The Expedition on Ceres

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Abstract: A project of the expedition on planet Ceres, which is carried out in two phases is considered. In the first phase at the surface of Ceres the space refueller and a mobile solar battery are delivered. The delivery is carried out with the help of the space locomotive, which is moved by electrorocket engine “MARS” of new design, and as source of electricity serves a solar battery of gallium arsenide. In the second stage the space train consists of space locomotive and habitable capsule, in which 5 astronauts are carrying out landing on Ceres surface and are carrying out the complex of astronomical, physical and geological researches. The design of space refueller is developed, which melts water ice on Ceres surface and using electrolyser and liquefier first produces working substance - oxygen for operation of electrorocket engines, and then refuels the locomotive on Ceres orbit. The duration of the expedition - 90 days at cost of 1 billion. USD.

Keywords: Ceres, space train, space refueller, arsenide-gallium solar battery, electrorocket engine «MARS»

The article is devoted to the exploration of the possibility of further human penetration inside the solar system.

The following object of penetration after Mars can become asteroid belt. For many years the main way of the asteroid belt research have been observations using telescopes. Starting from the 80 ies of the last century past the asteroid belt began to fly spacecrafts, the first of which “Galileo”, launched by NASA, has photographed an asteroid "Ida" in 1993 year. And only in September 2007 an automatic interplanetary station "Dawn" was sent towards the largest asteroids Ceres and Vesta.

In July 2011 the "Dawn" has reached Vesta, on which orbit the scientific researches were carried out during six months. Then "Dawn" went to Ceres - dwarf planet in the solar system, which was reached in the year 2015. Remarkable design of the spacecraft, "Dawn" and its equipping with the newest research instruments have allowed scientists-astronomers to make a number of important scientific discoveries.

Especially impressive are technical solutions adopted by the engineers-developers of the "Dawn".

Thus, a space system of electrical propulsion has been demonstrated, which uses solar cell of gallium arsenide as on-board power source and traction force is created by electrorocket engines of ionic type using xenon as working substance.

Useful mass of the spacecraft „Dawn“ is 150 kg, and mass of working substance which has been consumed for 10 years of work amounted to 400 kg.

As a result of the researches carried out by "Dawn” ice volcanoes (cryovolcanoes) were found on the surface of Ceres. The biggest cryovolcano Ahuna Mons has a height of 4 km.

Is it possible in the nearest future to implement a scientific expedition on the dwarf planet Ceres?

To get answer to this question will help researches carried out by the author of this article at 2014 -2017. As a result of these studies the typical design of space train to perform flights towards all the planets of the solar system was developed [1]. The space train is formed in Earth orbit by means of docking of separate components. Each component is entered onto the Earth orbit using known (being already in service) carrier rockets. The space train is set in motion using magnetoplasma electrorocket engine "MARS" of new design, developed and investigated by the author [2], [3].

For power supply of engines, an onboard power unit was developed, consisting of a nuclear reactor, a MHD generator and a turbo generator [4].

In 2017 author has made a study, which has showed that for flight towards Mars the onboard power plant can be upgraded. The specifications of the solar batteries already manufactured by industry at present provide the power needed to operate electrorocket engines.

A new design of locomotive was developed that combines a tank with working substance and a solar battery in one rocket. Calculations of processes occurring when movement of the space train, made on a mathematical model have shown that simplification of design of on-board power plant makes flight to Mars a reality of the near future.

In this paper, the project of an expedition to planet Ceres is presented. It is known that Ceres refers to dwarf planets of the solar system, has spherical shape and diameter of 990 km. It is located in the asteroid belt, at a distance of 2.76 AU from the Sun. When moving in orbit around the Sun, it is committing one turnover in 4.6 years, rotating simultaneously around its own axis with a period of 9h 4min. The latest studies made by automatic interplanetary station Dawn revealed that 30 % of Ceres surface is covered with water ice.

Abstract:
This fact allows to use water as the raw material for obtaining its components - hydrogen and oxygen, which can become a working substance for chemical and electrical rocket engine.

The similar scheme of water ice usage was previously developed for expedition towards planet Jupiter [4] In addition, it should be noted one more favorable circumstance. Free fall acceleration at the equator of Ceres is only 0.27 m/s², which greatly simplifies the task of movement over its surface.

