Method of the initial optical design and its realization

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ABSTRACT

The initial optical design concerns the determination of the thin-component parameters based on the knowledge of ray coordinates, requirements and restrictions. The ground of the approach is heuristics that relies on an analysis of aims and means. The method may be used twice either as development of some new algorithms or the numerical computation of the optical thin-component model. In the first case, from the beginning we may select relations, and next establish the proper mathematical forms. In the second case we have been changing the introductory state influencing on results in this way. The methodological table plays an important role in this method. Different types of parameters are found in lines of this table while successive components are in columns. In this table we show in the initial state, methodology for applying relations in the right order and check for its correctness.
Computation for the riflescope illustrating possibilities, and advantages of the improved version is given in this paper.

Keywords: initial optical design, optical software.

1. INTRODUCTION

Initial optical design is being realized in the thin component model of the optical system using laws of paraxial optics. Such design is intentional when our information about the system is incomplete in this range. The task consists in determining all parameters of the system and coordinates deciding for its performance.
Despite the long-standing tradition, the general approach and methodology of the initial design is missing so far. In case of the chosen optical instrument it is possible to find detailed approaches in many books e.g.: Rusinov [1], Turigin [2], Czuriłowsky [3], Slusarev [4] and Tudorowsky [5]. Existing difficulties in the realization of the initial design aren't caused by the complicated mathematical set but are resulting lack of adaptation to present possibilities and computer means.
Kryszczyński [6] in 1977 presented the first version of the initial optical design while Leśniewski and Magdziarz [7,9] gave later the other version of the method in form of an interactive computer application. Determination of the optical powers in the four-component zoom systems by Kryszczyński [8] was an important application of this method. The present method and software are the improved versions of the former one.

2. BASIC ASSUMPTIONS

Imaging through the single thin component with the focal length "f" and the magnification "m" may be described by means of paraxial conjugation distances x and x '. Grounds are given in three following formulae:

$$\frac{1}{x'} - \frac{1}{x} = \frac{1}{f} \tag{1}$$

$$x_{+1} = x' - e \tag{2}$$

$$m = \frac{x}{x'} \ . \tag{3}$$

Conjugation distances are able to accept values from the very broad interval from $-\infty$ to ∞ - what is not good for automation of computations. In the formulae (2) "+1" means the relative index tied with the next component. Shortcomings of this computation are clearly visible when we want to calculate for example the magnification $M_{1,k}$ of the total optical system. In this case it will express itself in the following way

$$M_{1,k} = \prod_{i=1}^{k} \left(\frac{x'}{x}\right)_i \ . \tag{4}$$

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From (4) is resulting that we have to know all paraxial intermediate distances x and x ' for determining the magnification of the system, besides there can easily appear indeterminate expressions.
Here for imaging we will be applying coordinates of paraxial rays i.e. angles α with the optical axis and heights "h". Computation of such coordinates of paraxial rays can be automated better. These coordinates are carrying more information interesting for the optical system designer of than the axial distances. Methodology of initial design built on coordinates of paraxial rays is thus much more simple and clear than that using axial distances.
Optical imaging by the single thin component with the power ϕ and magnification "m" can be described by means of coordinates of the paraxial rays i.e. angles α with the optical axis and heights "h". New approach is given in three following formulae:

$$\alpha - \alpha_{-1} = h \cdot \phi \tag{5}$$

$$h_{+1} = h - \alpha \cdot e \tag{6}$$

$$m = \frac{\alpha_{-1}}{\alpha} . \tag{7}$$

In the approach according to (5-7) angle coordinates are able to accept values comparable with the numeric aperture whereas heights of the incidence are tied with crosswise sizes of the system, what is very suitable for the automation of computation. In (5-7) relative indices "-1" and "+1" refer to the previous or next component respectively. Advantages of the new approach of initial design are peculiarly visible during determining the magnification $M_{1,k}$ of the whole system. In this case we obtain the following formula

$$M_{1,k} = \frac{\alpha_0}{\alpha_k} . \tag{8}$$

From (8) is resulting that the magnification equals the ratio of the input numeric aperture to output one. For further considerations let us introduce two paraxial rays going through the system - the first will be the aperture ray whereas the other – the field ray. Normalization manner relying on that input coordinates both of paraxial rays were being regulated in certain conventional scale is not used anymore. Determined coordinates inside the system were keeping proportion to input coordinates and were thus leading to determining the paraxial intermediate and final distances adequate for the real distances.
In this work it is recommended to assign the input paraxial coordinates of both rays concrete values tied with the aperture and the field view of the system.
Let us accept, that paraxial input angle of the aperture ray will be identified with the maximal numeric aperture of the system according to formula

$$\alpha_0 = \sin(u_{max}) . \tag{9}$$

Using (9) we assume, that each component in the system is regarded as the aplanatic element. With this assumption relations of intermediate apertures inside the system will be exactly correspond to the paraxial intermediate magnification. From here it will be possible to widen the paraxial region approximately for whole real aperture.
Let us accept moreover, that paraxial input angle of the field ray will be identified with the tangent of the maximal angle field of view w_{max} according to formula

$$\beta_0 = tg(w_{max}) . \tag{10}$$

Using (10) we assume, that each component in the system is regarded as the orthoscopic element, in other words component distortion is insignificant. With this assumption relations of intermediate tangents of field angles inside the system will exactly correspond to the paraxial field magnification, at the extra assumption that the spherical aberration given by each component in intermediate pupils is negligible. In other words the whole system and every component are fulfilling the ortoscopic condition measured with tangents ratio of without the spherical aberration in the pupil. From here it will be possible to widen the paraxial region for whole real field of view with good approximation.
Assumptions made previously are corresponding to the situation where the system is constructed of components with corrected aberration properties.
It is possible to characterize every working component in the infinite conjugation distance by the distance between the intermediate object and his image (o-i distance) what can be written as follows:

