with reference to the accompanying drawings, in which

the **Fig. 1** shows, to scale and in sagittal section, an electric thruster according to the invention;

the **Fig. 2** shows, to scale and in cross-section, a possible realisation of the gas inlet conduit in the thruster

the **Fig. 3** shows, to scale, a first group of components according to claim 1, and highlights the lines of the aforementioned magnetic field;

the **Fig. 4** shows, to scale, a second group of components according to claim 1; and

the **Fig. 5** presents the schematic operation of the thruster.

**[0017]** In the present document, the measurements, values, shapes and geometric references (such as perpendicularity and parallelism), when associated with words like "about" or other similar terms such as "approximately" or "substantially", are to be considered as except for measurement errors or inaccuracies due to production and/or manufacturing errors, and, above all, except for a slight divergence from the value, measurements, shape, or geometric reference with which it is associated. For instance, these terms, if associated with a value, preferably indicate a divergence of not more than 10% of the value.

**[0018]** Moreover, when used, terms such as "first", "second", "higher", "lower", "main" and "secondary" do

not necessarily identify an order, a priority of relationship or a relative position, but can simply be used to clearly distinguish between their different components.

**[0019]** The measurements and data reported in this text are to be considered, unless otherwise indicated, as performed in the International Standard Atmosphere ICAO (ISO 2533:1975).

**[0020]** Unless otherwise specified, as results in the following discussions, terms such as "treatment", "computing", "determination", "calculation", or similar, refer to the action and/or processes of a computer or similar electronic calculation device that manipulates and/or transforms data represented as physical, such as electronic quantities of registers of a computer system and/or memories in, other data similarly represented as physical quantities within computer systems, registers or other storage, transmission or information displaying devices.

**[0021]** With reference to the Figures, the electric thruster according to the invention is globally referred to as number 1.

**[0022]** The thruster 1 can be configured to generate a propulsive action by accelerating ionised gases. It is configured to be used as a propeller for a spacecraft such as a satellite, rocket or other space vehicle or space platform.

**[0023]** The spacecraft can therefore comprise at least one electric thruster 1 and optionally at least one additional endo-reactor, configured to, for example, move the spacecraft in ascent and/or descent.

**[0024]** Preferably, the spacecraft and thus the electric thruster 1 can be configured to fly in an orbit around a planet such as Earth.

**[0025]** In detail, the electric thruster 1 can be configured to operate with atmospheric gas (hereinafter simply referred to as gas) appropriately having a minimum density substantially at least equal to  $1 \times 10^5$  particles/m<sup>3</sup> more in detail to  $1 \times 10^{10}$  particles/m<sup>3</sup> more in detail to  $1 \times 10^{15}$  particles/m<sup>3</sup> and to a precision substantially between  $1 \times 10^{15}$  particles/m<sup>3</sup> and  $4 \times 10^{15}$  particles/m<sup>3</sup>.

**[0026]** It should be noted that the expression atmospheric gas identifies, as is well known, the gas envelope that covers a celestial body such as a planet.

**[0027]** The minimum density identifies the minimum value of gas density required to guarantee the operation of the electric thruster 1. It can therefore work with gases having a density greater than this minimum density.

**[0028]** In the case of Electric thruster 1 operating in earth orbit, it is configured to operate at an altitude substantially lower than 400 km, and to be precise substantially between 120 km and 250 km.

**[0029]** The electric thruster 1 may define a longitudinal axis 1a preferably configured to fly parallel to the forward direction of the electric thruster 1 and thus the spacecraft. The gas flows through the electric thruster 1 defining a flow moving predominantly along the longitudinal axis 1a.

**[0030]** The longitudinal axis 1a can be substantially barycentric to the electric thruster 1.

**[0031]** It should be noted that in this document terms

identifying a relative positioning between two components (such as downstream, upstream, interposed) are to be understood in accordance with the direction of the gas flow. Furthermore, terms such as axial, radial or angular define directions/trajectories/forces respectively nearly parallel to axis 1a, substantially perpendicular to axis 1a and substantially circular centred on longitudinal axis 1a.

**[0032]** The electric thruster 1 may comprise an inlet section 1b of gas into the thruster 1 and an expulsion section 1c of gas from the thruster 1.

**[0033]** The thruster 1 may include a gas inlet conduit 2 in electrical thruster 1.

**[0034]** The inlet conduit 2 can define inlet section 1b.

**[0035]** The inlet conduit 2 can develop along the longitudinal axis 1a.

**[0036]** It can be of constant cross-section or alternatively tapered with an inlet section 1b of maximum extension.

**[0037]** The inlet conduit 2 may include a tubular body 21.

**[0038]** The tubular body 21 can develop along the longitudinal axis 1a.

**[0039]** The tubular body 21, as shown in the section of Fig. 2, can be subdivided into gas flow channels having a ratio of channel length to hydraulic diameter substantially greater than 1 in detail of 10 and appropriately of 50.

**[0040]** It may therefore comprise at least one radial wall 211 running parallel to said longitudinal axis 1a; and/or at least one partition 212 dividing the tubular body 21 into annular sections.

**[0041]** Said at least one partition 212 may extend the full extent of the tubular body 21 along the longitudinal axis 1a.