Nevertheless, the question arises: is it possible to use solar battery as a source of electrical energy for movement of the space train with a crew of expedition. One should keep in mind that due to the increasing distance from the Sun the power of solar panel at Ceres is in 7 times less as compared to the power at orbit of the Earth. The obtaining of answers to questions related to the possibility of expeditions on Ceres surface, as well as to the further exploration of the asteroid belt is the subject of this work.

I. THE CONCEPT OF THE EXPEDITION ON CERES

Preliminary studies carried out on the mathematical model have showed that an expedition on Ceres should be carried out using rocket train, which is assembled in Earth orbit from individual components using docking. This space train should consist of two functional parts: a space locomotive and takeoff–landing capsule with a cabin for astronauts–researchers.

The space locomotive having combined design can be also assembled in Earth orbit.

Studies have also shown that the most appropriate to use oxygen as working substance to operate electric rocket engine. As it is already was indicated, on the surface of Ceres there are large reserves of water in the form of ice. Therefore, the optimal solution is usage the process of ice melting, getting gaseous oxygen and hydrogen from liquid water by means of electrolysis and conversion of gaseous oxygen in the liquid phase using liquefier.

For carrying out the locomotive refueling with working substance in the project has been developed a space refueller, which design is described below.

The space refueller gets required electric power from a stationary solar battery, which is delivered on the Ceres surface in assembled form.

The expedition on Ceres consists of two consecutive phases.

At the first phase on the Ceres surface the space refueller and solar battery are delivered.

At the second stage, the takeoff-landing capsule with crew of the expedition is delivered into Ceres orbit. The scheme of the interorbital space train for the first phase is shown in Fig.1.

![Fig.1](image-url)

Delivery of the space refueller and its power supply unit is performed by means of two locomotives. Locomotive 1 is being connected with locomotive 2 by means of docking unit 3. Docking of the locomotives in Earth orbit is carried out in an automatic mode with the help of electrorocket engines 4. Then into the orbit, the space refueller 5 is put, which makes maneuvers with help of chemical oxygen-hydrogen rocket engine 6. The space refueller 5 is approaching locomotive 1 and is docking it with the help of docking unit 7.

The power supply unit is located in rocket 8, which has chemical rocket engine 9.

After entering into Earth orbit the rocket 8 is approaching and docks with locomotive 2 using docking unit 10.

With the help of locomotives 1 and 2 the space train moves along the calculated trajectory from Earth's orbit towards asteroid belt, reaches the planet Ceres and goes into circular orbit around this planet at a distance of 100 km from its surface. After going into the Ceres orbit the space train (Fig. 1) is divided using docking units 7 and 10.

Very important is the choice of a landing place for refueller and the solar battery on the Ceres surface. It is advisable to have in the landing place a smooth icy surface. Such possibilities exist in equatorial band of the extinct cryovulcan “Kerwan”.

![Image](image-url)
According to the plan of the first phase the landing of the space refueller 5 is carried out in the selected point on the surface. The chemical rocket engines 6 are switched on and being in braking mode the space refueller goes into vertical position. Its speed is reduced to zero and it hovers above the point of landing. Next a smooth touch of amortization racks of the rocket 6 with Ceres surface takes place.

After landing of the refueller 5 the similar operation is performed with the rocket 8, in which the fully assembled solar battery is located.

The chemical rocket engine 9 is switched on and the rocket 8 hovers above the surface at a height of 20 m. Simultaneously, its horizontal movement takes place. And it is necessary to provide that the landing point of rocket 8 was located at a distance of 50 m from the landing point of the rocket 5.

Locomotive 2, being connected with the locomotive 1, continues to orbit around Ceres and rockets 5 and 8 remain on its surface until the arrival of the expedition.

Calculations made using an astrodynamical program have identified the flight trajectory of the space train and have showed that the duration of the flight of space train (Fig. 1) from the Earth orbit towards orbit of Ceres is 98 days.

After delivery of refueller and solar battery on the Ceres surface the second phase of the expedition begins.

For this purpose three space locomotive, which tanks are filled with liquid oxygen, are delivered on Earth orbit using carrier rocket Delta. Scheme of the space train for the main flight on the Ceres is shown in Fig. 2.

Fig. 2

First in orbit locomotive 4 is put. After unfolding of solar battery the electrorocket engine 5 is switched on for orbital trajectory correction. By means of the next launch the locomotive 1 is put into orbit. After unfolding of solar battery the electrorocket engine 7 is switched on. The locomotive 1 makes a maneuver and moves in direction of locomotive 4.

