PANDAO
FROM OPTICS TO FABRICATION

Manual

And

Frequently Asked Questions (FAQ)

Content

1. GENERAL USAGE

PanDao abstract

The human-to-human interface between optical design and manufacturing is now supported by the novel data-based **PanDao software tool** (www.PanDao.ch). PanDao reads in lens data and determines tha optimal fabrication chain at minimum cost and risk.

PanDao is a cost and risk minimization software and the first of its kind:

- PanDao enables **optics designers** to optimize their designs for minimum fabrication cost and thus saving substantially:
  - It takes usually a maximum of 6 to 8 "ask PanDao" requests to optimize a two-sided lens, which can save up to thousands of Euros (taking into account a typical European batch sized fabrication order of some hundred lenses, only).
- PanDao informs **purchasing managers** and **optics engineers** about the producibility of optical designs:
  - It takes only one "ask PanDao" request to receive information about (a) the best fabrication chain, (b) essential technologies needed and (c) fabrication <u>cost</u> level.
  - Having that data, you are able to choose the optimum supplier at minimum risk and to negotiate the best <u>price</u>, usually with a considerable savings potential.
- PanDao informs **executive management** and **controlling** about fabrication cost performance of their in house production department with respect to State-of-the-Art in industry.
- PanDao supports **optical shop floor managers** and **production planners** in optimizing their fabrication chains, steering the capacity of in-house technologies, and evaluating investment projects for new technologies to be implemented.

PanDao can be used with three different databases:

- PanDao default database,
- PanDao company-owned database ,
- PanDao company-specific database;

And there are four ways to get access to PanDao's services:

- company-wide license,
- single-user license,
- Design-to-Fabrication (DesToFab) service,
- PanDao (www.PanDao.ch) and JOYA Team (https://www.joyateam.com/) joint Engineering service.

For further reading, please consult the our references at the end of this document or contact us at *info@PanDao.ch*.

Which topics are covered by PanDao?

For a complete list of topics covered by PanDao, please refer to the development stage listed in chapter 5 of this manual.

Which topics will be added next to PanDao?

The next topics to be added are determined by PanDao customer surveys and are displayed in Chapter 5, the development stage.

How does PanDao work?

PanDao reads in optics elements data (according to ISO10110 standard) and determines the optimum fabrication chain: the most cost-efficient and the fastest.

PanDao can be operated using three different databases which can be selected in the *options* section of the input data surface. Please note that option "b" (company-owned) and option "c" (company-specific) are upon special request only and are not included into the PanDao default package:

Technology selection:	Technology selection:	Technology selection:
PanDaoDefault ⌄	CompanyOwned ⌄	CompanySpecific ⌄

a) **Default**: optimal fabrication chain is determined out of about 360 different optical fabrication technologies (OFTTs) performing at State-of-The-Art processing level.
b) **Company-owned**: is an extra option where the OFTTs of your company are used (protected by NDA). That way, PanDao can generate the optimal fabrication chain using only OFTTs available at your company. Company-owned technologies are considered performing at State-of-The-Art level.
c) **Company-specific**: is extra option where the OFTTs of your company are used (protected by NDA) together with their individual machining performances in your workshop. That way, PanDao can generate the optimal fabrication chain using your company-specific OFTTs performing at your individual machines level of quality, throughput and cost structures.

What is PanDao's policy in handling my optics data?

As a principle (see GTC) PanDao tries to store as less user data as possible. If not explicitly allowed in the user tab, any optics data entered into PanDao is only used to calculate the result and immediately after that lost on the server side. Your optics data is not stored on the server and can therefore not be stolen if there would be a security breach on our side. The transfer of the data to the server is protected by https encryption. If you use company-owned or -specific OFTTs than your data will be hard compiled into PanDao will therefore be really hard to extract if there would be security issues.

The only data stored on our side are the user data entered at registration. On the client side (the device using PanDao) the last optic requested and the last result displayed are stored in the local cookies. We can not influence how you handle security on your devices. If this is a concern for you please discuss this with your companies IT department.

How is the cost calculation in PanDao composed?

PanDao's cost calculations
a) **including**: machining, tooling, operators' salaries and attention needed, setup machine, machine's invest cost, bank payback time and interest, workpiece material, center grinding, protective chamfering and facets, non-circular circumference generation, workpiece mounting, dismounting, quality testing during fabrication, coating, uptime and downtime of machines per day, month and year, etc.;
- Please note that when determining the machining cost, PanDaoi always assumes that the machine has not yet been depreciated (this means that when the depreciation period of a machine is reached, a new machine is purchased again to keep the machinery up to date).
b) **excluding**: companies' overhead, assembly, packaging and delivery cost.

Which yield level is considered by PanDao?

