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MOA²—an R&D paradigm buster enabling space propulsion by commercial applications ☆

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ABSTRACT

More than 60 years after the late Nobel laureate Hannes Alfvén had published a letter stating that oscillating magnetic fields can accelerate ionised matter via magneto–hydrodynamic interactions in a wave like fashion, the technical implementation of Alfvén waves for propulsive purposes has been proposed, patented and examined for the first time by a group of inventors.

Consequently improved since then, the name of the latest concept, relying on magneto-acoustic waves to accelerate electric conductive matter, is MOA²—Magnetic field Oscillating Amplified Accelerator. Based on computer simulations, which were undertaken to get a first estimate on the performance of the system, MOA² is a corrosion free and highly flexible propulsion system, whose performance parameters might easily be adapted in operation, by changing the mass flow and/or the power level. As such the system is capable of delivering a maximum specific impulse of 13116 s (12.87 mN) at a power level of 11.16 kW, using Xe as propellant, but can also be attuned to provide a thrust of 236.5 mN (2411 s) at 6.15 kW of power. First tests—that are further described in this paper—have been conducted successfully with a 400 W prototype system at an ambient pressure of 0.20 Pa, delivered 9.24 mN of thrust at 1472 s I_{SP}, thereby underlining the feasibility of the concept.

Based on these results, space propulsion is expected to be a prime application for MOA²—a claim that is supported by numerous applications such as Solar and/or Nuclear Electric Propulsion or even as an 'afterburner system' for Nuclear Thermal Propulsion. However, MOA² has so far seen most of its R&D impetus from terrestrial applications, like coating, semiconductor implantation and manufacturing as well as steel cutting. Based on this observation, MOA² resembles an R&D paradigm buster, as it is the first space propulsion system, whose R&D is driven primarily by its terrestrial applications. Different terrestrial applications exist, but the most successful scenarios so far revolve around MOA²'s unique features with respect to high throughput/low target temperature coatings on sensitive materials. In combination with its intrinsic high flexibility, MOA² is highly suited for a common space-terrestrial application research and utilisation strategy.

This paper presents the recent developments of the MOA² R&D activities at Q_2 Technologie(s), the company in Vienna, Austria, which has been set up to further develop and test the magneto-acoustic wave technology and its applications.

1. MOA²—a unique space thruster

It was in 1942, when the late Nobel laureate Hannes Alfvén published a letter, stating, that oscillating magnetic fields can accelerate ionised matter via magneto–hydrodynamic interactions in a wave like fashion [1].

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These waves were later called “Alfvén waves”, in honour of their discoverer. Although the evidence for Alfvén’s hypothesis came already rather early with the observation of certain plasma phenomena, such as being connected with high solar wind Wolf-Rayet stars, more than 60 years had to pass by before a technical implementation of Alfvén waves for propulsive purposes was proposed for the first time.

The name of this concept, utilising Alfvén waves to accelerate ionised matter for propulsive purposes, is MOA^2—Magnetic field Oscillating Amplified Accelerator. It is a highly flexible propulsion system, whose performance parameters are easily adapted in real-time, by changing the mass flow and/or the power level.

Its working principle is based on specific magneto-acoustic waves that are utilised to accelerate ionised matter for propulsive purposes. Alfvén waves or magneto–hydrodynamic waves are transverse waves, which move parallel to the magnetic field with the Alfvén velocity v_A and depend only on the magnetic field density B and the mass density ρ_m of the Plasma. Eq. (1) shows the exact relation for calculation of the Alfvén velocity [2].

$$v_A = \frac{B}{\sqrt{\mu_0 \rho_m}} \tag{1}$$

Typical Alfvén velocity values are in the order of 34.7 km/s for Argon plasmas (Ar^+) used in illumination applications and 7700 km/s for Deuterium plasmas (D^+) as being used in fusion applications [2].

