The Application of the Laser Plasma Combined Propulsion Subsystem in God's Grace System

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Guo Zongshuai[1]
N.E.Zhukovskiy National Aerospace University "Kharkov Aviation Institute"61070, Khakov, Kharkov oblast, Ukraine
Nan Chang Institute of Technology, 330013, Nan Chang, Jiangxi, China

Qiu Xiaolin[2] **and Guo Pengfei**[3]
Nan Chang Institute of Technology, 330013, Nan Chang, Jiangxi, China

and

Qian Weiding[4]
Kharkov National Automobile and Highway University,61024, Khakov, Kharkov oblast', Ukraine

Abstract:

The "God's Grace" deep space probe and the loaded comet combined system is designed by our group as a new exploratory mode (that is an economical, namely loaded-by-the-comet mode), which is brought forward during the research and application on the astrophysics and deep space detection technology. According to the research, analysis and demonstration of the relevant information, relying on the special comet orbit, the peculiarity of the flying speed of the comet itself and the energy sources of the probe itself, the probe can be driven forward and detects certain celestial bodies. This project describes the economical, namely loaded-by-the-comet mode and the design plan of the "God's Grace" deep space probe and the loaded comet combined system as well as the system composition, working out the novel configuration and its engineering design, with the illustrations of the operation principle of its subsystems, of its system assembly, and of its components and parts. Besides the scientific objectives are obviously given. Technologically, combining the design idea and experiments effectively, the fundamental system structure and the system testing prototype have been designed. Its research and its further tests as well as demonstration, provides the scientists an opportunity of further creative studies on the moon exploration

[1] Technician The Research Centre of Laser-and-Plasma Combined Rocket Engine in Nan Chang Institute of Technology .Email:guozongshuai@gmail.com

[2] Professor and Doctor Nan Chang Institute of Technology.Email:139709666@163.com

[3] Laboratory Assistant Nan Chang Institute of Technology.Email: 306198151@qq.com

4 Technical Translator Kharkov National Automobile and Highway University.Email:guozshuai@yahoo.com.cn

engineering technique and the deep space detection technique and opens up a bright prospect. One of the scientific pursuits of the God's Grace project is to verify and assess the stability of the probe as well as that of the laser plasma combined propulsion system on each orbiter. The Laser Plasma Combined Propulsion Subsystem(LPCPS) is a brand new propulsion system depending on the research above as well as the research on the propeller of the deep space detector. In accordance with the research and the demonstration of the propulsive theory, and the analysis of the graphic in which the electron in pre-plasma is able to obtain the maximum energy with the mutation in density of the pre-plasma, the high power laser can transfer its energy to the plasma. The Avalanche effect occurs when the high power interact with plasma, and the effect aggrandizes the ionizability of the plasma, and

increases the speed of the ejection of the working substance, thus acquires the higher specific impulse and higher efficiency. This dissertation describes the operation principles of the LPCPS in detail, designs the structure creatively and provides the function diagram. The LPCPS is a highly effective combination of the two advanced propulsion systems, especially when it combines with the God's Grace system, its high efficiency and excellent propulsion performance shows positive creativity and bright prospects.

Nomenclature

F = the incident photon flux density

$\dot{m}_g$ = the high-speed discharge propellant mass flow

u_h = high-speed discharge propellant exhaust velocity

$\dot{m}$ = the propellant mass flow

u = effective exhaust velocity

k = thrust correction coefficient caused by the jet beam divergence

η_m = the propellant efficiency

I_S = Specific impulse

M_s = the instantaneous mass of spacecraft

βF = the effective force of thruster to spacecraft

M_L = mass of structure and payload

M_L = the mass of the power subsystem and power converter control subsystem

M_p = the mass of propellant

t = thruster work time

V_s = the instantaneous acceleration of the spacecraft

β = factor for the effective use of thrust,

η_P = the propulsion efficiency

a = the ratio of the sum of propulsion power

ηt = the total efficiency

Uc = effective characteristic exhaust velocity

W = Pulse laser energy

Cm = the coefficient of momentum coupling

M = the total mass of detector

Δv = increments of flight velocity

P = continuous-wave laser output power

F = thrust

g = The value of space gravitational field

ΔE = Increments of energy

I = laser intensity

ε_0 = vacuum dielectric constant

c = the velocity of light

e = electron charge

m_e = electron mass at rest

w_0 = laser circular frequency

P_{osc} = electronic jitter

I. Explorative targets of God's Grace deep space probe and the loaded comet combined system

A. The explorative targets of God's Grace deep space probe and the loaded comet combined system

1. Soft touchdown object: 67 P/ Churyumov-Gerasimenko
2. Standby objects: Halley's Comet, Tempel 1 comet
3. The first phase of releasing cruising detector, landing and exploring: an asteroid of the asteroid region (Vesta), Jupiter
4. The second phase of releasing cruising detector, landing and exploring: trans-Neptunian objects

(Plutino: Pluto, Charon), Kuiper Belt, Oort cloud.

5. Emative celsestial target a cruise and landing probe(Satum,Neptune,2003UB313) objects.

B. emsion description of celestial bodies that God's Grace deep space probe must fly over

The first explorative task of God's Grace probe (hereinafter it is written "God's Grace probe" for short) is to explore Vesta asteroid all-dimensionally. First of all, God's Grace probe is launched onto its near-earth orbit by the carrier rocket system of God's Grace combined system. After three times' orbital transfers, God's Grace probe is sent to 67P/Churyumov-Gerasimenko, on the first one of the fifth of its journey the orbiter of Vesta orbit subsystem is released from the matrix probe, which continues moving along its preconcerted route. The orbiter of Vesta orbit subsystem flies to the orbit of Vesta. On the orbit of Vesta the orbiter gets to explore the surface of Vesta.

The second explorative task of God's Grace combined system is to detect Jupiter in all directions. On the way of God's Grace probe flying to 67P/Churyumov-Gerasimenko, the orbiter of landing-on-Jupiter subsystem is released from the matrix probe on two of the fifth of its journey. The matrix probe moves along its scheduled route while the orbiter of landing-on-Jupiter subsystem is flying to Jupiter orbit, as well as exploring Jupiter and releasing a lander. When the lander falls on the surface of Jupiter, it releases Shenzhou messeger 1 explorative vehicle which will detect Jupiter all-dimensionally and come back onto the orbit after detection.

The third task of God's Grace combined system is to catch up 67P/Churyumov-Gerasimenko, to implement soft touchdown and to explore 67P/Churyumov-Gerasimenko in all directions. The matrix probe starts carrying through scientific demonstration and turns into dormancy to reserve energy for further exploration on other celestial bodies.

The fourth explorative task is to explore Pluto and its moon-Charon. The matrix probe is static and releases Pluto orbiter. At a certain altitude above Pluto, the orbiter releases a lander and Shenzhou messenger 2 explorative vehicle, which will detect Pluto in all directions. After that the orbiter will fly onto Charon orbit and implement explorative task on Charon.

The fifth task of God's Grace combined system is to explore Kuiper Belt and Oort could. The matrix probe flies away from Pluto with 67P/Churyumov-Gerasimenko, successively entering into Kuiper Belt and Oort cloud and exploring certain celestial bodies. It will detect a certain area of above two objects in detail, draw a flying route of the area, confirms dimensional orientations and implement celestial investigation task.