PanDao applies optics manufacturing at a high industrial quality level, aiming for a yield of 95%. To achieve this goal, an overproduction of 5% is considered. Thus, if 100 lenses are to be produced, PanDao assumes a production quantity of about 105 lenses.

How does PanDao manage to stay up to date?

In order to ensure PanDao's State of the Art level, PanDao is regularly being updated: for more details, please consult the blog section at the PanDao webpage (www.PanDao.ch) and PanDao's LinkedIn page (www.linkedin.com/company/pandao-gmbh) or contact us at info@PanDao.ch.

How do I get started?

Each purchase of a PanDao license includes free training sessions; please contact us at info@PanDao.ch.

The best way to get started is:
- follow the free PanDao training sessions that are included in any license purchase,
- consult this manual,
- check out the videos on our YouTube channel,
- read our publications (see reference list at the end of this document),
- follow us for frequent news and tips and tricks at PanDao's LinkedIn page,
- read our blog entries at www.PanDao.ch and
- consider to book extra training sessions with PanDao's team, if needed,

To start PanDao, please log in at www.PanDao.ch using the log in data you received with your license.

Where can I check my current number of PanDao requests?

Please check the "PanDao/user" site which is located here:
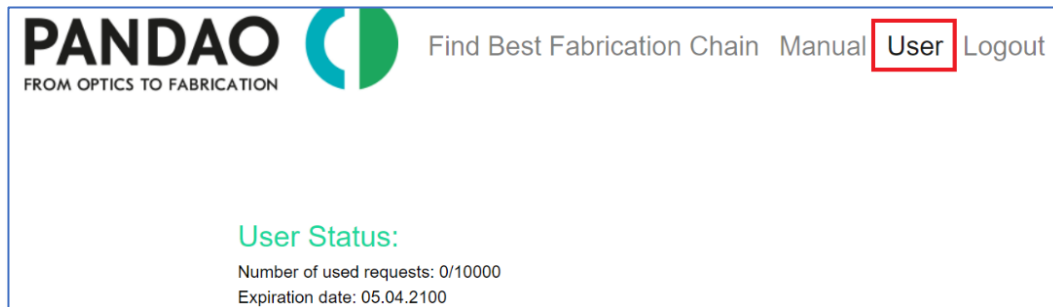
Is PanDao generating fabrication cost or selling price?

PanDao generates fabrication cost, without any financial security cushion along the fabrication chain.

How does PanDao deal with the wage levels of different countries and companies?

Please note that in every country the wage level of different companies might differ and that production qualities not necessarily depend upon the wage levels. PanDao distinguishes 3 different types of companies; high wage companies, medium-wage companies and low-wage companies. In addition, it is possible to enter one's own commercial conditions into PanDao.

The wage level can be adjusted in the options section.

Why is there a difference between <u>absolute fabrication cost</u> between my company's production department and PanDao?

Please consider that PanDao is determining fabrication cost and not selling price. PanDao is not dealing with companies' overhead cost, assembly, packaging and delivery cost.

In order to be able to compare absolute cost levels, ensure that you are comparing the same fabrication chain.

Please customize the wage level of your or your supplier's company in the options section:

Wage level:

high wage companies ▾	✅ Customize level

Bank interest [%]:
5

Loan payback time [y]:
10

Salary operator semiskilled [€]:
3000

Salary operator technician[€]:
4000

Salary operator engineer[€]:
6000

Daily working hours:
14

Working days per month:
26

Working months per year:
11

The delta that might remain depends on the following information that <u>would be requested</u> by PanDao:
- all individual commercial information of your company, e.g., varying bank interest rates and level of salaries, invested machines cost and age of machines applied etc.,
- detailed description of the fabrication chain currently in use (types of machines, tools and processes etc.) and which machines are currently depreciated,
- calculating machining cost, PanDao takes only machineries into account that are applied along the fabrication chain; often departments hourly rates are calculated based on all machinery existing within the department including those, being not used this time,
- calculating operator cost, PanDao takes operator hours needed for this lens into account and not salaries of all people being employed within this department.

2. INPUT PARAMETERS

2.1. ALL SHAPES

How should I describe my lens parameters and tolerances

PanDao reads in optics elements data according to ISO10110 standard and determines the optimum fabrication chain.

PRO-OPTIC-CONVERTER: How can I determine and convert lens tolerances so that PanDao can read them?

You can export lens data from your optical design software tool in a format that PanDao can read in.

Nevertheless, often technical drawings use different ways to describe tolerances (like the radial tolerance in mm instead of the power value in fringes) or apply different standards (such as the MIL standard instead of the ISO10110 standard). Furthermore, certain parameters are sometimes missing on technical drawings.