**[0042]** The tubular body 21 may comprise several suitably radially spaced 212 dividers. Preferably, the tubular body 21 comprises several walls 211 suitably spaced at equal angles.

**[0043]** Each wall 211 may extend the full extent of the tubular body 21 along the longitudinal axis 1a.

**[0044]** Each combination of partitions 212 and walls 211 may define a cylindrical conduit suitably radially spaced from the other cylindrical conduits. Alternatively, each combination of partitions 212 and walls 211 may define a hexagonal conduit suitably radially spaced from the other hexagonal conduits. In some non-limiting examples, the tubular body 21 may thus have a honeycomb cross-section or as presented in Fig. 2.

**[0045]** The inlet conduit 2 may include a compartment 22 for collecting the gas entering the electric thruster 1 and in detail exiting the tubular body 21.

**[0046]** The compartment 22 can be interposed between the tubular body 21 and the rest of the electric thruster 1.

**[0047]** The compartment 22 may extend along the longitudinal axis 1a with a suitably tapered section. It may define an inlet section of the gaseous flow into the compartment 22 facing the tubular body 21 and an outlet sec-

tion of gas from the compartment 22 facing the rest of the thruster 1 and of smaller extension than the inlet section.

**[0048]** The inlet section of compartment 22 can be equal to that of tubular body 21.

**[0049]** The compartment 22 may be devoid of walls or other dividing elements in the volume bounded by the compartment.

**[0050]** The inlet conduit 2 can be free of coils or ferromagnetic materials.

**[0051]** The electric thruster 1 may comprise -downstream of the inlet conduit- an ioniser **3** configured to ionise at least part of the atmospheric gas entering the thruster 1 by defining an ionised fraction of said atmospheric gas, and an accelerator **4** configured to accelerate at least said ionised fraction towards the outlet section 1c generating a thrust for the electric thruster 1 (and therefore for the space vehicle) and suitably leaving at least part of the non-ionised atmospheric gas in the inlet conduit 2 and in particular in the compartment 22.

**[0052]** The ioniser 3 can be upstream of accelerator 4.

**[0053]** The ioniser 3 can define an ionisation chamber **3a** downstream of duct 2, in particular compartment 22.

**[0054]** The ionisation chamber 3a can be annular and have a decreasing monotonic cross-section, with the inlet cross-section from the chamber 22 maximum, and the outlet cross-section to the accelerator 4 minimum.

**[0055]** The accelerator 4 can define an acceleration chamber **4a** downstream of ionisation chamber 3a.

**[0056]** The acceleration chamber 4a can be annular and have a substantially constant cross-section.

**[0057]** The acceleration chamber 4a can define, in its distal part from the ionisation chamber 3a, essentially the expulsion section 1c.

**[0058]** In this document, the terms chamber and compartment identify a free internal space delimited by the same thruster 1.

**[0059]** The ioniser 3 is configured to generate a first magnetic field suitably poloidal and more suitably angularly substantially constant with respect to the longitudinal axis 1a. The magnetic field, as can be seen from the Fig. 3, can thus be variable exclusively along or radially to said longitudinal axis 1a.

**[0060]** Said first magnetic field is present at least in ionisation chamber 3a and appropriately at least in the portion of conduit 2 (in detail compartment 22) adjacent to said chamber 3a.

**[0061]** The ioniser 3 may comprise a central magnet **31** housed in said ionisation chamber 3a and at least a first side magnet **32** located at the first side wall of the ionisation chamber 3a and more suitably a second side magnet **33** located at the second side wall of the ionisation chamber 3a.

**[0062]** The first side wall identifies the wall of the ionisation chamber 3a lateral, internal (i.e. facing chamber 3a) and proximal to axis 1a, while the second side wall identifies the wall of the ionisation chamber 3a lateral, external and distal to axis 1a.

**[0063]** The central magnet 31 can comprise a coil appropriately axis 1a.

**[0064]** It may be toroidal preferably comprising a first face parallel to the first side wall and a second face parallel to the second side wall.

**[0065]** The central magnet 31 may have substantially less axial extension than at least one side magnet 32 and/or 33.

**[0066]** In this document, the term axial identifies a direction, a length, an extension along the longitudinal axis 1a.

**[0067]** The side magnets 32 and 33 can have essentially the same axial extension.

**[0068]** They may be concentric with respect to the longitudinal axis 1a.

**[0069]** The side magnets 32 and 33 are on opposite sides of the central magnet 31.

**[0070]** The first side magnet 32 may comprise a coil appropriately axis the longitudinal axis 1a.

**[0071]** The second side magnet 33 may comprise a coil whose axis is appropriately the longitudinal axis 1a.

**[0072]** The magnets in ioniser 3 generate a first magnetic field whose field lines are closed and surround the central magnet 31.

**[0073]** Said closed lines are preferably partially entering the inlet conduit 2 and more precisely in the compartment 22 as shown in Fig. 3. Preferably the intensity of the first magnetic field of the ioniser 3 is at least 5 mT and in detail substantially between 5 mT and 100 mT and more precisely between 10 mT and 50 mT.