C. Scientific objectives of "God's Grace" project

1. To test the matching attribute between each system of "God's Grace" deep space probe
2. To test and demonstrate propulsive stability of the laser plasma combined propulsion system applied in the "God's Grace" deep space probe and its orbiters
3. To obtain three two-dimensional and one three-dimensional external images of 67 P/ Churyumov-Gerasimenko, Vesta asteroid, Jupiter, Pluto and Charon by stereo imagers in the "God's Grace" deep space probe and its orbiters.
4. To research physical and chemical characteristics of Vesta , its kinematic attributes(e.g. revolution), asteroid surface and environment of Vesta; to compare external attributes of Vesta and other asteroids to learn about differentiations between various asteroids and interaction between solar wind and Vesta.
5. To research surface physical change and chemical attributes of Jupiter, its kinematic attributes, gas

components, gas flow characteristics and spot change.

6. To observe cometary kinematic trajectory, cometary mass decrement in the dynamic course; to describe nuclei of 67 P/ Churyumov-Gerasimenko and confirm its existing compounds; to research cometary activities and evolutions.
7. To investigate celestial external changes and influencing factors after “God’s Grace” deep space probe’s landing.
8. To research Pluto trajectory characteristics, planetary structure; to measure its volume and draw its scale.
9. To make clear that among recorded comets in human’s history whether some of them that came into the inner solar system were from Oort cloud and some of short-periodic comets were from Kuiper Belt.
10. To protract flying route of the “God’s Grace” deep space probe in Kuiper belt and Oort cloud; to confirm space orientation and complete drawing its celestial survey map.

II. Ystem compo nents of God’s Grace probe

“God’s Grace” deep space probe consists of four great systems: carrier rocket system, ground control and maintenance system, probe combined system and relay communication and transmitting system.
according to various functions and detecting destinations, God’s Grace combined system is divided into 12 subsystems, they are celestial orbit subsystem, tracking-localizing-interfacing subsystem, automatic navigation cruise subsystem, power and thrust subsystem, payload intelligent detection subsystem, near-earth relay communication subsystem, landing-on-comet subsystem, Vesta orbit subsystem, landing-on-Jupiter subsystem, Pluto orbiter subsystem, Kuiper belt cruising detection subsystem and Oort cloud cruising detection subsystem.

Main body of God’s Grace probe consists of a cube integrated module, two oblate oblong integrated modules, three pyramid integrated modules, a circular cone integrated module and a solar panel integrated module.

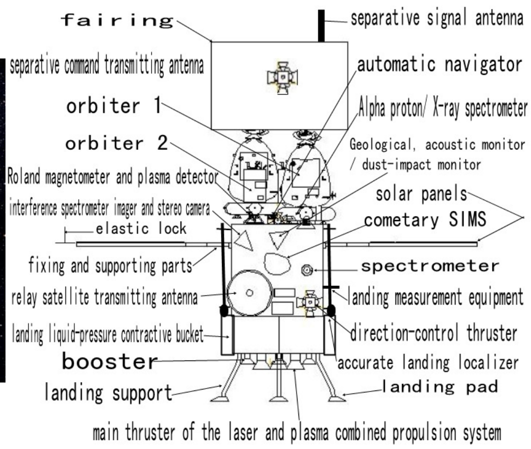


Figure. 1 The integral construction of God's Grace probe

A. Table 1. Dimension of the main body

the cube integrated module	5×5×5M
the first oblate oblong integrated module	5×0.5×5M
the second oblate oblong integrated module	5×0.5×5M
the first pyramid integrated module	5×0.5×5M
the second pyramid integrated module	the first arris is 5M, the second arris is 5M, the third arris is 5M, the height is 1.5M
the third pyramid integrated module	the first arris is 2M, the second arris is 2M, the third arris is 2M, the height is 0.2M
A disk structure	diameter is 2M, thickness is 0.2M
A circular cone	diameter is 1.5M, 1.5M high
A drilling head	1M long
The biggest circular cone integrated module	diameter is 5M, 5.4M high

B. Kuiper belt cruising detection subsystem

The Kuiper belt cruising detection subsystem shares the same systematic structure with the Oort could cruising detection subsystem within the main system of God's Grace probe.

C. Oort cloud cruising detection subsystem

The Oort could cruising detection subsystem shares the same systematic structure with the Kuiper belt cruising detection subsystem within the main system of God's Grace probe.

D. Vesta orbit subsystem

The orbiter of Vesta orbit subsystem is composed by orbit unit, control unit, energy and power combined unit The orbit unit has 8 equipments and 12 assembly units, they are an orbit chamber, connecting parts, a pair of solar panels (2.5 meters long , 1 meter wide), an interplanetary navigator, a data transmitting antenna, an ion/ neutron analysis orbiter and spectrometer, a magnetic mass spectrometer, an interference spectrometer imager, a stereo camera, , an ultraviolet spectrometer, a direction-control thruster, Gamma and X-ray spectrometer, a control-command antenna and a relay satellite receiving antenna.

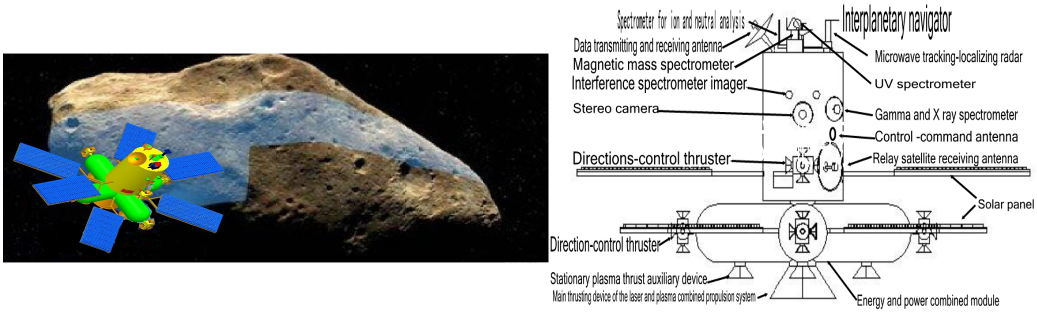


Figure 2. The orbiter structure of Vesta orbit subsystem

The energy and power unit includes energy and power combined module, a pair of solar panels (2.5 meters long , 1 meter wide), a pair of solar panels (1.5 meters long , 1 meter wide) , 1.2.3.4 plasma propulsion systems (Hall thrusting system), laser and plasma combined propulsion system and direction-control thruster.

E. The configuration and design data of Vesta orbit subsystem

- The Vesta orbit subsystem includes a cylinder integrated module, a cross column integrated module, two big solar panels integrated modules and a small solar panel wing integrated module.
- Physical dimension of Vesta orbit subsystem

Table 2.

The cylinder integrated module	diameter is 1.2M, 1.8M high
The cross column integrated module	diameter is 0.72 M, the long side is 3.22M, the short side is 1.61M
The first big solar panel integrated module	a single wing's length is 2.5M, 1M at width, thickness is 0.2 M
The second big solar panel integrated module	a single wing's length is 2.5M, 1M at width, thickness is 0.2 M
The small solar panel integrated module	a single wing's length is 1.5M, 1M at width, thickness is 0.2 M

F. Landing-on-Jupiter subsystem

The orbiter is composed by three main units, they are orbit unit, release-control-return unit, energy and power unit.

