Modern lens design using a lens manufacturing database

C. Theodore Tienvieri ctt@tropel.com
Tim Rich trich@tropel.com

Tropel Corporation
60 O' Connor Road
Fairport, New York 14450
(716) 377-3200 ph
(716) 377-6332 fx

Abstract

This paper will discuss the usefulness of a lens manufacturing database to the optical designer. Manufacturing statistics can readily be computed to assist with tolerancing studies. This tool can easily report manufactured element parameters to assist with manufacturing compensation models prior to lens assembly.

Introduction

Computer databases are not a new concept to the lens design community. Many optical design oriented databases have been written to assist the designer in searching for lens starting points that can be used to begin new design activity. These codes provide mechanisms for the user to input a set of lens properties (focal length, wavelength, field size,....) that are desired by the optical designer. This input is utilized as search criteria by the program to extract the closest matches within its lens archive to begin design activity. Such programs include Lensview[1], a vast database of patent designs, Optics Toolbox[2,3], a lens archive of various designs, and Magellen[4,5], an archival database containing design and analysis information.

Optical design activity does not exclusively consist of designing new lenses for a given set of customer specifications. Other crucial tasks include the tolerancing of systems for manufacture and overseeing the engineering duties of high performance optical systems that require custom element selections and compensation of manufactured parts prior to assembly and test. These are often background tasks performed by the designer to support manufacturing and aid the shipment of lens product. At Tropel, a Lens Manufacturing Database (**LMD**) has been developed to assist the lens designer with these duties. This paper addresses the benefits of a manufacturing orientated database to the optical designer.

Benefits of a Manufacturing Database

There are numerous benefits to having an online database of manufacturing information. It is a cumulative, regularly up-dated electronic source for all manufactured element data. Measurements recorded on manufactured elements can be ported, via electronic means, directly

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to the LMD. Several layers of hand transcriptions, a serious potential error source, of critical lens information can be eliminated. Hard copy records that were once needed to track element data can now be avoided. Historical and current records of element data can easily be accessed to compute manufacturing statistics and gauge ability to achieve specifications. Manufacturing information can readily be exported to external programs for analysis when needed. Overall communication of manufactured element data is efficiently distributed to all departments that need to assess process capability and control.

Computer Configuration / Software Platform

The computer configuration (Figure 1) implemented to run the LMD consists of an Ethernet computer network of personal computers. This configuration allows several users to have the most recent manufacturing data at their disposal. Areas within Tropel that interact with the LMD on a daily basis include optical design, optical manufacturing, thin film coating, final assembly & test, and production control.

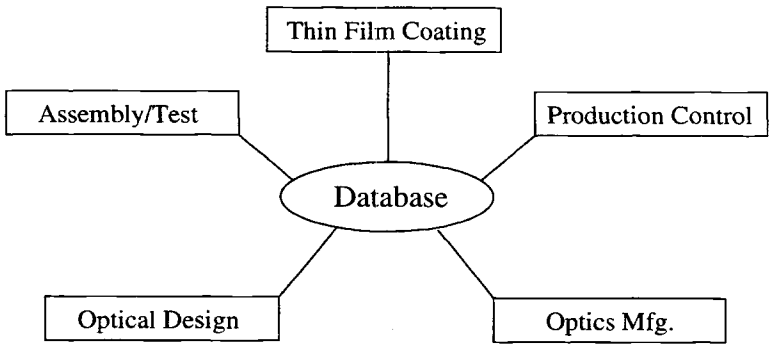

Figure 1
The Lens Manufacturing Database (LMD) resides on a networked computer system to allow multiple users access to the contents

The Tropel Lens Manufacturing Database has been developed with Microsoft Access as the primary software platform. This package was selected because of its compatibility and similarity with other Microsoft software programs. Access provides a programming environment that allows you to easily create a database customized to your needs. Users interact with the LMD to input, view, and export pertinent information through a series of interface windows that contain mouse activated click buttons and pull down menus.