**[0074]** The accelerator 4 can generate a second magnetic field interacting with the first magnetic field emitted by ioniser 3, thus defining a magnetic field resulting from the sum of these magnetic fields, which is characterised by having at least one zone of low magnetic intensity (and in detail at least one magnetic zero) at the boundary between chambers 3a and 4a, and to be precise in the zone of ionisation chamber 3a proximal to acceleration chamber 4a.

**[0075]** Appropriately, the resulting magnetic field has two low magnetic intensity zones between chambers 3a and 4a. Optionally, the two low magnetic intensity zones can overlap, defining a double magnetic zero.

**[0076]** The second magnetic field and thus the resulting magnetic field can protrude from the acceleration chamber 4a appropriately opposite the ionisation chamber 3a.

**[0077]** Fig. 3 shows the resulting magnetic field lines and in particular the closed lines representing the first and second magnetic fields.

**[0078]** The accelerator 4 may comprise an inner magnet **41** located at the first side wall of acceleration chamber 4a and an outer magnet **42** located at the second side wall of acceleration chamber 4a.

**[0079]** In this case, the first lateral wall of acceleration chamber 4a identifies the lateral wall, internal (i.e. facing chamber 4a) and proximal to axis 1a, while the second lateral wall of chamber 4a identifies the lateral wall, ex-

ternal and distal to axis 1a.

**[0080]** The inner 41 and outer 42 magnets can be toroidal, concentric and have essentially the same axial extension.

**[0081]** The inner magnet 41 may comprise a coil suitably of longitudinal axis 1a.

**[0082]** The outer magnet 42 may comprise a coil suitably of longitudinal axis 1a.

**[0083]** The accelerator 4 may comprise one or more ferromagnetic elements configured to channel/direct the magnetic field lines of Fig. 3 and in particular to obtain at least one low magnetic field zone (and in detail at least one magnetic zero) at the boundary between the chambers 3a and 4a. In particular, it comprises a first ferromagnetic element **43** at least partially surrounding the inner magnet 41 and a second ferromagnetic element **44** at least partially surrounding the outer magnet 42. Preferably, the inner magnets 41 and outer magnets 42 have only the face facing the acceleration chamber 4a not covered by said ferromagnetic elements 43 and 44.

**[0084]** The magnetic field generated in the acceleration chamber 4a may be predominantly radial. It may have a maximum radial intensity distal to the entrance section 1b, and in particular proximal to the expulsion section 1c.

**[0085]** The electric thruster 1 may comprise an assembly **5** generating an electric field that overlaps and interacts with the magnetic fields described above (Fig. 4).

**[0086]** The electric field defines a flow of electrons passing from the acceleration chamber 4a to the ionisation chamber 3a and at least partially entering a portion of the conduit 2 (in detail compartment 22) close to the ionisation chamber 3a. In particular, the assembly 5 generates an electron flow which is attracted towards the ionisation chamber 3a going to interact with at least part of said atmospheric gas ionising it and in detail defining said ionised fraction of atmospheric gas.

**[0087]** Said flow of electrons, when in the acceleration chamber 4a, is at least slowed down by the second magnetic field and moved, suitably orbitalised, along its lines, thus defining a concentration of electric field (i.e. electrons) in said second magnetic field zone; this concentration accelerates the ionised fraction of the atmospheric gas towards the outlet section 1c, thus generating a propulsive thrust for the electric thruster 1 and hence for the space vehicle.

**[0088]** The assembly 5 may comprise a negative electrode (cathode) **51** configured to generate a flow of electrons; and at least one positive electrode (anode) configured to attract said flow of electrons by conveying it to chambers 3a and 4a.

**[0089]** The negative electrode 51 can be external to chambers 3a and 4a.

**[0090]** It can be arranged along the longitudinal axis 1a.

**[0091]** The at least one positive electrode is in ionisation chamber 3a.

**[0092]** In particular, the assembly 5 comprises several

positive electrodes preferably having the same electrical potential. Preferably, it comprises a first positive electrode **52** placed on the first side wall of the ionisation chamber 3a; a second positive electrode **53** placed on the second side wall of the ionisation chamber 3a; and a third positive electrode **54** interposed between the central magnet 3a and the ionisation chamber 3a and to be precise at least partially enveloping in full detail the central magnet 31.

**[0093]** The first positive electrode 52 may lie between the ionisation chamber 3a and the first side magnet 32. It may be of conductive metallic material and have an annular shape with an axis 1a.

**[0094]** The second positive electrode 53 may lie between the ionisation chamber 3a and the second side magnet 33. It may be of conductive metallic material and have an annular shape with an axis 1a.

**[0095]** The third positive electrode 54 can be of conductive metal material placed all around the central magnet 31.

**[0096]** The first positive electrode 52 and the second positive electrode 53 are on opposite sides of the third positive electrode 54.

**[0097]** In some cases, the assembly 5 may additionally include at least one additional positive electrode **55**, appropriately only one, housed in chamber 4a.

**[0098]** The additional positive electrode 55 can be of conductive metal material.

**[0099]** It can be accommodated at the first side wall of acceleration chamber 4a.

**[0100]** The additional positive electrode 55 can be annular in shape, with axis 1a.

**[0101]** The additional positive electrode 55, as illustrated in Fig. 4, can be kept at a higher potential than the negative electrode 51.

