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SAPO — the optical design system for IBM microcomputers

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The system of optical design calculations named SAPO is briefly described. Corresponding hardware requirements are the IBM PC/AT micro with at least 512 kB RAM and 8087 arithmetic co-processor, two floppy disk drives, a hard disk of 10 MB, and a standard printer. Typical examples of application, including optical design teaching at the university level, are presented.

1. Introduction

It is well known that optical design calculations usually lead a designer to computational problems of great numerical complexity. Typical optical procedures, like raytracing, automatic correction, image assessment, setting fabrication tolerances, are very troublesome and good computer programs are necessary to design even the simplest optical systems. That is why the case of optical design was among the earliest applications of electronic computers: first computer procedures for general raytracing and Seidel aberrations were developed as early as in the 1950's [1], [2]. Along with the development of the computing technology, optical designers from different optical enterprises were able to employ sophisticated programs to handle their problems much more completely, and a lot of optical design modules for different purposes to be achieved with various computers appeared. Such a big development of separate optical design modules had obvious disadvantages, namely:

– necessity to use different data input schemes for different programs,

– need for rearrangements of the computed results that are to be implemented as the input data for the next program,

– need to modify the programs when changing the computer,

– troubles in fast and easy access to the machine and in working in interactive mode,

– troubles in cooperation between different optical centers due to different hardware & software systems.

For the reasons mentioned above, the first complete systems of optical design were created and implemented using big computer systems. Some of them (like CODE V, ACCOS V, for instance) have gained a widespread acceptance and are commercially available nowadays.

Since 1980 the introduction of microcomputers into the domain of optical design calculations has been observed [3]–[6]. Owing to their interactive nature, freedom from mainframe queues, acceptable speed and sufficient storage capacity, 16-bit micros are quite popular in the field of optical lens design at present. What is especially important from the viewpoint of the optical design, is that microcomputers offer excellent graphic capabilities: in consequence, not only is the optical system under study (as well as its components) drawn in accordance with the usual optical workshop requirements, but also the complete raytracing along with associated aberration curves, optical wavefront map, and diffraction-based optical responses can be shown graphically. This simplifies greatly the tedious process of evaluation of successive versions of the system just designed because of avoiding the need of analysing big amount of numerical data.

In the present work, the new IBM PC-dedicated system of optical design is briefly described. Although it has been developed taking into account the teaching needs at this University, its usefulness in the professional design process is obvious.

2. System description

The SAPO is nothing but a typical example of interactive, user-friendly, menu-driven computer system of modular structure, with many corresponding submodules to be chosen optionally. Due to the existence of short and simple "help" messages the system is very easy to use even by a beginner (who is not very familiar both with computing technology and optical design procedures). The system enables one to design various optical systems, starting from a simple lens up to sophisticated refractive-reflective optics, provided that the maximum number of spherical optical surfaces does not exceed 30.

The SAPO consists of the following basic modules (see, also, Fig. 1):

- EDIT (input data preparation, saving, and edition),
- RAYS (fundamental raytracing procedures),
- ABER (computation of aberrations),
- OPTY (optimization by means of automated optical design),
- TOLE (setting fabrication tolerances),
- DOCU (graphical display of an optical system & components),
- GABA (dimensional predesign of optical systems).

The communication and transfer of data between different basic modules is easily performed by means of a working data file called FORT 07. DAT. The optical system data can be input from keyboard, from working files, or from a catalogue of optical systems associated with the SAPO. The current optical system file can be edited with a specially-designed screen editor, erased or saved as one of the working files (of course, the transfers from working files to the catalogue of optical systems and vice versa are also possible). The optical glass data are restored from a SAPO-associated optical glass catalogue, or can be input from keyboard. All the calculations can be carried out for 4 arbitrarily selected spectral lines, or the following default values are chosen: 587.1 nm, 486.1 nm, 656.3 nm, and 435.8 nm.

Drawings of optical lenses and components can be saved and/or transferred with a screen dumper to make appropriate copies on any IBM-compatible printer.

The very important feature of the SAPO is that it permits one to make both fast and easily many extensive modifications of the optical system under study. Namely, any component of the system (or a few successive components arbitrarily selected)

Fig. 1. SAPO system with the main menu displayed on the screen

can be rescaled to arrive at a given focal length, inverted with respect to the direction of light rays, completed with extra-surfaces of even with a complete system taken from another file, bodily displaced in accordance with paraxial optics calculations (for use in analysis of zoom lenses), and, if necessary, removed.