Data Storage

There are two primary storage bins for the LMD: 1) a nominal data table and 2) manufacturing data table. The nominal data table consists of final element information that is committed to manufacturing blueprints. This bin contains information such as: radii, thickness, material, and manufacturing tolerances. In addition this table contains performance merit sensitivities to manufacturing parameters and project bookkeeping data. The manufacturing data table houses all the parameters that are measured and recorded on completed components prior to shipment from

the manufacturing area. This includes final measurements on thickness, radii, surface profile information, and project bookkeeping. The two data tables are linked through project bookkeeping parameters (Figure 2) which provides the ability to compute manufacturing deltas (difference between measured value and ideal value) from the design and compare values to specification. The sensitivity data can be used to estimate the amount of aberration that would be introduced to a lens system from manufactured parameters.

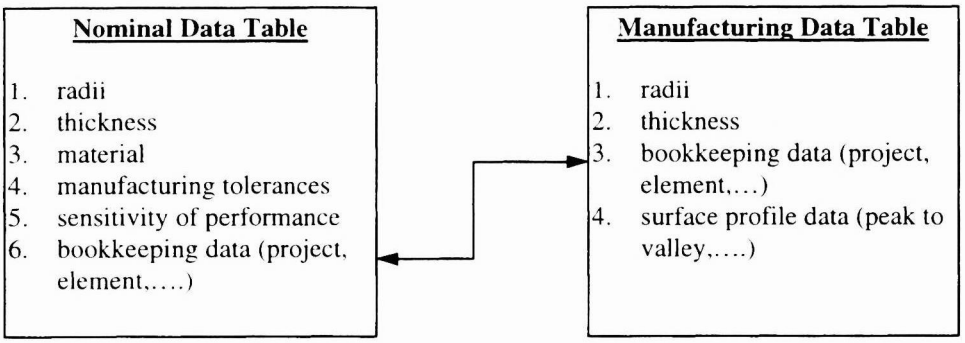

Figure 2
The nominal and manufacturing data tables are linked to a provide easy comparison of manufactured element quantities to the design

Interfacing with the Lens Manufacturing Database

Interfacing with the LMD is accomplished through various forms that are activated by click buttons. These options provide the capability to view data, input data, or export data. Many forms contain search parameter boxes that allow the user to view a general set of data or be very specific about the type of information that is queried from the LMD. Figure 3 shows the LMD Main Menu where user interfacing begins.

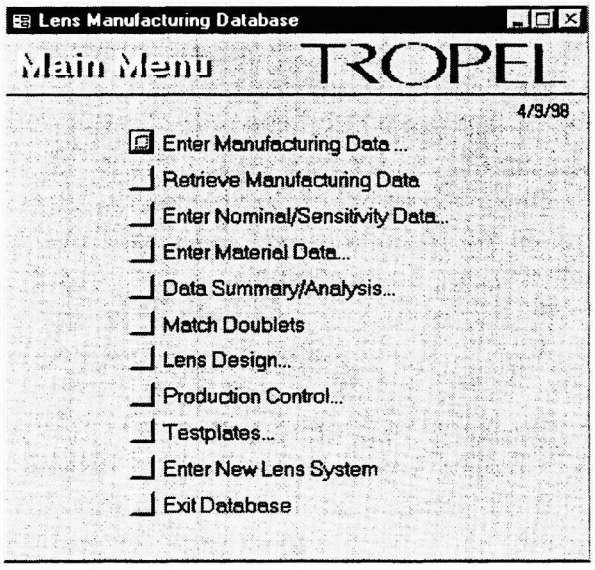

Figure 3
LMD main option menu

Several buttons are dedicated to the needs of individual departments that interact with the LMD and its contents (Production control, lens design, and manufacturing). Other options are more global in nature and may be used by all departments. This paper does not discuss all of the options listed on the Main Menu, but will highlight a few specific options.