**[0102]** Preferably, the one or more positive electrodes 52, 53 and/or 54, as illustrated in Fig. 4, can be maintained at the same electrical potential, with a positive potential difference (i.e. at a higher potential) with respect to both the negative electrode 51 and the possible additional positive electrode 55.

**[0103]** In their movement towards the positive electrodes 52, 53 and/or 54 and -if present-55, the electrons emitted by the negative electrode 51 are initially slowed down and redirected by the magnetic field lines of the accelerator 4, and follow a spiralling path first towards the possible additional positive electrode 55, and in any case towards the positive electrodes 52, 53 and/or 54, as illustrated in Fig. 5. The resistance generated by the magnetic field to the motion of the electrons causes the axial electric field of the accelerator 4 to be concentrated in the vicinity of the outlet section 1c.

**[0104]** The electrons that manage to overcome the magnetic field of accelerator 4 are then attracted to the positive electrodes 52, 53 and/or 54 in chamber 3a, the potential of these electrodes being higher than that of the possible additional positive electrode 55.

**[0105]** On reaching chamber 3a, the electrons are

again slowed down and redirected by the first magnetic field lines generated by ioniser 3. At least part of these electrons reach chamber 22. On their way, said electrons collide with the atmospheric gas atoms in the chamber 22 and ionise by collision at least a part of said atoms, thereby generating a further electron and a positive ion.

**[0106]** The effect of the magnetic field on the motion of the electrons, combined with the electric potential imposed on the electrodes in the ioniser 3, causes an electric field to be generated in the ionisation chamber 3a around the central magnet 31. The positive ions, influenced by the electromagnetic fields in the ioniser 3, are attracted by the negative potential generated by the negative electrode 51 (and if present by the additional positive electrode 55) downstream of the ioniser 3, until they overcome the low magnetic field zone at the interface between chambers 3a and 4a and arrive in the acceleration chamber 4a. At this point the ions are accelerated by the electric field concentrated at the second radial magnetic field generated by the accelerator 4 near the outlet section 1c.

**[0107]** Finally, it should be noted that a part of the electrons generated by the negative electrode 51 is attracted by the beam of positive ions coming out of the output section 1c and neutralises them, ensuring the electrical neutrality of the entire system.

**[0108]** The electric thruster 1 may include a power supply circuit configured to define the above-described potentials of said electrodes.

**[0109]** The electric thruster 1 may include a control board for at least ioniser 3 and accelerator 4.

**[0110]** The electric thruster 1 may include a power supply for at least the ioniser 3, the accelerator 4 and appropriately the control board.

**[0111]** The power system may comprise a power generator (comprising, for example, at least one photovoltaic panel) and/or energy storage comprising, for example, at least one battery.

**[0112]** In some cases, the system may include an additional propellant storage tank.

**[0113]** The operation of the ionisation and acceleration stages and thus of the electric thruster 1 described above is as follows.

**[0114]** The electrons emitted by the negative electrode 51 are attracted to the positive electrodes 52, 53 and/or 54. The path of the electrons crosses the radial magnetic field which is developed between the inner magnets 41 and outer magnets 42 and which is directed by the ferromagnetic elements 43 and 44, and which forces the electrons to slow down and causes them to move in a circular direction in the distal part of the acceleration chamber 4a, at the outlet section 1c.

**[0115]** The electrons that manage to overcome the force of the magnetic field manage to enter the acceleration chamber 4a, and are attracted by the positive electrodes 52, 53 and/or 54 and -if present- 55, which push them towards the ionisation chamber 3a. On their way they encounter the magnetic field developing between

the central magnets 31 and side magnets 32 and 33, which again slows them down and forces them on a circular path around the central magnet 31 and partially entering the chamber 22. This magnetic field can be so strong that the Larmor radius of the electrons (and appropriately of the ions) is less than the characteristic transverse dimensions of the stage.

**[0116]** In their circular motion, the electrons can impinge on the oxygen and nitrogen atoms (proper to the atmospheric gas) located in compartment 22, and by collision result in an ionisation of the atoms themselves (thus of at least part of the atmospheric gas), which will then be positively charged.

**[0117]** The positive ions, which are much larger than the electrons, are scarcely affected by the magnetic field, and are therefore free to go to the lower potential zone, represented by the cloud of electrons emitted by the negative electrode 51 and trapped in zone 1c by the magnetic field generated by the accelerator.

**[0118]** The concentration of electrons at the second radial magnetic field generated by the accelerator 4 in the vicinity of the outlet section 1c produces an attraction/acceleration on the ions, which are ejected from the accelerator 4 with preferential exit direction substantially parallel to the longitudinal axis 1a, and produce thrust for the space vehicle.

**[0119]** Finally, some of the electrons emitted by the negative electrode 51 neutralise the outgoing ions.

**[0120]** The electric thruster 1 and thus the spacecraft according to the invention achieve important advantages.

**[0121]** In fact, it introduces an innovative dual-stage thruster that allows a significant fraction of the collected gas to be ionised thanks to a clear separation between the gas ionisation stage and the acceleration stage. The electric thruster 1 is thus able to operate without using propellant stored on board.

**[0122]** This aspect therefore makes it possible to have a spacecraft which, if equipped with at least one electric thruster 1, is able to remain in very low orbit for long periods, i.e. between 250 km and 120 km altitude. This possibility is precluded by the thrusters/thrusters of the earlier technology.

