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HIGH CURRENT/HIGH POWER BEAM EXPERIMENTS FROM THE SPACE STATION

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1-INTRODUCTION

In this over-view on the possible uses of high power beams aboard the Space Station I will consider the advantages of the Space Station as compared to previous space vehicles, the kind of intense beams that could be generated, the possible scientific uses of these beams and associated problems. I have chosen this order deliberately to emphasize that the "means", that is, the high power particle ejection devices, will lead towards the possible "ends", scientific measurements in the Earth's upper atmosphere using large fluxes of energetic particles.

2-THE SPACE STATION PLATFORM

The availability of the Space Station as a platform should markedly relieve some of the limits that have constrained the use of energetic particle ejection sources on sounding rockets, satellites and the Space Shuttle. Because the Space Station and its auxiliary structures provide a large platform, several emission systems and sensing devices can be placed, oriented and operated simultaneously. The components can be separated by distances required for the use of high voltages. The astronaut-crew will be able to start, stop or modify experiments at a safe distance from high power devices. Energy storage devices, rechargable by the power generation systems, can supply pulsed power. One benefit of the Space Station is that it will allow the use of oxide-coated cathodes for thermionic electron emission in devices required for the generation of both electron and ion beams. The result will be an enormous gain in efficiency of power use. Oxide coated cathodes aboard space vehicles are difficult to use because low work function surfaces are poisoned by water vapor coming from the outgassing of other surfaces. The Space Station could provide a relatively water vapor free environment (water vapor partial pressure less than 10-6 torr) which would allow the use of low work function cathodes. One new problem on the Space Station will be the effects of the impact of ambient atomic oxygen over long periods on the cathodes. A suggested solution to this problem is the reconditioning and manual or robotical replacement of oxide-coated cathodes without displacing main ejector optics. The availability of long (~100 m) structures, would allow the stacking of linear accelerator drift tube sections. These sections could be tuned and positioned in a vibration-free environment. The availability of large rectangular structures, (100 m by 50 m) would allow the use of cyclotron type devices. Larger dimensions for all types of accelerators would become available by constructing and launching free flyers from the Space Station. To avoid radiation effects on personnel during and after the operation of accelerators, the accelerators would be controlled and serviced at a safe distance by the Space Station crew.

One of the major problems in using space vehicles has been the choice of proper ground or low altitude sites for measurements of beam effects . Having a platform from which repetitive ejections can be made will permit iterative measurements and repositioning of sensing instrumentation. It will also allow the repositioning of instrument bearing balloons and aircraft and the timely launching of instrumented sounding rockets. We could patiently await the proper but rare combinations of solar, magnetic and atmospheric conditions. Solar eclipse, magnetic index values, or ionospheric plasma concentrations could be used as separate control conditions for the start of measurements.

The zero or near-zero g forces on accelerators aboard the platform will probably not influence the particles ejected from the plasma sources; however, they could affect the energy storage and transfer systems. Investigations of these effects will be an important part of the research on the use of high power particle ejection devices on orbiting platforms.

3-BEAMS

About 50 kilowatts will be available from the active power sources on the Space Station, not much better than what has been available up to now from stored energy sources on space vehicles. The power sources can be used to continuously eject ampere beams of keV electrons. However, by using the mass and volume available for energy storage devices, and by using these energy storage devices for pulsed power, a new capability for the use of intense beams in space could be achieved. One ton of energy storage devices on the Space Station, a modest assumption, could easily store one megajoule of energy. Unloading this energy in one millisecond will make a megawatt of power available for cathode heating and beam generation, and for the ejection of kiloampere beams of keV electrons.

How often could such a large power pulse be produced? Only 10 kilowatts of the real time power devoted to charging the energy storage, could produce one pulse per day. Increased energy storage per mass unit and an increased orbited mass could provide high power for beams emitted in short pulses. Space charge limitations would obviously play a large role in limiting the current ejected from a single gun. However there are proven techniques of using positive ion and neutrals to decrease the effects of space charge and thereby increase the beam current per gun. Of great importance is the consideration that the Space Station would also allow a large number of guns to be used concurrently; each could deliver a large current per pulse. The use of a large number of ejection devices at one time greatly increases the importance of using low work function emissive cathode devices.