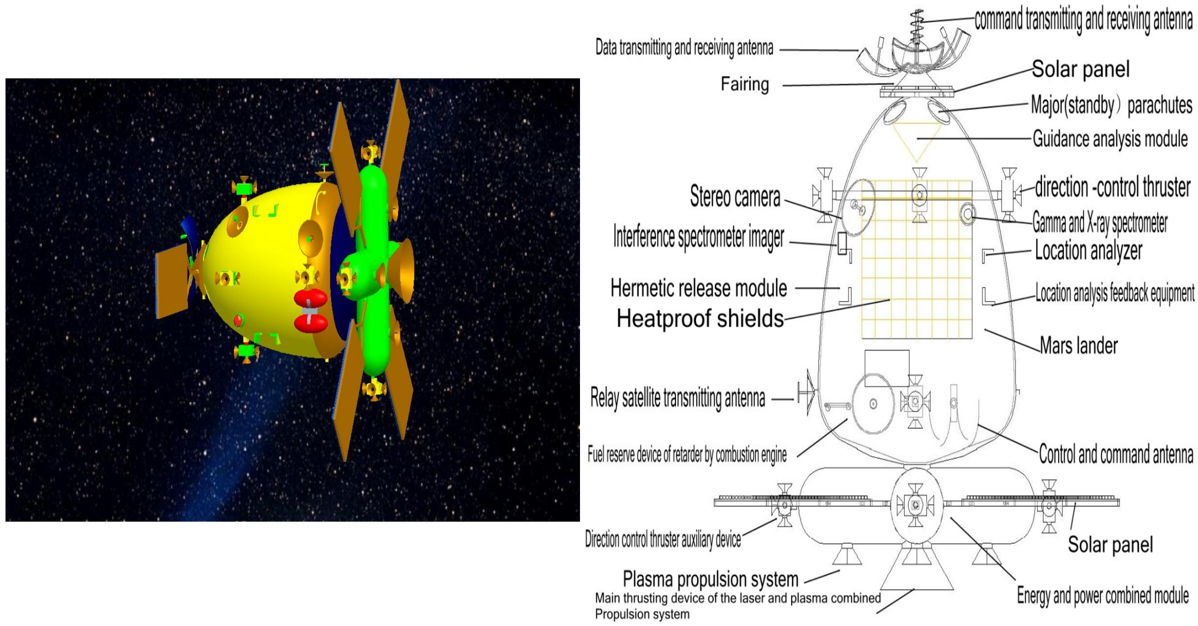


Figure 3. Landing-on-Jupiter subsystem structure and its payload

G.. The orbiter of landing-on-Jupiter subsystem

The orbiter is composed by three main units, they are orbit unit, release-control-return unit, energy and power unit.

The orbit unit includes a main control module, connecting parts between modules, a pair of solar panels (2.5 meters long , 1 meter wide), four data transmitting and receiving antennas, a command transmitting and receiving antenna, fairing, an ultraviolet spectrometer, a navigator and a direction-control thruster and etc. 12 assembly units and 14 equipments.

The release-control-return unit includes 24 assembly units and 6 equipments, they are hermetic release module, guidance analysis module, hermetic module gate, gate opening assembly, heat-proof shields, parachute suite (retarding parachute, major parachute, standby parachute), connecting parts between modules, landing retarder by combustion engine, fuel reserve device of retarder by combustion engine, relay satellite transmitting antenna, control-command antenna, direction-control thruster, interference spectrometer imager, stereo camera, Gamma and X-ray spectrometer, localizer, location analysis feedback equipment.

The energy and power unit consists of energy and power combined module, connecting parts between modules, a pair of solar panels (2.5 meters long , 1 meter wide), a pair of solar panels (1.5 meters long , 1 meter wide) , 1.2.3.4 plasma propulsion systems (Hall thrusting system), laser and plasma combined propulsion system and direction-control thruster.

Table 3.

The tumbler module	the biggest diameter is 2.5M, 3.5M high
Supporting parts of hermetic release module	2×2×2M
The hermetic release module gate	1.8×1.8×1.8M
The cross column integrated module	the long side is 3.22M, the short side is 1.61M, and diameter is 0.72M
The cylinder integrated module	diameter is 2M, 1M high
The four-curved-surface-body module	the biggest diameter is 1.5M

The first big solar panel integrated module	a single wing's length is 2.5M, 1M at width, thickness is 0.2 M
The second big solar panel integrated module	a single wing's length is 2.5M, 1M at width, thickness is 0.2 M
The small solar panel integrated module	a single wing's length is 1.5M, 1M at width, thickness is 0.2 M

1. Pluto orbiter subsystem

The Pluto obiter subsystem includes a tumbler module, a cross column integrated module, a circular cone integrated module, a four-curved-surface-body integrated module, two big solar panel integrated modules and a small solar panel integrated module.

Physical dimension of Pluto orbiter subsystem.

2. (Table4) The configuration and design data of Pluto orbiter subsystem

The tumbler module	the biggest diameter is 2.5M, 3.5M high
Supporting parts of hermetic release module	2×2×2M
The hermetic release module gate	1.8×1.8×1.8M
The cross column integrated module	the long side is 3.22M, the short side is 1.61M, and diameter is 0.72M
The cylinder integrated module	diameter is 2M, 1M high
The four-curved-surface-body module	the biggest diameter is 1.5M
The first big solar panel integrated module	a single wing's length is 2.5M, 1M at width, thickness is 0.2 M
The second big solar panel integrated module	a single wing's length is 2.5M, 1M at width, thickness is 0.2 M
The small solar panel integrated modulea thickness is 0.2 M	single wing's length is 1.5M, 1M at width,

H. dynamic energy supply sub-system

In accordance with the Application of the Laser Plasma Combined Propulsion Subsystem in God's Grace System, choosing dynamic and energy system, considering how to realize in our project, meanwhile, according to international dynamic and energy deep space probe, we choose dynamic and energy sub-system as Vesta.

According to "God's grace ", comet orbit mission deep space probes to detect objects and goals, the choice of power and energy subsystems, considering this project in the realizing of power and energy, but also according to international power deep space probes and the reference energy system. And ultimately we use the following power and energy as the main propulsion power subsystem (device) system.

Aircraft main propulsion power (device) system.

Table 5

No.	the name of dynamic energy supply sub-system	numbers

1	Laser plasma combined integrated apparatus LPCPSLaser plasma combined integrated apparatus propulsion systems	5
2	Lithium - Loren magnetic thrusters (Lithium - Lorenzen magnetic propulsion system)	6
3	Plasma thrusters (Hall propulsion system SPT - 100)	32

III. Laser Plasma Integrated Propulsion Sub-system

This thesis deeply probes the electric rocket and puts forward a newly rocket propulsion sub-system---Laser Plasma Integrated Propulsion Sub-system.

Based on the electric rocket propulsion technology, this thesis proposes and demonstrates a new type of rocket propulsion technology in-depth ---combined laser-plasma rocket propulsion subsystem.

A. Definition of the Laser and Plasma Combined Propulsion System

Under the condition of ionization in the high-voltage plasma flow, the spacecraft carried the neutral propellant (Xenon),. Plasma flows into the main channel and the role of strong laser pulses to increase the ionization degree after the formation of high-energy high-speed particles.The role of the electromagnetic accelerator, the spray from the nozzle at high speed, counter-productive thrust which push forward the deep space probes of the special flight rocket engine.

B. The Laser and Plasma Combined Propulsion System

1. Xenon storage: tank, ventilation flow control, flow control pumps, micro flow control valve.
The gas propellant—xenon:

2. Laser generating apparatus: flying second(10^{-15}) Solid-state lasers , focus lens, beam expander etc.

3. Plasma generation apparatus: plasma generation apparatus (plasma), electrode, electromagnet, electro-insulation, energy supply etc.

4. Effect room, main propulsion nozzle

5. Electromagnetism accelerator apparatus
ing field coil, pole field coil, neutralization ect.

6. Power supply: mains, solar panels, wind surfing attitude control, current control devices, propeller brackets, the module circuit board etc..

7. Vacuum chamber system: Spherical main vacuum chamber
(Stainless steel ball) Turbo molecular pump, mechanical pumps, solenoid valves, gate valves, main frame, automatic controllers and other components.