**[0123]** An important advantage is the un-ionised portion of the atmospheric gas, which, continuing in its random motion substantially in compartment 22, allows the amount of gas in ioniser 3 to be maximised by greatly increasing the ionised fraction of the atmospheric gas and thus exploited for acceleration generation.

**[0124]** Another advantage is the high specific impulse that the electric thruster 1 is able to generate compared to known thrusters, thus ensuring high efficiency and the possibility for the spacecraft equipped with the electric thruster 1 to effectively counter atmospheric resistance.

**[0125]** Other advantages are to be found in the compactness, simplicity of construction and thus reduced costs that characterise the electric thruster 1 compared to those based on front-end technology.

[0126] The invention is susceptible to variations within the inventive concept as defined by the claims.

[0127] Here, all details can be replaced by equivalent elements and materials, shapes and sizes can be any.

## Claims

### 1. Electric thruster (1) comprising:

- an inlet conduit (2) defining an inlet section (1b) of said atmospheric gas into said electric thruster (1); and
- an expulsion section (1c) of said atmospheric gas from said electric thruster (1);

and **characterised by** comprising interposed between said sections (1b, 1c) so as to receive said atmospheric gas entering said inlet section (1b) and expelling said atmospheric gas from said expulsion section (1c):

- an ioniser (3)
  - defining an ionisation chamber (3a) configured to receive at least part of said atmospheric gas from said at least part of said atmospheric gas from said inlet conduit (2) and
  - configured to generate a first magnetic field in at least said ionisation chamber (3a) and in at least a proximal portion of inlet conduit (2) proximate to said ionisation chamber (3a)
- an accelerator (4)
  - defining an acceleration chamber (4a) configured to receive at least part of said atmospheric gas from said ionisation chamber (3a), and
  - configured to generate a second magnetic field interacting with said first magnetic field of said ioniser (3) by defining a resultant magnetic field having at least one low magnetic field region at the boundary between said chambers (3a, 4a);
- an assembly (5) generating a flow of electrons from said acceleration chamber (4a) to said ionisation chamber (3a) so that
  - said electron flow, when in said acceleration chamber (4a), is at least slowed down by said second magnetic field and moved along the lines of said second magnetic field defining an electric field concentration in said acceleration chamber (4a):

- at least part of said electron flow reaches said ionization chamber (3a) where, moved along said first magnetic field, it affects at least part of said atmospheric gas defining an ionized fraction of said atmospheric gas;
- said ionized fraction being attracted by said electric field concentration in said acceleration chamber (4a) towards said expulsion section (1c) generating a thrust for said electric thruster (1) and leaving said non-ionized atmospheric gas in said ionization chamber (3a).

2. Electric thruster (1) according to claim 1, wherein said first magnetic field is poloidal and has at least one low magnetic intensity zone at the boundary between said chambers (3a, 4a).

3. Electric thruster (1) according to at least one preceding claim, wherein said ionizer (3) comprises a toroidal central magnet (31), a first side magnet (32) and a second side magnet (33) placed opposite to the first side magnet (32) with respect to said central magnet (31); said magnets (31, 32, 33) are in said ionization chamber (3a) and define said first magnetic field.

4. Electric thruster (1) according to the preceding claim, wherein said first side magnet (32) is placed in correspondence with the first side wall of said ionization chamber (3a); and wherein said second side magnet (33) is placed in correspondence with the second side wall of said ionization chamber (3a).

5. Electric thruster (1) according to at least one preceding claim, wherein said accelerator (4) comprises an inner magnet (41) located at the first side wall of said acceleration chamber (4a) and an outer magnet (42) located at the second side wall of said acceleration chamber (4a); and wherein said inner magnet (41) and said outer magnet (42) define said second magnetic field.

6. Electric thruster (1) according to the preceding claim, wherein said accelerator (4) comprises a first ferromagnetic element (43) at least partially surrounding said inner magnet (41) and a second ferromagnetic element (44) at least partially surrounding said outer magnet (42),

7. Electric thruster (1) according to at least one preceding claim, wherein said assembly (5) comprises a negative electrode (51) external to said chambers (3a, 4a), and at least one positive electrode (52, 53, 54) placed in said ionization chamber (3a).

8. Electric thruster (1) according to claims 3 and 7, wherein said ionization chamber (3a) is annular; and wherein said at least one positive electrode (52, 53, 54) comprises a first positive electrode (52) placed on the first side wall of said ionization chamber (3a); a second positive electrode (53) placed on the second side wall of said ionization chamber (3a); and a third positive electrode (54) interposed between said central magnet (3a) and said ionization chamber (3a); and wherein said positive electrodes (52, 53, 54) are substantially equipotential.
9. Space vehicle comprising at least one electrical thruster (1) according to at least one preceding claim.

