High Precision Attitude Control System Based on the Emission of Electromagnetic Radiation

IEPC-2017-273

Presented at the 35th International Electric Propulsion Conference
Georgia Institute of Technology – Atlanta, Georgia – USA
October 8–12, 2017

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From basic physics it is known that the active emission of 1 W of electromagnetic power is associated with a generated force of 3.3 nN. This physical principle has been frequently suggested as a main propulsion system for space missions, despite the huge power demand for significant forces. On the other hand, it has not been thoroughly exploited for attitude and orbit control purposes with ultrahigh precision demands, where very small forces are certainly of interest. General concept and some ideas for the underlying technology and the integrated system components for this idea, named high-Precision Attitude Control system based on the emission of Electromagnetic Radiation (PACER), are presented. PACER is a scalable, fuel-less thrust vectoring system, facilitating the conduction of protracted space mission profiles and providing an exhaust-free environment. By exploiting the thrust and torque generating effects due to the emission of electromagnetic radiation, an unprecedented accuracy in attitude control could be achieved. Due to its inherent scalability, the system could facilitate an adjustable thrust level undercutting the 10 nN order of magnitude, if required. In addition, the paper summarizes some ideas about a high precision thrust stand, which shall enable performance characterization and thrust measurements of the unit. Here, the concept of resonant operation during measurements is currently investigated as one option to achieve the required level of precision. Finally, essential system sub-components required for the electrical power system including power generation, distribution, allocation and storage are also briefly addressed.

Nomenclature

PACER = Precision Attitude Control by Emission of Radiation
ACS = Attitude and Orbit Control System
EPS = Electric Power System
PV = Photovoltaic
S/C = Spacecraft
CoM = Center of Mass
LED = Light-Emitting Diode
SSP = Solar Sail Propulsion
PDAM = Power Distribution and Management

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I. Introduction

Many upcoming and planned satellite missions within the commercial as well as scientific sector impose ever increasing demands on precision and accuracy of their respective attitude and orbit control systems (AOCS), leaving a steady rise in overall system complexity in their wake. In addition to a fine-tuned torque resolution and pulsed thruster operability, fast reactivity and reproducibility in response to adjustment commands are also of major concern. Aside from its main task to provide the precise steering of the spacecraft (S/C) with respect to a specified orientation, compensation of parasitic moments due to adverse effects of the space environment, e.g. solar radiation pressure or residual atmospheric drag, is also important.

Additionally, precise formation flight for a series of future high-end missions, consisting of two or more spacecraft arranged within a cluster will rely on a highly capable AOCS. A very prominent example is the eLISA gravitational wave observatory, a proposal for the ESA L3 Cosmic Vision Program, which consists of a cluster of three identical satellites trailing Earth orbit in a triangular pattern with a S/C-to-S/C separation of $2.5{\cdot}10^6$ km arms length each, requiring precise steering, relative velocity and attitude control.

Ambitious system requirements that emerge from these applications as well as additional stand-alone advantages justify further effort in research and development of a high-*P*recision *A*ttitude *C*ontrol system based on the emission of *E*lectromagnetic *R*adiation (PACER), utilizing the basic principle that the emission of 1 W of electromagnetic power is associated with a generated force of 3.3 nN. In the following, a brief summary of the performance characteristics of current AOCS thruster technologies is given and, although well known from basic physics, also an introduction into the basic physical principle of PACER. Next, a potential setup of PACER including the core components is addressed, followed by some ideas concerning its experimental investigation and its potential applications. Generally, this conference paper is intended to present some first conceptual ideas about the design and development of this novel AOCS technology.

II. Overview Current AOCS Technologies

Many present attitude and orbit control systems require propellant-based thrusters, which generate thrust and/or torque for example by oxidation and subsequent expansion of the reactants or, in a simplest way, by the expansion of inert gases like nitrogen. Thrust can also be provided by various electric propulsion systems using electric and/or magnetic fields to heat-up, eventually ionize, and accelerate a fluid. In any case, thrust is generated by propellants, which must be carried along by the S/C, thereby limiting onset time as well as penalizing S/C volume and mass constraints due to fuel storage compartments. Of course, the amount of available fuel mass limits finally the operational lifetime.

