A New Kind of Ion-Engine

An idea for future developments

This is about the development of rocket-engines especially ion-engines used for small space-crafts and an idea to use laser-accelerated ions to come to a tabletop device named LIEBLA that maybe one day will navigate space-vehicles across the sky.

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Motivation
Since anno 1232 when Chinese used rockets for the first time to scare their enemies’ horses, the rocket-development has come a long way. The technology we have now brought us a lot of achievements, like satellites we send out of our solar system or brought mankind to the moon. But still there are a lot of problems that make the development and usage of rockets for space-flights really expensive and still cause a lot of thinking to accomplish different missions. With retirement of the Space-shuttles the big authorities like NASA and ESA still search for better possibilities to get into and operate in space. One of the main goals is to find a kind of rocket-engine that is useable for a long time and do not need a lot of fuel-quantities. There are some types of engines who already have those abilities but where ever to look this technologies still got problems like a to high requirement of wattage or that they just give to less impulse. One of those is the ion-engine who is already used in light satellites to control the angular turning.

Ion-Engine's
This kind of engine normally works with a gas that will be ionized in the first step and accelerated to its exhaust-velocity in the second step. So the total gained impulse just comes from some fast exhausted ions and gives enough impulse to accelerate the space-vehicle.

\[ I = v_e m_f \]

The development of ion-engines started in the 1960s, where cesium- and mercury-drops were the used as fuel. One of the big problems in this time was the corrosion of parts in the engine where ions are created. In this time actually the gas xenon is used as fuel that can be ionized much more easily than liquid metal-drops. But there are still problems like the energy-hunger or the charge-separation and that they do not work in a vacuum.
One light satellite that has an ion-engine is SMART-1. Its engine exhausts xenon-ions to get a thrust of 70 mN. This sounds in comparison with chemical engines like nothing, but the relation of working-time although shows that a ion-engines can work over month and so like thousand times longer than chemical-fuel driven engines. If we now look insight of a typical setup (see picture below) from an ion-engine we see a chamber where neutral atoms are ionized by fast flying electrons which are created from a cathode in the back of the cabin. After the ionization the electrons are collected on the side of the chamber to bring them to another cathode and into a beam that neutralizes the ejected plasma to prevent the space-vehicle from getting charged. The heavy ions drift slowly to the acceleration-segment where a potential-difference between two grids of more than 1000 V is accelerating them electrostatically out of the engine. Their speed varies from 10 km/s to 130km/s.
The Idea

With the idea of the most rocket-engines to get the impulse of a fast ejected gas or plasma, I thought how to improve working of ion-engines, when I remembered a colloquium about laser-acceleration of ions to use them for medical treatment. So the idea was to exhaust these accelerated ions as plasma just like in a normal ion-engine. The difference besides the setup is only the velocity of the ions that can go up to relativistic scales. This would make up another positive effect when the mass of the ejected matter could be increased just by a speed near to the light-speed.

To accelerate ions with lasers there are two possibilities, direct and indirect. With laser-intensities over $10^{27}\, \text{W/cm}^2$ it would be possible to accelerate ions directly in the electric light-field in the focus of a laser beam. However the best laser-systems on the planet have only intensities around $10^{21}\, \text{W/cm}^2$ there is now only the indirect way for a sharp acceleration of ions, which needs at least $10^{18}\, \text{W/cm}^2$ as the beam-focus-intensity. The technology behind this setup is not easy to build up, as one can imagine it is hard to control such laser-beam when intensities over $10^9\, \text{W/cm}^2$ are enough to ionize matter. One step further such systems do not work efficient and need in this way much more energy than they use. Although the most systems who work near the frontier of science are susceptible for defects. But nevertheless this could be one technological step that will be taken in the next centuries to build up a tabletop setup that works much more efficient and with a long lifetime to navigate space-crafts without a big need of fuel and with applicable trust through space that is called New-Ion-Engine-By-Laser-Acceleration (NIEBLA).

How does it work?

As far as a high-intensive laser-field hits a metallic target the intensity is so high that in front of the Target there will be created an so called pre-plasma made of electrons, which will expand with sonic-speed. When this pre-plasma as shown in the figure on the right side is struck by a second pulse on the free-electrons acts the Lorentz-force in that way that the electrons start to oscillate in the electric field
perpendicular to the direction of the laser-beam. But as shown in the equations below when
the velocity of the oscillating electrons will increase to a velocity near the speed of light the
second part of the equation will force this electron to drift in the direction of the beam (z-
direction) reverse to the electron-pre-plasma-expansion.

\[
\vec{F}_L = -e\left(\vec{E} + \vec{v} \times \vec{B}\right)
\]

\[
\vec{F}_L = -e\left(\vec{E} + \vec{v} \times \left(\frac{\vec{e}_z}{c} \times \vec{E}\right)\right)
\]

This relativistic effect takes place from electric field-strength over \(3.2 \cdot 10^{12} \text{V/m}\) which is
connected to the mentioned intensities over \(1.37 \cdot 10^{18} \text{W/cm}^2\). However this drift of
electrons back to the target, although called Wakefield-Acceleration creates a high density
electron shockwave that is accelerated from the laser-field until the plasma becomes from
the refraction-index which depends on the plasma-frequency as well as on the light-frequency of the laser,
invisible for the laser-beam who is reflected there. The
cloud of electrons is now propagating into the target and
creates on the other side of the target a high electric field
because the electrons cannot leave the solid body. The
electric field on this side is as high or ever higher as the
field of the laser-focus and can ionize the atoms there as
well. From this point surface cold ions feel a strong electric
field that accelerates them parallel to the target-normal to relativistic energies. This is called
Target Normal Sheath Acceleration (TNSA).

Not completely understood are the processes that drive the electron-shockwave into the
target and hold the high density electron-plasma on the target-back-side up to 700 fs.
Explanations for this phenomena deal with effects like bubble-acceleration. The actual
research is focused on dealing with this ion-beam, on designing better target-geometries,
more efficient target-materials and to homogenize the beam geometrically and in its energy.
Experiments on the PHELIX-System at the Helmholtz-center for Heavy-Ion-Research in Darmstadt had shown that protons coming from organic-conjunctions on the target-surface can be accelerated to energies over 30 MeV.

For a usage of this technology for driving a space-vehicle it is possible to neglect a lot of problems like the research to homogenies beams because it is just not necessary. But Questions like how to produce a constant beam or at least a fast repeating pulse-system have to be solved. From another view high efficient and small or light laser systems which do not need a lot of overhauls are needed. Maybe semiconducting laser-systems will get much more powerful the next years. Another thing that has to be evaluated on a research for these engines is equal to normal ion-engines, the need to neutralize the exhausted ion-beam with electrons.

**Summary**

With the possibility to accelerate ions by the help of high intensive lasers to relativistic scales there is an opportunity to develop a new kind of ion-engine that is called NIEBLA.

But to this it will be a long way of research to get science about the physics behind this technology and many things like the used laser-systems have to be improved to build an engine like this.

**References**

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