While using the docking unit 11, locomotive 4 docks locomotive 1. By means of the third launch space locomotive 2 is put into orbit. After unfolding of solar battery the space locomotive 2 with the help of electrorocket engine 6 is moved towards tandem of locomotive 1 and 4. The power part of the space train, assembled using the docking unit 10 and consisting of locomotives 4,1 and 2 connected in-line along the horizontal axis is ready for an interorbital flight. Now it is only necessary to connect the power part with takeoff-landing capsule, where the cabin of expedition crew is located. The expedition crew, consisting of 5 persons is delivered in advance on the international space station (ISS). Using carrier rocket Delta, the takeoff-landing capsule is put into orbit of the ISS.

After entering into orbit of the ISS the takeoff-landing capsule using chemical rocket engine 8 is approaching a moorage of the ISS and the docking with the moorage of the ISS takes place using nasal docking unit 13. Astronauts leave the ISS and come into the capsule 9. Then they switch on chemical rocket engine 8 and push off the moorage ISS. Next, using the engine 8 capsule goes into orbit, where it is expected by the power part of the space train collected from three locomotives 4,1 and 2.

The maneuver of approaching and docking of two parts of the space train is carried out using a docking unit 9. Now the space train is assembled as shown in Fig. 2. The system of artificial gravity cabin with astronauts is being switched on and the capsule begins to roll around the longitudinal axis. The second phase of the expedition - achievement of the Ceres and landing on its surface, begins.

After switching on the electric rocket engines the space train (Fig. 2) while gaining the second space velocity goes into the calculated trajectory of flight.

The flight trajectory from Earth orbit into the Ceres orbit is built using astrodynamical program that continuously determines the strength of the interaction of the space train with the Sun and the planets Earth, Mars, Jupiter and Ceres during their joint movement along orbits [5].
Simultaneously the picture of the solar system’s gravitational field is determined, in the movement area of the space train, which is a body of variable mass being under the influence of this field. In addition, the traction force of the electrorocket engine in every point of the trajectory depends on the distance of the space train from the Sun. This factor is taken into account using by calculation the method of the successive approximations.

The resultant trajectory of the flight is shown in Fig. 3 and the changing process of the speed and weight of the train and as well the power on-board power supply source is shown in Fig. 4.

As it can be seen from Fig. 3, the start is planned at the time of the least confrontation between the orbit of the Earth (point 1) and the orbit of Ceres (point 1’).

As it can be seen from Fig. 4 the acceleration of the space trains up to speed 180 km/s occurs within 16 days. During this period engines are operating with maximal power, which value continuously decreases from 4500 kW up to 3600 kW. Simultaneously due to emission of the working substance mass of the train decreases from 78 tons up to 60 tons. Through 17 days the space train makes the maneuver (“dead loop”) in order to change the traction direction of the electrorocket engines on 180°. After this 180-degree turn, the space train braking begins, which continues for 32 days. The speed of the space train is reduced from 180 km/s to the orbital velocity on Ceres (0.36 km/sec), which equals the speed of aircraft-fighter.

As it can be seen from Fig. 3, after crossing the Mars orbit the space train reaches the main asteroid belt which is located at a distance of 2AU from the Sun, and is a part of the middle zone of the belt. Ceres, whose angular speed of movement around the Sun at 4.6 times less than that of Earth, at this moment is at point 2, and the Earth is at point 2’.

According to the program of the expedition astronauts conduct scientific observations of asteroids, past which the space train is flying.

After going onto Ceres orbit the space train moves at altitude of 20 km from its surface with the orbital velocity.

Astronauts are watching the movement of the tandem consisting of two space locomotives, which are also moving along orbit around Ceres. It should be reminded that they were delivered there during preliminary flight (fig. 1).

Navigator-astronaut finds the place on the surface of Ceres, where previously the landing of space refueller and solar battery was performed. (Radio beacons were installed on both objects).

Making maneuvers around Ceres using electric rocket engines 5 (fig. 2), space train goes into orbit around Ceres, from which astronauts are watching the refueller and the solar battery being situated on Ceres surface.