The *Retrieve Manufacturing Data* button provides the user a mechanism to view manufactured element data on any specific element for any lens system project. User input on this form includes pull down boxes to narrow down the data extracted by lens system name, set number, element number, element identification, or element side. The user checks the appropriate boxes for the desired manufacturing information. Figure 4 depicts the user interface form and the LMD data that has resulted from input in the search boxes. This form is useful to any department that needs to extract manufacturing information.

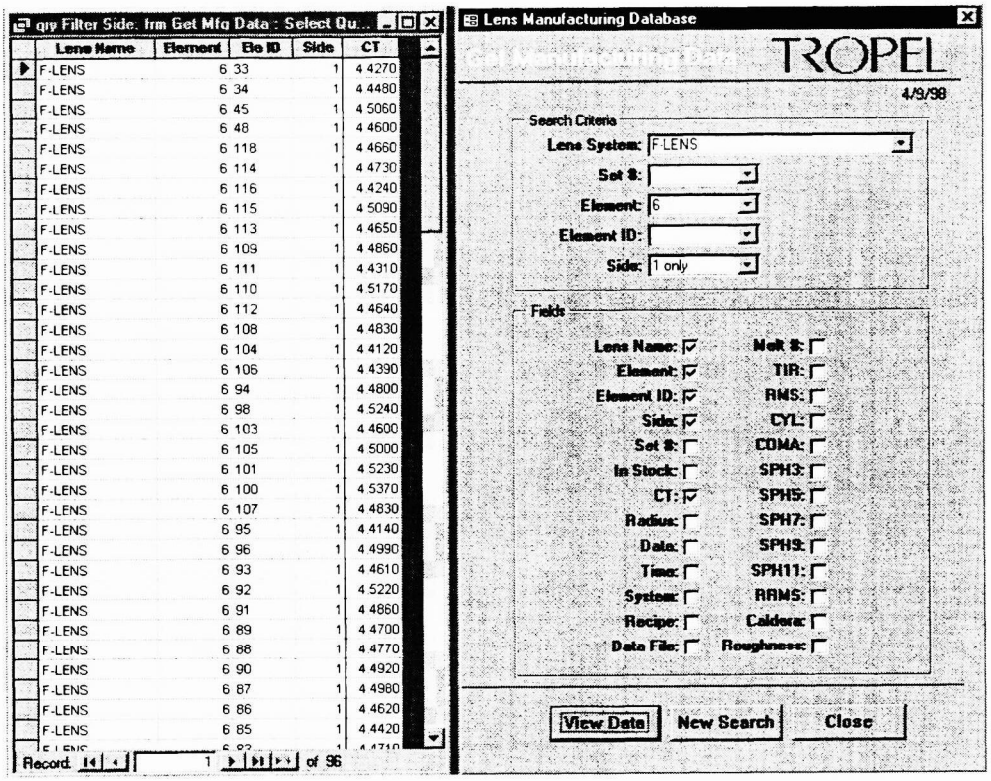

Figure 4
Snapshot of manufacturing data retrieval form and LMD data

Optical Designer Interaction

The optical designer may interact with the LMD for very specific reasons: 1) Perform custom set selection from manufactured elements prior to compensation and release to assembly for building, 2) Export manufacturing data to download into optical design code for compensation, 3) Review manufacturing statistics and distributions for performance tolerancing studies, and 4) Review manufacturing records to gauge ability to achieve certain specifications.

Optical Designer Set Selection and Compensation

Many state of the art optical systems require attentive optical design monitoring to ensure the highest attainable performance is achieved by a set of manufactured optical elements. This may entail custom selection of optical elements from the manufactured population to minimize the amount of aberration build-up in a custom lens set prior to compensation. In many cases air spaces are optimized to cancel the aberration build-up introduced by manufactured components. A rigorous compensation method consists of inserting the manufactured element quantities, radii, thickness, melt index, and surface profile data into the optical prescription file. The "manufactured" lens set is fine tuned for performance using optical design code. The *Lens Design* option from the LMD Main Menu provides an interactive form (Figure 5) to assist the optical designer with these tasks.