At any stage of the optical design process, the optical system or its separated part determined by a designer, can be analysed in a complete manner. In particular, the following options are available:

— raytracing (including general skew rays, meridional rays, paraxial raytracing, astigmatic raytracing, on-axis Gaussian beam propagation),

– dimensional computations (focal lengths, diameters of elements, geometrical distances) and their matching with the basic standards of optical fabrication technology,

– aberration computations along with graphical display of aberration curves, and evaluation of Zernike and/or Hopkins coefficients of wave aberration polynomials,

– computation of Strehl ratio,

– automatic correction of aberrations with respect to input target values (iterative method),

– setting fabrication tolerances and appropriate tolerance sensitivity analysis (including decentrations),

– workshop drawings of the optical system just considered and its single components as well,

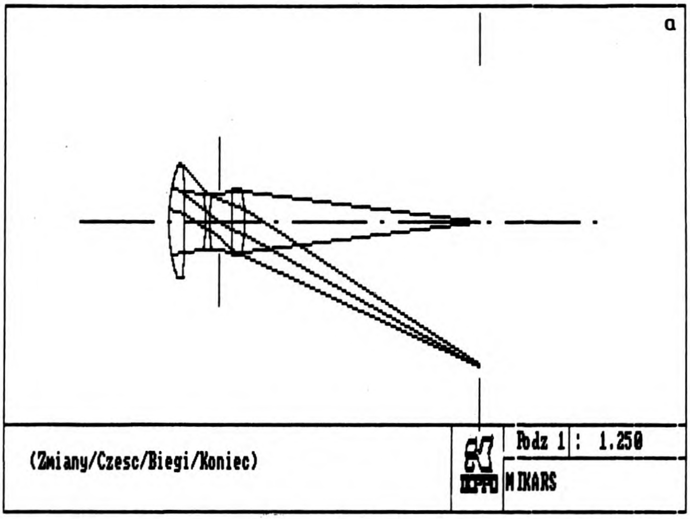
– dimensional predesign of composed optical systems (including paraxial-optics-based iterative algorithms).

The last option is a unique one because of employment of the GABAR program which, in fact, creates the totally independent structural module of SAPO called GABA. The GABAR is completely described in our recent paper [7], and, for this reason, it is not discussed here.

3. Example of application: academic teaching

Typical examples of optical design calculations carried out with the help of SAPO are shown graphically in Fig. 2. They present the example of basic raytracing (a Cooke-triplet-based lens for photo enlargers) and corresponding aberration curves as well. The example of graphical display of a sophisticated zoom lens is also given, and finally, the dimensional predesign example of a three-component lens is displayed.