An alternative method for an efficient attitude control relies on various types of reaction wheels. By means of adaptive spin-up or altering the orientation of a gyrating mass, a counterbalancing torque is created on the S/C. However, these solutions exhibit a maximum value of inducible cumulative torque and require intermittent desaturation by propellant-based thrusters or other kinds of torque-producing devices like magnetorquers, which in turn require the presence of a planetary magnetic field for general operation. Also, applying a Δv is impossible, even if it is very small e.g. for high-precision formation flying. In all cases, micro-vibrations due to the inevitably present friction of the required bearings have to be taken into account.

As another alternative, solar radiation pressure, i.e. radiation from an external source, has also been used for stabilization and propulsion purposes.

A summary of the typical characteristics of these technologies is given in the following subsections.

A. Chemical ACS Thrusters

Primarily designed for comparatively high impulsive maneuvers, chemical thrusters for AOCS applications are based on the ejection of a reaction mass. Both highly reactive and, in equal measure toxic, inorganic compounds like Hydrazine (N_2H_4) as well as propellants requiring less stringent safety handling measures like hydroxylammonium nitrate derivatives (AF-M315E) are common propellants. A series of thrusters using non-toxic inert propellants like compressed nitrogen are also available, representing some of the most technically mature high precision systems. For overview purposes, Table 1 summarizes some of the state of the art chemical thruster technologies for AOCS applications.

Product	Manufacturer	Thrust	I_s	Propellant	Status
Micro-Thruster	Marotta	0.05-2.36 N	65 s	Nitrogen	TRL 9
Butane Propulsion System	SSTL	0.5 N	80 s	Butane	TRL 9
BGT-X5	Busek	0.5 N	220 s	AF-M315E	TRL 5
GR-1	Aerojet Rocketdyne	0.26-1.42 N	231 s	AF-M315E	TRL 9
HYDROS	Tethers Unltd. Inc.	0.2-0.6 N	258 s	Water	TRL 5
POPSAT-HIP1	MicroSpace	0.083-1.1 mN	32-43 s	Argon	TRL 8
MEMS	NanoSpace	0.01-1 mN	50-75 s	Butane	TRL 8
CNAPS	UTIAS/SFL	12.5 - 40 mN	40 s	SF_6	TRL 9
CPOD	VACCO	25 mN	40 s	R134a	TRL 6

Table 1. Current state of the art chemical propulsion systems applicable to small spacecraft. Compiled from refs. [1], [5], [6] and sources therein.

B. Electric AOCS Thrusters

Electric thrusters generate internal electric and/or magnetic fields, heating up and acting upon an eventually ionized fluid, causing a highly accelerated particle stream. In comparison to chemical systems, electric thrusters have a lower thrust to mass ratio. However, depending on technology and maturity of the system components, the individual specific impulse is significantly higher. Common thruster technologies include resistojets (R), electrospray thrusters (ES), ion engines (I), pulsed plasma thrusters (PPT), vacuum arc thrusters (VARC), and Hall Effect thrusters (HE). Focusing on applications for attitude control, a variety of propellants is accessible ranging from solid materials such as PTFE used for PPTs to ionized liquids for various types of electrospray thrusters. A compilation of some selected technologies is given in Table 2.