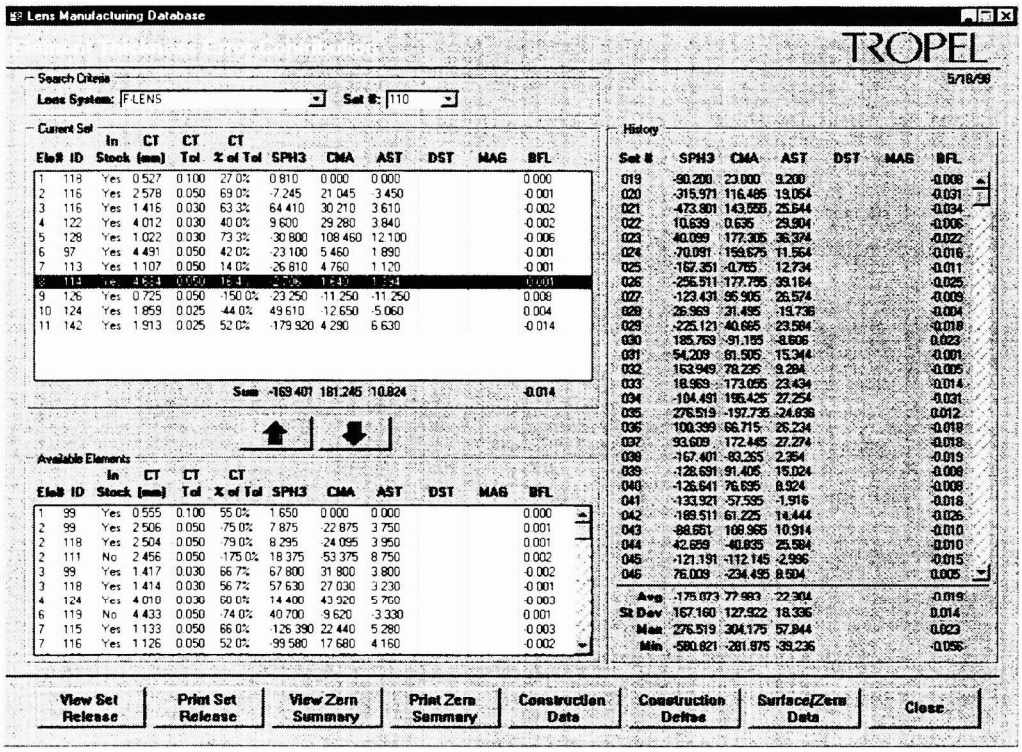

Figure 5
Interactive lens design form to assist with custom element selection and export of manufactured element quantities to optical design code

The optical designer initially selects the project for which a custom mix of elements is required. The system set number may be selected with the drop down box to recall an existing set, or a new set number may be entered into the input box. The top window, Current Set, shows the selection of elements in the active lens set. The bottom box contains a list of elements available for selection. The windows also provide useful information on each element: 1) Bookkeeping information (element number, identity), 2) Availability, 3) Manufactured thickness, 4) Thickness

tolerance, 5) Comparison to specification, and 6) Aberration contribution (spherical, coma, astigmatism,...) due to manufactured thickness. Aberration sums for the active lens set are calculated and reported. Elements may be swapped between the current set and available elements by highlighting the appropriate element and then selecting the desired directional arrow keys. All of the screens are refreshed to display updated information. The box to the right displays the historical statistics and aberration sums of lens systems that have previously been matched. The option buttons at the bottom of the form provide various hard copy manufacturing reports or can be used to export element constructional data (radii, & thickness) and surface profile data to optical design code.

