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Simulation and optimization of the dynamical-optical behavior of mirror systems

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Abstract
In this work, methods and simulation environments are proposed for investigating and optimizing the dynamical-optical behavior of general high precision optical systems like lithographic objectives or telescope optics, which can be treated as elastic multibody systems. For this, software-tools and interfaces are developed and mechanical and optical simulation models are derived and implemented. On the one hand, the elastic multibody simulations can represent the mechanical behavior resulting from any external excitations and on the other hand, the related optical behavior can be predicted. Furthermore, methods for structure optimizations can be proposed, in order to decrease the sensitivity of a projected image against mechanical vibrations. In order to clarify these methods in a first step, academic examples are chosen.

Dynamical-Optical Behavior, Mirror, EUV, Elastic Multibody System, Dynamics, Vibration, Optimization

1. Introduction

High-performance optics, especially lithographic objectives or astronomic telescopes, are highly resoluting optical systems consisting of precise mirrors or lenses. The optical elements are mounted with high accuracy and they are very sensitive with respect to vibrations. Wafer scanning systems use lithography objectives to project structures in a reticle onto wafers, and the wafers are exposed for a certain time. During that time, even small vibrations of the mirrors or lenses can be sufficient to produce aberrated images [1]. Sources of these small vibrations can be minimal excitations at the objective frame, e.g., from noise of coolers or influences of the wafer motion system. The mechanical behaviour of the optical systems can be described by a combination of rigid body motion, small deformations and the related stresses which also influence the optical behaviour. This leads to the utilization of elastic multibody simulation technics [2]. In order to investigate the overall dynamical-optical behaviour, multi-disciplinary methods and software tools with suitable interfaces are necessary.

2. Dynamical-optical simulations

Here, methods are proposed for simulating the performance of dynamical-optical systems. A generalized workflow for dynamical-optical simulations using cooperating software packages according to Figure 1 can be introduced.

On the one hand, existing software tools for the FE-simulation can be employed and on the other hand, a model reduction and elastic multibody simulation toolbox for general use was developed within our research group. Furthermore, an optical simulation toolbox with an interface to elastic multibody simulation is developed. This is necessary, since common optical software like ZEMAX or ODESIS are not appropriate for the consideration of local stress effects and are not convenient in combination with dynamic multibody simulations.

The first step of creating a dynamical-optical simulation is to model the sensitive optical components separately as elastic bodies using a FEM software. Therefore, a FE-tool like Ansys can be utilized and a modal analysis can be performed. The equations of motion and the mode shapes can afterwards be imported into MATLAB using an interface function, which is part of the MatMorembs-toolbox. Since FE bodies usually have many degrees of freedom which results in expensive calculation effort, a model reduction based on the mode shapes has to be applied. Therefore, several functions and methods are provided in this toolbox.

For the assembly of the system and the mechanical simulation, the functions of the toolbox Neweul-M^2 are effective. They are able to import and to join several rigid and elastic bodies into an elastic multibody system. The equations

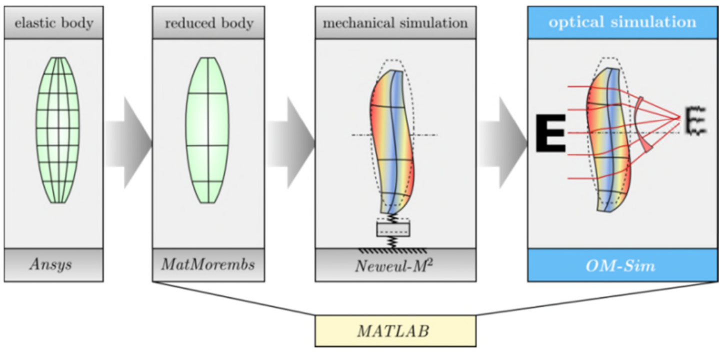

Figure 1. General workflow of dynamical-optical simulations.

of motion can even be provided in symbolic form. The movements, deformations and stresses are resulting from a numerical integration in the time domain. The supplied graphical user interface allows further investigations of the mechanical simulation results.

In order to calculate the optical aberrations of deformed surfaces, the mode shapes of a reduced body have to be approximated accurately e.g. using a minimal set of Zernike polynomials. Depending on the complexity of the shape, this could be very challenging. In this context, sophisticated methods are proposed and can be discussed. Furthermore, an optical simulation yields the related wavefront aberrations. For this task, the toolbox OM-Sim is developed, where ray tracing and Fourier optical methods are implemented. In order to validate the toolbox, the optical simulation software ZEMAX is used.

Since the deformation of a dynamically excited surface results from the superposition of the mode shapes, the corresponding wavefront aberrations can also be superposed. In conclusion, the nonlinear dynamical-optical behaviour can be investigated and assessed.