To support you in such situations, PanDao offers the *free PRO-OPTIC-CONVERTER* tool, which covers currently the following topics:

Issue	Description of the mathematical PRO-OPTIC-CONVERTER tool
Slope to mid-spatial-wavelength converter	Reads in the midspatial tolerance in terms of max. slope allowed [minutes] and converts this into the maximum allowed mid-spatial-wavelength [mm].
Radial tolerance to power converter	Reads in the radial tolerance (delta R in [mm]) and converts this into power (the "A" of 3/A(B) in ISO10110 in [fringes])
Determination of asphericity	Reading in the absolute aspherical shape, the asphericity is determined: the maximum vertical distance between the asphere's surface and its removal sphere.
Determination of the radius of the enveloping spherical surface of an asphere (the removal sphere)	Reading in the absolute aspherical shape, the radius of the enveloping spherical surface (the removal sphere) of an asphere is determined. The enveloping spherical surface is located above the aspherical surface without intersecting the asphere; this spherical surface is located as close as possible above the asphere enabling minimum volume removal during production.
Determination of the smallest radii of curvature (ROC) of aspheres and freeforms	Reading in the absolute aspherical shape, the overall smallest ROC as well as the smallest ROC of the concave parts of the surface are determined.
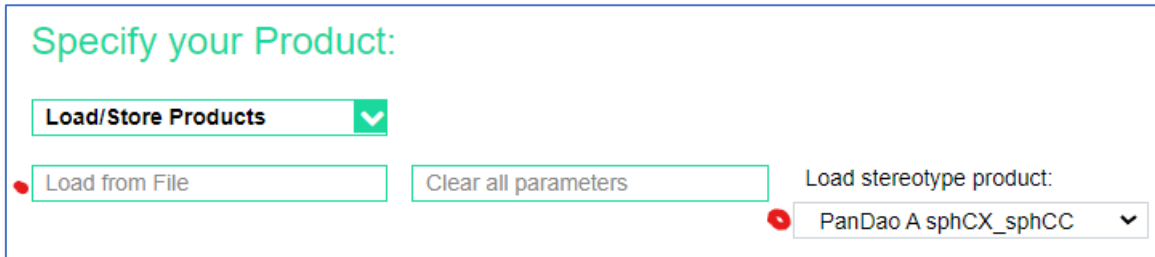
Check the PRO-OPTIC-CONVERTER out at:
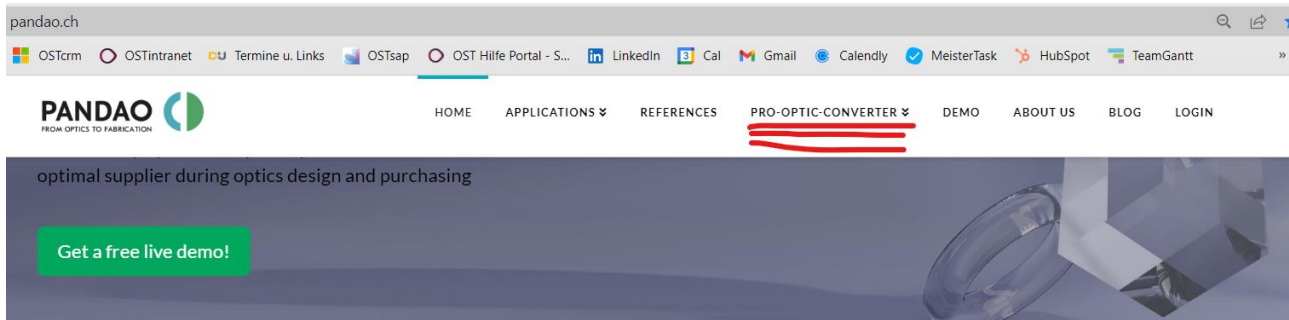
How do I input lens parameters into PanDao?
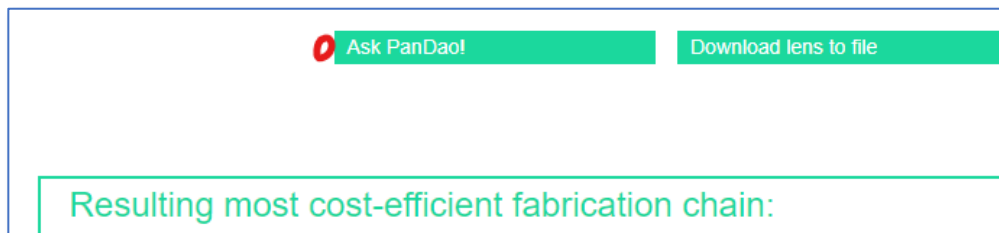
To run a PanDao analysis to determine the optimal fabrication chain for your lens, you need to enter the parameter values and tolerances of your optical element on the PanDao website.

