Optimal Design for a Varying Environment

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This project involves using mathematical models to optimize the performance of a diffractive optical element. Unlike the usual optimization problem, we will seek methods for finding an optimal design in the presence of environmental variability. Sources of variability can include changes in manufacturing or operating conditions. The methods will be applied to designing a diffractive optical element for homogenizing a laser beam.

Optimizing a design requires selecting values for a set of design variables to ensure that the design meets specified performance targets. The performance target for our design is a specified profile of laser light intensity $I_{Target}(x,y)$ in a given plane. Using standard theories of diffractive optics, we can compute the intensity profile of a particular design $I_{Design}(a,b,g,...;x,y)$, where a,b,g are the design variables. The mathematical problem in optimal design often reduces to minimizing a merit function M. In the case being studied, one might seek a design that minimizes

$$M(a,b,g,...) = \iint dxdy \left(I_{Target}(x,y) - I_{Design}(a,b,g,...;x,y) \right)^2 . \qquad (1)$$

The design that minimizes equation (1) is the optimal design for *ideal* conditions, but with real products and processes, we often operate in conditions that depart from the ideal. For example, changes in the manufacturing process that are difficult to control may cause the design variables to deviate from their ideal values. If the intensity profile is very sensitive to particular design variables, then the ideal design may not be the best one.

We can generalize the merit function of equation 1 to take this variability into account. If the design variables deviate from the selected values according to some distribution that can be characterized, then a reasonable merit function to minimize is

$$\tilde{M}(a,b,...) = \sum_{i,j,k,...=1}^{N} \iint dxdy \left(I_{Target}(x,y) - I_{Design}(a+\Delta a_i, b+\Delta b_j,...;x,y) \right)^2 , \qquad (2)$$

where the $\Delta\alpha_i$ and $\Delta\beta_j$ are drawn from the distribution of design variables. Finding practical means to address this type of problem is the focus of the project.

We will further restrict our efforts to designing a diffractive optical element for shaping a laser beam. The intensity profile of a laser beam, perpendicular to the direction of propagation, is approximated well by a Gaussian. In many instances, one desires a more uniform profile than the Gaussian within a particular work area. An ideal working profile might be constant within a given work area and drop rapidly to zero outside of that area. A diffractive optical element adjusts the local phase of the laser light in order to create the uniform profile. Thus, we seek a phase function $f(x,h)$ capable of transforming our input Gaussian profile $I_0(x,h)$ into an output $I_{Target}(x,y)=rect(x/L_x)rect(y/L_y)$. The environmental variation for which we wish to compensate is the drift in the position of the input Gaussian. The profile coming from the diffractive element depends on both the phase function and the input Gaussian profile; therefore, we seek phase function designs that both homogenize the beam and are insensitive to variations in the input profile. In the search for a robust design, we will be looking at different merit functions and different optimization techniques.

Bibliography

For an introduction to diffractive optics, see J. W. Goodman, *Introduction to Fourier Optics*, McGraw-Hill, New York, 1968.

For an example of a diffractive homogenizer design, see R. L. Guenther and C. L. Shoemaker, *Diffractive homogenizer with compensation for spatial coherence,* US Patent 6072631 (6 June 2000) and WO 00003286 A1 (20 Jan 2000).

For other examples of diffractive optics design, see:
C. C. Aleksoff, K. K. Ellis, and B. D. Neagle, *Holographic conversion of a Gaussian beam to a near-field uniform beam*, Optical Engineering 30, 537-543 (1991);
N. C. Roberts, *Beam shaping by holographic filters*, Applied Optics 28, 31-32 (1989).

For a fun look at designs for more complicated intensity profiles, see Joseph N. Mait, Optics and Photonics News **21**, 21-24, November 1998.