Product	Manufacturer	Thrust	I_s	Propellant/Type	Status
CHIPS	VACCO	19 - 30 mN	47-82 s	-/(R)	TRL 5
BHT-200	Busek	13 mN	1390 s	Iodine/(HE)	TRL 4
CHT	UTIAS SFL	6.2 mN	1139 s	Xenon/(HE)	TRL 5
BIT-3	Busek	1.4 mN	3500 s	Xe-Iodine/(I)	TRL 5
MAX-1	Accion Systems Inc.	120 µN	2000 s	-/(ES)	TRL 5
Electrospray 100μ	Busek	100 µN	2300 s	-/(ES)	TRL 5
S-iEPS	MIT	74 µN	1160 s	-/(ES)	TRL 6
RIT μX	Airbus	50-500 µN	300-3000 s	Xenon/(I)	TRL 5
PPTCUP	MSCS Ltd.	40 µN	655 s	PTFE/(PPT)	TRL 6
BmP-220	Busek	80 µNs-impulse bit	827 s	PTFE/(PPT)	TRL 8
PETRUS 2.0	IRS	15-40 µN	880-1560 s	PTFE/(PPT)	TRL 4
μCAT	GWU and USNA	1-50 µN	2500-3000 s	Titanum/(VARC)	TRL 7

Table 2. Current state of the art electric propulsion systems applicable to small spacecraft. Letters in parentheses depict the type of thruster technology. Compiled from refs. [1], [5], [6], [12] and sources therein.

C. Reaction Wheels

Small torques for precise attitude control can also be generated by reaction wheels. Main advantages are high precision, quick response time, low mass, volume and power consumption. However, it has to be considered that vibrations might occur and that all reactions wheels need to be desaturated at some point. As examples, the reaction wheels as summarized in table 3 could deliver their nominal torque for about 50 seconds, before a desaturation would be necessary. Reaction wheels are also not able to create thrust.

Reaction Wheel	Manufacturer	Nominal Torque $[Nm]$	Mass $[g]$	Power $[W]$
RW 1 Type A	Astro- und Feinwerktechnik Adlershof GmbH	$23 \cdot 10^{-6}$	20	0.7
RW 1 Type B	Astro- und Feinwerktechnik Adlershof GmbH	$6 \cdot 10^{-6}$	12	0.7
RWP015	Blue Canyon Technologies	$4 \cdot 10^{-3}$	130	1
100SP-O	Surrey Satellite Technology	0.11	2600	10

Table 3. Current state of the art reaction wheels for small moments^{9,10}.

D. Other Propellant-less Systems

The major advantages of propellant-less systems are obviously a significant reduction in overall system complexity and theoretically unlimited lifetime. Alternatives to reaction wheels are based on the exploitation of the solar radiation pressure exerted on a extendible collector membrane and are mostly contemplated for passive main propulsion purposes. However, concepts have also demonstrated that passive attitude control by means of selective reflectivity is feasible to a certain extent. Two examples are the missions Mariner IV (launched in 1964) and Ikaros (launched in 2010)^{2,3}. The main attitude control of Mariner IV was provided by 12 cold nitrogen gas thrusters and three gyros, but was assisted by solar radiation pressure vanes, which were attached to the tips of the solar panels. Ikaros, the first spacecraft to use solar sailing as main propulsion system, used for attitude control the reflectance variation of 80 liquid crystal panels embedded in the sail.

Another class of active propellant-less thrusters gaining increasing attention envisage onboard high-power laser systems for thrust generation. Suitable applications comprise main propulsion for small S/C, control for formation-flying satellite clusters, photon thrust amplification via recirculating photons between space platforms, and even photon propulsion for interstellar flight (e.g. Ref. 11). However, according to our knowledge, these systems have not yet been foreseen for any kind of AOCS-like application.

As an interesting side note, the spacecraft-induced radiation was identified as reason for the so-called Pioneer anomaly, which was an observed deviation from predicted accelerations of the Pioneer 10 and Pioneer 11 spacecraft on their trajectories out of the Solar System. This ”‘anomaly”’ was of very high interest for many years, including various suggestions for new physics, but has been finally explained as an anisotropic radiation pressure caused by the spacecraft's heat loss. The latter came from the radioisotope thermoelectric generator (RTG), the heat of which is emitted in a preferred direction due to the design of the spacecraft^{8}.

E. Summary

Due to the large amount of thruster systems currently available and new systems under development, the tables provided in the previous subsections are far from exhaustive. In conclusion, a summary of characteristic performance values for the different thruster technologies is given in Table 4. Also of interest for future investigations are certainly the reaction characteristics of the different concepts.

