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A2_5 Deep Space 3: Power from afar

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Abstract
This paper discusses the use use of external power generation for the generation ship, and specifically the transmission of this power from the Sol system to the ship using either laser light or positrons to carry the energy to the ship as well as the methods for converting this transmitted power into energy the ship can use. It is determined that either method could work but both have severe drawbacks.

Introduction

In Deep Space 1, the start of this paper series [1] we briefly discussed the energy required to power a ship accelerating constantly at 1g- on the order of 10GW of power. Obviously, such a power output is impossible for an on board generator, so this paper looks at the feasibility of using an external generator orbiting the sun and beaming the power to the ship using a laser and photovoltaic cells or in the form of positrons which then heat a lead plate with gamma rays. This will also take into account the redshift using numbers calculated in Deep Space 2 for the velocity of the craft [2].

Laser transmission

Wireless transmission of power has been the subject of research since the turn of the century and one such solution uses short-wavelength ($\sim 300nm$) lasers to transmit power to a photovoltaic cell. As the light is monochromatic, efficiency of the cell can be as high as 50%. Of course, for continuous power transmission multiple generators would be needed, as they would orbit the sun over the course of the mission and move out of range. Additionally there would need to be considerably more than 1 laser as even the highest output free electron lasers (FELs) can only manage $\sim 1MW$ [3]. This would mean that, at any one time 20,000 lasers would have to be pointing at a large array of solar cells. This may seem like a lot, but if each beam could be focused to a $7 \times 10^{-3}m^2$ spot (radius 5cm)on the array (which would mean the beams are assumed to be dispersionless), then it would only have dimensions of $\sim 14 \times 14$m of 0.1×0.1m photovoltaic cells, which would fit neatly on the back of our 10m radius ship, although this would require thrusters to be mounted externally or have the array mounted to one side of the main body of the ship. The latter of these two options would prevent a misaligned beam from hitting the side of the ship, something which would be catastrophic to the mission (as the lasers in question are used as anti-ship weaponry by the US navy) [3]. Unfortunately the power from these lasers would be diluted due to the velocity of the ship, this would also prevent the photovoltaic cells design being truely monochromatic. To work out the maximum change in frequency and therefore power we use the equation for redshift

$$1 + Z = \gamma(1 + \frac{v}{c}), \tag{1}$$

using the highest velocity calculated in Deep Space 2 [2]: $\gamma = 3.1$ and $v_{max} = 2.84 \times 10^8 ms^{-1}$ we get that $1 + Z = 6$ meaning that the wavelength at maximum redshift would be $1.8\mu m$, meaning the light has shifted from near UV to near IR. This would have a big impact on the efficiency of the photovoltaic cells. Additionally as energy is inversely proportional to wavelength, the power output would drop to 1/6 of its original power. The only way to get around this problem would be to tune the FELs to produce shorter wavelength light to compensate as the ship increased in velocity. This is possible with FELs but would require novel undulator design to allow the change in cavity length.

Antimatter transmission

By accelerating positrons in a similar way to a collider and firing them at an electron plasma at the back of the ship, gamma rays would be produced which would terminate in a lead plate, heating it up which can then be used to power the ship. By using 50GeV positrons (which is the highest energy available to SLAC [4]), most collisions would produce 2 gamma rays of energy $\sim$ 25GeV (as rest mass energy of both electron and positron is negligible at that energy). The amount of energy deposited per length of lead the ray travelled through is given by:

$$I = I_0 e^{-\mu_l L} \tag{2}$$

where I/I_0 is the proportion of transmitted intensity, μ is the attenuation coefficient- which for Lead at this energy is $\sim 10cm^{-1}$ [5], and L is the path length. For this energy the point at which 99% of the energy is in the Lead is only 0.5cm into the plate. Assuming this is thermal energy and given a thermal to electrical generator efficiency of 10% we would need the lead to receive around 101GW of power from the antimatter, corresponding to 1.2×10^{10} positrons per second on average, which is not an unreasonable number for a collider to produce, although producing this amount of antimatter constantly for 20 years may prove more difficult. Additionally the power would again be redshifted, by approximately the same amount- positrons of that energy are travelling extremely close to the speed of light. This would mean that at peak velocity there would need to be 6 times this number outgoing positrons from the source. This assumes, of course, that there is no intervening matter between the ship and the power source and that any effects due to the charged particles moving through the various magnetic fields present in the solar system and beyond have been accounted for in the aiming of the beam.

Discussion

Both methods of power generation have their merits, but what has not been discussed in much detail is the drawbacks to these methods of generation. Firstly, the generation of the power in first place would require huge solar farms in orbit about the sun, and both transmission methods would require substantial development in space. By the time this is possible, all of the technology discussed in this paper will have progressed considerably and the numbers discussed would need to be updated to reflect this. Both transmission methods are horrendously dangerous to the crew- a tiny misalignment of the laser could cut the ship in two and antimatter produces a lot of gamma radiation, which is generally considered to be harmful to humans (and again, misalignment of the antimatter beam would break the ship apart). In regards to the antimatter method, there would need to be the same number of electrons as positrons, which the ship would have to carry on board, this corresponds to about $2 \times 10^1 8$ electrons, which would have to be generated by ionising fuel, as there would be no way to ground the ship, this would produce a large charge build up on the ship.

Conclusion

Whilst both transmission methods could theoretically transmit the power required, both have considerable drawbacks, although they would allow for a much lighter ship as there would be very little fuel required compared to having to power the ship with an on-board generator as well as not having to carry the generator. This may loosen the power constraints, meaning that some of the problems could be abated slightly. Additionally, as has been discussed in the previous two Deep Space papers, an acceleration of 1g is very high, especially for a ship of this size.

References

[1] M. Bryan, J. Forster, A. Stone *A2_1 Deep Space 1: Staying Cool*, PST 11, (2012).
[2] M. Bryan, J. Forster, A. Stone *A2_3 Deep Space 2: Journey to another star*, PST 11, (2012).
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[4] `http://www.slac.stanford.edu/gen/grad/GradHandbook/slac.html` accessed on 6/11/2012.
[5] M. B. Chadwick et al. *ENDF/B-VII.0: Next Generation Evaluated Nuclear Data Library for Nuclear Science and Technology* Nuclear Data Sheets, Volume 107, Issue 12, p. 2931-3060, (2006).