

LensForge - a user-friendly lens design program

M.W. Reynolds*

Ripplon Software Inc., 4794 Fernglen Drive, Burnaby, BC, Canada V5G 3V7
www.ripplon.com

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1 Introduction

LensForge is a new easy-to-use lens design program that was published by Ripplon Software in January 2007.¹ Presently LensForge is available only on computers using the Mac OS X operating system. It is compiled as a universal binary so that it is compatible with both PPC and Intel processors.

As an example of ease-of-use, one element of the user interface is the surface data editor shown in figure 1. Here you can select a sequence of surfaces in the spreadsheet and edit their properties *simultaneously* using the form in the lower part of the window. This facilitates common operations such as giving a sequence of surfaces a common diameter, aperture type, etc. In the spreadsheet surfaces may be re-ordered using the mouse by the method known as drag-and-drop. Stock lenses and glass types may be dragged from catalogs into the spreadsheet.

2 Ray tracing

LensForge traces meridional and skew rays using a physical formalism that describes the full nonlinearity of Snell's law of refraction without recourse to trigonometric functions. The optical path length traversed by each ray is accumulated for use in diffraction diagnostics like OPD.

*E-mail: meritt@ripplon.com

¹This refers to version 1.1. The preliminary version 1.0 of LensForge was published May 2006. Version 1.0 did not possess optimization capabilities, the hallmark of a full-fledged lens design program.

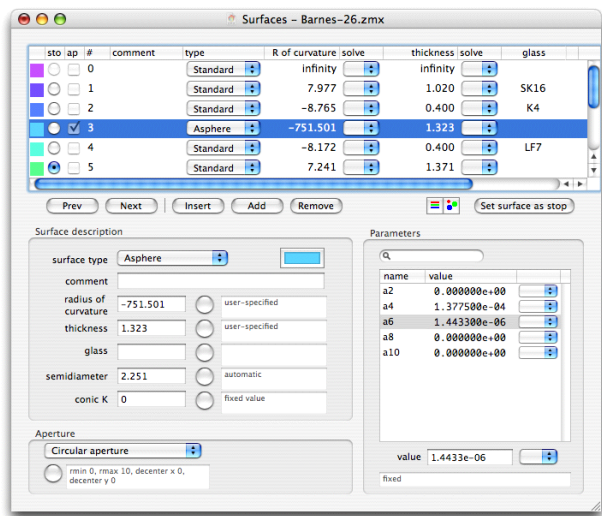


Figure 1: The LensForge surface data editor window. The upper part is a spreadsheet, the lower part gives additional parameters like conic constant and aspheric coefficients and also permits simultaneous modification of several surfaces.

3 Surface types

The imaging effect of the refraction of light at each interface is determined by the shape of each surface. Axially symmetric surface types are planar, spherical, conicoid, and aspheric surfaces, defined by the equation

$$z = \frac{cr^2}{1 + \sqrt{1 - (1+k)c^2r^2}} + a_2r^2 + a_4r^4 + \dots$$

The surface shapes described by the above equation are sufficient to implement most lens designs. There is also a general bivariate polynomial surface defined by

$$z = a_1x + a_2y + a_3x^2 + a_4xy + a_5y^2 + a_6x^3 + \dots$$

A coordinate break surface is provided to implement tilted or displaced surfaces, or to create folding mirrors.

Additional surface types can be added as part of the support provided by Ripplon Software to its customers.

4 Glass library

A built-in glass library is provided that includes the glass catalogs from many major vendors (Hikari, Hoya, Ohara, Schott, Sumita). The catalog data is obtained directly from the vendors. The built-in library contains as well some plastic materials.

There is a tool in LensForge to plot the refractive index versus wavelength for any of the catalog glasses. It can also plot the difference between glasses for closer comparison.

5 Source specification

The rays originate at points (the field points) that are specified in a table according to their position or to the angle of the chief ray. The angle specification may be used with points at infinite distance. The divergence of the point sources may be specified by any of the following: entrance pupil diameter, stop size, object space numerical aperture (N.A.), object cone angle (degrees), or the focal ratio ($f/\#$) of the system. The chief ray is aimed toward the paraxial entrance pupil by default, but a ray-aiming mode may be enabled in order to better trace wide-angle systems. It is possible to apply vignetting factors to partially fill the entrance pupil of the lens.

