Additive manufacturing in precision engineering applications

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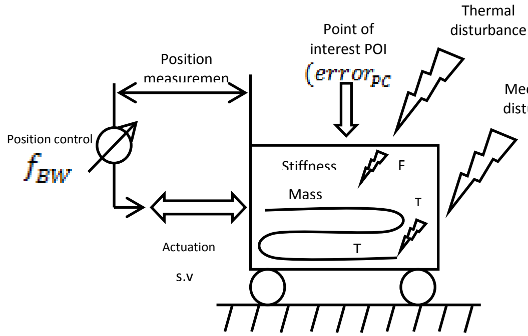
Abstract

Additive Manufacturing (AM) technology facilitates the production of complex monolithic and highly functional integrated components. The inherent freedom of design creates opportunities in significant performance improvements, integrated complexity and functionality with a potential reduction of development, production and assembly cost when applied in the right manner. For example, precision motion controlled stages with high thermal and dynamic requirements result in extremely complex designs and topologies which may be produced relatively cheaply with AM.

At ASML we see potential benefits in several crucial aspects like the performance of fast high precision stages and its motion control. The design freedom of the current parts for these stages is limited by conventional machining and thus also limiting the performance. By introducing AM in combination with topology optimization, a performance gain can be achieved. Next conventional machining starts with a massive block of material machined back to a light weight stage where only 5% is left and 95% removed. The low removal rate and material costs of the used high tech materials make these parts quite expensive. Because AM uses only the material needed for the functional part and the absence of intensive machining AM can lead to a price reduction. At last the flexibility of AM makes it possible to integrate hundreds of parts in an assembly in a single monolithic printed part which leads to reduced assembly time and lower failure rates.

1. Challenges in high tech systems

In order to keep up with our customer's roadmaps ASML needs to continuously improve the overlay and focus performance of their systems. One of the main contributors to these performance specifications is the high precision waferstage. When we consider a basic model of a positioning stage as depicted in Figure 1, the position error ($error_{PC}$) of this system is dependent of the control bandwidth (f_{BW}) of the position controller and the disturbance forces (F_d). The control bandwidth of a position control system (f_{BW}) is determined by the mass (m) and stiffness (k) of the mechanics, the disturbance forces (F_d) can be from an external origin, but can be generated inside the system like for example flow induced vibrations.



$$\frac{error_{PC}}{F_d} = \frac{1}{0.5.m.(2\pi f_{BW})^2}$$

$$f_{BW} \sim f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Figure 1: Schematic model of a stage

The position error in the point of interest is also influenced by thermal disturbances from the environment or the actuators that drive the stage. The challenges in mechanically improving the performance and precision of a stage can be found in:

- increasing the bandwidth of the system by designing a lightweight and high stiffness stage by improving the efficiency of the used material
- reducing the internal disturbance forces by preventing undercuts and use of fluent sections in channels
- applying more efficient cooling of the heat sources by increasing the contact surface and moving the coolant closer to the heat source.

2. Additive Manufacturing Solutions to the Challenges in high tech systems

Additive Manufacturing processes come with a freedom of design which is not available with conventional manufacturing techniques. Conventional machining operations are basically limited by the need of cutting tools attached to a spindle for removing material, where additive manufacturing only builds up material where needed without any tools touching the part during building. Additive Manufacturing still has some limitations to design freedom dependent on the process chosen, but offers a lot of possibilities to solve the challenges in high precision stages. With the help of additive manufacturing ASML has already implemented a number of solutions to these challenges in his stat of the art litho tools:

2.1 Increasing the bandwidth of the system

In a stage that has to position with sub-nanometer accuracy every part needs to be connected with high stiffness and needs to contain the least mass possible in order not to disturb the control bandwidth of the system. Figure 2. shows a part that has been designed for additive manufacturing. It contains a main body that is made hollow which is not manufacturable by conventional machining methods. A mass reduction was achieved of over 50% compared to conventional machining. Because this part was mounted at a large distance to the center of deformation it contributed substantially to the increase of the bandwidth of the system.

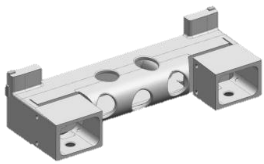


Figure 2: support

2.2 Reduction of internal disturbance forces

One of the sources causing disturbance forces in a high precision stage is flow induced vibrations due to turbulent flows in cooling channels. These small forces can generate position errors in the order of 10nm which is to much in case of a litho tool. Figure 3 shows an example of a plastic water distribution manifold which is designed for conventional machining with the inherent limited design freedom on the left side and its Titanium alternative designed for additive manufacturing on the right side.

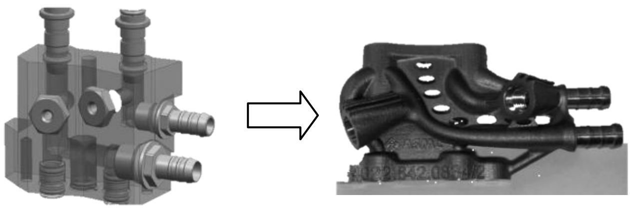


Figure 3: water distribution manifold redesigned for additive manufacturing

The redesigned part has smooth transitions and corners eliminating turbulance in the flow through the part. The redesign delivered equal thermal isolation between the in- and outflow, less weight and almost no more disturbance forces in the system.

2.3 Improved cooling of heat sources

Temperature gradients or variations in a stage can cause the point of interest to drift away from its intended position because of the thermal expansion of the heated materials. Therefor it is important to extract the generated heat as close as possible from the heat source. Figure 4 shows a magnet yoke bracket with a cooling plate connected directly to the magnet back iron. With the design freedom in additive manufacturing we were able to bring the cooling medium closer to the heat source and maximize the contact area of the coolant to the heat source to improve cooling efficiency.

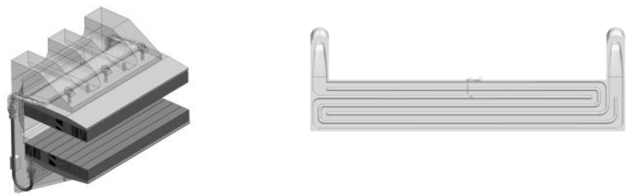


Figure 4: magnet yoke bracket and cooling plate

3. Developments needed to expand the possibilities in high tech systems

The use of additive manufactured parts in high tech systems can even be expanded but advances need to be made on a number of materials and technologies: size and cost price of metal parts in order to compete with conventional machining for less critical parts, the availability of non-porous, non-outgassing and flammability certified high tech plastics like PEEK, the availability of large size technical ceramics like Alumina and zero-CTE ceramics like cordierite and zerodur. Design optimization tools for free-form design can help profiting even more from the inherent freedom in design of additive manufacturing.

References:

[1] All examples and pictures used are ASML materials