General discussion and conclusions of the IPAIA2017 workshop

To introduce the discussion, Cavenago (co-chair) asks two questions:

1) what is the status of the market of ion thruster for satellites, and the collaboration between institutions and companies? (we have the pleasure to see the participation of Sitael SpA, an italian company, and of CIRA and Italian Space Agency (ASI), as well as of researchers collaborating with several national and international companies);

2) since most of the talks concentrate on Hall Thrusters (HTs), what are their advantages over electrostatic system, such as traditional GIT (Gridded Ion Thruster) and other novel concepts (Helicon, HEMPT[i])?

As noted by the audience the accelerating voltage is typically in the order of 300 V for HET and may reach 20 kV for GIT, with obvious changes in the ion speed v_i. Ion engine is typically constrained by two limits: available electric power P_a (from solar panels or, only for deep space mission, nuclear decay generators) and available gas quantity m_g (alias propellant mass); required perfomance is measured by Δv, the total velocity increase needed for the whole mission. These three parameters determine a range of optimal v_i and therefore preferences in Thrusters design.

Of course, air breathing can mitigate the propellant mass constraint; and a large v_i implies a lower ratio of thrust to power.

Kaganovich relates some Y. Raitses general remarks: "Thrust density is larger and also Thrust to power ratio is larger for the Hall thruster. These are important advantages when fast maneuvering is needed. Because power on board of satellite is a limited factor by solar panels, $P_a \cong$Thrust $*v_i$ (or I_{sp}*g) [with v_i the exhaust velocity and I_{sp} the specific impluse], ion thrusters are not efficient for exhaust velocities that are slower than 30 km/sec, i.e. I_{sp}=3000 sec. In contrast, the Hall thrusters are efficient for I_{sp} between 1000-3000 sec. I_{sp}=1500 sec corresponds to the discharge voltage of about 300 V. Therefore Hall thrusters are capable to deliver larger thrust for the same power. Larger thrust gives a shorter trip time $t \cong \Delta V * M_S$/Thrust, where ΔV is specific for every space mission, M_S is satellite mass.A shorter trip time are improtant for missions, for example, transfer from LEO to GEO orbits, or to move faster through Van Allen belt. 2) Hall thruster is simpler than ion thruster and therefore probably is more reliable and less expensive to build. The biggest problems for Hall thrusters as compared to ion thrusters: 1) shorter lifetime and 2) smaller efficiency."

HET lifetime is indeed limited by wall sputtering, which may be mitigated protecting walls by some parallel magnetic field, as discussed in some talks. Mazouffre emphasizes on the fact that indeed Magnetic Shielding configurations drastically elongate the Hall thruster lifetime (by a factor of 10 or more) and allow to replace BN (boron nitride) by another less expensive material for the cavity wall. Besides, performances are maintained compared to a standard configuration.

There is some general agreement that best thruster depend from operating conditions, which can be classified into

1) low power (P_a less than 200 W), typically used on satellites of 50 kg or less; this implies motor mass below 0.5 kg;

2) medium power (P_a between 200 and 5000 W), typically used on satellites of 1000 kg or less, for maintenance of low orbit flight, and so on.

3) large power (P_a larger than 5 kW typically ranging from 20 kW to more), used or envisioned for demanding application, as deep-space exploration. A large propellant mass is required, and sometimes use of more economical Kr or of CO_2 recycling were proposed instead of Xenon.

The market is subjected to intermittent request due to regulation changes (for example, safety rules for satellite end of life) or to new initiatives being planned. For example, telecom and the Mega Constellation problem rely on small HET units. Fast maneuvers requires a large thrust, so requiring comparatively larger motor or even chemical engines, perhaps electrical assisted (2 km/s jet being accelerated to $v_i \cong$ 6 km/s by electrical methods).

Pulcino note the need of a mailing list of workshop partecipants, for follow up discussion.

Companies and institutions: Kinetic, Fortech, SSTTL, Safran, Thales, Cira, Sitael, Aerospazio tech.

Among area of improvement discussed for performance gain we note: the cathode (see Paganucci slides); the double stage Hall thruster (where gas ionization is decoupled from ion acceleration): plasma X points from fusion projects (Morozov, Galatea project) can be coupled to HET, so obtaining a compact double stage thruster (O. Secheresse et al., Snecma Patent , 2003, see L. Garrigues slides). A comparison between ion engines and old cell phone suggest the question of limit of improvements which naturally lead to status of develop of simulation tools, covered in several talks.

Merino notes the importance of improving our understanding of the physical mechanisms behind the operation of the thrusters, and developing more accurate models. This involves the anomalous transport of electrons in HET and other devices. In general, other electromagnetic plasma thrsuters (e.g. helicon, ECR, MPD) still require advances in modeling.

Finally, Taccogna (co-chair) remember that the Hall thruster and related mechanisms of anomalous transport were rediscovered in the modelling of the electron filter in negative ion sources (fundamental in neutral beam injectors for neutral research). In both applications, the chemical and physical properties of the wall was shown to be important, so opening a new interdisciplinary field of study. Common computational challenges in 2D and 3D have emerged both in the PIC4NIS workshop (preceding IPAIA) and in the modelling talk here presented.

Cavenago note that workshop fits perfectly into the scope of the Network on Accelerator Application (WP4) of the Eucard2[ii] project, that is to make a map of existing and promising applications of accelerator and ion source technology.

As actions for the divulgation of the workshop result, all speakers agree to post a suitably edited version of their slides on the workshop web site (edited slides should send within 2 weeks, otherwise local copies will be used). Cross links with other Eucard2 workshops will be added as possible.

Moreover, a list of email of workshop participants will be shared in the process of revision of this discussion minute.

As closing remarks, the chairs wish to thanks the administration officers (for CNR, G. Bonasia and Dr. E. Sansone, and for INFN-LNL and Eucard2, R. Battistella and Dr. B. Lava) for important work done, and all the participants and the presenters for contribution and discussion, and for their participation (notwithstanding the short organization times).

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[i] HEMPT High Efficiency Multistage Plasma Thruster, see patent of Thales ED Gmbh
[ii] Enhanced European Coordination for Accelerator Research and Development