5

10

15

20

25

30

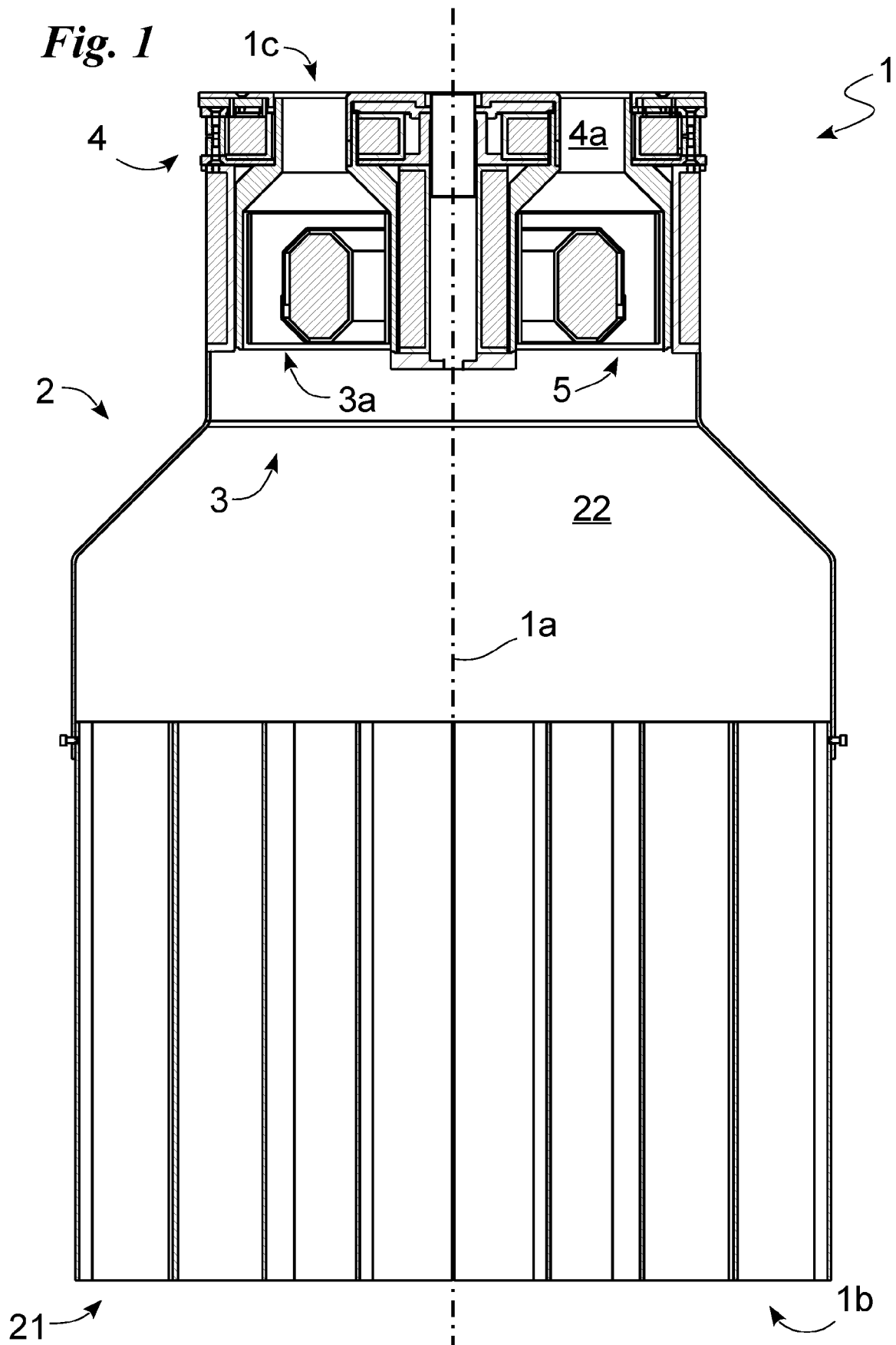
35

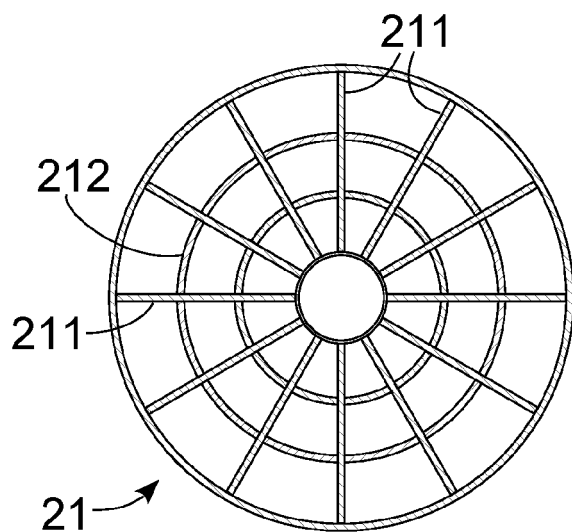
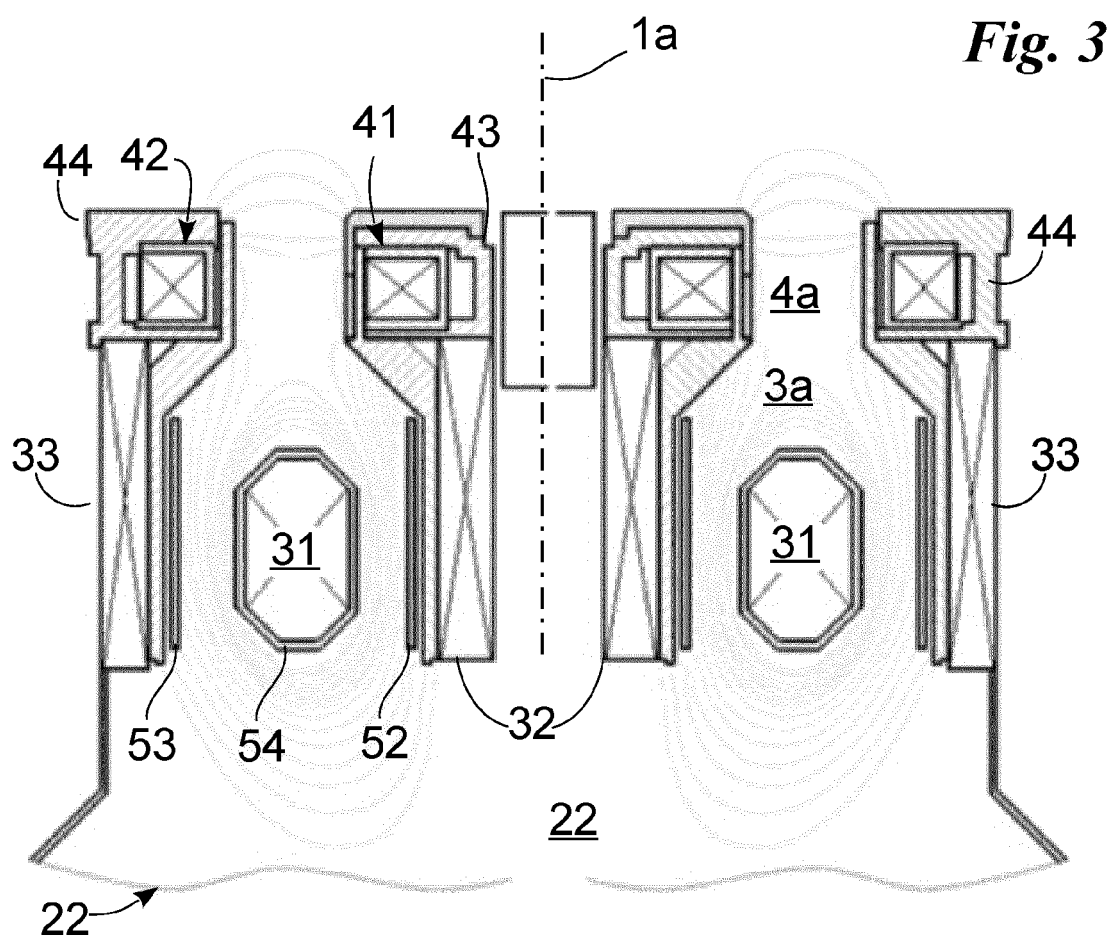
40

45

50

55









## EUROPEAN SEARCH REPORT

Application Number

EP 23 15 9635

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category                                                                                                                                                                                                                                               | Citation of document with indication, where appropriate, of relevant passages                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Relevant to claim                                                                                                                                                                                                                                                                     | CLASSIFICATION OF THE APPLICATION (IPC) |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------|
| X                                                                                                                                                                                                                                                      | US 2018/216606 A1 (MARCHANDISE FRÉDÉRIC RAPHAËL JEAN [FR] ET AL)<br>2 August 2018 (2018-08-02)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | 1, 2, 5-7, 9                                                                                                                                                                                                                                                                          | INV.<br>H05H1/54<br>F03H1/00            |
| A                                                                                                                                                                                                                                                      | * figures 1, 2 *<br>* paragraph [0058] - paragraph [0113] *<br>-----                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 3, 4, 8                                                                                                                                                                                                                                                                               |                                         |
| A                                                                                                                                                                                                                                                      | Andreussi Tommaso ET AL: "Development and Experimental Validation of a Hall Effect Thruster RAM-EP Concept RAM-EP = Air-Breathing Electric Propulsion RAM-HET = Air-Breathing Hall Effect Thruster VLEO = Very Low Earth Orbit",<br>Georgia Institute of Technology,<br>8 October 2017 (2017-10-08), pages 