8. Measuring devices: gas flow meter, plasma diagnostic probes, spectroscopy, high-imaging cameras, laser intensity measuring instrument, measuring the thrust device (electromagnetic balance), compound vacuum gauge etc.

C. The Laser and Plasma Combined Propulsion System.

(Figure 4 shows), Under the effect of the high-voltage electrons from the cathode to the anode, launching into the discharge chamber, and the gas propellant - Xenon also be injected into the discharge chamber. Xenon atoms and electrons collide, the collision part of the nucleus after the xenon electrons will hit open, making the xenon atoms are ionized, after re-ionization laser pulse increased ionization degree, and then through the electromagnetic accelerator, the ionization of the ion movement is faster, the formation of high-density plasma flow ejected from the ion generator nozzle. Finally, after the electronics and to collect excess spray and put them into the plasma stream (to prevent engine wear a lot of positive charge), high speed from the engine exhaust nozzle to produce reaction thrust to promote the deep space probe flight.

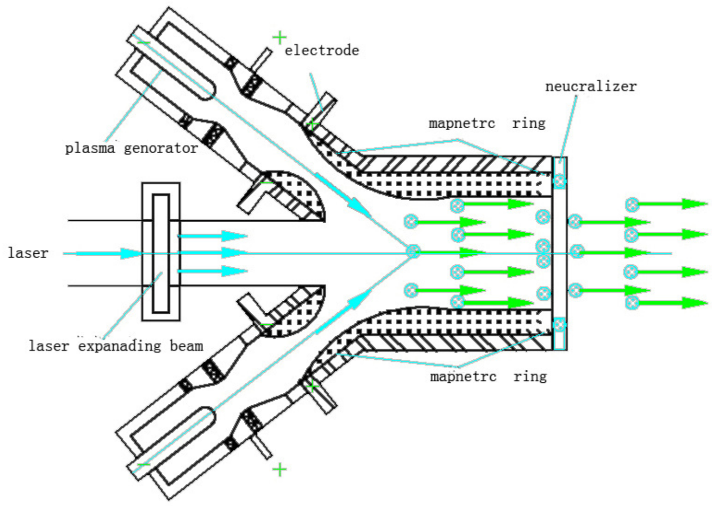


Figure 4: The operation principle of the laser and plasma combined propulsion system

D. The plasma apparatus

The plasma generation apparatus has two electrode s--positive one and negative one, which forms a plasma passage with the electro-insulation sidewall. This sidewall is vertical with the electricity field with its intensity of E, meanwhile, goes through the magnet flow, which was generated magnet induction B by electromagnet. Then plasma will be generated in the plasma generator, then go into the accelerator. Since plasma is electrified body, in the electromagnetic accelerator, electric current will runs through plasma from the positive electrode to the negative. And it is learnt from the theory of electromagnetic-field acceleration, that acted by both the electrical and the magnetic fields, plasma will shoot out toward the outlet of the electromagnetic-field accelerator at a high speed. In the hydrogen plasma with its temperature of leV, its positive ion moves at an average of 1.56 x 104 m/s, its electron movesat an average of 6.7 x 104 m/s.

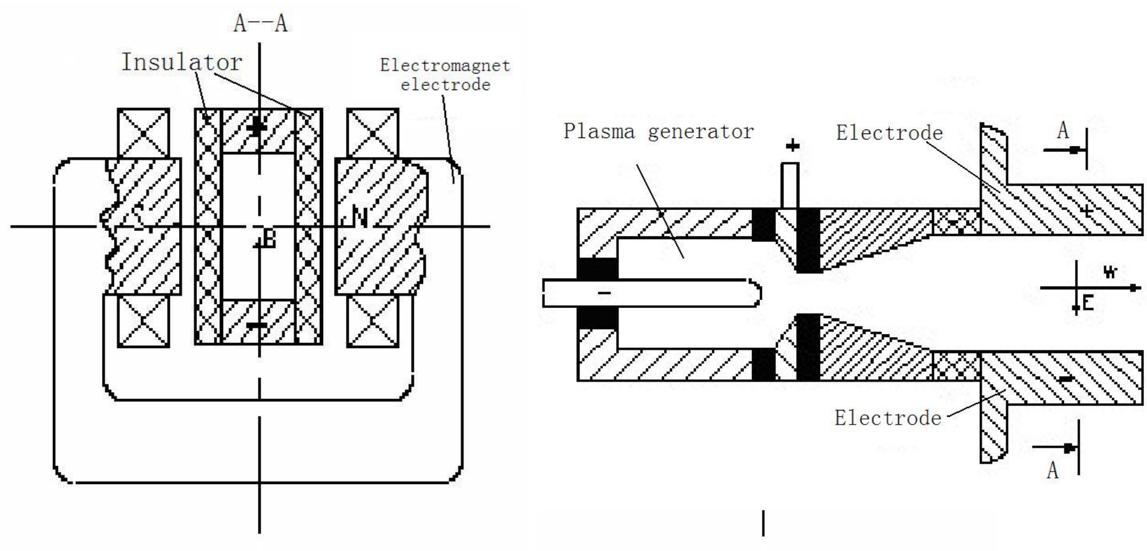


Fig5. the principle operation of plasma generator

The Laser and Plasma Combined Propeller have four hollow cathode, among three of them are Main cathode, anther is Neutralizer cathode.

.Main cathode lies in the discharge room, originating in the primary electron which cylindrical anode and the discharge chamber in the joint action of the magnetic field.

Accelerating spiral along Magnetic line to the anode, high-energy electrons with neutral gas molecules collide with indoor, the gas part of the ionization in the discharge chamber to form plasma.

Plasma ion and laser photon will have avalanche effect, the energy increasing, under the action of the screen grid and acceleration grid,to form an ion beams, high-speed spray to space, to generate thrust.

Neutralizer cathode ion beams produces equal electron to flow to neutralize the beam space charge, which this charge can be avoided charged with electricity due to God's Grace exploreWorking gas (in space technology, the hollow cathode of the working gas is usually Xe) enter into the cathode tube, under the action of cathode tube, of the pressure is usually higher several orders of magnitude than outside the hole, approximately up to 1 ~ 2 kPa. Using the heater will slowly heated to 1300 K or so, most of the cathode in contact who added the ignition voltage of about several hundred volts, the emitter and the ignition gas discharge between electrodes.

Setting up gas discharge in the cathode tube to produce high-density plasma, the surface of the emitter-scale sub-micron scale for the plasma sheath, formed on the surface of the emitter 10 V / m of the strong electric field, leading to emitter produce field enhanced thermal emission, the initial electron emission, accelerating in the double sheath potential space under the barrel oscillation in the cathode and the collision with Xe atoms, the ionization step by step approach based ionized Xe atoms, the plasma cathode tube body is maintained; the same time, plasma ion emitter surface in the double-sheath acceleration, the constant bombardment heating emitter, to maintain the temperature of the cathode emitter, this time, turn off the heater power, will hold pole switch to the touch 8 ~ 20 V power supply on the pole holding the touch, the hollow cathode in a self-sustaining hot-cathode arc discharge state. In a state of self-sustaining arc discharge inside the hollow cathode plasma density of 10 20cm 2 3, then, if the downstream hollow cathode potential is higher than most potential contacts who will be in the leads from the hollow cathode electron; if the potential is lower than the downstream hollow cathode great potential contact who will be in the leads from the hollow cathode plasma.

E. **The analysis of the Laser and Plasma interaction and analysis of energy**

From point of the micro-view mechanism, laser
the role oflaser is the role of free electrons in the material or bound electrons on high-frequency electromagnetic field.