$$t = x' - x . \tag{11}$$

When we apply coordinates of the paraxial aperture ray then we will receive the following formula

$$t = h\left(\frac{1}{\alpha} - \frac{1}{\alpha_{-1}}\right). \tag{12}$$

From (7) and (12) it is possible to eliminate coordinates of the rays and to receive interesting relation binding parameters ϕ, t and m

$$\phi \cdot t = -\frac{(1-m)^2}{m}. \tag{13}$$

It is worth noticing, that in relation (13) coordinates of paraxial aperture rays aren't occurring.
Idea to utilize coordinates of paraxial rays for the initial design is facilitating perfectly understanding of performance of the optical system.

3. METHODOLOGY OF THE INITIAL DESIGN

3.1 Paraxial aperture ray

First of all we will consider paraxial aperture ray and its refraction by the single component and the passage to the next component. Paraxial aperture ray coordinates are given on Fig. 1.

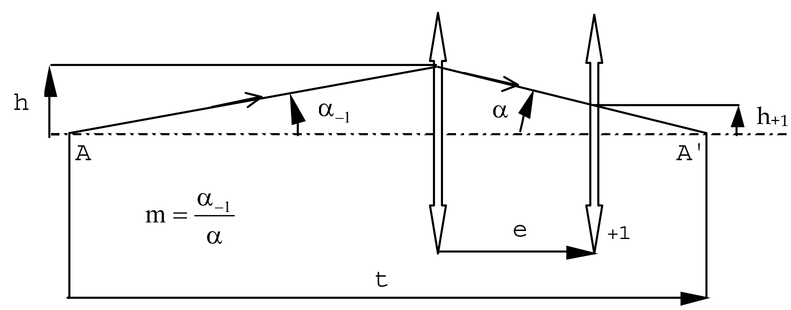


Fig. 1: Paraxial aperture ray coordinates: A, A'- intermediate object and image points respectively, t – object to image distance (o-i distance), α_{-1}, α - paraxial angles identified with the numeric apertures, h, h_{+1} - heights of the incidence for the current and neighbor components, e - space between components.

Paraxial imaging of the aperture ray through the single component and transferring the height to the next component give us the following group of relations

$$\alpha \cdot m - \alpha_{-1} = 0 \tag{14}$$

$$\alpha - \alpha_{-1} - h \cdot \phi = 0 \tag{15}$$

$$\alpha \cdot (1-m) - h \cdot \phi = 0 \tag{16}$$

$$\phi \cdot m \cdot t + (1-m)^2 = 0 \tag{17}$$

$$\alpha \cdot \alpha_{-1} \cdot t + h \cdot (\alpha - \alpha_{-1}) = 0 \tag{18}$$

$$\alpha_{-1} \cdot t + h \cdot (1-m) = 0 \tag{19}$$

$$h_{+1} - h + \alpha \cdot e = 0\,. \tag{20}$$

In this group of relations eight parameters are occurring: ϕ, e, h, h_{+1}, α_{-1}, α, m and t. One relation has the number of 4 or 3 parameters. Most simple relations (14) and (17) have only 3 tied parameters. The general rule is here in force that the unknown value can be determined only when the values of remaining parameters are known. Exceptions from this principle are trivial cases when zero values lead to determination of indefinite parameters.
Relation (16) is absolutely necessary because it enables to determine the aperture when parameters ϕ, h and m are known. However, assigning the power ϕ from relation (16) at known values α, m and h is possible in one step, but it is also possible to solve this task in two steps using relations (14) and (15).

We are avoiding, if it is possible, determining the magnification m from relation (17) because it is only case forcing to choose the proper solution from a square equation.
Likely, relation (19) is indispensable because we are able to determine the aperture α_{-1}, when parameters t, h and m are known. However assigning t from relation (19) at known values α_{-1}, h and m is possible in one step, but it is also possible to solve this task in two steps applying relations (14) and (18).
Applying relation (18) is making sense only when one of apertures α_{-1} or α is the unknown parameter. When in the opposite case magnification m is known as the extra parameter the problem can be solved with the use of other relations.
Relation (20) is embracing with its range the next component with the relative index +1. It is giving the possibility to synchronize two conventional parts of the system separated by distance e. It consists on determining either the required distance e or the aperture angle α between components or any height h, h_{+1} of the aperture ray incidence.
Above-mentioned remarks are justifying the correctness of the selection of relations (14-20) characterizing the aperture ray. The aperture ray should go through the edge of the entrance pupil, aperture stop and of the exit pupil.

3.2 Paraxial field ray

We will now consider paraxial field ray and its refraction by the single component and the passage to the next component. Paraxial field ray coordinates are given on Fig. 2.