The wavelength of the point sources is also specified by the user, and wavelengths may be given different weights for use in chromatic diagnostics like the polychromatic OTF.

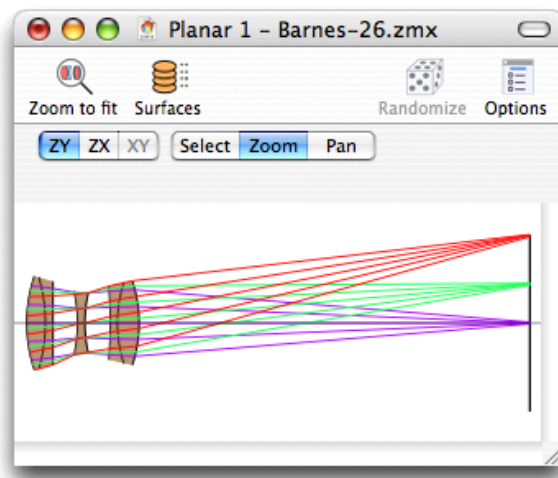


Figure 2: The LensForge planar view window.

6 Layout views

LensForge displays the lens design in a planar view, as shown in figure 2 or in a “solid” view. In the planar view it is possible to adjust surface thicknesses; additional interactivity is being developed. In the solid view the lens design may be rotated about any of the surfaces. In either view, fans of rays can be displayed. Fan type can be linear y -fan or x -fan or a pupil-filling hexagonal, random, or spiraling pattern. A test ray of specified field and pupil coordinate can be traced and displayed as well.

7 Diagnostics

Diagnostic listings include a surface-by-surface listing of Seidel aberrations, and a table of paraxial properties.

The traditional diagnostic plots implemented are: ray fan, OPD fan, distortion plot, field curvature (including astigmatism) plot, OSC fan, and spot diagram. The encircled or ensquared energy may also be calculated and plotted. The plots are interactive, in the sense that by clicking with the mouse on any point the program will display the value of the quantity plotted. You can also scan through the plotted

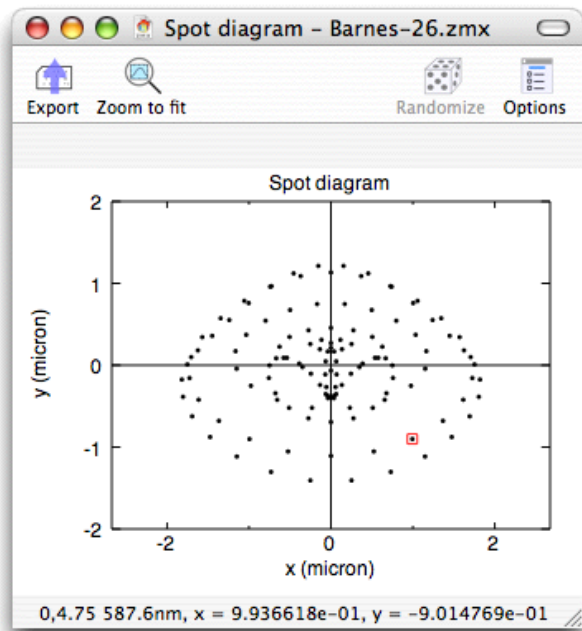


Figure 3: The LensForge spot diagram window. The text at bottom describes the selected ray. In the toolbar at the top of the window are a number of tools. The export tool allows you to export the data to the clipboard, for use in other programs. The Options tool opens a window with many plot options, such as ray fan style, choice of field(s) and wavelength(s), and how to color the plotted rays.

curve with the arrow keys.

Also implemented is the geometrical optical transfer function (OFT), which includes the modulation transfer function (MTF). This plots the imaging contrast versus spatial frequency. A variation is the so-called through-focus OTF, which plots the OTF at a particular spatial frequency as a function of focus.

Another diagnostic is the diffraction optical transfer function.