Type	Propellant	Thrust	Specific Impulse I_s	Status
Chemical	Hydrazine	0.5-4 N	150-250 s	TRL 5
Chemical	N_2/Butane	10 mN - 10 N	65-70 s	TRL 9
Chemical	HAN/ADN	0.1-27 N	220-250 s	TRL 8/TRL 6
PPT and VARC	PTFE/Titanium	1-1300 µN	500-3000 s	TRL 8/TRL 7
Electrospray	ionic fluids	10-120 µN	500-5000 s	TRL 6
Hall Effect	Xenon/Iodine	10-50 mN	1000-2000 s	TRL 8/TRL 4
Ion Engines	Xenon/Iodine	1-10 mN	1000-3500 s	TRL 8/TRL 4
Solar Sails	-	0.25-0.6 mN	N/A	TRL 6/TRL 7

Table 4. Overview of performance values and system maturity for different thruster technologies. Compiled from [1], [5], [6] and sources therein.

III. Physical Function Principle

PACER relies on the physical principle of the force generated by the emission of any kind of electromagnetic radiation, and in particular of photons. Considering its particulate nature, any individual photon within an emitted radiation flux has no rest mass but carries nevertheless an inherent momentum p that relates to the photon frequency ν or its corresponding wavelength λ:

$$p = \frac{h\nu}{c_0} = \frac{h}{\lambda} \tag{1}$$

where $h = 6.626 \cdot 10^{-34}$ J·s is Planck's constant and $c_0 = 299\ 792\ 458$ m/s the speed of light in vacuum. From this, due to its evanescent momentum, it is comprehensible that only the cumulative effect appearing in an intense photon flux renders possible thrust generation. The product $h\nu$ from Eq. 1 represents the energy E_γ of the emitted photon. Considering a flux ϕ of n photons within the time t and denoting the effective output power of the photon flux with P_γ, the corresponding force F exerted by the total photon flux is

$$F = \frac{\phi h\nu}{c_0} = \frac{nh\nu}{tc_0} = \frac{E_\gamma}{tc_0} = \frac{P_\gamma}{c_0}. \tag{2}$$

Thus, each Watt of emitted electromagnetic radiation power P_γ is equal to a force F of 3.3 nN, which is exerted on the emitting device in opposite direction - in essence the basic definition of a thruster.

The same physical principle is the basis of solar sail propulsion (SSP) devices which produce net thrust by exploiting the collective momentum transfer of solar radiation photons irradiating a reflective plane of appropriate configuration. The difference is simply that of an external radiation source.

It should be noted here that no assumptions have been included on the actual spectral distribution of the emitted radiation and hence, any fraction of emitted power produces thrust in equal measure. In essence, waste heat or more precisely, thermal radiation as the inevitable byproduct of any energy conversion process, would equally add to the thrust generation. Limiting the emitted power to the thermal range of the spectrum self-evidently would lead to a theoretical 100 % conversion efficiency. However, incorporating significant fractions of "‘thermal"’ thrust generation into the AOCS feedback control is challenging since an intricate physical modeling of the particular ramp and fading characteristics for individual electro-optical components would be required. Furthermore, these inherent emission characteristics of thermal radiation in particular have an adverse effect on an eligible swift thruster throttle response time compared to emitted radiation within other parts of the spectrum.

As a simple example, consider switching a conventional light bulb of comparably high power. Closing the circuit leads (almost immediately) to the emission of the corresponding radiation power mainly within the thermal range of the spectrum (the visible fraction amounts to roughly 5 %). Due to heating of the internal components and the surrounding, opening the circuit again is not accompanied by an instantaneous cessation of emission but rather is accompanied by a decaying behavior. Transferring to the implementation as a thruster, this fading complexity constitutes a significant issue that is difficult to govern. Therefore, unless an appropriate method for creating thermal radiation with stringent response characteristics can be accomplished, our first approach tends to include components with low thermal power dissipation in order to avoid the aforementioned drawbacks.