Manufactured element data is easily exported to optical design code by selecting the option button for the desired element parameters. This information is exported as a text file that can be imported into optical design code with custom written macros (Figure 6). Hence, the loading of manufacturing data into compensation lens files is handled very efficiently through electronic methods. Data for a particular lens is collected rapidly and several layers of hand transcription of important lens information is eliminated.

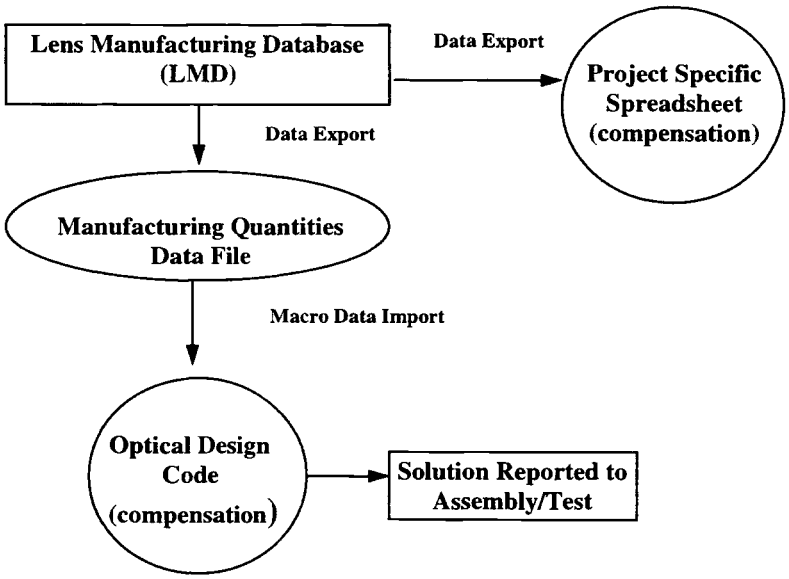

Figure 6
LMD data is easily exported to design code or spreadsheets for manufacturing optimization prior to assembly.

Before we developed the LMD, large amounts of time were spent collecting element data for manufacturing compensation, selecting a mix of elements, loading the data into prescription decks, and checking results after each step of the process. The time savings are immense especially in precision stepper lenses (Figure 7) produced for the lithography industry. One objective lens[6] can contain over twenty optical elements which equates to several hundred pieces of information that need to be tracked and utilized in the manufacturing compensation process.

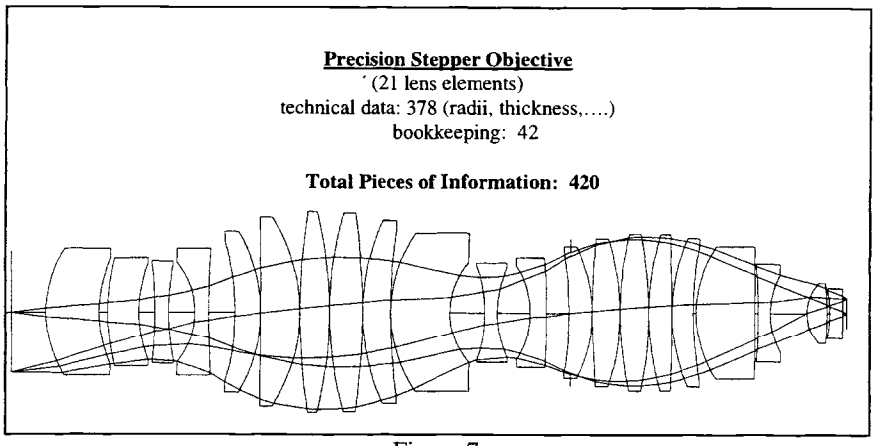

Figure 7
Typical lithography stepper lens

Spreadsheet Compensation

Other lens systems may not require the attention of a lens designer or optical design code to perform compensation. In these cases a spreadsheet may be used to perform air space optimization with a simple algorithm.[7] The LMD can be linked to a spreadsheet to provide the necessary manufacturing data (Figure 6). Utilities within the LMD are provided to input element set selections by production control personnel. The assembly department can download the pertinent manufacturing data to a custom spreadsheet tailored to the active project. A customized spacer report can be generated and supplied to the model shop along with the hardware to be machined.