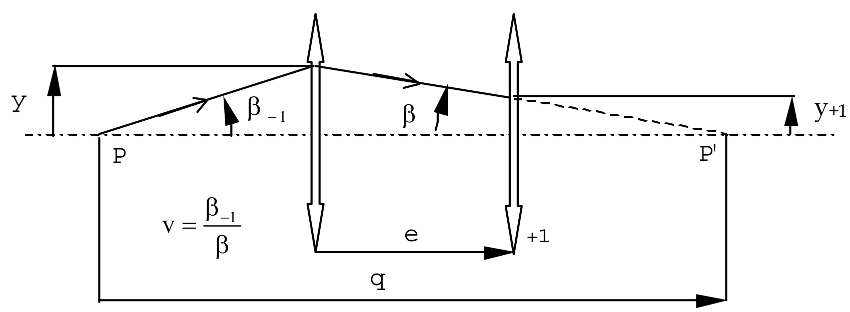


Fig. 2: Paraxial field ray coordinates: P, P'- intermediate entrance and exit pupils respectively, q – distance between entrance and exit pupils (e-e distance), β_{-1}, β - paraxial angles identified with the tangents of the field angles, y, y_{+1} - heights of the incidence for the current and neighbor component, e - space between components.

Paraxial imaging of the field ray through the single component and transferring of the height to the next component give us the some similar group of relations

$$\beta \cdot v - \beta_{-1} = 0 \tag{21}$$

$$\beta - \beta_{-1} - y \cdot \phi = 0 \tag{22}$$

$$\beta \cdot (1 - v) - y \cdot \phi = 0 \tag{23}$$

$$\phi \cdot v \cdot q + (1 - v)^2 = 0 \tag{24}$$

$$\beta \cdot \beta_{-1} \cdot q + y \cdot (\beta - \beta_{-1}) = 0 \tag{25}$$

$$\beta_{-1} \cdot q + y \cdot (1 - v) = 0 \tag{26}$$

$$y_{+1} - y + \beta \cdot e = 0 \tag{27}$$

In the group of relations from (21) to (27) eight parameters are also occurring: ϕ, e, y, y_{+1}, β_{-1},β v and q. Apart from the power and distance e parameter coordinates of the field ray are marked in a different manner.
In relations number of parameters is 4 or 3. Most simple relations are (14) and (17) which have only 3 tied parameters.
Relations (21-27) characterizing the field ray are analogous to those of the aperture ray. Therefore also to the new group of relations (21-27) are assigned the same remarks as to the earlier group (14-20). Correctness of the selection of relations (21-27) characterizing the field ray is justified similarly. The field ray should go through the center of the entrance pupil, aperture stop and exit pupil.

3.3 Lagrange-Helmholtz invariant

Aperture and main field rays are going through the same thin component model described by powers ϕ and distances e. It is possible to characterize every system by Lagrange-Helmholtz invariant (L-H invariant in brief) denoted customarily by J.

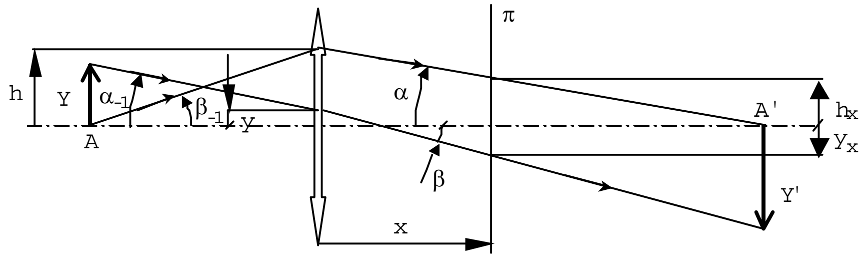


Fig. 3. Lagrange-Helmholtz invariant on one component: A, A '- point on the optical axis and its image; Y, Y' – object and image heights respectively for the object and the image, π- any plane perpendicular to the optical axis: h_x, y_x - heights of incidence on plane π of the aperture ray and field ray respectively.

This invariant has the constant value both in the object and image space. In case of the single component (see on Fig.3) the L-H invariant can be determined in the intermediate object plane or the image plane knowing heights of the object and the image Y and Y 'and *numerical apertures at these planes α_{-1} and α

$$J = Y\,\alpha_{-1} = Y'\alpha\,. \tag{28}$$

In case of the thin component model consisting of k components the L-H invariant can be determined using the following formula

$$J = Y_0 \cdot \alpha_0 = Y'_{k+1} \cdot \alpha_k\,. \tag{29}$$

From (29) is resulting that during optical imaging in the intermediate image planes given by the component product of the linear field by numerical aperture is constant. Comparing systems of the various types it is possible to state that bigger is the L-H invariant the difficult are working conditions of the system.

Determining the L-H invariant from (29) is not always possible. The good example of such system may be telescopic system (e.g. Kepler or Galileo type). Formulae (28) and (29) refer to the classic form of the L-H invariant. The generalized L-H invariant that will give below is considerably more convenient to apply in the initial design because may be determined on any thin component and even in any plane perpendicular to the optical axis.

Comparing formulae (15) to (22) and (20) to (27) we will receive

$$\phi = \frac{\alpha - \alpha_{-1}}{h} = \frac{\beta - \beta_{-1}}{y}, \qquad e = \frac{h - h_{+1}}{\alpha} = \frac{y - y_{+1}}{\beta}\,. \tag{30}$$

The formulae (30) may be given in some other form as follows:

$$\alpha_{-1}\,y - \beta_{-1}\,h = \alpha\,y - \beta\,h = \alpha\,y_{+1} - \beta\,h_{+1}\,. \tag{31}$$

Equation (31) states that the expression linking angles and heights is equal regardless off whether angles are taken left-sided (α_{-1}, β_{-1}), or right-hand (α, β). Leading consideration recursively through all components we attain the conclusion that expression (31) are equal on every thin component of the system.