There are three possibilities of doing this:

Specify your Product:

Load/Store Products ▼

Load from File   Clear all parameters   Load stereotype product:
                                                       PanDao A sphCX_sphCC ▼

a) Read-in the lens data saved by your optics design software (or by yourself from PanDao),
b) load one of the stereotype lenses and change its values and tolerances to the ones you need,
c) enter the values and tolerances of your optics directly.
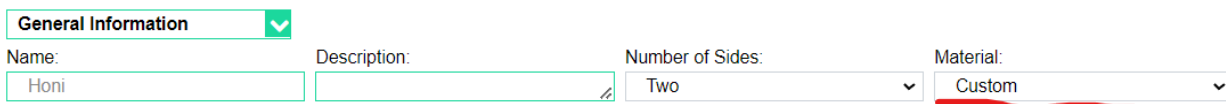
Having done that, you are now ready to start PanDao by clicking on "ask PanDao" and get the optimal manufacturing chain for your optics at minimum cost and manufacturing risk.

Ask PanDao!   Download lens to file

Resulting most cost-efficient fabrication chain:
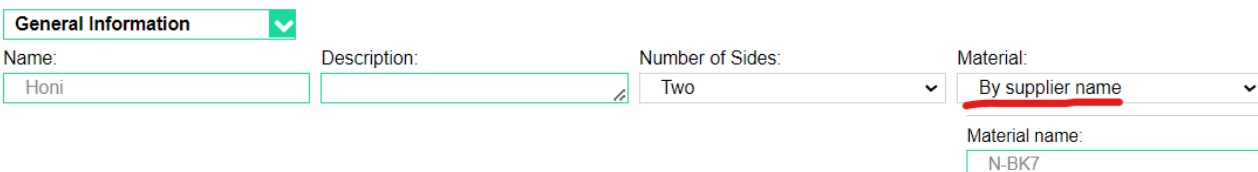
How do I input workpiece material into PanDao?

For a list of materials currently covered by PanDao see the development stage at the end of the manual.
Choose workpiece material in the general section. There are two choices: you can either select materials directly ba choosing "Custom"

General Information ▼

Name:	Description:	Number of Sides:	Material:
Honi		Two ▼	Custom ▼

or, in case you want to select a specific glass brand name of one of the leading glass suppliers, select "By suppliers name" and specify e.g. N-BK7 glass:

General Information ▼

Name:	Description:	Number of Sides:	Material:
Honi		Two ▼	By supplier name ▼
			Material name:
			N-BK7

In this case, PanDao will determine material cost per liter and its techical parameters such as acid resistance automatically:

Material:
By supplier name

Material name:
N-BK7

Material cost per Volume [€/l]:
57.73

Knoop hardness (HK):
610

Acid resistance (AR):
AR2

Material suited for precision glass molding

What should I do If my lens material is not listed in PanDao's material scroll down menus?

Please check if the material is part of a PanDao material group like e.g. metals or crystals. If not, contact us at info@PanDao.ch and we will help you.

How do I determine workpiece material cost in PanDao?

The selection of a suitable blank for optical manufacturing is similar to that of the sculptor who already saw the Laocoon group in the block of marble he wanted to use and only had to uncover it.

Gruppo del Laocoonte excavated in Rome in 1506, Wikipedia and Vatican Museums
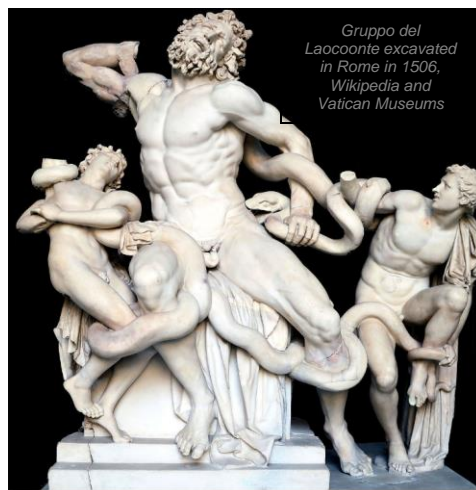
Optical elements consist of many different materials (from PMMA to sapphire), have different dimensions (e.g., diameters from a few micrometers to several meters) and geometries (from planar plates to freeforms to conformal optics). Thus, the selection of a suitable blank is challenging and diverse, and, among others, the following blank variants exist:

- cut blocks from a melt
- purchase of a whole glass melt
- grow a crystal
- bar stock for cutting to length
- cylinders for direct rough shaping
- spheres, gobs, semi-finished products (e.g. for PGM)
- powdered or liquid workpiece blank (e.g. for injection molding, 3D printing or coatings).