Space train (Fig. 2) is divided using docking unit 9. The takeoff-landing capsule 3 using chemical rocket engine 8 departs from the locomotive 2. Landing of the capsule (Fig. 2) on the surface of Ceres is carried out. Chemical rocket engine 8 is being switched on and the movement speed of the capsule begins to decrease. When the speed reaches magnitude 0.3 km/s, the capsule loses weightlessness and while using the rocket engine 8 it is smoothly approaching Ceres surface.
The pilot and navigator are implementing slow horizontal movement of the capsule towards the landing point having coordinates: 0-120° and being located in the crater "Kerwan" at the equator of Ceres. Here there are already two spacecraft: space refueller and solar battery.

After landing on the Ceres surface the astronauts are leaving the landing capsule and are bringing refueller back into service. The works are beginning in accordance with the plan of staying on the Ceres surface. Firstly, it is necessary to provide all the devices with electric power. Astronauts open the container in which there is the solar battery. Using a special mechanical device astronauts install two coils with photoelectric transducers. This does not require much efforts because the force of gravity on the surface of Ceres in 33 times less than on Earth's surface.

Astronauts unfold two solar panels, each of which has a length of 120 m providing 100 kW of power. The first battery is connected to the ice melter. The second solar battery is connected to the electrolyser and liquefier. Ice melter, electrolyser and liquefier are located in casing of refueller, which is described below.

After connecting of solar battery to the the refueller, astronauts switch on all the systems of refueller and check their operation. They control the process of formation of unfrozen pool of water and provide control the work of electrolyser and liquefier with the help of instruments.

When liquid oxygen and liquid hydrogen begin to come in tanks of liquefier, astronauts are returning into the cabin of takeoff-landing capsule. According to the plan, the adjustment phase of the refueller must take 2 earth days. This corresponds to 5.3 days on the surface of Ceres. Refilling of refueller tanks with liquid components is made in automatic mode.

When the tanks are filled, the command to takeoff for refueller is given. The chemical rocket engines are being switched on, and refueller smoothly rises from the surface of Ceres and moves vertically, increasing the speed up to 360 m/s.

Being in state of weightlessness the refueller is moving towards the space train consisting of three locomotives (Fig. 2). The refueller makes approach along axis of the train and docks it with the help of docking unit 12, located in the fore part of the locomotive 4. Using the cryogenic pump installed inside refueller, liquid oxygen is pumped from the tank of refueller into tank locomotive 1.

After refueling of locomotive 1, the refueller is detached from docking unit 12, turns around and makes landing on the surface of Ceres in the 30-meter zone from energy source - solar battery. Next, the operations of water production out water ice, water decomposition in gaseous components using electrolysis, liquefaction of the components and pumping of liquid hydrogen and liquid oxygen in tanks of refueller, are repeated (in the automatic mode). After the second takeoff of the refueller, the tank of locomotive 4 is filled with liquid oxygen. After the end of the refueling the refueller returns to the surface of Ceres. The space train moving in orbit around Ceres, is ready to reverse flight of the expedition towards Earth orbit.

The calculations performed in the project have indicated that the operation of refueling takes two earth days. The refueller, which after refueling has arrived to the base of the expedition, is again connected to the solar battery. Now, while producing liquid hydrogen and oxygen, which accumulates in its tanks, he can play the role of energy accumulator. For this purpose on board of the refueller a battery of fuel cells is installed. The fuel cells produce electricity and replenish the volume of liquid water. This allows the crew to work at nights.

After finishing of the works on the expedition preparation to return flight, astronauts embark to the implementation of the scientific researches. Firstly it is the study of the surface of Ceres and clarification of the existing cartographic descriptions. Astronauts take their places in the cabin of the takeoff – landing capsules, which now can serve as a magnificent rocket plane. The free fall acceleration on the surface of Ceres is only 0.27 m/s². With the help of chemical rocket engine which is installed in bottom of the takeoff-landing capsules chemical rocket engine capsule lightly reaches the first space speed (orbital velocity).

The capsule rises above the Ceres surface and while using a steering rocket device it can move towards any point on a spherical surface. Astronauts commit the first trip from crater "Kerwan" (180°/0°), (which is the base of the expedition) towards crater "Okkator" (240°/22°). After a vertical take-off and acceleration up to orbital velocity the capsule flies by inertia along the Ceres equator. The distance of 1100 km long the capsule overcomes during 50 minutes. After braking the capsule hovers over the crater "Okkator". The Navigator and pilot are choosing landing place. Using the manual control the pilot performs a soft landing exactly on the bright spot, which has been photographed by the station "Dawn" in August 2017.
The nature of these spots still remains a mystery for scientists. After landing, the astronauts go out on the surface of the crater and are beginning to explore it.