Let us assume (see Fig.3) the certain plane π is located behind the component and perpendicular to the axis. It is positioned in the distance x from the chosen component. It is of no importance whether its position is to the left or to the right from the component. Heights of the incidence h_x and y_x of rays on the plane π will be equal

$$\begin{aligned} h_x &= h - \alpha \cdot x \\ y_x &= y - \beta \cdot x \end{aligned}\,. \tag{32}$$

After substituting (32) to expression (31) we receive

$$\alpha\,y - \beta\,h = \alpha\,y_x - \beta\,h_x = \alpha_{-1}\,y_x - \beta_{-1}\,h_x\,. \tag{33}$$

If expression (33) will be referred to the object and image plane (h_x=0, y_x=Y or Y ') the expression will receive the classic form L-H invariant (29).

From expressions (33) results that the L-H invariant can be determined on every thin component of the system with index i from 1 to k and in the arbitrary plane perpendicular to the optical axis according to the following formulae

$$\begin{aligned} J &= (\alpha \cdot y - \beta \cdot h)_i = (\alpha_{-1} \cdot y - \beta_{-1} \cdot h)_i \\ &= (\alpha \cdot y_x - \beta \cdot h_x)_i = (\alpha_{-1} \cdot y_x - \beta_{-1} \cdot h_x)_i = J_x \end{aligned} \quad . \tag{34}$$

Formulae (34) present the generalized L-H invariant in both forms i.e. with right-hand and left-sided apertures on any component and in any plane.

The L-H invariant is determined also in the aperture stop plane, when the height h_d of the aperture ray and the tangent of the field angle passing by center of stop are known in accordance to the formulae

$$J = -h_d \cdot \beta_d \, . \tag{35}$$

3.4 Paraxial mixed rays

It may happen in systems working at the finite aperture and field of view, that the number of known coordinates tied with one ray on the single component is less than 2 and it isn't enough, in the general case, for determining remaining parameters. It may also happen that the number of known coordinates tied with the other ray on the single component is less than 2 and it isn't also enough for continuing calculations. It turns out that when total number of parameters of both rays on the single component is equal 3 then it is possible to determined further missing parameters of the mixed rays and continue calculations in accordance with two groups of relations given before.

The new group of relations is necessary for this purpose to describe the imaging both of rays. This group is created by the following formulae:

$$\alpha \cdot y - \beta \cdot h - J = 0 \tag{36}$$

$$\alpha_{-1} \cdot y - \beta_{-1} \cdot h - J = 0 \tag{37}$$

$$\alpha \cdot y \cdot (m - v) - J \cdot (v - 1) = 0 \tag{38}$$

$$\beta \cdot h \cdot (m - v) - J \cdot (m - 1) = 0 \tag{39}$$

$$m \cdot J \cdot (1 - v) - \alpha \cdot y_{-1} \cdot (m - v) = 0 \tag{40}$$

$$v \cdot J \cdot (1 - m) - \beta_{-1} \cdot h \cdot (m - v) = 0 \, . \tag{41}$$

Distinctive feature of the group of relations from (36) to (41) is the fact that constructional parameters of the system are missing (powers and distances), and four parameters are occurring in each relation. Two are referred to the aperture ray, whereas two remaining – to the field ray. The L-H invariant value is occurring in this group of relations as the constant of the system. Two initial relations (36) and (37) are nothing else but two the generalized L-H invariant forms. Relation (38) should be used to determine α, relation (39) - to determine β, relation (40) - to determine α, whereas relation (41) - to determine β_{-1}. Other possibilities to determine the parameters from relations (38), (39) and (41) are not recommended because it is more convenient to continue computation using relations (14) to (21).

As it can be seen from relation (36-41), knowledge of the J value as the constant of the system is needed for easier calculations in the situation when mixed ray' parameters are known. But it is not all. It is possible to determine the power ϕ of the component, when only apertures and field angles are known (α, α_{-1}, β, β_{-1}). Other possibilities rely on determining the e distance when only heights of the incidence of both rays are known (h, h_{+1}, y, y_{+1}) in accordance to the formulae

$$\alpha_{-1} \cdot \beta - \alpha \cdot \beta_{-1} - J \cdot \phi = 0 \tag{42}$$

$$h \cdot y_{+1} - h_{+1} \cdot y - J \cdot e = 0 \, . \tag{43}$$

Relation (42) can be received by multiplying (22) by α and (15) by β and by subtracting sides of equations, whereas relation (43) - multiplying (20) by y and (27) by h and also by subtracting sides of equations.

3.5 Formulating requirements

The thin component model should fulfill variously formulated requirements. In the simplest case we are able to require the chosen ray coordinates to reach given values in designated planes of the model. Requirements may refer to the constructional parameters of model. Given coordinates of characteristic rays on borders of the model should be suitably selected to determine positions of the object and the image and also entrance and exit pupils.

In more complex case requirement is characterized by means of relations. Relation has assigned parameter of the

requirement and component indices. Parameter of requirements may be the intermediate position of the object or image (S_i or S'_i) and also the intermediate local positions of the entrance or exit pupils (P_i or P'_i) at the component indexed by "i". Other example of formulating requirements is setting the intermediate magnification for object-image distances or pupils ($M_{p,k}$ or $V_{p,k}$) for the selected part of the model with indices from "p" to "k".
Discussed requirements can be described by means of the group of relations:

$$\alpha_k M_{p,k} - \alpha_{p-1} = 0 \tag{44}$$

$$h_i - \alpha_i \cdot S_i^{'} = 0 \tag{45}$$

$$h_i - \alpha_{i-1} \cdot S_i = 0 \tag{46}$$

$$\beta_k V_{p,k} - \beta_{p-1} = 0 \tag{47}$$

$$y_i - \beta_i \cdot P_i^{'} = 0 \tag{48}$$

$$y_i - \beta_{i-1} \cdot P_i = 0 . \tag{49}$$

We sometimes require the assigned part of the thin component model to possess the given optical power $\Phi_{p,k}$. Presentation of this requirement is not always directly realized by means of coordinates on the edges of the separate part. In this case we are using the generalized version of relation (42)

$$\alpha_{p-1} \cdot \beta_k - \alpha_k \cdot \beta_{p-1} - J \cdot \Phi_{p,k} = 0 . \tag{50}$$

Relation (50) is also applied, when the model or his separate part is the telescopic system working at non-standard finite distances (then $\Phi_{p,k}$=0).