High energy (megavolt) and high current (kiloampere) electron emission devices require more space than their low energy analogues. Large volumes (cubic meters) are required for the cathodes and associated power-processing devices; these dimensions would be available on the Space Station.

As with electrons, the ejection of high currents of keV ions or neutrals will require a large number of elements that draw on the high power available from the energy storage devices. Because mass will not be a prime consideration, the ion sources can be used to accelerate large quantities of gases with atomic weights starting at one, hydrogen atoms, to large molecules. For the keV regimes biased sources will provide adequate accelerations. However, high energy ion emission, as for very high energy electron emission, will require linear or curved accelerators. A great deal of effort is being expended to miniaturize the elements of such systems for possible space use, but the Space Station may give us the opportunity of using elements such as massive Cockrot-Walton sources, now used very successfully on the ground.

4-USES

Projected uses of high power beams on the Space Station can be considered in one of two categories: previous uses now extended by the Space Station characteristics, and new uses not previously feasible because of beam, power, or platform limitations. The factors that extend the previous uses include: use of more intense beams to increase the signal-to-noise ratio at detectors; use of an extended network of detectors over a large distance, areas, or volume to work independently or as a phased array; the availability of time to allow for modulated and phase sensitive filters; the ability to simultaneously use multiple beams with different energy electrons to induce desired excitation of ionization levels; and the ability to change directional response of detectors.

One of the earliest uses of electron beams on sounding rockets was in the in-situ measurement of the atmosphere. Characteristics such as ambient composition, neutral particle density, and temperature were sought. The measured signals included scattered electrons as well as the visible, ultraviolet, x-ray, and infrared emissions induced by electron beam excitation of the atmospheric gases. The major problem, especially at low altitudes, has been to measure the normal ambient in the presence of gases coming from the platform itself. For example, the ram wake effect has been utilized to distinguish atmospheric nitrogen from outgassed nitrogen. However, for some constituents, e.g., atomic oxygen, such a technique is not feasible because the atoms cannot be concentrated by the use of normal enclosures. In addition to the improvements already noted it is hoped that the Space Station will be able to provide places of measurements at some distance from contaminants. The ability to make measurements as a function of distance away from surfaces should make possible the extrapolation to normal ambient conditions. This use of electron beams will allow for in-situ measurements of temporal changes of ambient conditions.

Intense beams of high energy electrons will allow for probing of the atmosphere at some distance from the platforms. Measurements of atmospheric properties, especially density will be possible from 100 km down to perhaps 50 km or below. The measurements will be made by having the range of the energetic particles correspond to the altitude regime to be measured while using detectors on spacecraft and on the ground to look at emission signals. It is exciting to contemplate having ground-based spectrometers and cameras focused on a region or volume of space at a specific altitude, having signals from that region every ninety minutes and being able to anticipate and change beam intensity, particle energy and even the type of excitation particle.

Of course the other side of the coin to measuring the normal ambient has been the ability to significantly modify the atmosphere; to choose specific altitudes, and look at the modification parameters such as the total energy, energy distribution, and pulse lengths that are required for heating a region to a new state. Kilowatt beams have already been used to induce atmospheric effects which can be measured from the ground; more intense beams will allow for more accurate as well as a new range of measurements.

One of the earliest uses of electron beams from sounding rockets was the creation of artificial auroras with the purpose of understanding natural auroras. With the new platforms beams of particles with the same energy and flux distribution as the natural beams can be ejected into the atmosphere. Ground based instrumentation could then be used at optimum sites for measurements. We probably are a long way from creating reactions in large regions similar to those in which natural beams occur, but it may be possible with smaller sized beams to duplicate most of the interesting features of high energy particle penetration into the atmosphere.