Manufacturing Statistics

The Lens Manufacturing Database is a valuable archive of historical data for computing distributions on specific manufacturing parameters. It is customary for the optical designer to take into account the optical shop's capabilities while conducting performance tolerancing models. A Monte Carlo algorithm may be implemented to simulate the actual production run and yield for a group of manufactured components and tolerances.[8] The LMD provides utilities for gathering manufacturing statistics on any recorded quantity. Statistics can be computed on the entire contents of the archived data or finer subsets of data depending upon specification, project, element size, shape, etc.... Figure 8 depicts a user interface to assist with extracting manufacturing distributions and performing data analysis. This form can be reached from the Main Menu through the *Data Summary/Analysis* option.

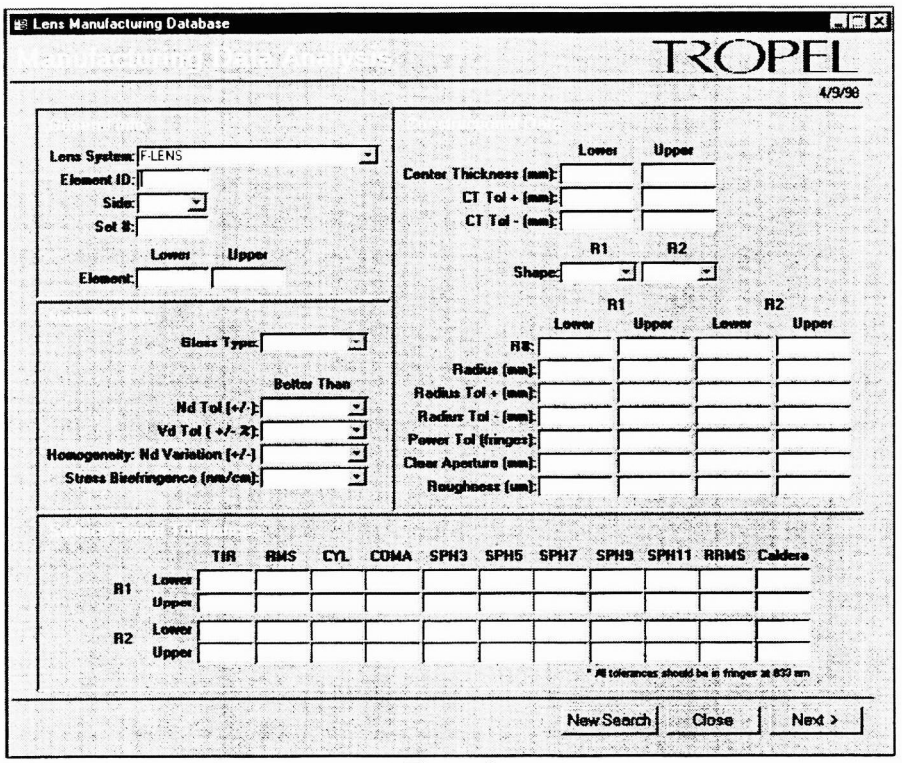

Figure 8
Data Analysis interface for selection of manufacturing distributions

If the user does not input a lens project the computations are performed for the entire contents of the LMD. Selecting the New Search button at the bottom of the form clears the existing input contents allowing for new criteria to be entered. Exit will close this form and return the user to the Main Menu. The Next > option opens a window (Figure 9) that will allow the user to select a distribution plot and statistics of the desired quantities. Provided in Figure 10 is a sample manufacturing distribution plot for thickness. Specific pieces of manufacturing statistics are normalized to the specification. Quantities are computed in percent for the maximum/tolerance, minimum/tolerance, mean/tolerance, and standard deviation/tolerance. This data can readily be input into tolerancing software.