Currently, PanDao's first fabrication step is rough shaping of surfaces (or molding). Therefore, PanDao generates material cost by taking cost-per-liter as input and calculating the volume material cost needed to generate the finished optical element, taking into account various fabrication process related issues such as the material to be removed and debris caused.

Due to the huge variance in selecting blank geometries, the material cost currently determined by PanDao represents an industrial-realistic benchmark that might be undercut: sometimes.

There are two options to enter the lens material into PanDao:
  b) either by entry of the ***supplier's glass material's name***, such as e.g. N-BK7. Please note:
    ▪ to select this material type by a scroll-down menu,
    ▪ that PanDao automatically knows if this material is being suited for precision glass molding (PGM),
    ▪ that PanDao automatically collects material costs (per volume) from the supplier's website;

  c) or by ***custom*** entry from a scroll down menu. Please note that
    ▪ in this case PanDao requires for glasses the entry of the Knoop hardness (HK) and of the acid resistance (AR) values. This data can easily be found in the internet from the relevant technical data sheet, e.g. N-BK7 with HK = 610 and AR = 2,
    ▪ in this case you need to specify if a glass material is suited for precision glass molding (PGM) or not,
    ▪ in this case have to enter material cost per volume by yourself.

In either case, PanDao will determine material cost of your lens:

Material cost:
Material cost for this lens: 0.02€

How do I enter shape accuracies into PanDao?

PanDao accepts currently (as described in ISO10110) shape accuracies in terms of 3(A(B) with "A" being the power tolerance and "B" being the irregularity. Units are fringes, wave (not surface) at 546.07nm wavelength. So, e.g. a hight deviation of the irregularity of 1 micron equaly B = (1000/546.07)*2 = 3.66 fringes; and if we assume a power error of 2 micron height the shape accuracy of this surface equals **3/7.32(3.66).**

How do I select if my lens should withstand a high level of Laser Induced damage Threshold (LIDT)?

Please select "suited for LIDT" to determine lens fabrication chains for lens intensity levels of up to appr. 30 J/cm^2. Please note that PanDao does not evaluate if the chosen lens material is suited for LIDT.

How do I input a rod lens into PanDao?

Fabrication chains for rod lens generation have special characteristics. Please notify PanDao at:

How do I select the right types of Optical Fabrication Technology Techniques (OFTTs) to be considered by PanDao's?

PanDao determines the optimal fabrication chain for a given lens. The following selections can be made for the Optical Fabrication Technology Techniques (OFTTS) to be considered by PanDao:

How do I select or omit block fabrication?

Whenever possible (if lens spherical radius is much bigger than lens diameter), PanDao considers block fabrication where a multiple samples holder is used to machine in parallel instead of sequentially: E.g.:

Block fabrication can be switched on and off in the options section:

How do I select or omit Optical Fabrication Technologies (OFTs) to be considered by PanDao?

Select the characteristics of Optical fabrication Technology Techniques (OFTTs) in the Option section of PanDao by using the two selection criteria "Applicability" and "level-of-Maturity":

a) *Applicability*: in the options section of the input surface at least one of the three choices must be activated with a tick: "in industry", "R and D" and/or "University",

b) *Level-of-Maturity*: in the options section of the input surface at least one of the two choices must be activated with a tick: "established" and/or "emerging technologies".

After you have received information about an optimal fabrication chain for one optical element you can omit one or several of the listed OFTs and start a new PanDao request to build the best chain possible without the selected OFTs available.

In order to do so, please copy and paste the OFT's name from the output into the field "exclude OFTTs" which is located in the options section:

How do I select the correct "Wage-Level" for my lens?

PanDao distinguishes 3 different types of companies: high, medium and low wage level companies. Please note that in every country the wage level might differ and that production qualities not necessarily depend upon the wage levels:

a) **High-wage companies:** e.g. existing in Germany, France, UK, USA, Japan, Singapore, Switzerland, Austria and Italy

b) **Medium-wage companies:** e.g. existing in Romania, Bulgaria, Turkey, Portugal, Mexico, Taiwan and Serbia.

c) **Low-wage companies**: e.g. existing in China, India, Indonesia and Korea

In addition, it is possible to enter one's own commercial conditions by choosing custom input: e.g. bank interest, investment payback time to the bank and salaries of engineers or technicians.

What are typical surface roughness ranges and values?

PanDao asks surface roughness values in terms of Sq [nm rms] over a spatial bandwidth of 0.002mm to 0.08mm; derived from DIN ISO 10110-8:

Range	Rq over spatial bandwidth of 0.002 mm to 1 mm
P1	≤ 8 nm rms
P2	≤ 4 nm rms
P3	≤ 2 nm rms
P4	≤ 1 nm rms

What are Facets?

