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CONF-830425--22

TITLE OPTICAL-DESIGN OPTIMIZATION WITH A PERSONAL COMPUTER

LA-UR--83-1670

DE83 014182

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SUBMITTED TO Los Alamos Conference on Optics '83
Sweeney Convention Center
Santa Fe, New Mexico
April 11-15, 1983

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Optical-design optimization with a personal computer

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Abstract

Advances in optical design have been closely related to advances in numerical computation. The microcomputer revolution now taking place promises to open the way for new and innovative optical design. This will take place as optical design becomes easier, more available, and far less costly, as the result of powerful "canned" design programs outfitted on low-cost personal computers.

A user-friendly program is described which makes possible low cost "automatic" lens design. Solutions to some typical optical design problems are presented. Prospects for future capabilities are described.

Introduction

Over the past thirty years, computerized optical design programs have progressed into a powerful tool for the optical engineer. Unfortunately the trend in these programs has been to grow in complexity and memory requirements such that a designer specialist and a mainframe computer or powerful minicomputer are required for operation. The large overhead time spent to master these programs, compounded by the usually complex or inadequate documentation, as well as high computer costs, restricts their use among occasional users, or those wishing to make nonfunded explorations in design.

This paper describes the Small Optical Design Analysis program (SODA) which is designed to increase user productivity by being easy to use, inexpensive to operate, yet effective.

Ideal versus actual features

The ideal program should be easy to use and insensitive to the machine it runs on, have no limitations set by the type or number of surfaces asked of it, output whatever is asked of it, and do it all instantaneously. (We are not quite there yet!) Table 1 states the main features required of SODA.

Table 1. Comparison between desired and attained features.

Features of the ideal program:

- *Trace real rays
- *"Automatic" optimization
- *Optimize using damped least squares or second derivative
- *Use real ray data for merit function
- *Have graphical and numerical output
- *Have a glass library
- *Perfectly documented
- *Be user friendly
- *Be inexpensive

Main features of SODA:

- *Ray tracing
- *Optimization
- *Damped least squares and modified second derivative
- *Uses real ray data for merit function
- *Spot diagrams, wave maps, etc., numerical output
- *Library of 100 glasses (user expandable)
- *Excellent documentation
- *User friendly, many prompts
- *Low cost operation

The actual program is extremely simple to use. Unlike any other optimization capable program, with which the user may have experience, the user is not confronted with a required 1-3 inch thick user notebook/reference manual and days or weeks of instruction to get going on lens design. In less than an hour's perusal of the 35 pages of instructions, the first-time user can be optimizing his first lens.

SODA was designed for versatility, ease of operation, and accuracy. It can trace rays through spherical or aspheric surfaces and can handle tilts and decenters. It provides first order ray trace for initial system layout, third order aberration calculation for system analysis and finally trigonometric ray and wave aberration calculation for system performance. It will plot ray and wave aberrations, field curvature and distortion, wavefront maps of the exit pupil, and spot diagrams. SODA uses a notation similar to many large optical design programs. All data entry is prompted and default values are provided wherever practical. In order to retain accuracy all trigonometric ray traces are done in double precision with all square roots calculated to 13-digit accuracy.

SODA consists of 16 major subroutines which are divided into six groups. The subroutines are called by entering a three letter command any time that the program is in the command mode, indicated by display of "INPUT COM" in the 32-character format. The documentation describes the commands, their function, acceptable entries, required entries, default values, possible errors, and leads the user through a design example.

SODA has been proven over more than two years' field use in designing dozens of real optical systems that have actually been built. In addition, SODA results have been confirmed by mainframe programs.

Operation costs

SODA has many of the generally most designer used features of the first rate large optical design codes. Assuming a \$3,000 hardware expense to run SODA, an operation time of ten hours per week for two years, the hourly cost is only \$2.88/hour. If the operation time is increased, the cost per hour declines.

This compares strikingly with the large programs, which commonly require 300+K bytes of RAM and must run on a mainframe computer or minicomputer. CODE V, considered by many to be the standard for comparison in the way of an excellent well supported program, cannot be purchased outright, but is leased. CODE V costs about \$80/hour to run on a VAX. SYNOPSIS on the other hand, is purchasable for about \$75,000. Assuming the same operation time of ten hours per week for two years, SYNOPSIS costs \$72/hour not including the cost of a VAX on which to run it.

Hardware requirements

SODA is at present configured for the TRS-80 model I and model III with a minimum of 48K bytes of RAM. Versions without the glass library and without optimization will run on 16K of RAM. Figure 1 pictures a typical hardware system and Table 2 lists the main requirements.

Figure 1. Typical computing hardware for using SODA.

Table 2 Hardware requirements.