The idea of using impacting electron beams on a free flying object to create spacecraft charging, to measure the charging, return currents, and ambient effects during beam impact, and to measure the rate and characteristics of discharging after beam cessation,has been around for some time. We know that the phenomena would be characteristic of low Earth orbit, and would not be directly applicable to geosynchronous orbit satellites. However, for low Earth orbit objects information could be obtained on questions that have remained after two decades of spacecraft charging measurements at even low Earth orbit. Investigations could be made of the relationship between spacecraft charging and such variables as object size and shape, orientation of the object to the magnetic field, plasma density, neutral particle density, object speed and orientation, surface characteristics and material distribution. From charging experiments the next steps are the study of discharging and the prevention of charge buildup. The ability to impact the free flying object with a wide range of currents, single particle energies and multiple energy spectra, will allow for basic understanding but also will provide the opportunity for the design and testing of active and passive discharging, and charging techniques.

Beam plasma interactions including the transfer of energy forms of beams of charged particles to wave energy in the plasma have been studied in some rocket and Space Shuttle experiments. The large dynamic range in beam energies and fluxes should allow for the investigation of these phenomena in regimes of beam and plasma properties not previously used either on the ground or in space. It will also be possible to compare laboratory results where walls of vacuum chambers are present to the new boundary conditions in space. An additional important aspect will be the comparison of the effects of single and multiple beams with the same total energies.

It will be possible to produce ionized layers on command. Beams of proper energy will now be available to efficiently increase the plasma density at various altitudes. The duration, extent, and effects of these artificial ionospheres as a function of beam parameters will be important experiments for both scientific and commercial interests.

The use of the Space Station will allow much more ambitious experiments than previously attempted on space vehicles. Examples are the new ability to produce beam currents in space with energy densities larger than the Earth's magnetic field, and to produce beams with currents and energies that create pinch effects on the beams themselves. Quasi-neutral plasma beams could be produced with energies large enough to flow across field lines; therefore experiments with astrophysical implications that previously could be done only in numerical form or in very limiting ground chambers will now be possible on a repetitive basis in the conditions of Space Station altitudes.

5-PROBLEMS

We know from the use of particle ejection sources on sounding rockets and satellites, that these sources can introduce problems and sometimes actual dangers to the space vehicle platform as well as to other payloads. The identification of these problems and the solutions will be critical aspects of the use of high power beams on the Space Station. Criteria must be established for determining and testing the limiting effects of high voltage components on space vehicles in the ionosphere. The need for enclosed containers and the types of such containers for high voltage components and systems must be determined. The trade-off between pressurized containers and other ways of using high voltages in the plasma conditions of the Space Station must be studied, tested, and carefully verified. In addition to the problem of exposing materials to normal ambient conditions which can cause a slow deterioration to insulating characteristics, there will be the problem of the changed ambient: the new density, temperature, and flux of high energy particles may cause a rapid change not yet predicted by the much different ground conditions. On the positive side the Space Station may allow the use of large quantities of heavy insulating materials, such as oil now regularly used on the ground but not yet used on space vehicles.

Of course there is the problem of spacecraft charging. Whether it will be solved actively by hollow cathodes, plasma sources, automatic plasma emitters, or passively, by grounding wires, or large areas for return currents, is yet to be determined. As emitted beam fluxes used increase, even the return flux of low energy particles to compensate for the high energy emissions will start to change the ambient around the grounded portion of the platforms. The return of high energy particles due to the Earth's magnetic field or simply by scattering will also be important. The emitted beams, the return fluxes and the activities of the high density energy storage devices used in short pulses, may influence the ability to emit signals (telemetry) or to send signals internally (commands) and will have to be carefully studied.

6-CONCLUSION

The Space Station will provide a good platform for the use of high energy high power beam emission devices. The use of massive energy storage systems will play a key role in allowing for the emissions of power beams. It will provide opportunities for a large number of interesting experiments in space. There are however significant problems which must be solved.