The main attribute for our system, aside from its deployment as an AOCS, is its inherent nature of active control of the amount of generated thrust by producing the electromagnetic radiation internally instead of requiring an incident flux (e.g. solar radiation or externally generated laser photons) to be deflected. Indeed, altering the amount of power emitted from the radiation source allows for a thrust or torque augmentation of arbitrary orders of magnitude.

IV. Setup of PACER

Different design layouts and options for system components are generally possible. Our currently favored setup for PACER comprises the main components depicted in Fig. 1. At the moment, it is assumed that separating the location of the radiation source and the thrust vectoring actuators from the final point of emission out of the thruster unit, allows for an optimized system mass distribution during integration of the individual components into the S/C.

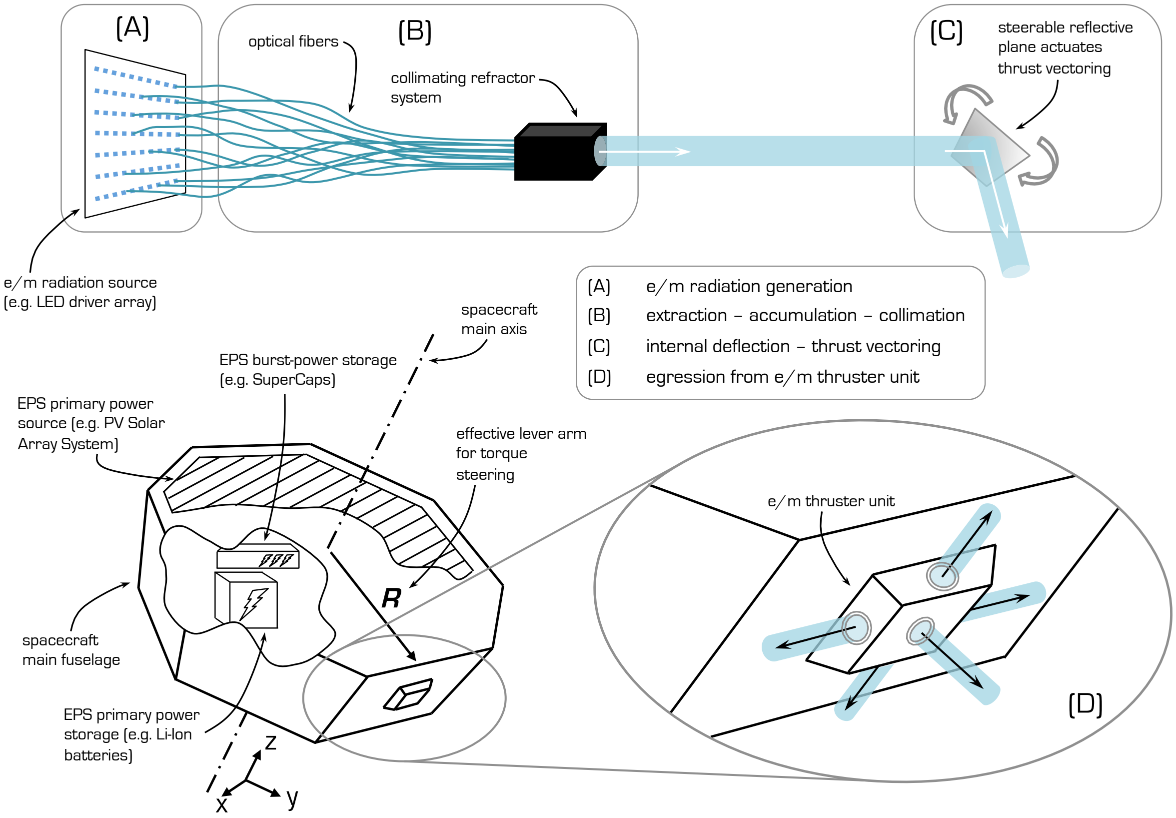


Figure 1. Initial sketch of a radiation-based attitude control system (PACER): Generation (A), extraction, accumulation and subsequent collimation of the electromagnetic radiation (B) and internal deflection for thrust vectoring (C) prior to final egression from the thruster nozzle (D).