Standard requirement for the length of the total model or his separate part (parameter $E_{p,k}$.) is relation

$$\sum_{i=p}^{i=k-1} e_i - E_{p,k} = 0 . \tag{51}$$

Requirements for the thin component model are rich in possibilities. It is a broad field for the designer's creativity here.

4. GENERAL APPROACH

At the beginning of the initial design, we usually know the type of this model, the number of its components, values of chosen parameters as well as requirements which this setup should fulfill.
The main problem of initial calculations consists in the fact that we know merely sketchy parameters of the first and/or second characteristic ray and alternatively certain constructional parameters (most often distances) of the model which should fulfill demanded conditions - and the task consists in determining all remaining parameters of the model.
To solve the main task of the initial design, in the most general way, we will apply the heuristic method. The set of parameters and requirements is the initial state of our task. Such a set is ill complete from assumption. The final state of the task is reached when we know all parameters regarded earlier as important for the model, i.e. full information about the model, which is fulfilling our expectations.
The final state of the task is a purpose of the initial design. Means for obtaining this purpose are given earlier groups of relations tied with the aperture ray (14-20), with the field ray (21-27), and mixed rays (36-43) enriched by chosen relations of requirements. In order to utilize those relations we must analyze them paying special affections to calculation of unknown parameters. We will call the cycle of calculation the one time analysis of all groups of dependences. The process of the initial design is dynamic, and therefore many cycles are necessary to repeat before the final state will be reached. In every cycle we should calculate at least one parameter with unknown value, because this guarantees progress in the achievement of the final state.
The main difficulty of developed methodology of the initial design relies on how to choose the initial state so that is solvable is not leading to the contradiction.
In the course of elaborating methodology of the initial design in the specific case tables of the graphical presentation of groups tied with the aperture ray (Table 1), field ray (Table 2) and mixed rays (Table 3) are very useful. During elaborating methodology of the initial design, first of all, we care deeply on detecting very relations but only later - for giving them the proper mathematical form. This temporary break away from exact formulae is permitting us to focus on idea of calculations, without getting bogged down in details.
Essence of the general approach to the initial design relies on so-called methodological table, which is allowing us to describe the initial state, methodology for applying relations in the right order and check for its correctness. Methodological table (Table 4) has the construction similar to tables with the graphical presentation of various groups of

relations. Various types of parameters or coordinates are located in rows whereas columns are corresponding to the thin components of model.
The methodological table is limiting itself for elaborating and presenting methodology of the initial design of the specific thin component model only in the successive steps without writing formulae out. After filling the methodological table, writing out of each formula is already a relatively simple activity.