3. Examples

As an example, the performance of simulating a flexible lens mounted on elastic supports according to Figure 2 is discussed and the results are presented. For that, the support is excited dynamically and the mechanical-optical results are extracted. Beside lens elements, mirrors can also be simulated and analysed applying the introduced workflow. It is shown how a parabolic mirror with obstruction depicted in Figure 3 can be modelled and investigated using FE-Tools, multibody software, and the optical simulation toolbox. In order to decrease the computational effort, different methods of model reduction are tested and compared within the workflow.

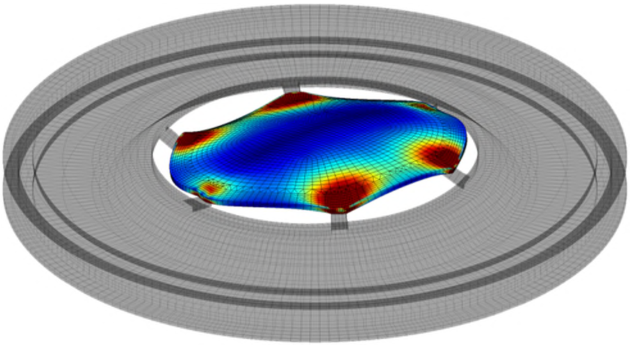

Figure 2. Mechanical **s**imulation of an elastic lens component.

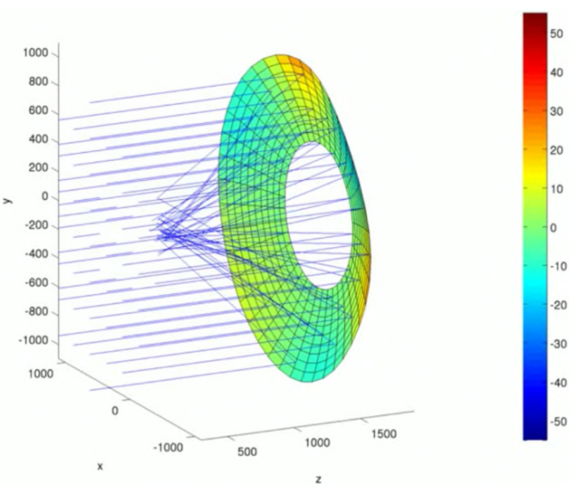

Figure 3. Optical simulation of an obstructed mirror.

4. Structure Optimization

Furthermore, an optimization method is introduced which describes the dynamical and optical behaviour by means of a transfer function [3]. Therefore, some simplifications and assumptions have to be made. For instance, the optical behaviour is characterized by a linear model using a matrix of optical sensitivities and assuming small deformations of the components. Instead of using active or passive damping strategies and suppressing any motion, it is proposed to optimize the suspensions by modifying the mass and stiffness distributions while analysing the optical response. Eventually, the aim of the optimization is to reduce the influence of mechanic excitations on the imaging error.

An exemplary optical system with two mirrors modelled as a rigid multibody system is investigated and optimized [4]. On the one hand, the defocus of the projected image is considered and on the other hand, the line of sight is minimized. Figure 4 shows the mechanical model of the system.

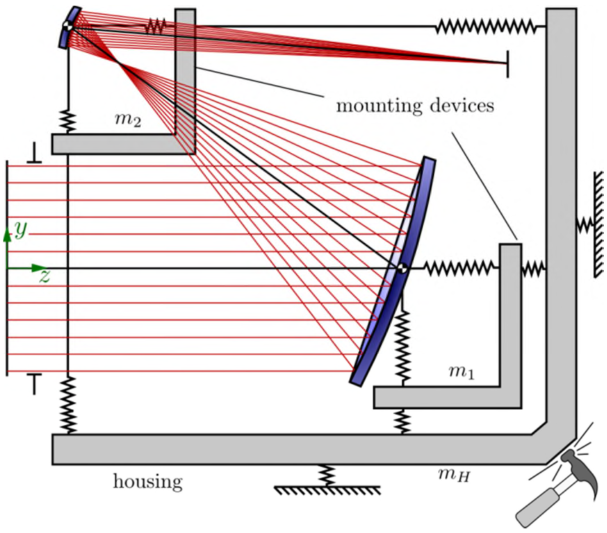

Figure 4. Mechanical model for the multi-criteria optimization process.

5. Conclusions

In order to investigate the dynamical-optical behaviour, multidisciplinary methods and models are proposed. On the one hand, a simulation environment and workflow strategies are provided and on the other hand, structure optimization approaches can be introduced regarding a linear dynamical-optical behaviour. Based on these approaches, many expansions are possible in order to improve the quality of optical systems. In particular within the structure optimization, the optical aberrations caused by mechanical deformations and stresses also should be taken into account. Furthermore the performance of the simulation environment should be tested with large and accurate models in comparison to other integrated optomechanical methods [5] and software tools [6].

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