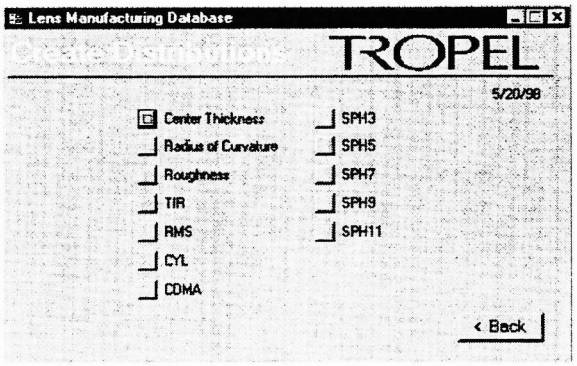

Figure 9
User interface form to select manufacturing quantity for distribution plot

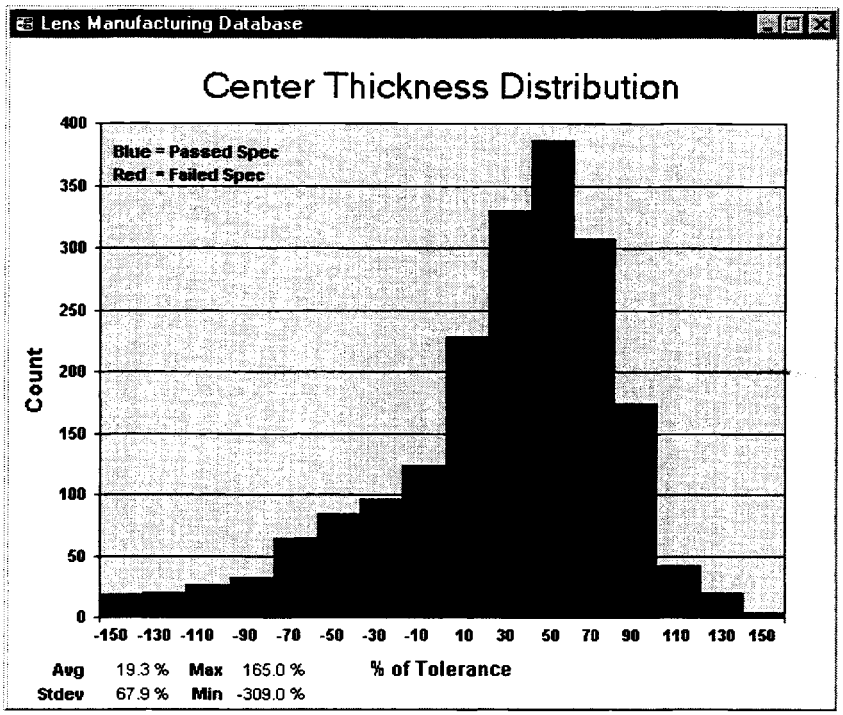

Figure 10
Manufacturing distribution plot for element thickness

The data presented shows a typical distribution plot for element thickness. The population average thickness is +19% of the tolerance. Often the optician will leave elements slightly on the thick side in case further polishing is needed to fix surface error or cosmetics.

Additional Uses

Several other kinds of information can be recorded and tracked in a lens manufacturing database. Any data contained within the LMD may be interrogated, analyzed, plotted, or reported. This can include optics manufacturing throughput of the percentage of finished components shipped monthly (Figure 11), or the number of components surface tested on production qualification interferometers (Figure 12). Another use of interest may be to record vendor supplied melt data of refractive index. The melt sheet indices can be electronically exported into index interpolation codes to compute the index of refraction for desired environmental conditions and wavelengths.

