Advances in the analysis and design of adaptive optics

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Abstract: Opto-mechanical analysis and design techniques for development of adaptive optics are presented. Topics include actuator stroke limits, actuator failures, optimum placement of actuators, and optimum structural design.
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1. Introduction

Integration of predictive engineering capabilities such as finite element analysis (FEA) and optical analysis enables high performance optical systems to be developed for optimum performance. Such integration is especially useful in the development of adaptive optical systems, which involve additional design considerations such as actuator layout, actuator reliability, actuator resolution errors and other issues associated with adaptive control of optical systems. Figure 1-1 shows a flow chart of this integrated analysis process. Mechanical loads representing environmental disturbances are used with a finite element model (FEM) of the optical system to generate disturbances of the optical surfaces. A similar process is used to generate analogous descriptions of the influence functions through simulation of each actuator in separate cases. These descriptions may be processed and subsequently used in adaptive control simulation to obtain predictions of rigid body motions and residual surface deformations of the adaptively corrected surfaces. These descriptions may be formulated for input into an optical analysis model to obtain optical performance predictions of the adaptively corrected system.

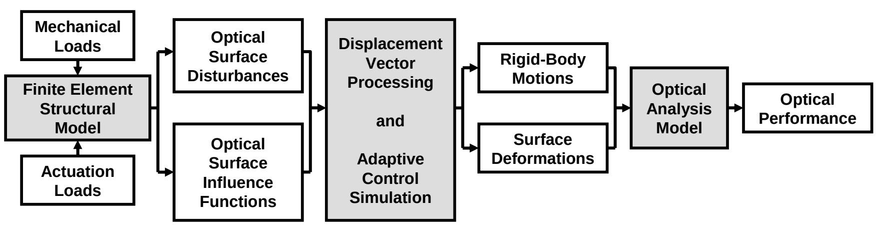

Figure 1-1: Flow chart of simulation of adaptive control of optical systems. While the shaded boxes represent processing steps, the unshaded boxes represent inputs and results to the processing steps.

The details of the process shown in Figure 1-1 with emphasis on the displacement vector processing and adaptive control simulation are discussed in References 1-8. Implementation of this process has been made in software called *SigFit* developed by the authors.

2. Adaptive Control Analysis Issues

2.1 Actuator Stroke Limits

The adaptive control simulation process presented in Reference 3 imposes no limits on the solution values of actuator control inputs. In practice actuators typically have limited strokes that can affect the ability to correct disturbances. The effect of such stroke limits can be included through various methods such as iteration or linear programming techniques.

Figure 2-1 shows the decrease in adaptive correctability with increased surface deformation due to the effect of finite actuator strokes. Adaptive correctability is measured as unity minus the ratio of the residual uncorrected surface RMS error after correction to the initial surface RMS error before correction expressed as a percentage.

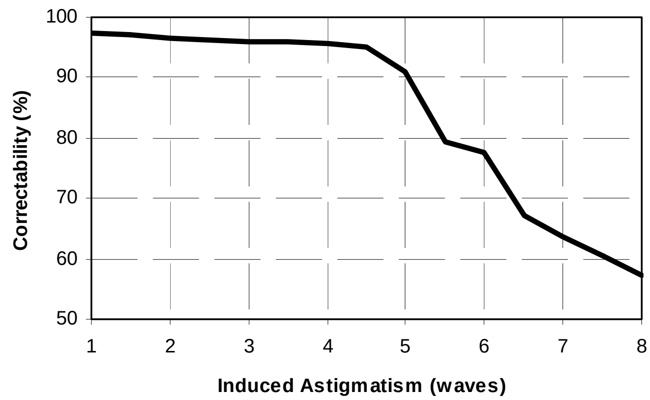

Figure 2-1: Correctability of an adaptive optic vs. induced astigmatism disturbance.

