Freeform precision motion solutions through high tech Additive Manufacturing

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Abstract

Rapid developments in Additive Manufacturing (AM) technology, are becoming interesting for high precision systems development. Mechatronic design approaches to make use of the freeform nature of AM are discussed, with some first results.

1. Introduction

Additive manufacturing is a rapidly developing technology, with increasing relevance for high precision systems development [2]. Particularly, the inherent freeform nature of AM offers new design possibilities for system engineering. Known bottlenecks in high precision motion systems concentrate around moving mass, thermal non-uniformity and system complexity. This paper adresses the question how AM enabled freeform design can provide precision mechatronic solutions to such bottlenecks, and pave the way to breakthroughs in system performance. Section 2 starts from system level. In Section 3 a variety of preliminary results will be presented, spanning up the contours of the freeform mechatronics potential. Conclusions are given in Section 4.

2. Freeform system design and precision mechatronics approach

Starting from system level, the biggest challenges in precision systems are found in performance critical parts such as substrate carriers for motion, positioning and substrate conditioning. Initial ideas on how AM could be a valuable manufacturing technology for high tech systems performance can be found in [1].

Three main routes are proposed to overcome future performance limitations:

- Open structures to achieve lightweight system designs with favourable mechanical, and dynamical properties
- Sophisticated mechanisms and flexures that can be manufactured in one piece. Solving tedious assembly, delicate alignment etc. of a many small parts
- Freeform flow and thermal solutions, dedicated to enable thermal performance

In pursuit of breakthrough solutions to these multi-criteria and multi-physics determined design challenges, topology optimization is a very promising area of research. Taking freeform design even a step further, multi-material, spatial distribution of mechanical/dynamical properties across a part are interesting ideas.

3. Freeform mechatronics research progress

3.1 Lightweight motion system part

The figure below illustrates a design study on a lightweight motion system part where the aim was to reduce mass while preserving the first resonance frequencies close to that of a massive part. The inner part is a lattice structure that could be manufactured with AM. In this case C-SiC was chosen as material. A mass reduction of a factor of two was achieved, while the resulting modes ($f_{torsion}$ = 1100 Hz, f_{saddle} = 1300 Hz), which is close to the massive monolith benchmark part.

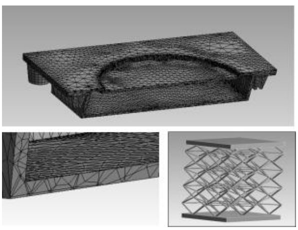

Figure 1: Lightweight motion part with internal lattice structure

3.2 Design optimization AM part experimental evaluation

This paragraph presents validation of a topology optimization example. From a 2D optimization results, a demonstrator has been manufactured with AM and has been subjected to a compression test. The calculated maximum force (2700 N) is in reasonable agreement with the measured force (2450 N), although the corresponding displacement in the measurement is clearly higher than the calculated displacement.

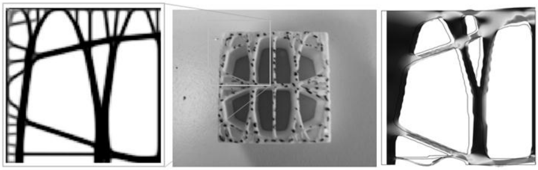

Figure 3: Optimized structure segment (left), printed sample for experimental evaluation (middle), stress analysis segment during compression loading (right)

3.3 Multiple segment, leaf spring-hinged tip/tilt mechanism

See Figure 4 for an example of an integrated mechanism with multiple segments, and leaf spring suspensions, that allow for individual tip-tilt actuation per segment. The part is obtained with AM out of one piece, so no assembly involved. Such part could be applied for local substrate manipulation for leveling at the area of performance.

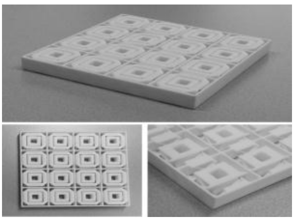

Figure 4: Integrated AM mechanism with tip/tilt segments and leafspring suspension

3.4 Freeform optimized cooling topology for substrate conditioning

Thermal conditioning is critical to performance in many high precision systems. Limitations in the cooling channel design, due to conventional manufacturing constraints do not apply to AM, which opens up new possibilities to design dedicated cooling channel topologies. A first topology optimization study has been carried out (see Figure below). A square cooling body, subject to a uniform and continuous heat load. The resulting cooling channel shows vein-like branches with variable width. From an engineering perspective this makes sense, but without the aid of model based design tools a designer would probably never have drawn such channel layout.

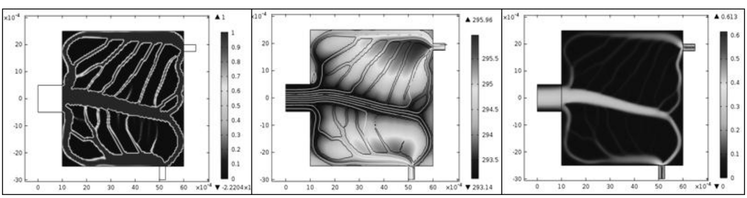

Figure 5: Thermal cooling channel topology optimization study: channel pattern (left), thermal perormance (middle), flow speed across conditioning body (right)

3.5 Enhanced vibration damping multi-material support strut

A practical multi-material case using constrained layer damping (CLD) has been investigated and implemented locally in the supporting struts in an optical instrument. Validation experiments on a simple structure showed good agreement between measured and predicted damping properties. The figure shows measurement results of increased damping at 285 Hz. The Q-factor has been reduced from 160 (undamped) to 60 (CLD), which is a significant improvement.

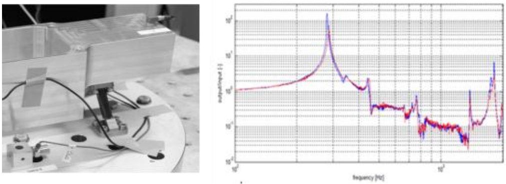

Figure 6: Multi-material support strut with increased damping: experimental setup (left), measured damping increase (right)

3.6 Multi-material substructures for favourable thermal properties

Very appealing, is to look for smart combination of materials, e.g. in micro-structures, resulting in parts with desirable properties at macro level. Here, an explorative 3D design and thermal result is presented combining materials with positive thermal expansion, into a geometrically repetitive microstructure with zero thermal expansion, yet having acceptable mechanical properties, see Figure below.

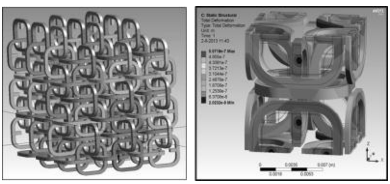

Figure 7: Multi-material substructure design (left) and thermal analysis (right)

4. Conclusions

This paper has touched upon the potential benefits of high tech Additive Manufacturing for high precision system solutions. Preliminary research results have been presented. The main conclusion is that confidence in the potential of AM enabled freeform mechatronics is growing, with some proof in practice (albeit in simple but meaningful research settings). This encourages further work in this field.

References:

[1] “Getting High Tech Systems in Shape and Fit for the Future”, Gregor van Baars (Mikroniek, april 2012)

[2] Wöhlers report 2013: “Additive manufacturing and 3D Printing state of the Industry”, ISBN 0-9754429-9-6