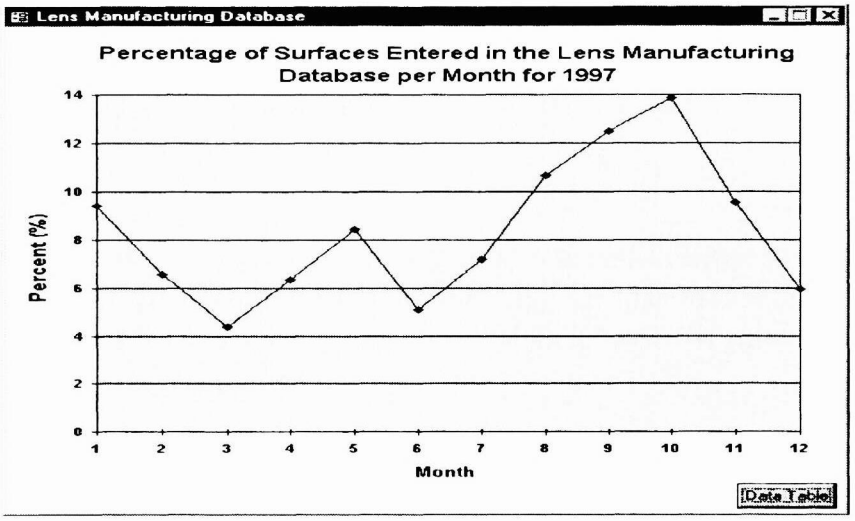

Figure 11
Percentage of surfaces per month completed by optical manufacturing

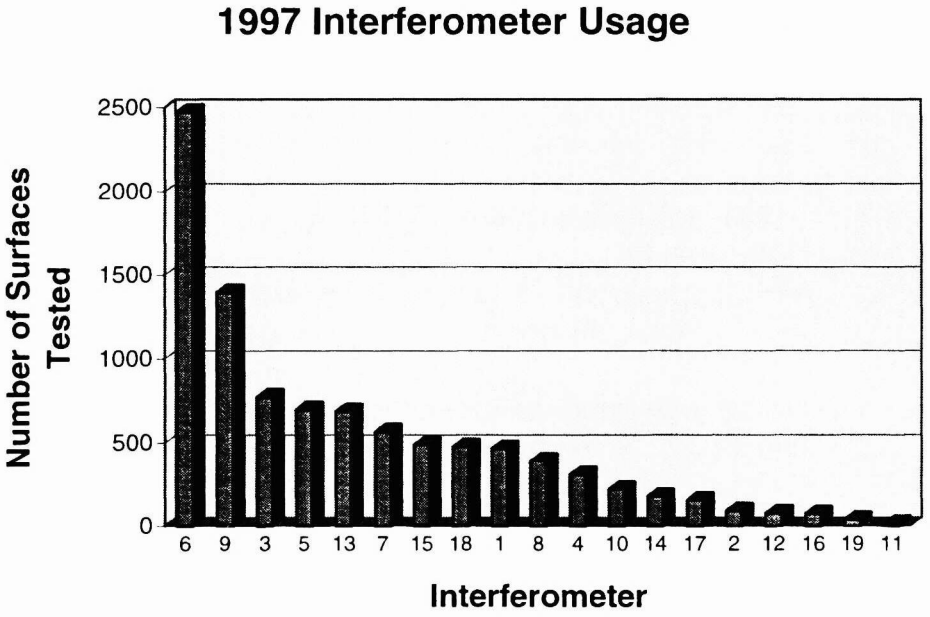

Figure 12
Component test interferometer usage

Conclusion

Several benefits of a manufacturing oriented database have been presented. A single regularly updated electronic source of manufacturing data is an effective tool for communicating important manufactured lens quantities. Once an electronic data source exists, it is easy to analyze the

information for various reasons with any type of software. Production oriented tasks performed by the optical designer have been simplified by providing tools to assist with custom element selection and the ability to export element data to optical design code.

Acknowledgments

We wish to thank the Tropel leadership by providing the tools and resources to make this project possible. The optical fabrication and QC inspection departments and especially Jenny Clark must be thanked for diligently loading manufacturing data into the LMD on a daily basis.

References

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