1-11, XP055965519,<br>Retrieved from the Internet:<br>URL: <a href="http://electricrocket.org/IEPC/IEPC_2017_377.pdf">http://electricrocket.org/IEPC/IEPC_2017_377.pdf</a><br>[retrieved on 2022-09-27]<br>* figures 1-9 *<br>* page 2, line 1 - page 10, line 14 *<br>----- | 1-9                                                                                                                                                                                                                                                                                   | TECHNICAL FIELDS SEARCHED (IPC)         |
| A                                                                                                                                                                                                                                                      | DIAMANT KEVIN D.: "A 2-Stage Cylindrical Hall Thruster for Air Breathing Electric Propulsion",<br>46TH AIAA/ASME/SAE/ASEE JOINT PROPULSION CONFERENCE & EXHIBIT,<br>28 July 2010 (2010-07-28), pages 1-9, XP055965542,<br>* the whole document *<br>-----<br>-/--                                                                                                                                                                                                                                                                                                                       | 1-9                                                                                                                                                                                                                                                                                   | F03H<br>H05H<br>H01J                    |
| The present search report has been drawn up for all claims                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                                                                       |                                         |
| Place of search<br><b>The Hague</b>                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Date of completion of the search<br><b>28 June 2023</b>                                                                                                                                                                                                                               | Examiner<br><b>Clemente, Gianluigi</b>  |
| CATEGORY OF CITED DOCUMENTS<br>X : particularly relevant if taken alone<br>Y : particularly relevant if combined with another document of the same category<br>A : technological background<br>O : non-written disclosure<br>P : intermediate document |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | T : theory or principle underlying the invention<br>E : earlier patent document, but published on, or after the filing date<br>D : document cited in the application<br>L : document cited for other reasons<br>-----<br>& : member of the same patent family, corresponding document |                                         |

