Powder-based additive manufacturing in micro-gravity conditions

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Abstract. Development of versatile in-space manufacturing technologies is vital for space missions to manufacture parts and tools during long space missions or emergencies. Powder-Bed Additive Manufacturing (PBAM) is a promising manufacturing technology which uses powders as the feedstock material to 3D print a final product from a CAD model. PBAM is believed to be more suitable for maturation due to the shortcoming of the other AM technologies, such as the Fused Filament Fabrication (FFF) technique, which have so far been considered for in-space manufacturing. In PBAM, a layer of fine powder is spread on a substrate and melted using a laser to fabricate objects which, on earth relies on gravity. Here, ultrasound transducer arrays are proposed for the delivery of powder particles in PBAM to fabricate small objects. An initial array is developed and validated by levitating Expanded Polystyrene (EPS). Levitation of much heavier and finer metallic powders (such as Inconel and Stainless Steel) which are commonly used in PBAM is much more challenging. Although, our current array can vibrate a collection of such powder to the point of levitation, more innovative designs guided by the Gorkov theory is being developed.

Keywords: Additive Manufacturing, Acoustic Levitation, Ultrasound transducer array

Near net shape objects can be obtained through Powder-Bed Additive Manufacturing (PBAM) techniques. PBAM is utilized in many sectors such as aerospace, medical, automotive, etc. Due to the increase in plans for long space missions such as NASA's Moon to Mars [1] and European Vision of Exploration [2], maturation of technologies for in-situ manufacturing of parts and tools from feedstock material is attracting significant attention. The process reduces the mass transported and allows astronauts to effectively deal with unexpected failure of tools and parts during the mission [3].

Additive Manufacturing (AM) can enable in-situ manufacturing in space [3]. Recent attempts to use AM in microgravity conditions started with the first-ever 3D printer sent to the International Space Station by Made in Space partnered with NASA in 2014 [4]. This machine uses the Fused Filament Fabrication (FFF) technique [5] which relies on polymer feedstock in form of a wire. Moreover, European Space Agency (ESA) developed a 3D printer prototype through the Manufacturing of

Experimental Layer Technology (MELT) project. This prototype is again based on the FFF technique and used High-performance Polyetheretherketone (PEEK) and can operate in any orientation to cope with the microgravity condition [6]. Although the FFF feasibility is demonstrated [7], it suffers from several inherent shortcomings including the need for support structures, low surface quality, slow build speed, and limited feedstock material [8], [9].

In contrast to FFF, PBAM can tackle in-space manufacturing of tools and small parts for space missions. During the process, a layer of fine powder ($D_p \approx 30$ μm) is deposited with a thickness of a few D_p. A laser is then used to heat the powder bed which fuses the grains through melting and solidification. PBAM with a few modifications can be used with high-performance thermoplastics through a sintering process, and metals including superalloys such as Inconel through a melting process [10].

Powder delivery and handling remain a hurdle with the in-space PBAM technology. German Space Centre developed a microgravity 3D printer using a vacuuming method that keeps the powder in place with the help of a suction and filter system [11]. There are difficulties due to the nature of the technology such as the filter getting covered over time as the layers develop which reduce the flow and the feedstock itself gets lost.

In this project development of ultrasound (US) transducer arrays is proposed to lock a packed bed of particles ready for processing. The new PBAM technology can be used in microgravity for the manufacturing of small objects with dimensions of O(10 cm^3). The acoustic locking using dynamic field US devices offers online digital process control, non-intrusiveness, and applicability to multiple layers of powder.

A prototype array is developed by 3D printing an array casing as shown in the Fig. 1. (b). This is similar to the design first proposed in by Asier et al [12]. It is demonstrated that the setup can levitate Expanded Polystyrene (EPS) as shown in Fig. 1. (c). Simulations based on the Gorkov theory [13] shows the amount of vertical and longitudinal forces applied to a 1mm EPS particle as shown Fig. 1. (a). The setup shown in Fig. 1. (c) has the potential to levitate multiple times of density of EPS such as water droplets. Furthermore, it can be demonstrated that the setup can vibrate much heavier and finer Inconel grains to the point of levitation although this could not be achieved with the current setup. Innovative array designs guided by numerical simulations based on Gorkov theory is being considered to enable fully levitation of heavy particles.

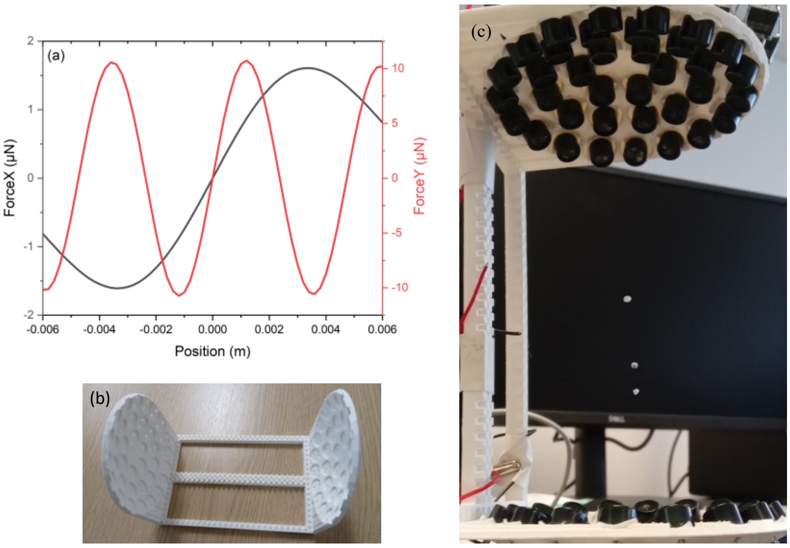

Fig. 1. (a) Ultraino simulation of the lateral (x) and longitudinal (y) forces acting on a 1mm diameter EPS kept at the centre of (b) a 3d printed setup and (c) three EPS beads are levitated by 72 US transducers

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