Table 1. Graphical presentation of groups tied with the aperture ray relations

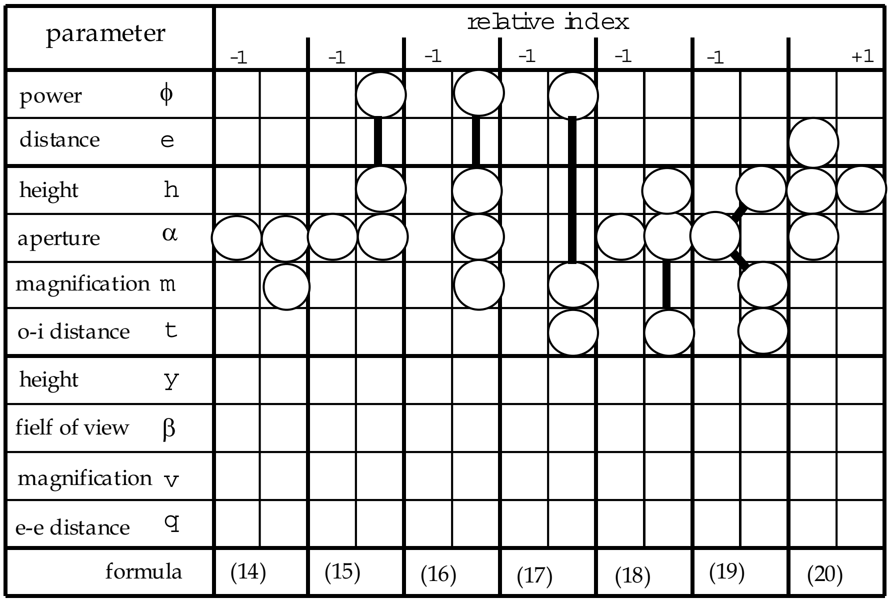


Table 2. Graphical presentation of groups tied with the field ray relations

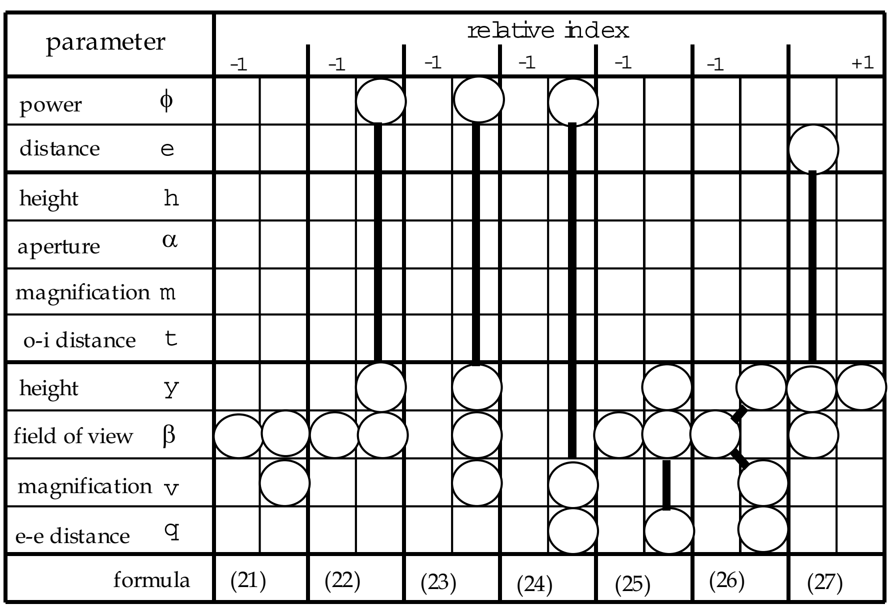
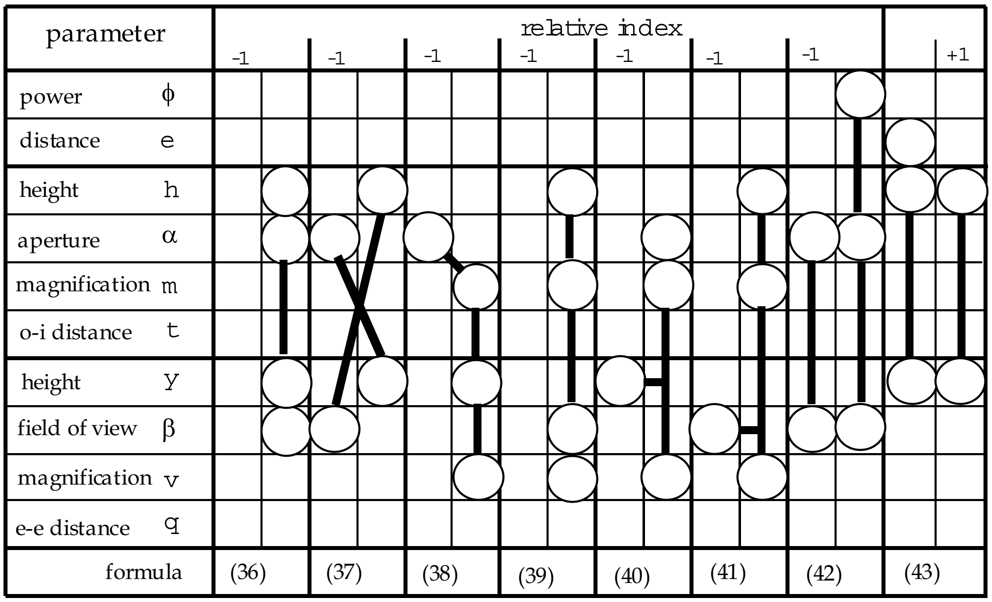


Table 3. Graphical presentation of groups of tied from mixed ray relations



In the second stage to determine the order of calculations, we are reviewing tables (Tables 1-3) trying to adjust the relation suitable for the specific situation according to the principle: only one parameter may be determined among tied parameters and remaining parameters must have known values. The initial design led in this way is the dynamic process. The calculated value of the parameter is participating in further calculations as the given parameter.

During determining unknown parameters certain difficulties may appear. Possible is the situation, where continuation of methodology is impossible. It means that the model is indeterminate and unsolvable under accepted assumptions included in the initial state. In this case it is necessary to supplement the methodological table with initial parameters, what will cause the model to become solvable. It may also come to situation, where the unknown parameter may be determined from two various relations. It means that at accepted assumptions the model is internally contradictory. In this case it is necessary to reduce the certain number of initial parameters in the methodological table or to change their setup so that the model became solvable explicitly.

At suitable practice both stages of filling in the methodological table are being realized at the same time. Methodology of the initial design may be formulated different ways depending on the initial state.

Success of methodology of the initial design with given parameters and requirements is decided by how accurately it is reflecting significant technical matters. Computing difficulties tied with some iterative parameters are currently easy to defeat.

5. SOFTWARE DESCRIPTION

To perform analysis mentioned above, the program GABAR was written in Excel application. The main task the program carries out is to fill the methodology table of paraxial parameters in the interactive mode. As numerical example of the thin component model is the riflescope shown on Fig. 4.