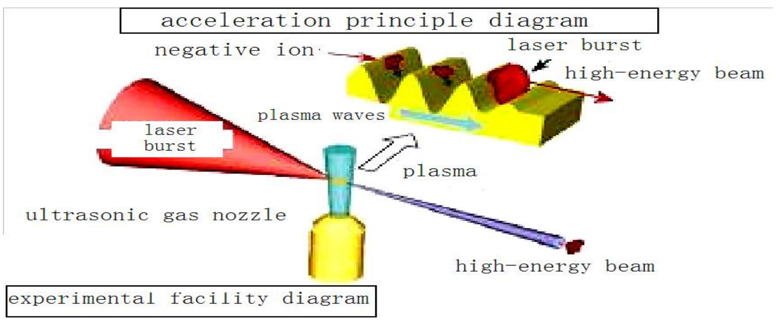
The absorption of the laser is related with its physical structure and electronic band structure.

High-density plasma flowing through the electromagnetic accelerator is subject to strong laser bombard further, and thus enhancing the charge separation with pulsing laser to pass part of the energy to the plasma flow. Between electron and ion collision more intense, the particle flow can be increased, the formation of high-energy high-speed particles.

The absorption of Laser energy can be realized by the plasma in the electronic.

Laser spreading in plasma, laser electromagnetic field is under the control of electronics. Because light itself is the high-frequency oscillations in the electromagnetic field, electrons in the high-frequency oscillations is accelerated by electromagnetic field to get energy, some electrons are heated to a higher energy state , then these electrons and the surrounding electrons, ions, atoms, photons Coulomb collisions, the electron energy is transferred to the plasma, and plasma through conduction, convection, and radioactive transfer to the surrounding cold refrigerant. Completion of the process from laser to energy emitted by the fuel work

Plasma is ionized gas under the special conditions .Laser in the plasma transfer, except for generating Electron inverse bremsstrahlung absorption, still have classical but there are still some classic anomalous absorption mechanisms (such as resonant absorption), and there are various interactions among waves and plasma , ion-acoustic waves.



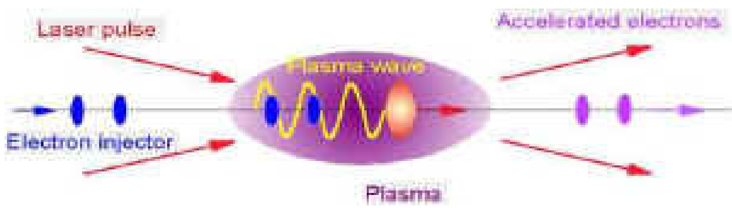


Figure 6. The micro-viewing of laser and plasma accelerting principle

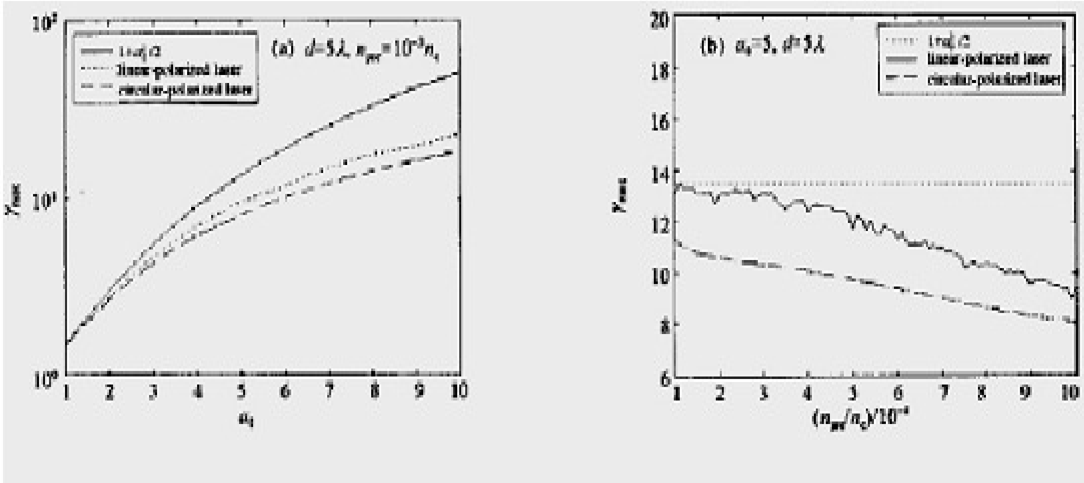
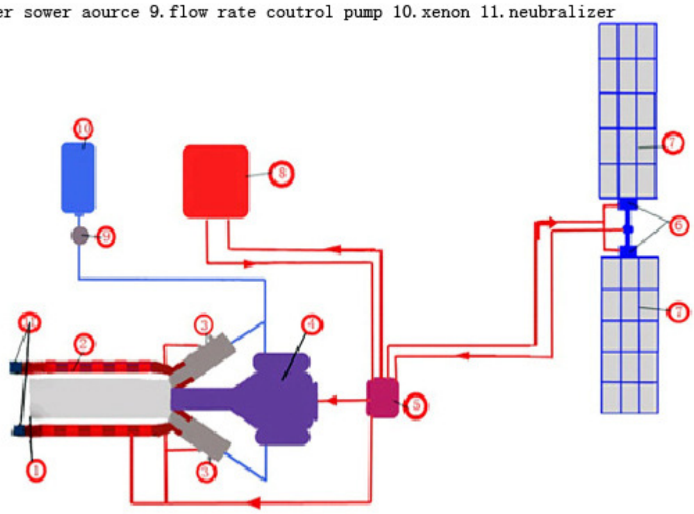


Figure 7. Dependsences of the maxinum electron energy of the laser intensity and piasma density

1. nozzel 2. eletromapnetic acceleration coil 3. plasma genorator lasers 4. lasers
5. currency regulator 6. currency regulator 7. solar energypanel substrate
8. power sower aource 9. flow rate coutrol pump 10. xenon 11. neubralizer



Tigure 8: The technological process flow of the laser and plasma combined propulsion system

F. Combined laser-plasma rocket engine operating in various characteristics of the structure

1. Laser parameters

Tigure 9. Femtosecond□ 10^{-15} □□ Solid-state lasers Figure

Laser Name Femtosecond Solid-state lasers Figure

The wavelength of pulsed laser 1.06 um

The width of Pulsed laser ≥100 fs

Repetition rate of pulsed laser ≥10HZ

Intensity of pulsed laser ≥ 10^{15} w/cm^2

Energy stability ± 3

Single pulse energy 2000MJ

2. Plasma generating device-related parameters

Plasma generators (plasma source, xenon or helium and nitrogen refrigerant),,electrode, electromagnet, insulators, energy supply and other components. Plasma generating device ignition voltage: 300VDC; Power: 1400V.

3. Laser re-ionization process

When the Xe atoms by strong laser irradiation, due to the photoelectric effect or effects of photon absorption of sufficient photon energy and ionized.

When the laser photon energy is greater than the ionization potential of Xe E, single-photon ionization may occur. When the ionization potential of Xe atoms close to a number of times the laser photon energy, the ionization potential multi-photon absorption. The conditions require photon absorption occurs, the laser wavelength satisfy the following inequality. Absorption of laser energy and heat up the gas and cause ionization and the absorption coefficient further increases, helps form the plasma.