This implementation facilitates minimizing the torque required for a swift S/C steering due to optimized moments of inertia. Questions concerning the S/C thermal design can be equally addressed by a careful distribution of possible heat sources providing for an internal S/C environment with constricting thermal stability and low temperature gradients. Maintaining a thermal equilibrium with small possible disturbances is of particular importance for high-precision science experiments carrying sensitive on-board sensor and readout electronics.

PACER exhibits a range of distinct advantages that sets it apart from conventional ACS thruster technologies. Design and propellant-less operation both avoid fuel handling safety complications and operational complexity as well as scaling challenges common to other systems. A discussion of the individual functional parts is given in the following.

A. Thrust Generation and Torque Vectoring

Thrust generation is realized by powering an electromagnetic radiation source. In the currently preferred technical solution, this source is an array of light-emitting diodes (LEDs) mounted on a power board. We chose LEDs not only because of their high conversion efficiency (even heat losses would contribute in a radiation-induced force!), but especially for minimizing response times and maximizing thrust reproducibility, and also towards a centralized radiation source. The latter seems important in order to minimize mass and control requirements, to maximize redundancy, and also considering a minimum transfer length of electrical currents to minimize potential disturbances. Each LED creates (visible) radiation that is extracted by individually attached optical fibers and thereafter redirected and jointly fed into a collimating refractor system. Collimating the extracted light facilitates manipulation of the radiation beam as well as reduction of unfavorable stray light and allows for precise thrust vector control as the beam enters the thruster "nozzle".

Component	Description	Estimated Mass $[kg]$	Necessary Amount
LED	Broadcom 3W LED Emitter	0.025	100
Collimator	Broadcom Collimator 15	0.005	100
Condensator	SkelCap Industrial Cell	0.111	3
Glas Fibers		0.05	1
Special Sensors		0.1	1
Massgain PCDU		0.1	1
	Rough total mass estimation	3.7	

Table 5. Overview over necessary components and rough mass estimation

In our current design layout, selective thrust vectoring is performed by actuating a steerable reflective plane within the thruster unit that eventually determines the point of emission from the thruster nozzle. However, due to the inevitable creation of perturbing moments arising from rotating parts, it is conceivable to replace this mechanical device by optoelectronic components in a later stage of development.

B. Electrical Power System

For any S/C, the electrical power system (EPS) arguably is the single most important on-board component. In order to ensure a minimized launch mass budget the EPS should exhibit a high power-to-mass ratio. Furthermore, a dedicated Power Control and Distribution Unit (PCDU) is indispensable to provide the most efficient power flow control. Considering the possible applications of PACER, the current design layout is expected to draw its power from an array of photovoltaic (PV) solar cells. This array is supposed to work in conjunction with a long-term power storage device currently envisioned by rechargeable secondary batteries. Since a significant amount of power is required during operations, e.g. 0.3 kW for a thrust of 1 μN, the system is designed to incorporate an array of super-capacitors fed by the secondary batteries for intermittent burst power allocation during short and precise activation periods. A very rough, first order estimation of the system's mass comprising commercially available units is given in table 5.

V. Applications for PACER

The inherent advantages of reduced system complexity, modular S/C integration capability, robustness and adaptable high-precision performance give PACER an edge over conventional AOCS thruster technologies and predestines it for deployments in long-term space-based science experiments with sophisticated AOCS requirements.