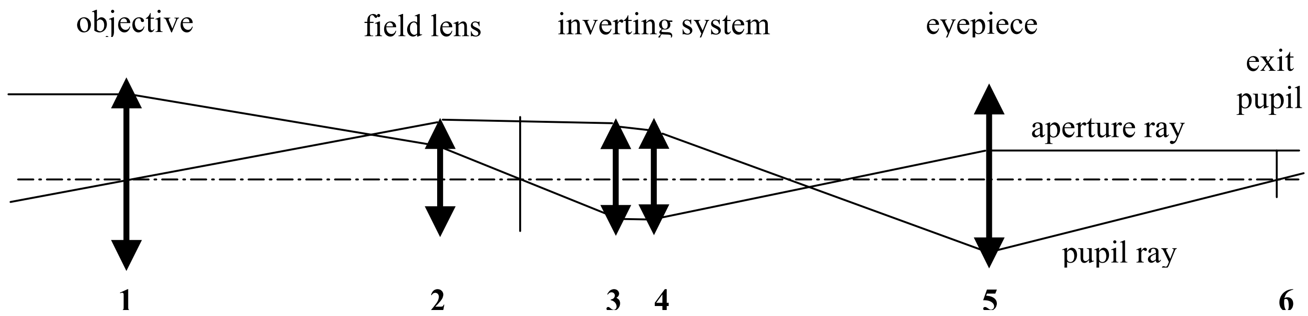
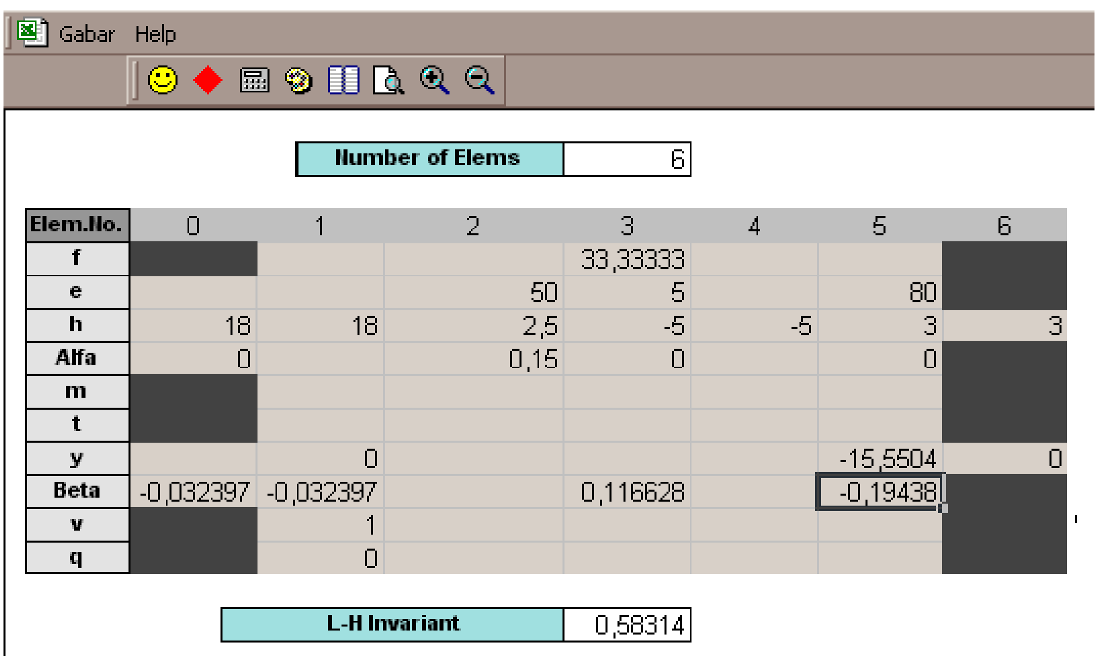


Fig. 4: Thin elements of the riflescope

Following main parameters are given: angular magnification - 6X, objective diameter - 36 mm, the image angular field of view - 2w = 22 deg., exit pupil distance - 80 mm, riflescope length - 300 mm. The following data are therefore put in the table of GABAR application: Number of Elems = 6, h1 = 18, alpha 0 = 0, alpha 3 = 0, alpha 5 = 0, h6 = 3 (exit pupil radius), e5 = 80, beta 5 = -0,19438 (tan 11deg), h3 = h4 = -5 (presumption), e3 = 5 (presumption), h2 = 2,5, the alpha 2 = 0,15 (the last two dimensions determine the distance between the field lens and objective focal plane).
Now the GABAR is ready to be run. The successive stages of numerical processing are shown in Fig. 5, Fig. 6 and Fig 7.



Number of Elems	6

Elem.No.	0	1	2	3	4	5	6
f				33,33333			
e			50	5		80	
h	18	18	2,5	-5	-5	3	3
Alfa	0		0,15	0		0	
m							
t							
y		0				-15,5504	0
Beta	-0,032397	-0,032397		0,116628		-0,19438	
v		1					
q		0					

L-H Invariant	0,58314

Fig. 5. First step: computing the group of parameters on the base of starting data