8 Sliders

A tool is provided that lets you adjust any construction parameter (surface thickness, curvature, etc.)

continuously by dragging a slider with the mouse. Other diagnostic plots update while you do this, so you can see right away the effect of the changes.

9 Merit functions

The quality of a lens design is quantified in LensForge (as in most lens design programs) by the value of a user-specified function called the merit function. A merit function is usually constructed as the sum of squares of signed quantities called residuals. Residuals pertaining to lens performance as traced by ensembles of rays are the RMS optical path difference and RMS spot size. It is also possible to use residuals pertaining to construction properties (total track, Petzval sum, edge thickness, glass thickness), paraxial properties (back focal length, focal length, front focal length), and third-order Seidel aberrations (spherical aberration, coma, astigmatism, field curvature, and distortion). Chromatic meritoids (Conrady axial and lateral color) are also available.

In keeping with the philosophy of ease-of-use, merit functions are built using pull-down menus. It is not necessary to commit any codes to memory.

A tool is provided to plot the merit function as a function of any construction parameter. Either the function value or the individual residuals may be plotted. The residuals are individually normalized by a user-specified tolerance, the better to compare them.

10 Optimization

The lens design may be optimized by varying any construction parameter. It is also possible to vary the refractive index of model glasses.

LensForge implements two optimization algorithms: the Levenberg-Marquardt (or damped least squares) algorithm and the Nelder-Mead algorithm. The Levenberg-Marquardt algorithm is the traditional workhorse of lens design; it works directly with the residuals of the merit function to rapidly converge to a solution. The Nelder-Mead algorithm works only with the merit function value, and is hence slower;

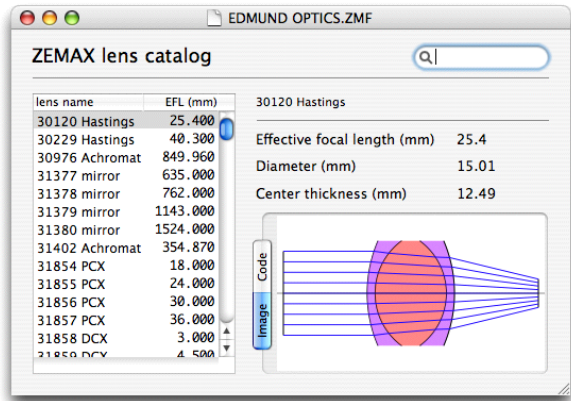


Figure 4: LensForge window for a ZEMAX ZMF format stock lens catalog.

but it is more robust and converges even when the residuals are not linear functions near the minimum.

11 File formats

LensForge reads and writes ZEMAX as well as the native LensForge format. The ability to read OSLO and Code V lens files is developing. Naturally, LensForge only reads supported surface types.

12 Stock lenses

The LensForge distribution includes the stock lens catalogs of Edmund Optics and ThorLabs. These are in the ZMF format used by the ZEMAX lens design program. LensForge provides a versatile ZMF browser window, shown in figure 4, that displays the catalog and shows a thumbnail image of any selected lens, complete with traced rays. From the lens list on this window, any lens may be dragged into the spreadsheet of a lens design.

13 Canvas feature

An image of an existing lens design may be used as a background image on the planar view of the lens be-

ing designed. You can then adjust surface spacings and curvatures to match those in the image. If the image used in the background also shows rays, you can adjust material properties to cause the traced rays to follow those in the drawing. In this way the existing design may be approximated in the computer.

14 Development

The development of LensForge aims to make the program even easier to use. Manipulation of lens designs mainly using the computer mouse is the ultimate goal, with very little keyboard input required. Full drag-and-drop editing on the graphical representation of the lens system is an active area of development. Dragging lenses from stock catalogs into (and out of the design) will soon be implemented. Another objective is to maximize compatibility with other lens design programs, in accordance with customer needs.

Improvements to the ray tracing algorithms are also being made to permit the accumulation of additional information, such as relates to polarization state.

15 About the author

Meritt Reynolds is the author of the software products of Ripplon Software Inc. He has a Ph.D. in experimental physics and has extensive experience with optical systems in both academia and industry.

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