- *Microcomputer with 48 kilobytes of random access memory
 - *TRS-80 model I, Level-2 compatible
 - *LNM model 1 or model 2
 - *LOBO MAX-80
 - *TRS-80 model III
 - *TRS-80 model IV
- *Twin disk drives
 - *5.25-inch diameter mini-disks
 - *TRS-80 format
 - *Single or double density
 - *either 35 or 40 tracks
- *Printer
 - *Centronics compatible
 - *Epson MX-80, FX-80, RX-80

Limitations and future features

SODA is presently limited to 20 optical surfaces. For special purposes this can be extended to 30. If the program is partitioned, making available more RAM for computing, number of surfaces can be increased.

SODA is also limited in speed. On a TRS-80 model I microcomputer with a clock speed of 1.1 MHz, SODA computes spot diagrams at one ray surface per two seconds of time, versus thousands of ray surfaces per second for mainframes and some minis. The speed of SODA will eventually be improved by a factor of approximately ten times. It should be said that tracing 5-7 rays will usually get the designer more than 90 percent of the information he needs to arrive at an optimum design solution.

Table 3 lists the main features to be added during the next two years.

Table 3 Future features of SODA.

- *Vignetting by apertures and central obscurations
- *Modulation transfer function analysis
- *Radial energy distribution analysis
- *Report routine with high resolution graphics
- *Availability for other microcomputers:
 - *Commodore 64
 - *Apple II
 - *IBM PC

Specific design examples

Four examples of solutions to design problems that the modern user might encounter are described in Appendix A. Each design problem made use of SODA's optimization capability. No example required more than six optimization cycles for a workable solution.

Each optimization cycle is actually an iteration where parameter weights are manually adjusted and where some parameters may be totally constrained prior to commanding the machine to optimize given those constraints. The user's skill is in knowing what to use for an initial design, where to place the parameter weights and constraints, and what to do next if there is insufficient convergence on a reasonable solution.

Availability

SODA exists chiefly because Don Small devoted more than 1500 hours of his own time, over a span of four years, to the project. The program in its entirety is private and copyrighted. The program will soon be available commercially.

Conclusions

Experience with SODA has demonstrated that many of the optical design requirements of the professional optical engineer can be met by use of a capable program and a personal computer.

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Example 1: Ultraviolet laser lens.

REQUIREMENTS

- 150 mm DIAMETER, F/2.5 SINGLET
- CORRECTED AT 351.3 nm

RESULTS

- 150 mm DIAMETER, F/2.5 SINGLET
- CORRECTED AT 351.3 nm
- RADII: SURF - 1 = 703.799 mm
SURF - 2 = -1398.01 mm
- THICKNESS: 25 mm
- INDEX: 1.47672
- ASPHERIC COEFFICIENTS, SURFACE - 1: C=4.9648E-03
K=0
A4= - 1.12885E-08
A6= - 1.95253E-13
A8= - 3.57407E-18
A10=0
- OPD, ON AXIS: 0.006 WAVE, OR 21 ANGSTROMS
- 4 OPTIMIZATION CYCLES WERE REQUIRED

Example 2: Null lens for testing and fabricating of aspheric lens.

REQUIREMENTS

- PRODUCE NULL TEST WHEN USED TO TEST SURFACE-1 OF LASER FOCUS LENS (EX - 1)
- CORRECTED AT 632.8 nm

RESULTS

- NULL TEST FOR SURFACE-1 OF LASER FOCUS LENS
- CORRECTED AT 632.8 nm
- RADII: SURF-1 = FLAT
SURF-2 = -1841.68 mm
- THICKNESS: 8 mm
- INDEX: 1.51509 (BK7)
- OPD, ON AXIS: 0.82 WAVE
- 4 OPTIMIZATION CYCLES WERE REQUIRED

Example 3: Ritchey-Chretien telescope.

REQUIREMENTS

- 200 mm diam. PUPIL
- 1200 mm FOCAL LENGTH, F/6
- PRIMARY MIRROR F/1.4
- 100 mm VERTEX BACK FOCUS
- NEAR DIFFRACTION LIMITED, OPD 0.25 WAVE AT 587.67 nm

RESULTS

- 200 mm diam. PUPIL
- 1200 mm FOCAL LENGTH, F/6
- PRIMARY MIRROR F/1.4
- OPD, ON AXIS: 0.27 WAVE AT 587.67 nm
- 2 OPTIMIZATION CYCLES WERE REQUIRED

Example 4: Laser doublet..

REQUIREMENTS

- 150 mm diam., F/6 DOUBLET
- CORRECTED AT 1060 nm AND 632.8 nm

RESULTS

- 150 mm diam., F/6 DOUBLET
- CORRECTED AT 1060 nm AND 632.8 nm
- GLASSES ARE COMMON BK 7 AND SF 10
- OPD, ON AXIS, 0.09 WAVE AT 1060 nm
- OPD, ON AXIS, 0.17 WAVE AT 632.8 nm
- 6 OPTIMIZATION CYCLES WERE REQUIRED