During a day the astronauts using drill installation carry out research of ground. Astronaut-geologist assembles a collection of minerals for delivery to Earth.

Astronauts carry out astronomical and astrophysical measurements of celestial objects of the asteroid belt. At the end of the researches the astronauts take places the inside of the capsule, and after switching of chemical rocket engine capsule rises from crater "Okkator". After reaching of orbital velocity astronauts commit flyby of Ceres with the purpose of studying topography of its surface and establishing of more accurate map.

The capsule moves above Ceres surface in direction of South Pole at altitudes 12-15 km at a speed of 1300 m/s. After 35 minutes of flight, the capsule flies across the mountain range and reaches the crater "Urvara". Landing in the crater and its exploration is carried out.

Next, the capsule moves towards crater "Toharu" (coordinates 150˚- 45˚), which has high-mountain border. After examination of the crater the capsule takes off and takes a course towards base of expedition. The circular flying around central area of Ceres is finished by return and landing of the capsule in the crater at a distance of 40 meters from the located there refueller and solar battery. Next object of study is the mountain "Ahuna Mous" which is located in the center of the crater "Kerwan" having diameter of 280 km. According to results of the processing of the data received by the probe "Dawn" the mountain "Ahuna Mous" is unique. She is an extinct cryovulcan [6]. It should be reminded, that the astronauts are in the capsule cabin at a distance of 80 km from the mountain "Ahuna Mous", which has height 4 km while it base - 18 km. The capsule takes off over the surface of the crater "Kerwan" and is moving to the foot of the mountain "Ahuna Mous".

After capsule landing astronauts come to the surface, install the metering devices and under the direction of geologist-astronaut, are conducting the first-ever scientific study of the cryovulcan.

After returning to the base the within 2 days the astronauts are doing research on the territory of the base. Using a telescope astronauts carry out astronomical observations of the asteroid belt and the planet Jupiter. Measurements of magnetic field, cosmic and solar radiation on the Ceres surface are also carried out.

Astronaut-astrophysicist performs researches of the negligible atmosphere of Ceres. Scientists suggest that under influence of solar ultraviolet radiation part of water on the Ceres surface dissociates and forms clouds of water vapor.

According to the program of the expedition astronauts must create on the Ceres the permanent laboratory, whose task is to conduct the comprehensive measurements with the transmission of information to Earth. This lab could be eventually expanded and be transformed into the space station, where one can conduct researches while changing constantly the composition of the expeditions.

This can be the beginning of human exploration of the asteroid belt. Really, already after the first expedition on the surface of Ceres solar battery is remained which is a steady source of electricity. In addition, the space refueller remains, which is capable in the automatic mode to produce oxygen and hydrogen out of water ice and to supply the space train with working substance.

It should be reminded that during day the temperature of the surface of Ceres -20°C and at night it goes down to -100°C. Thus this conditions are similar to those, in which work the polar explorers on ice floe. However, there are significant differences. First of all, it is weightlessness. But the main difference is the absence of the atmosphere, which protects all life on Earth from cosmic radiation. Calculations made in the project have showed that the task of protection from cosmic radiation can be solved through the construction of shelters made of water ice. This kind of structures are being built sometimes on Earth, and they are used by the Northern peoples (for example, Chukchi) even for long residence.

Astronauts begin to build ice house, intended for location of measuring devices, whose power supply and heating is provided by solar panels. The thickness of the walls and the roof of the icy house shall be not less than 1.5 m. Astronauts are making icy bricks with dimensions 0.75 x 0.5 x 0.5 m. This brick weighs on Ceres only 4.8 kg. For the production of the bricks is delivered a special plastic form, which is filled with liquid water. The icy house of 10 m length, of 7 m width and of 5 m height is being built according to an in advance developed project. In this icy house is placed the equipment for regular physical measurements, as well as the communication system and transmission of images of the surface of Ceres and starry sky to Earth.
This ends the stay of the expedition on the surface of the dwarf planet Ceres, which lasted 10 days. Astronauts take their places in the cabin of the takeoff-landing capsule.

