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Novel active driven drop tower facility for microgravity experiments investigating production technologies on the example of substrate-free additive manufacturing

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Abstract

Through the striving of humanity into space, new production processes and technologies for the use under microgravity will be essential in the future. Production of objects in space demands for new processes, like additive manufacturing. This paper presents the concept and the realization for a new machine to investigate microgravity production processes on earth. The machine is based on linear long stator drives and a vacuum chamber carrying up to 1000 kg. For the first time high repetition rate and associated low experimental costs can provide basic research. The paper also introduces the substrate-free additive manufacturing as a future research topic and one of our primary application.

Keywords: Microgravity and hypogravity; Drop tower; Additive manufacturing; Laser beam melting (LBM); Laser metal deposition (LMD); Linear motor

1. Introduction

Humanity strives towards the population of space and astronomical objects like planet mars or the moon. Production of equipment or spare parts in space or on extraterrestrial bodies will therefore be important (Bollinger, 1987). This requires new processes and technologies, which are useable under weightlessness/microgravity (approx. 10^{-6} g) and hypogravity (below 1 g), such as additive manufacturing. For microgravitational research on earth, sounding rockets, parabola flights and traditional drop towers are available. However, these facilities are cost and time intensive. Hypogravity cannot be established in large scale for use in scientific research on earth until today. The consideration of production processes in space or under extraterrestrial conditions requires a high number of test executions and a continuous modification of the experimental setup. For a better knowledge of process details under these unusual conditions, a machine had to be designed with a high repetition rate and good accessibility for experiments at low costs.

The current development in space industry leads to an increasing demand for micro- and hypogravitation research facilities and, in particular, a higher throughput

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of experiments with the installed drop towers around the world. The current techniques are time intensive and increase the operating costs. For an increase in capacity and microgravity quality, as well as for the realization of hypogravity various concepts are discussed (Könemann et al., 2015; Urban, 2015).

The presented machine *Einstein-Elevator* is an ambitious enhancement of a traditional drop tower. By the use of a new drive technology based on linear motors in combination with a novel control and guidance concept an actively driven test sequence becomes possible. Linear motors accelerate a moveable vacuum chamber holding the integrated experimental setup to the necessary flight speed and compensate for the occurring air and rolling resistance during the subsequent free fall (microgravity) or a modified vertical parabolic flight curve (hypogravity). Deceleration is realized via the drive and eddy current brakes. Due to this automated concept, the repetition rate of the test sequence is greatly increased.

All manufacturing processes on earth involve gravity. Examples are chips dropping downwards during milling and melt flowing to the lowest point during casting. Other processes are for instance laser cutting or laser beam welding with gravity-influenced solidification. In case of additive manufacturing under gravity, a substrate is always necessary. Under microgravity and for the use in hypogravitation, each of these mentioned processes has to be adapted. Substrate-free additive manufacturing will be used to describe the possibilities for future investigations of production processes under microgravity.

This paper focuses on a new machine to analyze production processes under microgravity conditions on earth. It presents in Section 2 the development of a unique machine. Section 3 introduces the substrate-free additive manufacturing focused on the use in microgravity as a new production process and explains its challenges. The integration of new processes and technologies into the novel facility *Einstein-Elevator* takes place in Section 4.

2. Microgravity research with high repetition rate

Research under microgravity on earth can only be realized during free fall in vacuum. In order to extend the duration of free fall, it can also be executed as a parabolic flight in sounding rockets, airplanes and drop towers. In a traditional drop tower, an unguided free fall takes place. Using a catapult, for example, enables a vertical parabolic flight. As a result, the duration is doubled compared to free fall by dropping.

Traditional drop towers with a vacuum chamber for the whole trajectory of the falling experimental setup have the disadvantage of low repetition rates due to high evacuation times. They have long recovery times after a test execution. This results in repetition rates of 2–3 experiments per day, which leads to expensive campaigns for experiments that require statistical analysis (Urban, 2015).

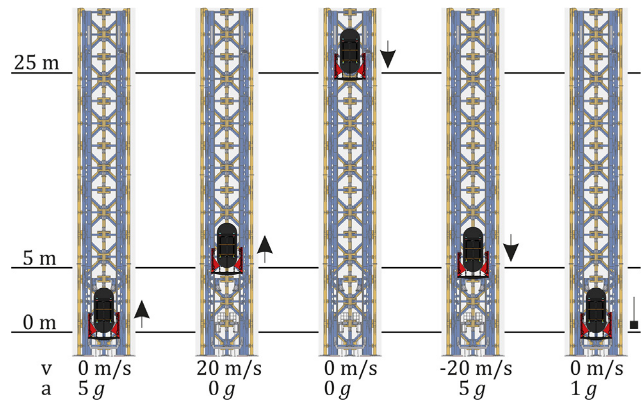

Fig. 1. Movement of the experimental setup in the *Einstein-Elevator*: Actual position, direction of motion, velocity and acceleration.

The function of the *Einstein-Elevator* involves a high degree of automation for the realization of a high repetition rate, as shown in Sections 2.1 and 2.2. The unique feature is the intended repetition rate in combination with a high microgravity quality for large experiments as described in Sections 2.3 and 2.4 with the necessary steps.

2.1. Function of the Einstein-Elevator

In the *Einstein-Elevator*, experiments with a mass of up to 1000 kg, a diameter of 1.7 m and a height of 2 m are to be performed for 4 s in microgravity up to 100 times per day (Lotz et al., 2014; Lotz et al., 2017). The experimental setup is placed in a vacuum chamber, a gondola, that is hardly larger than the setup, which saves a significant amount of time while producing the vacuum atmosphere required for the test execution. The movement of the gondola and the experimental setup is shown in Fig. 1.

Two linear synchronous motors with an output power of approx. 5 MW accelerate this gondola within 5 m to 20 m/s. Subsequently, the experiment carrier is released from the gondola floor and flies autonomously up and down over a distance of 20 m. During the free fall sequence, the drive balances the occurring air and rolling resistance of gondola and guides and keeps the distance between the gondola floor and the experiment carrier constant. After touchdown, the drive and eddy current brakes decelerate the experiment carrier and gondola together to a standstill. In preparation for the next test execution, an automatic alignment device centers the experiment carrier in the gondola without opening it. As an advantage, the vacuum is maintained. The worldwide unique basic setup allows for this automated process for the first time.

2.2. Basic setup

The system is designed for automated operation at high repetition rates and at the same time very low residual acceleration or high microgravity quality as illustrated in Fig. 2a. The design aims to transmit as few vibrations as

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