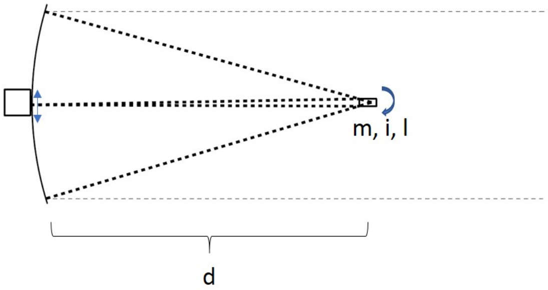
A typical mission scenario that could benefit from the integration of a high-precision AOCS thruster technology is the eLISA gravitational wave observatory. As a highly sophisticated space-based science experiment, eLISA is designed to probe the universe for traces of gravitational waves emerging from astrophysical sources like black holes or neutron star mergers. Three satellites are flying in a triangle with distances of 25 million kilometers, dedicated to measure gravitational waves and to locate the sources by comparing the shifts towards each other. As a precursor to eLISA, the technology demonstrator LISA Pathfinder was launched in December 2015 and has passed a series of on-orbit verification tests with great success. A preliminary launch date for eLISA is scheduled for 2034.

Other future astronomy missions could also profit, as the resolution of telescopes is proportional to the diameter of the mirror. With a high precision AOCS it would eventually be possible to create a telescope composed of several individual satellites. A possible scenario for a large telescope composed of two satellites could impose that the secondary mirror of the telescope is placed 50 km away, having to reflect the bundled waves back to the receiver. Because of the large distance, small changes in the angle would mean a great change of the focal point. Assuming that the secondary mirror has a mass of 50 kg with a moment of inertia of 8,3 kgm^2, and the power of the LEDs is 50 W with an efficiency of 70%, it would be possible to move the focal point exactly 1 cm within 10 seconds! Of course, the main mirror could be divided in small parts composed of a cluster of several satellites. In this case, a high precision AOCS would also have the requirement to avoid any contamination of other mirrors. Another similar example, would be an even bigger telescope with the primary mirror installed on the Moon surface, the secondary mirror located in the second Lagrange point of the Earth-Moon system. With properties as shown in Fig. 3, the focal point back on the Moon surface could be moved 1.3 m within 10 seconds. Finally, another example would be to control the position of the second satellite such that it can act as a stellar coronagraph, allowing eventually the direct spectral measurement of radiation emitted by exoplanets.

Future missions for measuring Earth's gravity fields, similar to the GRACE mission, could also profit from this technology. GRACE conducts detailed measurements by the precise detection of distance changes between two satellites flying in the same orbit. Certainly, a more precise attitude and orbit control system would allow more detailed measurements.

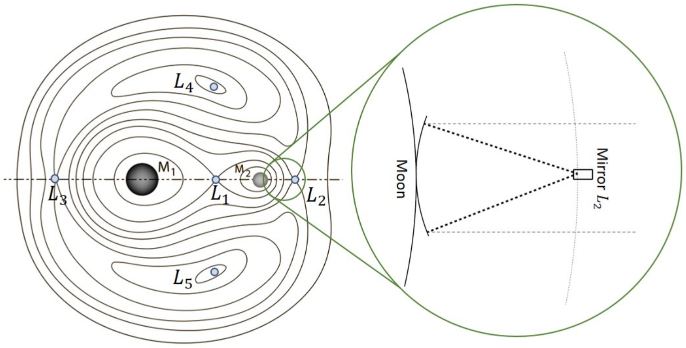
Finally, another aspect is communication over long distances, e.g. between Lagrange point 4 and 5. The more precise the satellites can be arranged, the smaller the opening angle of the antenna needs to be and less energy is required for data transmission. Even a laser link would be possible.

Overall, it can be assumed that especially missions with more than one satellite and formation flight could benefit from a high precision attitude system like PACER.



d : $distance$ $= 50\,km$
m : $Mass\ 2^{nd}\ mirror$ $= 50\,kg$
i : $Moment\ of\ Inertia$ $= 8.3\,kg\,m^2$ $(cube\ with\ 1m^3)$
l : $Lever\ of\ LED$ $= 1\,m$
p : $Power\ of\ LED$ $= 50\,W$

Figure 2. sketch of telescope concept



d : $distance$ $(Moon\ to\ L_2)$ $= 64700\,km$
m : $Mass\ 2^{nd}\ mirror$ $= 1000\,kg$
i : $Moment\ of\ Inertia$ $= 666\,kg\,m^2$ $(2m^3)$
l : $Lever\ of\ LED$ $= 3\,m$
p : $Power\ of\ LED$ $= 100\,W$

Figure 3. sketch of moon based concept

VI. Development of a High-Precision Thrust Stand

Design and construction of a novel high-precision AOCS thruster system equally requires the availability of a device with corresponding precision measurement capabilities. Thus, the development of a high-precision test stand is currently under investigation at IRS. The system is envisaged to enable performance characterization and thrust measurements of the thruster unit with unprecedented precision.