Pilot switches on the chemical rocket engine 8 (fig. 2) and the takeoff-landing capsule rises from Ceres surface. When reaching speeds of 380 m/s, the capsule goes into orbit of Ceres, along which is moving the space train composed of locomotives 1, 2 and 4, refueled with working substance. Using the docking unit 9, docking of the capsule with the rocket train is carried out, as shown in Fig. 2. Recall that along the same orbit around Ceres moves one more space train. This is two locomotives which have been left after the delivery of refueller and solar batteries (fig. 1). Calculations show that the solar panels of these locomotives is rational to use as an additional source of electrical energy to power the electrorocket engines during the return flight to Earth orbit. By maneuvering with the help of electrical rocket engines 6 of locomotive 2 (fig. 2), the formation of "big" space train, which is shown in Fig. 5, is being carried out.

![Fig. 5](image)

Space train fig. 2 goes to rapprochement with space train fig. 1. After reaching of identical speed, the docking of five space locomotives in one line, using the docking unit 12 (fig. 5) is carried out. The design of the space train which is formed in such way allows to increase the power of on-board power plant up to 1500 kW. After assembling of "the big train", electric, the rocket engines of locomotives 4, 1 and 2 are being switched on.

Electric rocket train leaves orbit of Ceres of and takes course to Earth orbit. The movement trajectory of electric rocket train (fig. 5) is shown in fig. 3. At the beginning of the return flight Ceres is on its orbit around the Sun at point 3 and the Earth is on its orbit in point 3.

When moving from orbit of Ceres onto the Earth orbit the space train should pass along the calculated trajectory from point 3 to point 4, where at the end of the flight Earth will be located. The calculation results of motion parameters over time are shown in Fig. 6.

![Fig. 6](image)

Here is how goes this process. During 18 days the space train accelerates to speeds of 170 km/s. It occurs due to the fact that when approaching to the Sun the energy of solar batteries is constantly growing, and after 20 days it becomes equal to 5.0 MW.

After space train maneuver, the nozzle direction of electrorocket engines is changed on 180 degrees. The phase of the train braking begins. The speed reduction up to 10 km/s takes 8 days. The return flight from Ceres orbit onto Earth orbit takes 28 days.

After going into Earth orbit, the decoupling of the space train is carried out (fig. 5). The space locomotives go on the orbital base, where they are refueled.

Subsequently they can be used for space programmes of various purposes, including the second flight to Ceres.

Using chemical rocket engine 8 the takeoff-landing capsule with crew moves towards the orbit of the ISS. The capsule taxis up to a moorage of the station and docks it.

The crew of the expedition moves from the capsule to the station. Thus the expedition towards dwarf planet Ceres, which lasted 90 days, ends.

It should be noted that the Earth revolves around the Sun with an angular velocity which in 4.6 times greater than Ceres. The next expedition to Ceres should be carried out in the moment of opposition between planets. And this happens through 15 months after the first expedition.
As regards to the cost of the expedition, it should noticed the following. Preliminary flight will require 4 launches of rocket Delta-4. The main flight will require another 4 launch of Delta-4. The total cost of launches will be 600 million $.

Preliminary calculations of space train cost has showed that for creation of locomotive will need 40 million$, for creation of refueller -100 $, for creation of solar battery - 50 million $, for creation of takeoff- landing capsule-60 million $.

Thus, the expences for implementation of the first expedition to the planet Ceres will be about 1 billion $

Superconducting electrorocket engine "MARS" (German abbreviation of the name: Motor für die Alle Rakete mit der Supraleitung)

Design of the superconducting electrorocket engine "MARS" is shown at fig. 7 (longitudinal section) and at fig. 8 (cross section).

The engine belongs to class of magnetoplasma electrorocket engines with external exciting winding. Its main difference from existing is that the winding 7 excites in the working chamber of the engine transverse magnetic field. Another difference is that in order to increase the value of the transverse magnetic field, the winding is made of superconductor and is placed in a cryostat. The engine was patented by author in Germany in 2013 [2].

In the working chamber along engine axis a cathode is located. An anode, that has a ring shape, is located on the outside of the cathode. The cathode 1 is fastened on the anode 2 using a cylindrical bushing 3 and an isolator 4, that has the shape of a ring. As working substance in the electric engine oxygen is used, which in the liquid state is kept in cylindrical external cryostat 12. In the internal cavity of the cryostat 12 the cryostat 9, filled with liquid hydrogen is located.
The superconducting magnetic system is located inside the cylindrical cryostat 9. The usage of liquid hydrogen is needed to ensure in the magnetic system the temperature at the level of 20° K. The superconducting magnetic system consists of three winding. The first winding 7 is used to create tangential magnetic field excitation in the working chamber. The second winding 14 has cylindrical form and is used to create a magnetic nozzle, compressing the plasma when leaving the working chamber.