In PanDao, for each optical element the cost for protective chamfers is included in the center grinding cost.

The so-called facet stages are being generated by molding or as a cnc grinding step after the center grinding step has been finished (on the same machine). Facet stages are binary-like step structures at the outer edge of the lens located between the clear aperture and lens diameter to e.g., serve mounting issues of the lens into the objective.
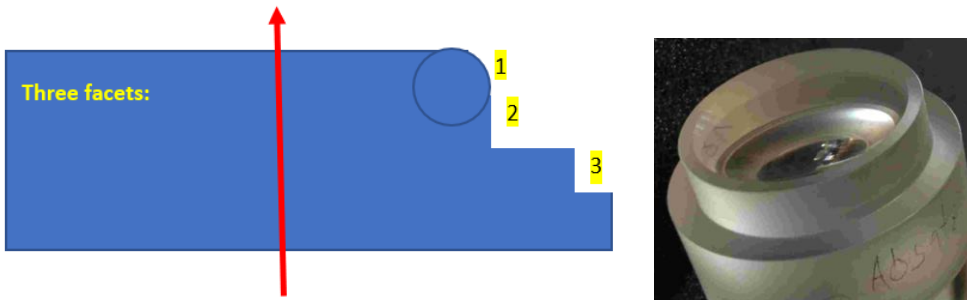
How do I enter Facets?

Choose at a side of the lens the number of facets required, e.g. 3

NumberOfFacets:

3

In this case three extra windows open each asking height and length of the facet [in mm].
- For rectangular facet shapes (No.2 and 3 in the picture in the facets chapter): enter the height and width e.g. facet 1: 0.5 mm / 0.1 mm.
- For circular or "axicon-like" chamfers (No.1 in the picture in the facets chapter): enter only their height and depth but neither the radius nor the hypothenuse (of the axicon).

Facet 1:

Height (parallel to optical axis in mm)	Width (rectangular to the optical axis in mm)

Facet 2:

| Height (parallel to optical axis in mm) | Width (rectangular to the optical axis in mm) |

Facet 3:

| Height (parallel to optical axis in mm) | Width (rectangular to the optical axis in mm) |

What are non-circular perimeters?

For mounting purposes, the outer lens cylinder might have a non-circular shape, e.g. a "D" shape. These non-"O" shaped lens cylinder shapes might be more complex than flat and circular shape segments (visible if the lens is observed parallel to the optical axis (top view)):
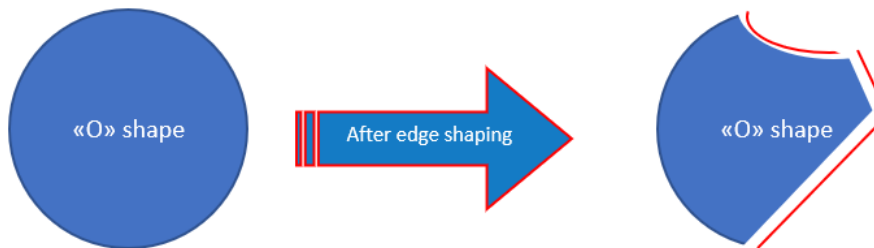
PanDao asks the overall ***non-circular circumference*** length which is the overall length of the non-cylindrical shapes along the lens perimeter as indicated with the red lines in the example above.

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Possible lens geometries and input parameters

(A)	(B)	(C)	(D)	(E)	(F)
meniscus	**planoParallel**	**convexPlano**	**biconvex**	**concavePlano**	**biconcave**

LEFT SIDE (side 1)
  clearAperture Φe
  prot.chamfer (length)
  coating (AR/special)
  3/power(irregularity)
  4/ (for flats use 3/)
  5/
  6/ (if > 10J/cm^2 = LIDT)
  Sq surface roughness
  smallest midSpatialWaelength:
  sag
if spherical surface (YES/NO):
  R:
if aspherical surface (YES/NO):
  smallest radius of curvature
  asphericity
  radius of removal sphere:
  contains concave parts (YES/NO)?
      smallest concave radius of curvature (SCRC)
if cylindrical surface (YES/NO):
  clearAperture shoulder length Φe:
if off-axis aspherical surface (YES/NO):
see off-axis aspheres section below
if freeform (YES/NO):
see freeformss section below

MATERIAL:
  if glass (YES/NO):
    HK:
    AR:

DIMENSIONS
  center thickness ct
  (for of-axis aspheres and freeforms:
  enter local minimum lens thickness)
  ct tolerance
  lens diameter
  diam tolerance

PRODUCTION ORDER
  totalNumber pcs
  batchSize pcs:

LEFT SIDE (side 2)
  clearAperture Φe
  prot.chamfer (length)
  coating (AR/special)
  3/power(irregularity)
  4/ (for flats use 3/)
  5/
  6/ (if > 10J/cm^2 = LIDT)
  Sq surface roughness
  smallest midSpatialWaelength:
  sag
if spherical surface (YES/NO):
  R:
if aspherical surface (YES/NO):
  smallest radius of curvature
  asphericity
  radius of removal sphere:
  contains concave parts (YES/NO)?
      smallest concave radius of curvature (SCRC)
if cylindrical surface (YES/NO):
  clearAperture shoulder length Φe:
if off-axis aspherical surface (YES/NO):
see off-axis aspheres section below
if freeform (YES/NO):
see freeformss section below

2.2. ASPHERICAL SURFACES

What is the "removal sphere" for a given aspherical, off-axis aspherical or freeform surface?

The removal sphere is the enveloping spherical surface that is located outside of the material not intersecting with the surface to be generated; it is located as close as possible above the surface to be generated without intersecting.

You can find this parameter in the output data generated by the optical design software.

What should I enter, if (e.g. for freeform surfaces) no "removal sphere" is known?

Please enter earth radius 6400'000'000 mm

What is "asphericity"?
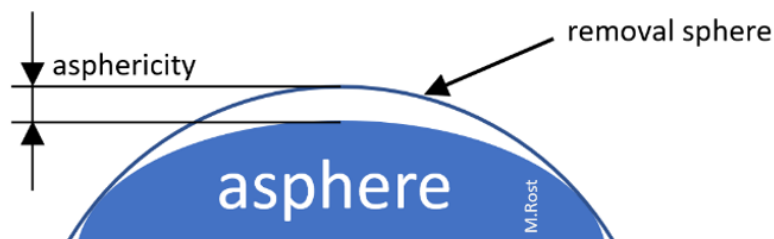
In contrary to optics design, PanDao defines asphericity as the maximum vertical distance from the "removal sphere" to the aspherical, off-axis aspherical or freeform surface.

You can find this parameter in the output data generated by the optical design software.

How do I define the centering tolerance for an aspherical surface?

Aspherical shapes have no point symmetry. Therefore, tilting and side shifting result in different decenter effects and have to be defined separately.

Consequently, for aspherical surfaces, ISO 10110 uses e.g., the following notation **4/x (y)** with "**x**" describing the lens tilt in minutes and "**y**" being the maximum allowed lens side shift in mm:

2.3. OFF-AXIS ASPHERICAL SURFACES

Off-axis aspheres: what is "offsetR"?

"offsetR" is the lateral distance from the symmetry axis of the asphere to the center of the clear aperture of the off-axis asphere.

Off-axis asphere: what should I enter at Center Thickness?

Please consult the stereotype lens drawings: Please enter the local minimum lens thickness called "gauge".

Off-axis aspheres: what should I enter at "smallest radius of curvature" and at "smallest concave radius of curvature (SCRC)"?

Please consult the stereotype lens drawings: Please enter the smallest radii of curvature of the whole aspherical surface out of which the off-axis asphere is being generated with production diameter = 2 * (minRClearAberture + lens diameter).

Off-axis aspheres: How do I enter the 4/ centering accuracy?

There is currently no 4/ specified: Please enter 4/ at the other side of the lens, only. Currently, no center grinding cost for freeforms are generated.

Please note that cost for setting *fiducials* needed for matching the coordinate systems of (a) the machine and (b) the testing device and (c) the mounting setup are not taken into account, currently.