Multi-photon absorption process refers to an atom simultaneously absorbs *K* photons, whose total energy not less than the atomic ionization potential, making it ionized. Assuming there are K virtual atomic level states, while absorption of *K* photons, equivalent to the gradual absorption single photon, the state gradually increased along the imaginary level, reaching *Kth* level that is true of virtual ionization state. Each virtual level changes on the atomic number is equal to its level below the transition to the second level, minus its top level transition and the instinct to the level of the atom number difference of attenuation, and then we can find the *Kth* level atoms, which ionization rate ω expression:

$$\omega = \frac{\sigma^k F^k}{\nu^{k-1}(K-1)!} = A_1 F^k \qquad 1$$

σ is a cross-section of level up , F is the incident photon flux density (per unit time by the number of photons per unit area), ν is excited atom photoionization frequency. A_1 is atomic ionization probability per unit time occurred under per unit stream of photons. Photon flux density of the laser beam and its pattern of polarization-related, not according to the type considered, the general assumption that: $\omega = \frac{N_1}{pn_0 v_\tau}$ (N_1 a gas laser irradiation the number of ions generated, p is the initial gas pressure, v and τ are the volume and the laser discharge zone radiation attenuation, Luo Xi Schmidt number $n_0 = 3.56 \times 10^{16} / cm^3$.)

In the role of intense laser pulses, laser plasma in the focus areas of high electric field acceleration, plasma collide with each other, lose more electrons to increase the number of free electrons, so continuous collision, become electronic collapse.

Cascade ionization process due to factors of loss such as diffusion, adsorption and complex , making the number of free electrons and the total energy reduction is the loss factor must be considered. When the electron concentration is not very high composite loss is negligible, r_e and r_a are the electron production rate and absorption rate, A and Λ are the electron diffusion coefficient and diffusion characteristic length, then the free electrons of the rate equation can be written as $\partial Ne / \partial t = (r_e - r_a - \mathrm{A} / \Lambda^2) Ne$ 2 integrate it to get the free-electron production rate at the end of laser pulse $r_e = \frac{1}{t_p} \ln[\frac{N_e(\tau)}{N_{e0}}] + r_a + \frac{\mathrm{A}}{\Lambda^2}$ $(t = t_p)$ (3)

On the other hand, r_e multiplied by ionization potential E_1 should be equal to the electronic unit of time obtained from the optical field energy $e^2 \wp^2 v_c / m_e(\omega^2 + v^2{}_e)$ minus other energy loss $\Delta\omega$, so the export intensity of the laser should satisfy the formula:

$$I = \frac{\varepsilon_0 c m_e (\omega^2 + v^2{}_e) E_1}{e^2 v_c} \left\{ \frac{1}{t_p} \ln[\frac{N_e(t_p)}{N_{e0}}] + r_a + \frac{\mathrm{A}}{\Lambda^2} + \Delta\omega \right\}$$

4. Electromagnetic acceleration apparatus

It is learnt from the principle of the electromagnetic acceleration, varying magnetic field generates electric field, and varying electric field generates magnetic field, which is the two great mainstays of Maxwell theory. Electrified particle will be acted on by Ampere's force in electric field, and by Lorenz's force in magnetic field, while the difference is, in the electric field, electrified particle will be accelerated by the Ampere's force; in the magnetic field, only will the direction of movement of electric charge be changed, not the speed. Namely, Lorenz's force will not work done on moving electric charge. What are discussed here is the condition that the two fields exist at the same time.

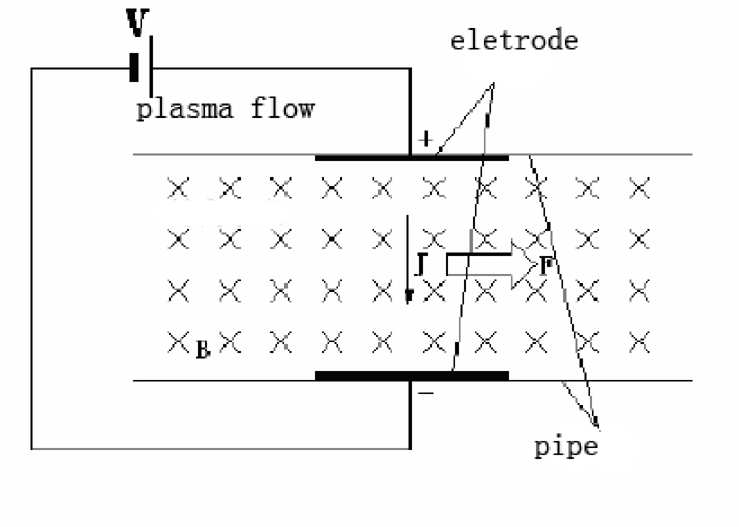


Figure 10. The basic operation principle diagram of the magneto-fluid thruster

Hereby, we'll describe the process of electromagnetic acceleration:In the electric field *E*, the electrified particle q is acted on by the electric-field force $F_{e,}$, F_e=q E , the speed is v; in the magnetic field B, the electric charge q is acted on by the magnetic-field force $F_{m,}$ F_m =q V B. If it is a area with two fields existing at the same time, thus in this area the force acting on the moving electrified particle will be the sum of the two vectors mentioned above, namely, $F = q\ E + q\ V\ B$. According to this, the movement of electrified particle can be regulated by adding electric or magnetic field.

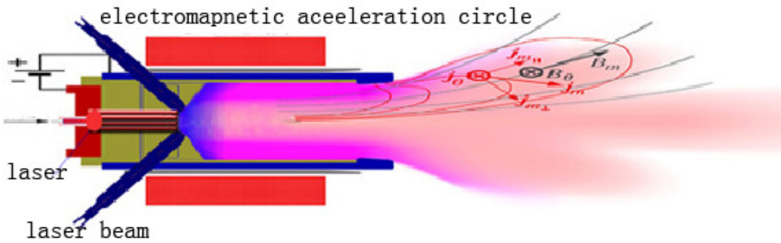


Figure 11. How the ion is, in the electromagnetic field, acted on by force

5. The index of the vacuum room system of the The Laser and Plasma Combined Propulsion System

The vacuum room system consists of the main spherical vacuum room (stainless sphere), vacuum system (turbine molecular pump, mechanical pump, electromagnetic valve, gate valve, main frame), components of the laser plasma system, and control system(automatic controller). The function of the vacuum room system is to provide a laboratory as well as a working environment. Its main pumping vacuum pump is a turbine molecular pump of 1500L, which connects with the main vacuum room by the vacuum gate valve. Still, the system is installed pre-drainaging line, inflation line and combined vacuum-meter, whose measurement, as to atmosphere pressue, is not above 1 x 10^{-3}pa, and whose chief pump is a mechanical one of 8L. Besides, the environment the vacuum room system provides for experimenting and working is 1 x 10^{-3}pa, The Laser and Plasma Combined Propulsion System (The main vacuum room of the spherical vacuum condition system) is shown in the Drawing 12.