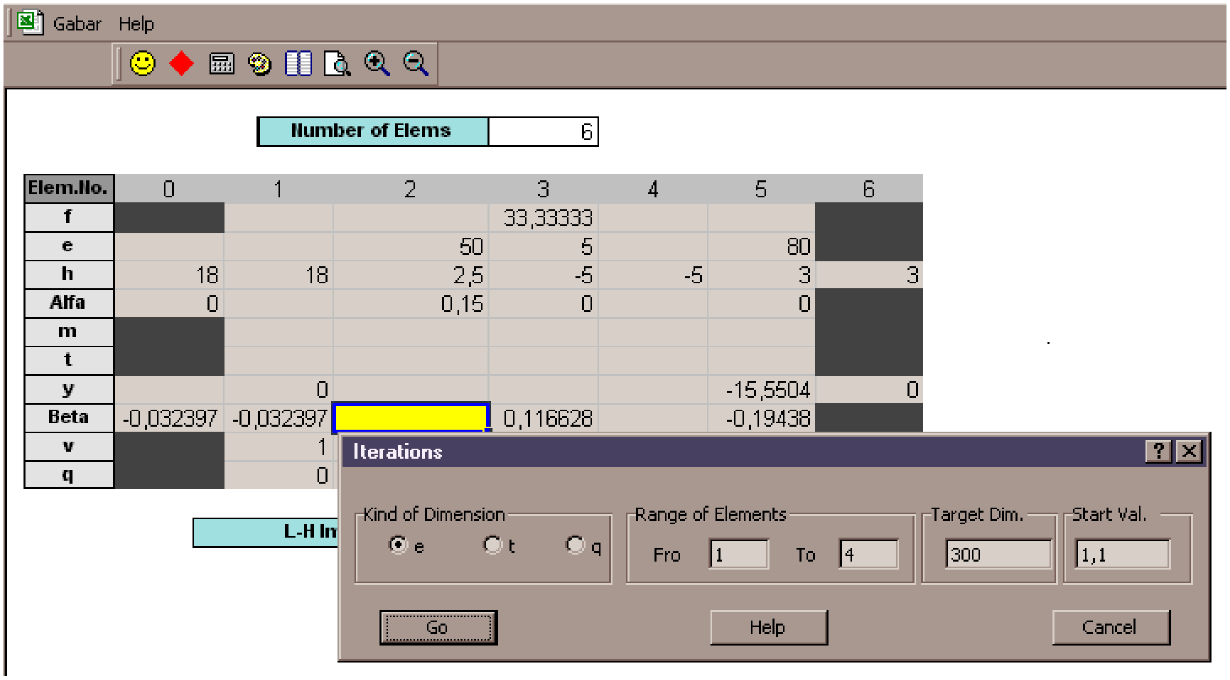
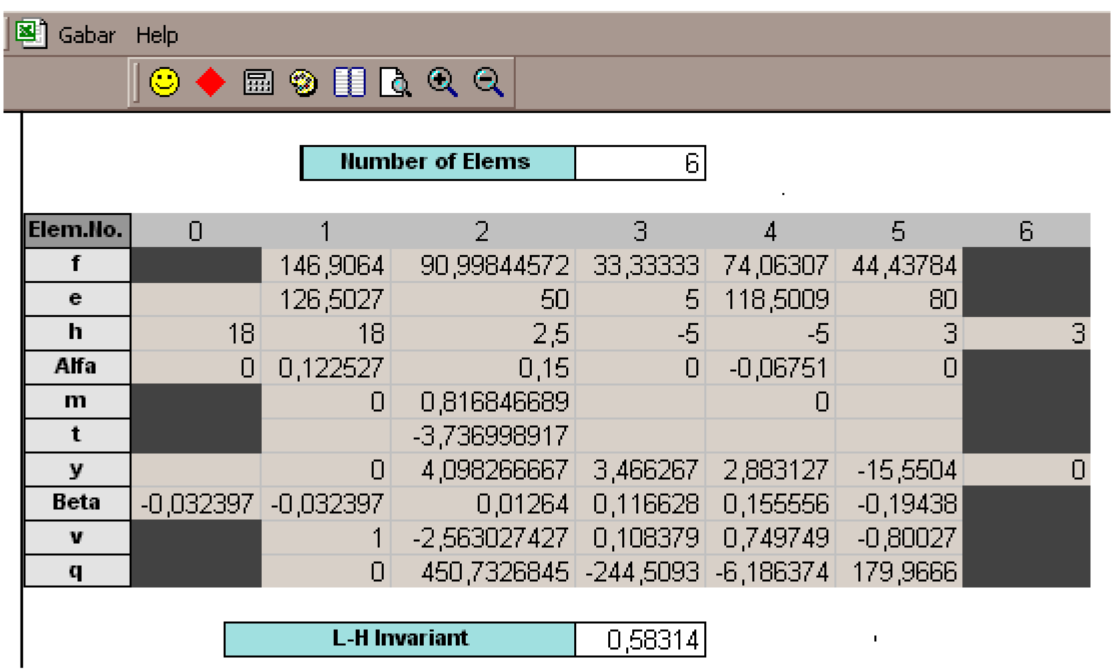


Fig. 6. Second step: initialization of iterations; the iterated parameter is beta 2, provided that the riflescope length (distance from first element - objective to the last - eyepiece) should be equal 300 mm.



Number of Elems: 6

Elem.No.	0	1	2	3	4	5	6
f		146,9064	90,99844572	33,33333	74,06307	44,43784	
e		126,5027	50	5	118,5009	80	
h	18	18	2,5	-5	-5	3	3
Alfa	0	0,122527	0,15	0	-0,06751	0	
m		0	0,816846689		0		
t			-3,736998917				
y		0	4,098266667	3,466267	2,883127	-15,5504	0
Beta	-0,032397	-0,032397	0,01264	0,116628	0,155556	-0,19438	
v		1	-2,563027427	0,108379	0,749749	-0,80027	
q		0	450,7326845	-244,5093	-6,186374	179,9666	

L-H Invariant: 0,58314

Fig. 7. End of calculation. All empty places in the methodology table are filled with numerical results.

6. CONCLUSIONS

The presented method of initial analysis is suitable for designing optical systems applied in various devices. The given method has important teaching and practical aspect. It is possible to apply it for elaborating the algorithms for designing any optical systems as well as for the automation of numerical analysis. Interactive program GABAR (Excel application) is a powerful tool very useful in initial stage of optical design, i.e. for determination of the paraxial dimensions of the arbitrary optical systems. Such dimensional analysis is absolutely necessary before starting with next, more advanced stage of automatic optical design. It is indispensable in any serious designing work.

7. ACKNOWLEDGEMENT

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