Since 1984 the SAPO has been extensively employed in academic teaching, especially during tutorials on optical design. Each of our students makes use of the system at various stages of his/her project starting from dimensional predesign and ending up with the final assessment of lenses, eyepieces, etc. Due to its user-friendliness, clear graphical displays and powerful editing capability, SAPO appears to be an ideal tool to enhance the teaching process; students are able to try and examine a great many versions of a system under study, including even very unconventional proposals and concepts. The general facts related to the teaching process and its efficiency are, in principle, in accordance with the remarks reported by Hopkins [8]. Specifically, the understanding of the fundamental ideas of optical design by our students is observed to be much better after implementation of the SAPO system, they gain a greater deal of designing experience during their tutorials, and their projects are much more professional now.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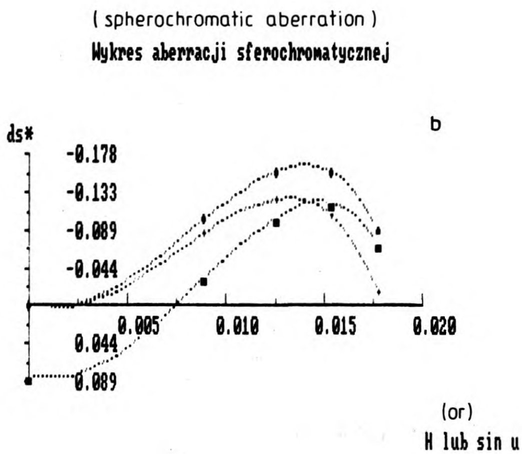
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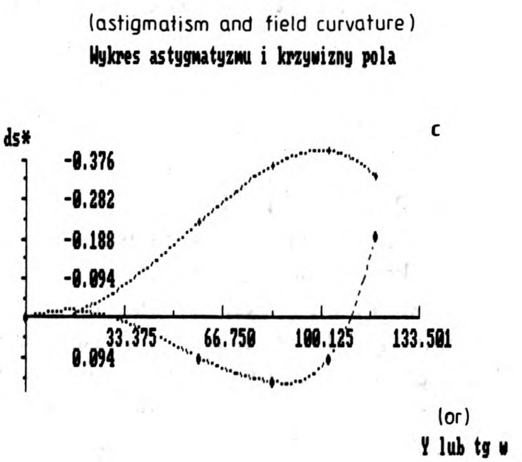
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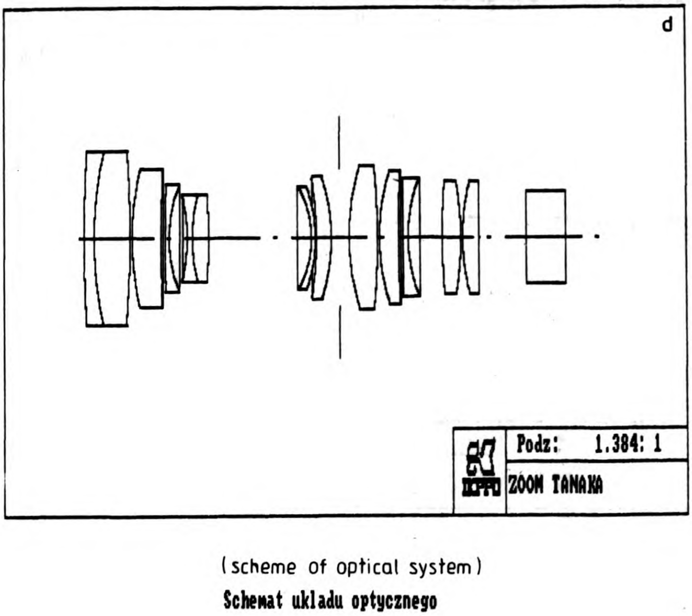

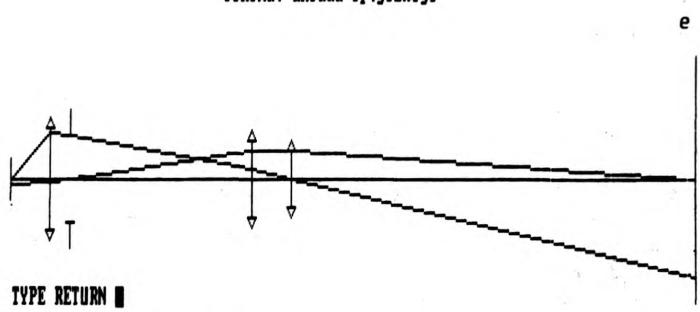

Fig. 2. Examples of application with basic graphic capabilities revealed: **a** – example of raytracing (the triplet lens for photo enlargers); **b** – corresponding curves of spherochromatic aberration for three spectral lines (ı|ı – *F'*, •|• – *g*, • – *e*, respectively); **c** – corresponding curves of meridional (|) and sagittal (·) field curvature, respectively; d – example of workshop drawing of the sophisticated zoom lens; **e** – example of dimensional predesign of a three-component optical system on the basis of paraxial optics

4. Final remarks

The initial version of the SAPO was written in BASIC in 1984; it included three fundamental modules: EDIT, RAYS and ABER. Since then the system has been enhanced with further modules. In order to make use of excellent mathematical libraries and standard parametric procedures as well as to speed up some routines, selected parts of the SAPO have been programmed in FORTRAN. At present the SAPO requires the IBM PC/XT/AT with high resolution colour graphic card, 8087 arithmetic co-processor, at least 512 kB RAM, and a hard disk of 10 MB capacity. It should be stressed, however, that shortened versions of the system for the most popular 8-bit home micros (like Sinclair Spectrum and Amstrad CPC 6128) are also available. The system is under constant development and further enhancements will be reported in future.

References

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SAPO — система микро-ЭВМ проектирования оптических систем, предназначенная для IBM PC

В статье представлена система микро-ЭВМ проектирования оптических систем SAPO, её потенциальнье возможности а также применения, в том числе использование в дидактическом процессе в Варшавском политехническом институте. Замечается следующие потребности в оборудовании: IBM PC/Xt/AT в полной конфигурации, с добавочньм арифметическим копроцессором 8087, твёрдым диском 10 MB, стандартным печатным устройством и графической картой.