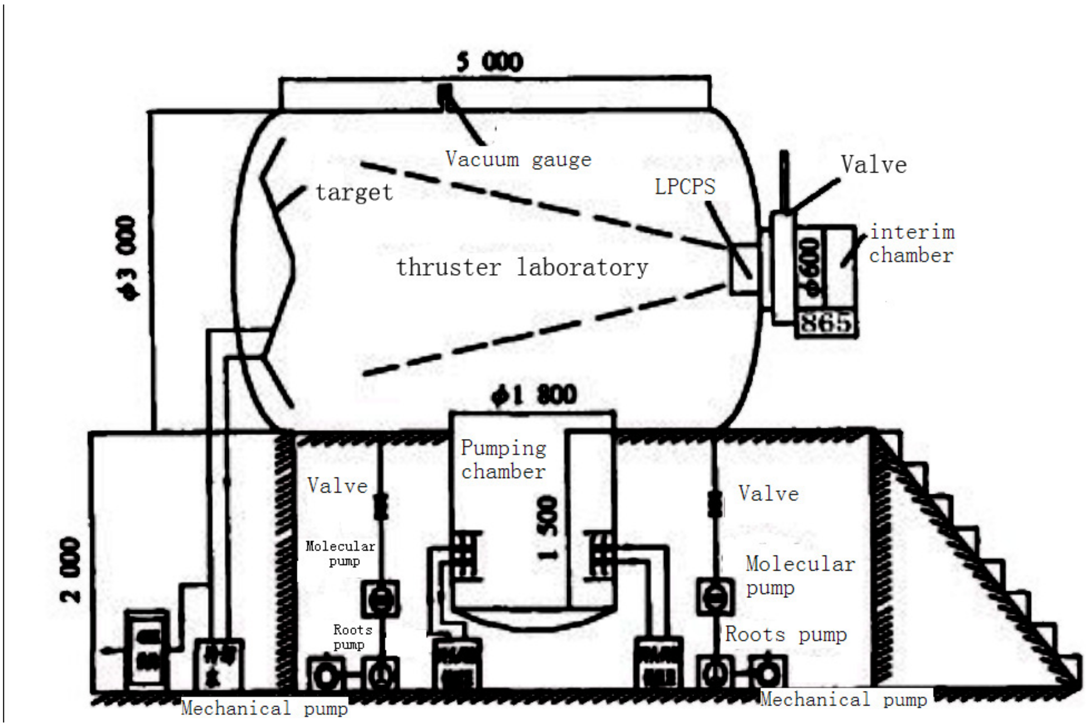


Figure 12: The Laser and Plasma Combined Propulsion System structural representation

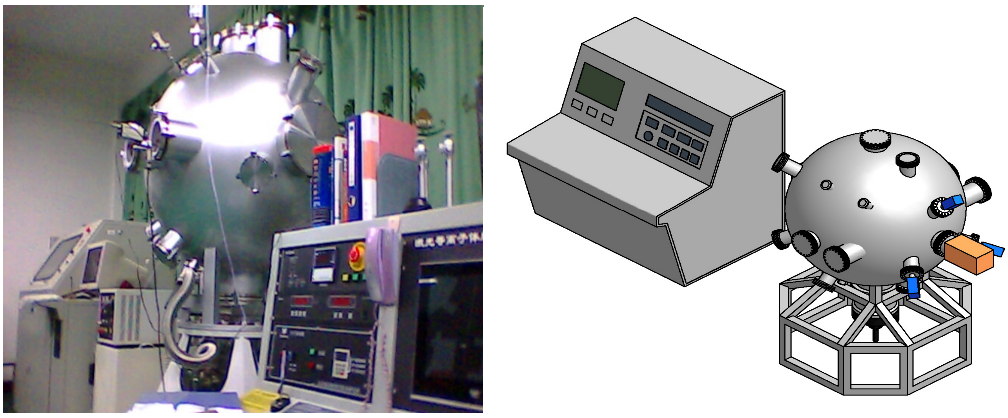


Figure 13: The prototype of ground experimental spherical vacuum condition system of The Laser and Plasma Combined Propulsion System

IV. The deducing process of the index of Preliminary estimates on the engine performance

The basic relation among arcjet impulse, electromagnetic field intensity, and laser intensity parameter:

propulsion $F = k \dot{m}_g u_g = \dot{m} u$ 5

In the formula(5), $\dot{m}_g$ is the high-speed discharge propellant mass flow; u_h is high-speed discharge propellant exhaust velocity (= 45KM / S); $\dot{m}$ is for the propellant mass flow rate; u is effective exhaust velocity; k is thrust correction coefficient caused by the jet beam divergence and so on. Among them, the high discharge of propellant mass flow can be expressed as:

$$\dot{m}_g = \eta_m \dot{m} \quad 6$$

effective exhaust velocity can be expressed as:

$$u = k\eta_m u_g \quad 7$$

In the formula (7), η_m is the propellant efficiency

"Specific impulse (I_S)" in the international system of units and the national standard unit system, the engine I_S is defined as the generated thrust by consumption of per unit mass flow of propellant, it can be expressed as:

$$I_S = \frac{F}{\dot{m}} \quad 8$$

Assuming the spacecraft is only affected by the engine thrust, without considering the role of aerodynamic and gravity, and the engine specific impulse and thrust keep the same; during the engine worktime, the instantaneous mass of spacecraft (M_s) and the effective force of thruster to spacecraft (βF), respectively, can be expressed as:

$$M_s = M_L + M_L + M_p - \dot{m}t \quad 9$$

$$\beta F = M_s V_s \quad 10$$

In the above formula, M_L is structure and payload mass, including the quality of the engine and the dry mass of propellant storage and delivery subsystem; and M_L the mass of the power subsystem and power converter control subsystem (hereinafter referred to as power quality); M_p the mass of propellant; t is working hour for the engine; V_s is the instantaneous acceleration of the spacecraft; β is factor for the effective use of thrust, and it's related with the thrust vector, the desired angle of needed thrust direction and the spacecraft orbit etc.

Propulsive efficiency, also known as "external efficiency", showed the propulsion power level changed from jet kinetic energy which produced by the engine. η_P η_P is defined as the propulsion efficiency made by the unit time engine to the aircraft, the propulsion engine power and the energy loss.

$$\eta_P = \frac{F_v}{pv + \dot{m}(u_e - v)^2/2} \quad v\text{——speed of the aircraft } 11$$

$$M_W = \frac{P}{a} \quad (12)$$

a is the gross ratio power of the power subsystem and the power converter and controller subsystem (hereinafter referred to as the power gross ratio power).

$$M_W = \frac{M_P u^2}{2k^2 \alpha \tau \eta_e \eta_m} = \frac{M_P u^2}{2k^2 \alpha \tau \eta_t} \quad (13)$$

In the formula(13), η_t the total efficiency of the electric propulsion system, and $\eta_t = \eta_e \eta_m$

.

$$\frac{M_W}{M_P} = \frac{u^2}{2k^2 \alpha \tau \eta_t} = \frac{u^2}{u_c^2} \quad (14)$$

Uc --------- effective characteristic exhaust velocity of electric propulsion system

$$u_c = k\sqrt{2\alpha \tau \eta_t} \quad (15)$$

$$\frac{M_L}{M_0} = \left(1 + \frac{u^2}{u_c^2}\right) e^{-\frac{\Delta V_s}{\beta u}} - \frac{u^2}{u_c^2} \quad (16)$$

$$\frac{u^2}{u_c^2} = \frac{2\beta}{\Delta V_s} \left(e^{-\frac{\Delta V_s}{\beta u}} - 1 \right) - 1 \quad (17)$$

$$I_s^* \approx u_c . \quad (18)$$

$$I_s^* \approx \frac{u_c}{\sqrt{2}} . \quad (19)$$

$$\Delta V_s < \beta u \quad \Delta V_s << \beta u$$

$$\tau = M_0 \frac{u}{F} \left(1 - e^{-\frac{\Delta V_s}{\beta u}} \right) \approx \frac{M_0 \Delta V_s}{\beta F} . \quad \mathbf{(20)}$$

$$\alpha_1 \left(\alpha_1 = \frac{P}{M_1} \right) \quad \alpha_2 \left(\alpha_2 = \frac{P}{M_2} \right) . \quad \mathbf{(21)}$$

$$\alpha \approx \frac{\alpha_1 \alpha_2}{\alpha_1 + \alpha_2} . \quad (22)$$

Pulse laser energy is W, the coefficient of momentum coupling of the God’s Grace detector's momentum coupling is Cm, God’s Grace system gross mass is m; increment of flight velocity is Δv, or continuous-wave laser output power is P, generated propulsion is thrust F, then

$$C_m = \frac{m \Delta v}{W} = \frac{F}{P} . \quad \text{□23□}$$

$$Q^* = \frac{W}{\Delta m_o} \quad (24)$$

$$C_m Q^* = v_{av} = g I_s . \quad (25)$$

$$2\eta_{AB} = \frac{\Delta m v_{av}^2}{w} = C_m^2 Q^* = g C_m I_s = C_m v_{av} . \quad (26)$$

$$\eta_{AB} = \frac{E_k + \Delta E}{E_{laser}} . \quad (27)$$

Tthe plasma spray mass of laser-assisted ionization is Δm, average speed is Vav, the incident plasma energy per unit mass (specific energy) can be expressed as $Q^* = \frac{W}{\Delta m}$

g=ga-------------- The value of space gravitational field
Is---------------------Impulse
ΔE=ΔEB------------ Increments of energy