The third winding 19 has cylindrical shape and is intended for stabilization of the electric arc arising between the electrodes 1 and 2 by means of its uniform rotation.

Fig. 8 shows, that coil of the first winding consists of two parts 3 and 4. The part of the coil 3 with half-turns which are reeled in forward direction is placed on the outer surface of the cylinder 6. Before laying this part of coil 3 by means of forming impart the form of cylinder. Another part of the coil 4 with half-turns which are reeled in opposite direction unbend and stack on radius. Similarly, the remaining three coils of the first winding are being laid.

Fastening of coils of the first winding is carried out using cylindrical bandage 13 and flat brace 10, which press the winding against rib 7 using winding holder 17. The internal cylindrical cavity of cryostat 18 (indicated at fig. 7 by index 9), which has the outer casing 16, is filled with liquid hydrogen. The outer shell is made of carbon and has a screen-vacuum insulation. Cryostat 17, which has ring shape, is located on the outside of the shell 19.

Cryostat 17 also has screen-vacuum coating of outer and inner casing. Cryostat 17 is filled with liquid oxygen (at fig. 7 it is designated by index 12). As it is shown in Fig. 7, when assembling the cryostat, 12 is inserted inside of cylindrical outer casing 8.

In the cryostat 12 the gaseous oxygen is formed which through pipeline 18 is fed into the working substance preparation chamber 6. Inside the camera 6 a dosing unit and a solenoid valve are located. Gaseous oxygen is fed into the working chamber of the engine through channel 5 in the sleeve 3. When creating an engine of magnetoplasma type, which has electrodes, resource problem arises. When cathode is subjected to bombarding by high-energy ions it loses mass. To resolve this problem the author has developed a new design of engine with movable cathode [7].

The cathode of cylindrical form is made of tungsten, and during operation is moving along the horizontal axis. The movement takes place in a metal bushing 21. The bushing is fastened inside insulator 4. End of the cathode 20 is rigid fastened on axis in the center of cross piece 22 that moves with the help of skids 25 and 26 along the inner surface of outer cylinder 17. To move the cathode 20 the power of magnetic interaction is used. With this purpose in spokes 22 the solenoids 27, 28 are mounted.

During the operation the electromagnets 27 and 28 are in a constant magnetic field, which is created by the superconducting exciting winding 7, which is located in cryostat 8.

When enabling of the electromagnets 27 and 28, the cathode 20 owing to attraction force starts to move along the axis of the engine. The magnets 27 and 28 are being switched on after a longer work of the engine, when due to loss of cathode mass the current of the engine is decreased up to inadmissible value. After the movement, other part of cathode 20 enters into the working chamber. The distance between the electrodes again decreases and current increases up to nominal value.

Calculated parameters and dimensions of the electric engine MARS are shown in Table 1

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Space locomotive

General view of the space locomotive is shown in Fig. 9.
The solar battery l has folding design. It is assembled from individual panels 4, which are made of carbon-filled plastic. From the outside in the panel a layer of photovoltaic converter made of gallium arsenide is closed up. Connection of panels is carried out with the help of hinges 16,17. Cross-section of the case design is shown in Fig. 11 and 12.

Fig. 11 illustrates the situation when the solar panel is assembled when delivered in orbit around the Earth. From the outside structure of solar panels is kept together using a cylindrical shell 4. Installation of the panels at working position is carried out by using the sliding rods secured on longitudinal beams 5 and 6.

Fig. 12 shows that sliding rods 6,7 are secured on the outside of end disk 2. The design of the sliding rods is accomplished in the form of concentric cylinders 6 and 7 which are inserted into each other. Cylindrical case (Fig. 10), made of aluminum alloy, forms the basis of the design. On both sides of the case 1 disks 2 and 10 are installed. In the internal cavity of the case the tank 3 of cylindrical shape with liquid oxygen is being installed.

The tank 3 with liquid oxygen is made of fiberglass in form of cryostat with screen-vacuum insulation. In the neck of the cryostat the cryogenic pump 8 is being installed for liquid oxygen pumping.

The electric rocket engines are installed in the end disk 2. To install the engines, the end disc 2 (Fig. 12) has four hole 4, angled 90°.
In the nasal part of the locomotive there is external case 15, in the inner cavity of which the blocks of automatic control system 12 are installed.