EPO FORM 1503 03.82 (P04C01)



## EUROPEAN SEARCH REPORT

Application Number

EP 23 15 9635

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category                                                                                                                                                                                                                                       | Citation of document with indication, where appropriate, of relevant passages                                                                                                                                                                                                                                                                                                                                                   | Relevant to claim | CLASSIFICATION OF THE APPLICATION (IPC)                                                                                                                                                                                                                                                                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| A                                                                                                                                                                                                                                              | <p>ZHENG PENG ET AL: "A Comprehensive Review of Atmosphere-Breathing Electric Propulsion Systems", INTERNATIONAL JOURNAL OF AEROSPACE ENGINEERING</p> <p>,</p> <p>vol. 2020</p> <p>7 October 2020 (2020-10-07), pages 1-21, XP055965514, ISSN: 1687-5966, DOI: 10.1155/2020/8811847 Retrieved from the Internet: URL:http://downloads.hindawi.com/journals/ijae/2020/8811847.xml</p> <p>* the whole document *</p> <p>-----</p> | 1-9               |                                                                                                                                                                                                                                                                                                                      |
| A                                                                                                                                                                                                                                              | <p>US 2006/290287 A1 (KUNINAKA HITOSHI [JP])</p> <p>28 December 2006 (2006-12-28)</p> <p>* figure 4 *</p> <p>-----</p>                                                                                                                                                                                                                                                                                                          | 1-9               |                                                                                                                                                                                                                                                                                                                      |
| The present search report has been drawn up for all claims                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                 |                   | TECHNICAL FIELDS SEARCHED (IPC)                                                                                                                                                                                                                                                                                      |
| Place of search                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                                                                                                 |                   | Examiner                                                                                                                                                                                                                                                                                                             |
| The Hague                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                                                                                                                                                                                 |                   | Clemente, Gianluigi                                                                                                                                                                                                                                                                                                  |
| Date of completion of the search                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                                                                                                 |                   |                                                                                                                                                                                                                                                                                                                      |
| 28 June 2023                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                 |                   |                                                                                                                                                                                                                                                                                                                      |
| CATEGORY OF CITED DOCUMENTS                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                 |                   |                                                                                                                                                                                                                                                                                                                      |
| <p>X : particularly relevant if taken alone</p> <p>Y : particularly relevant if combined with another document of the same category</p> <p>A : technological background</p> <p>O : non-written disclosure</p> <p>P : intermediate document</p> |                                                                                                                                                                                                                                                                                                                                                                                                                                 |                   | <p>T : theory or principle underlying the invention</p> <p>E : earlier patent document, but published on, or after the filing date</p> <p>D : document cited in the application</p> <p>L : document cited for other reasons</p> <p>.....</p> <p>&amp; : member of the same patent family, corresponding document</p> |

EPO FORM 1503 03.82 (P04C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.**

EP 23 15 9635

5 This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.  
The members are as contained in the European Patent Office EDP file on  
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

28-06-2023

| Patent document<br>cited in search report | Publication<br>date | Patent family<br>member(s) | Publication<br>date |
|-------------------------------------------|---------------------|----------------------------|---------------------|
| <b>US 2018216606 A1</b>                   | <b>02-08-2018</b>   | <b>BR 112018000271 A2</b>  | <b>18-12-2018</b>   |
|                                           |                     | <b>CN 107850055 A</b>      | <b>27-03-2018</b>   |
|                                           |                     | <b>EP 3320208 A1</b>       | <b>16-05-2018</b>   |
|                                           |                     | <b>FR 3038663 A1</b>       | <b>13-01-2017</b>   |
|                                           |                     | <b>IL 256754 A</b>         | <b>29-03-2018</b>   |
|                                           |                     | <b>JP 6756814 B2</b>       | <b>16-09-2020</b>   |
|                                           |                     | <b>JP 2018525557 A</b>     | <b>06-09-2018</b>   |
|                                           |                     | <b>US 2018216606 A1</b>    | <b>02-08-2018</b>   |
|                                           |                     | <b>WO 2017006056 A1</b>    | <b>12-01-2017</b>   |
| <hr/>                                     |                     |                            |                     |
| <b>US 2006290287 A1</b>                   | <b>28-12-2006</b>   | <b>JP 2006147449 A</b>     | <b>08-06-2006</b>   |
|                                           |                     | <b>US 2006290287 A1</b>    | <b>28-12-2006</b>   |
| <hr/>                                     |                     |                            |                     |