Active mode-locking is one of the main techniques to generate ultrashort laser pulses, because of the output pulse in this way of mode-locking has characteristics of high stability, high average and high repetition rate. Currently used the diode laser as pumping source, the researchers have done a lot of continuous frequency modulation and passive mode-locking laser researchs, and successfully obtained high-power continuous laser and a width of ns, several ps and fs magnitude pulse laser.

In the laser - plasma interaction process, the suprathermal electron can be generated through a different mechanism of absorption or heating, and the mechanism of absorption or heating is sensitive to laser parameters, because many of the basic nature of the plasma is controlled by the strong laser field rather than by its own density and temperature.

Resonance absorption and vacuum heating mechanism: to determine whether these two mechanisms are being stimulated, first to calculate the laser electric field amplitude:

$$E_0 = (2I/\varepsilon_0 c)^{1/2} = 2.75\times10^3 I^{1/2} \quad (28)$$

In the above formula:

I——laser intensity

ε_0——vacuum dielectric constant

c——velocity

Put $I = 7.0\times10^{17} Wcm^{-2}$ into the above formula, you can get $E_0 = 2.3\times10^{12} V/m$

So electronic jitter amplitude can be expressed as:

$$X_{osc} = eE_0 / m_e w_0^2 \approx 0.1\lambda \qquad (29)$$

In the above formula:

e——electron charge

m_e——electron rest mass at rest

$w_0 = 2\pi c / \lambda$——laser circular frequency

As the vacuum heating requires $L = X_{osc}$, resonance absorption requires $L >> X_{osc}$, for our experimental conditions, the plasma scale length $L = (1 \sim 2)\lambda$ or $L = (10 \sim 20)X_{osc}$. Therefore, the resonance absorption is the primary heating mechanism.

Ponderomotive force heating mechanisms:

normalized momentum from the electronic jitter

$$\alpha = P_{osc} / m_0 c = eE_0 / m_e w_0 c = 8.53 \times 10^{-10} (I\lambda^2)^{1/2} \qquad (30)$$

In the above formula, P_{osc} is electronic jitter; λ is in μm. Put $I = 7.0 \times 10^{17} W \bullet cm^{-2}$, $\lambda = 0.8\mu m$ into the formula, you can get

$$\alpha = 0.57 < 1 \qquad (31)$$

Therefore, in the different reference coordinate $V \times B$ heating is not the dominant heating mechanism, Moreover, acceleration of electrons of this mechanism is along the propagation direction of laser and placed in inconsistent position against the electronic magnetic spectrometer; Besides, $V \times B$ heating requires vertical incidence of laser. But in experiment, the laser incident at an angle of 45°. However, if α <1 , the radial component of the ponderomotive force.

$F_r = -(e^2 / 2mew_o{}^2)\Delta_r$ (E) electron acceleration is along the vertical direction of Laser (the same with the reflection direction).

Under normal circumstances, the suprathermal electron, generated by laser - plasma interaction, whose energy spectrum distribution is the Maxwell, there is a proper given temperature scaling law:

$$\frac{Th}{[keV]} = \alpha \left(\frac{I\lambda^2}{[10^{17} W \mu m^2 cm^{-2}]} \right)^{1/3 \sim 1/2} \qquad (32)$$

For moderate-intensity short-pulse, the index is 1 / 3, given our experimental temperature $Th = 165keV$. The suprathermal electron energy spectrum fitted temperature (530 and 85keV) are not satisfied with this law, mainly due to the platform has changed the type of suprathermal electrons Maxwell distribution

V. Combined laser plasma promotion subsystem performance indicators

(Table 6)

Name of the Propulsion system	Laser Plasma Combined Propulsion Subsystem LPCPS
Application	God's Grace Comet and Deep Space Exploratory System Number of LPCPS 5 God's Grace System noumenon applies the LPCPS□1 Vesta Orbiter subsystem LPCPS:1 Jupiter Landing Subsystem LPCPS:1 Pluto Orbiter subsystem LPCPS:1 Alternate Vesta orbiter subsystem LPCPS:1
Propulsion Type	Basic Propulsion
Propellant in the protophase of the ground experiment Propellant in the formal ground experiment	Mixed gas of helium and nitrogen Xenon
Propellant in space application	Xenon
Flow of the working medium in the system	Xenon in A1 .24 mL/s Xenon in A2 .20 mL/s Xenon in A3 .24 mL/s Xenon V Total .68 mL/s Nitrogen .40 mL/s Helium . mL/s Mixed gas of helium and nitrogen . mL/s
Output energy of the high power laser system	2000mJ
Specific Impulse	4700 s
Force	0.6—0.8N
Times of laboratory experiments(planned)	First term 1200 middle term 4800 Later term 18000
Expected laboratory working hours	First term 102 middle term1680 Later term 28000
Efficiency	85□

VI. Conclusion

As the deep space exploration technology continues to evolve, the requirements of objectives and tasks of the space is ever increasing, the difficulty of space missions is also increasing, such as interplanetary exploration and so on. The completion of these space missions requires detector system to be intelligent, high efficient, more energy saving, and to have advantages of long life, all-weather Sky Survey, and the accuracy of probe target. Deep space exploration technology is expanding to deeper space.

The proposal and future application of “God’s Grace” deep space probe and the loaded comet combined system has shown its high intelligence, high efficiency, more energy saving and long life advantages, and it is difficult for the conventional detector system to achieve. The innovation of “God’s Grace” deep space probe and the loaded comet combined system is based on the energy saving concept of each country's designed deep space probes, the innovation proposed and applied energy-saving and comet carried explorion model, in other words, detector is carried by comets and combined into a joint system model to detect the target in an economic way. The concept and technology of the platform model is today deep space exploration's innovation, which has the potential for development in the future. Completion of deep space exploration missions requires rocket propulsion systems to have high efficiency, more energy saving, and long life advantages. Electric rocket propulsion systems in engineering applications has shown high specific impulse, high efficiency and long life advantages which chemical rocket propulsion systems can be difficult to achieve. Combined laser plasma in the electric propulsion subsystem is based on electric propulsion and developed as a more advanced new propulsion system. The theory and technology is an advancing technology innovation in today's deep space exploration, and is potential for the development in the future.

This article made a systematical introduction to the process of the combined laser plasma subsystems' work in physics, according to the feasible data obtained from experimental verification program in the experiments. The prototype is in development, and the application of the “God’s Grace” deep space probe and the loaded comet combined system is feasible in our country's future projects. The propulsion technology for deep space exploration can provide a reference in the future international deep space exploration technology research activities, and have broad prospects for development and application.

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