2.2 Actuator Failure

Reliability studies can be conducted to understand the effect of actuator failures. Actuator failures may be simulated by simply not including the influence functions associated with failed actuators. Figure 2-2 shows the relationship between adaptive correctability and the number of failed actuators. The shape of the curve shown in Figure 2-2 is dependent on the choice of actuators considered to be failed. A Monte Carlo analysis incorporating the statistical reliability of each actuator would yield a system reliability performance prediction.

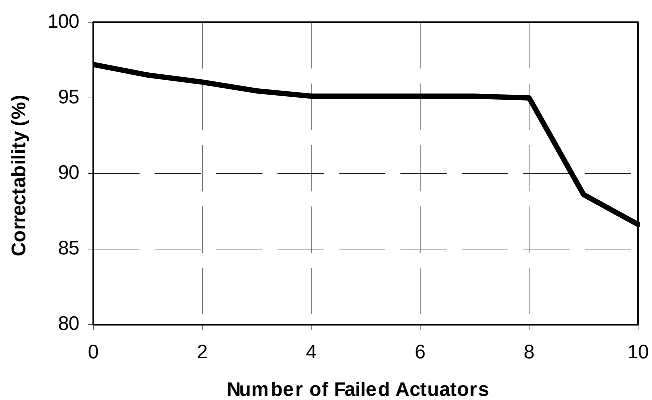

Figure 2-2: Correctability of an adaptive optic vs. number of failed actuators.

2.3 Actuator Resolution

Many actuator designs are limited to a finite number of actuator input levels. Such levels may be discrete positions or forces in contrast to the continuous control assumed in adaptive control simulation analysis. The effect of such resolution in actuator input levels causes a random error in the shape of the corrected optical surface related to the size of the actuator resolution. The statistics of this error may be predicted by a Monte Carlo method.

2.4 Optimum Placement of Actuators

The placement of the actuators is an important factor in the development of the design of adaptively controlled optics. The variability of the design space and the opposing effects of different load cases can cause such design development to be to overwhelming for a manual process. Genetic optimization techniques are very effective in finding near global optimum layouts of actuators for such design problems [9].

2.5 Optimum Structural Design

The structural design of adaptive optics can play a major role in their correctability performance. Figure 2-3 shows plots of the finite element model of the SPOT mirror developed by NASA Goddard [10]. Structural design optimization was performed to minimize the deviation of the optical surface from a spherical shape through a range of actuation. Adaptively corrected performance predictions were made through calls to an external subroutine version of *SigFit*. While the initial design shown in Figure 2-3(a) exhibited 225 nm of surface RMS error for a 2mm radius-of-curvature change, the optimized design exhibited 33 nm of surface RMS after the same actuation range.

(a) (b)

Figure 2-3: Plots of finite element models of (a) initial adaptive mirror design and (b) optimized adaptive mirror design.

3. Interfacing Mechanical Analysis With Optical Analysis

Once mechanical predictions of the optical surfaces have been obtained, they may be recast into a format useable for optical analysis so that optical performance metrics may be generated. The details with which mechanical results may be recast into a format useable by optical analysis depend on the optical analysis software being used, but there are generally four methods of describing deformed optical surfaces for optical analysis as illustrated in Figure 3-1.

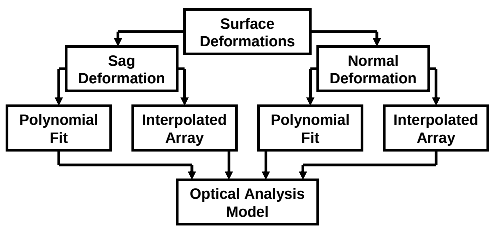

Figure 3-1: Methods of representing surface mechanical deformation predictions in optical analysis. Rigid body motions of each surface are imported in separate data formats.

4. Conclusions

Opto-mechanical adaptive control simulation can be used to address many design issues in the development of adaptive optical systems. Subsequent interfacing to optical analysis allows prediction of meaningful adaptively corrected performance metrics due to the effect of mechanical disturbances.

5. References

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