II. TAKEOFF-LANDING CAPSULE (TLC)

Takeoff-landing capsule is designed to deliver the expedition towards the asteroid belt and for a stay of the expedition on the planet Ceres. The capsule is an autonomous spacecraft for landing and take-off from the surface of Ceres. It is capable to maneuver in orbit around Ceres as well as to carry out maneuverings on orbit around the Earth and docking with the international space station ISS. The design of the capsule is a further modification of the structure, which was developed by the author in the year 2016 for landing and take-off from the surface of Uranus satellite Oberon [8].

The TLC design is shown in Figs. 13.

Fig.13

where:
1 – chemical hydrogen-oxygen rocket engine with tractive force of 6 KN and specific 400 s.
2 – bottom of rocket case of the capsule.
3 – fuel tank with liquid hydrogen.
4 – cargo compartment.
5 – hatch for exit to the surface.
6 – tank with liquid oxygen.
7 – cabin for expedition crew.
8 – a superconducting solenoid located in the cryostat with liquid hydrogen and designed create in expedition cabin a constant magnetic field.
9 – the docking unit for junction with orbital circumterrestrial space station.
10 - tunnel and gateway to exit from the capsule.
11 – cone of external casing of the rocket.
12 – container for measuring devices.
14 – damper of landing support.
15 – shoe of supporting upright
16 – the docking unit for junction with locomotive of space train.

Mass of takeoff-landing capsule on Earth – 22 t
TLC length – 15 m, external diameter of TLC – 5,8 m.

III. MOBILE SOLAR BATTERY

Mobile solar battery is designed to provide electricity for expeditions while staying on the surface of Ceres. Mobile solar battery (MSB) is delivered on Ceres during the preliminary flight, as it shown in Fig 1. For landing on Ceres surface the MSB has a chemical rocket engine. The MSB design is shown in Fig. 14.
After unloading the astronauts are unrolling the assemblies. From the assembly 8 on the Ceres surface the solar battery No. 1 is being installed, and from the assembly 9 the solar battery No. 2 is being installed. The solar battery dimensions in operating position: length-100 m, width-10 m. Power of each solar battery on Ceres surface near in the equator - 95 kW. Solar battery mass on Earth-5.6 tons.

IV. THE ORBITAL SPACE REFUELLER ON CERES

The refueller is an autonomous spacecraft that is designed for refueling of the space locomotive located on orbit of Ceres, with the working substance - the liquid oxygen. The design of the refueller is a further modification of the refueller, which was designed to work on the surface of Jupiter's satellite - Europe [4].

The design of the refueller for the expedition on Ceres is shown in Fig. 15

Fig. 15

where:

1 - Ceres surface covered by water ice at temperature of 167 °K.
2 - unfrozen patch of water, formed as a result of thermal electric heater.
3 – external case of rocket made of aluminium alloy.
4 - hollow cylindrical tank with liquid hydrogen.
5 - cylindrical tank with screen-vacuum insulation, which is filled with liquid oxygen.
6 - cryogenic pump for liquid oxygen pumping-over refueling.
7 – screen-vacuum insulation of tank 4 with liquid hydrogen.
8 – Thermic heater. Thermic heater has cylindrical shape and is installed in the bottom of the rocket on its longitudinal axis along which it moves using pneumatic motor.

Structurally, the thermic heater consists of separate blocks of nichrome electric heaters, which are connected in series.

When external surface of the electric heater 8 comes in contact with icy surface 1, the unfrozen patch of water 2 is formed. Electric heater power - 100 kW.

9 - electrolyser for production out of liquid water hydrogen and oxygen.
Electrolysis power - 60 kW.
10 - pipeline for water supply from unfrozen patch of water into electrolyser.
11 - liquefier to convert gaseous components (oxygen and hydrogen) in liquid state
12 – liquid oxygen tank at the exit of liquefier
13 - chemical rocket engine for landing and take-off from the surface of Ceres. Fuel- hydrogen, oxidizer -oxygen. Engine thrust - 12 KN.
14 - fuel tank for chemical rocket engine 13. Oxidizer the engine operation comes from tank 12.
15 - docking unit for connections to the locomotive during refueling.
16 –shock absorber of landing upright
17 – shoe of landing upright

Refueller dimensions: Height-17 m. Diameter-6.0 m. Refueller weight on Earth-26 tons.

REFERENCES