It is now planned to create a mockup of a satellite that is balanced on one single point and has one degree of freedom. To eliminate all disturbing torques, the demonstrator will be installed under a vacuum bell. With two LEDs of 100 W on each side, a lever arm of 0.25 m, a mass of 2 kg, a cube length of 0.2 m and a assumed system efficiency of 50%, a laser installed on the demonstrator could move its projected point 6 cm within 20 seconds on a screen located 50 m away.

By comparing the actual with the calculated movement, the assumed efficiency can be updated. In a

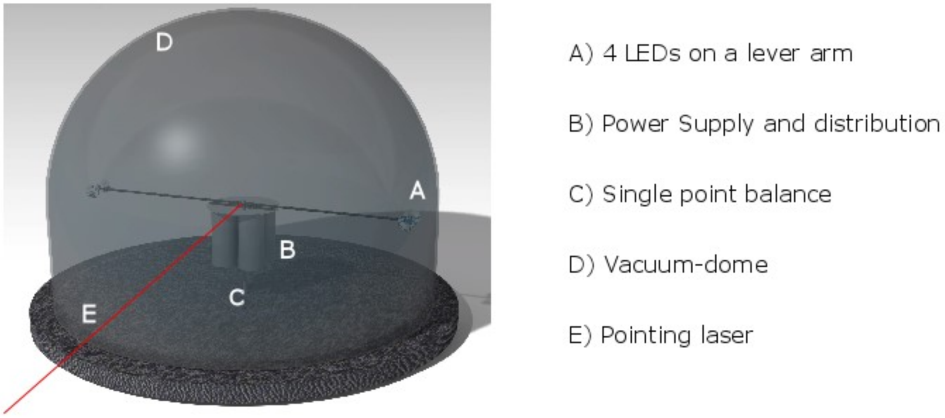


Figure 4. Concept of technology demonstrator

further step, experiments can be conducted to compare the results of single LEDs on the edges with mounting an LED panel in the center with an optical fiber system installed.

A second option for a test stand exhibits the operating principle based on a mechanical pendulum architecture supporting the respective thruster unit. By operating the thruster in a pulsed mode with a frequency matched to the eigenfrequency of the pendulum, a resonant behavior of the stand is triggered, facilitating a considerable gain in minimum thrust measurement and resolution performance. By carefully designing the eigenfrequency of the setup, adverse effects of external vibrations are minimized due to frequency mismatch and therefore inefficient energy feed to the swing arm oscillation. Furthermore, due to its differential measurement method, performance characterizations are insensitive to thermal fluctuations or thermal drift of the system. This resonant operation principle has already been successfully demonstrated in a former setup [4]. By upgrading the existing pendulum test stand already available at IRS to adapt the resonance method, a significant boost in measurement precision and performance rating is expected.

VII. Conclusion

Propellant-less thruster technology has significant advantages over conventional fuel-based thruster systems. For active attitude and orbit control purposes, our group is currently developing PACER as a novel propellant-less precision ACS technology based on the active emission of electromagnetic radiation. Due to its inherent design, the performance scalability of the system could allow for a wide range of applications within future space mission scenarios. The main tasks could be high precision attitude and distance control for long distance communication links and scientific missions with high AOCS-demands such as telescopes or gravitational wave observatories. One important advantage is that the mission lifetime is not effected by limited fuel supplies and the precision of the system is maintained over the entire lifetime. Due to the high precision, system complexity and power consumption of other S/C systems could eventually be reduced significantly. A set-up of a complete system and its experimental investigation is now planned as the next step.

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