The Alfvén waves of the MOA^2 concept are generated by making use of two coils, one being permanently powered and serving also as magnetic nozzle, the other one being switched on and off in a cyclic way, deforming the field lines of the overall system. This deformation is at the very heart of the MOA^2 concept, as it generates the Alfvén waves, which are in the next step used to transport and compress the propulsive medium, in theory leading to a propulsion system with a much higher performance than any other electric propulsion system. Mathematic models suggest that MOA^2 is capable to deliver a maximum specific impulse of 13116 s (12.87 mN) at a power level of 11.16 kW, using Xe as propellant, but can also be attuned to provide a thrust of 236.5 mN (2411 s) at 6.15 kW of power.

One of the biggest strength of MOA^2 is that it is in principle capable of using all sorts of propellants, as long as they can be ionised. Gases that we have used in our tests so far include Nitrogen and Argon, in the future Hydrogen, Helium and Xenon are to be tested as well. Fig. 1 shows an early MOA^2 prototype in its test rig within the vacuum chamber.

Expert opinions on the MOA^2 concept, such as the one of Prof. Horst Löb, one of the fathers of electric propulsion, which were commissioned by the inventors, have validated the inventors’ model and stated the feasibility of the overall concept. When checking the MOA^2 concept against his own plasma dynamic models, Prof. Horst Löb derived the following parameters for MOA^2, which suggest that MOA^2 has an excellent potential as a North–South Station Keeping (NSSK) propulsion system, outperforming all other systems currently available (Table 1).

Due to its high flexibility, the MOA^2 developing consortium considers the application of MOA^2 not only as a NSSK thruster for geostationary satellites, but also as an Attitude Control and Kick-Booster system. At higher power levels in the MW-regime, such as provided by a nuclear space reactor, higher thrust values can be achieved as well, thereby allowing for exploration missions. It has to be noted however that MOA^2 is not expected to deliver a thrust to weight ratio bigger than 1, so if MOA^2 is to be ever used for a manned exploration mission, this will then be only for the interplanetary travel, but not for operations deep inside a planetary gravity field.

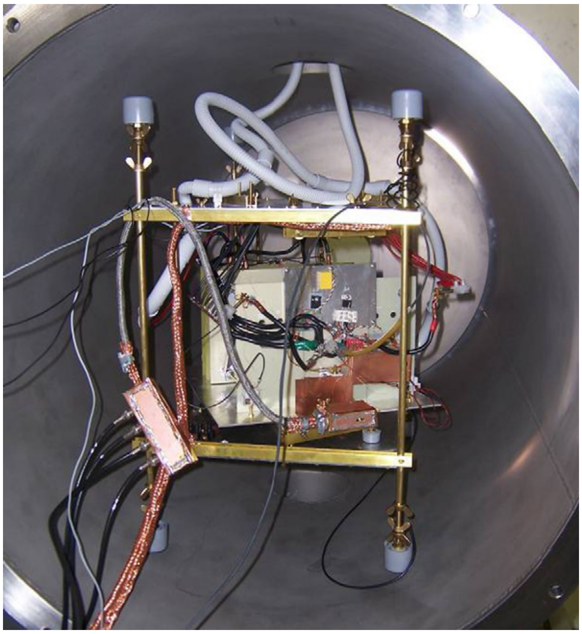

Fig. 1. MOA^2 prototype inside the vacuum chamber.

Table 1
Assumed parameters of a MOA^2 NSSK-system (Simulation Prof. Löb).

MOA thruster with H_2 propellant	
Thrust	80 mN
Beam power	1.6 kW
Specific impulse	4000 s
Specific power consumption	20 W/mN

2. MOA^2—characterisation and principle of work

A basic characterisation of the MOA^2 thruster quickly leads to one result: MOA^2 falls in the class of electric propulsion systems as it requires an external energy source, which afterwards accelerates the propellant by electromagnetic means. In trying to characterise the MOA^2 system further by comparing it with:

- Electrothermal systems (e.g. arcjet, resistojet);
- Electromagnetic, electrodynamic systems or plasma engines (e.g. MPD, PPT, VASIMR); and
- Electrostatic systems or ion engines (e.g. FEEP, colloid engine, RIT, HET);