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Off-axis aspheres definitions
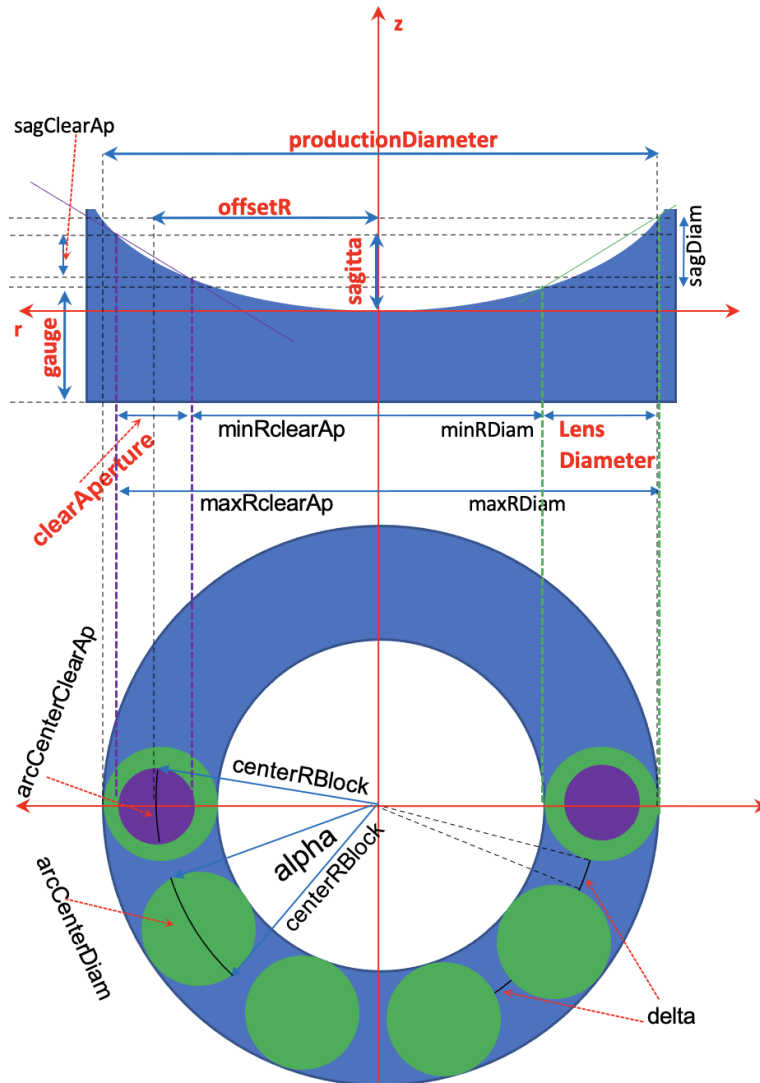
LEFT SIDE (side 1)

clearAperture Φe:
prot.chamfer (length):   -
coating (AR/special):
3/power(irregularity)
~~4/centering asccuracy~~, not applicable: *see FAQ*
5/
6/ (if > 10J/cm^2 = LIDT)
Sq surface roughness
smallest midSpatialWaelength:
sagitta

off-axis asphere:

smallest radius of curvature
(of the whole asphere within
production diameter)
asphericity
radius removal sphere:
contains concave parts (YES/NO)?
SCRC
(smallest concave radius of curvature
of the whole asphere within production diameter)
offsetR
sagDiam
sagClearApp

MATERIAL:

if glass (YES/NO):
HK:
AR:

DIMENSIONS

"center thickness"**ct = gauge**
*(for of-axis aspheres and freeforms: enter local
minimum lens thickness = gauge as center
thickness)*
ct tolerance
lens diameter
production diameter
(= 2*(minRdiam + 2*lensDiameter))
diam tolerance

PRODUCTION ORDER

totalNumber pcs
batchSize pcs:

RIGHT SIDE (side 2):
currently flats only !

2.4. FREEFORMS

What should I enter at Center Thickness?

Please consult the stereotype lens drawings: Please enter the local minimum lens thickness called "gauge" located under the maximum sagitta (sag) of the freeform.

What is the definition of the parameter "MLC of SCRC"?

The "MLC of SCRC" is the Maximum Local Cross section (MLC) of the area with the Smallest Concave Radius of Curvature (SCRC). Please consult the freeform stereotype drawing.

Do freeform surfaces have any symmetry?

No. Freeforms do not have any kind of symmetry and are defined by a data cloud: $z(x,y)$.

What should I enter at "MLC of SCRC" (Maximum Local Cross section (MLC) of the area with the Smallest Concave Radius of Curvature (SCRC))?

Please consult the stereotype lens drawings:
   a) if MLC is known, please enter MLC of SCRC in mm;
   b) if local radii are continuously varying along the clear aperture ($dR/(dx, dy) \neq 0$) then Please enter 0.01 mm (which is a typical incremental distance between data points used in CNC programming).
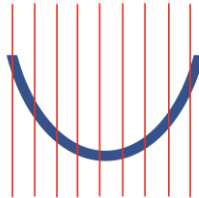
How do I enter the 4/ centering accuracy for freeform optics?

There is currently no 4/ specified: Please enter 4/ at the other side of the lens, only. Currently, no center grinding cost for freeforms are generated.

Please note that cost for setting *fiducials* needed for matching the coordinate systems of (a) the machine and (b) the testing device and (c) the mounting setup are not taken into account, currently.

What is the definition of the parameter "localSag at SCRC"?

The "localSag at SCRC" is the local sagitta at the point $z(x,y)$ where the smallest concave radius of curvature (SCRC) is located. Please consult the freeform stereotype drawing.

Why is PanDao not informing about centering of freeform optics?

There is currently no industry standard for free-form centering; it is done, for example, by fiducials, extended ring assembly, or optically or by wafer stack technologies.

PanDao advises on request within the DesignToFabrication service

Freeforms definitions
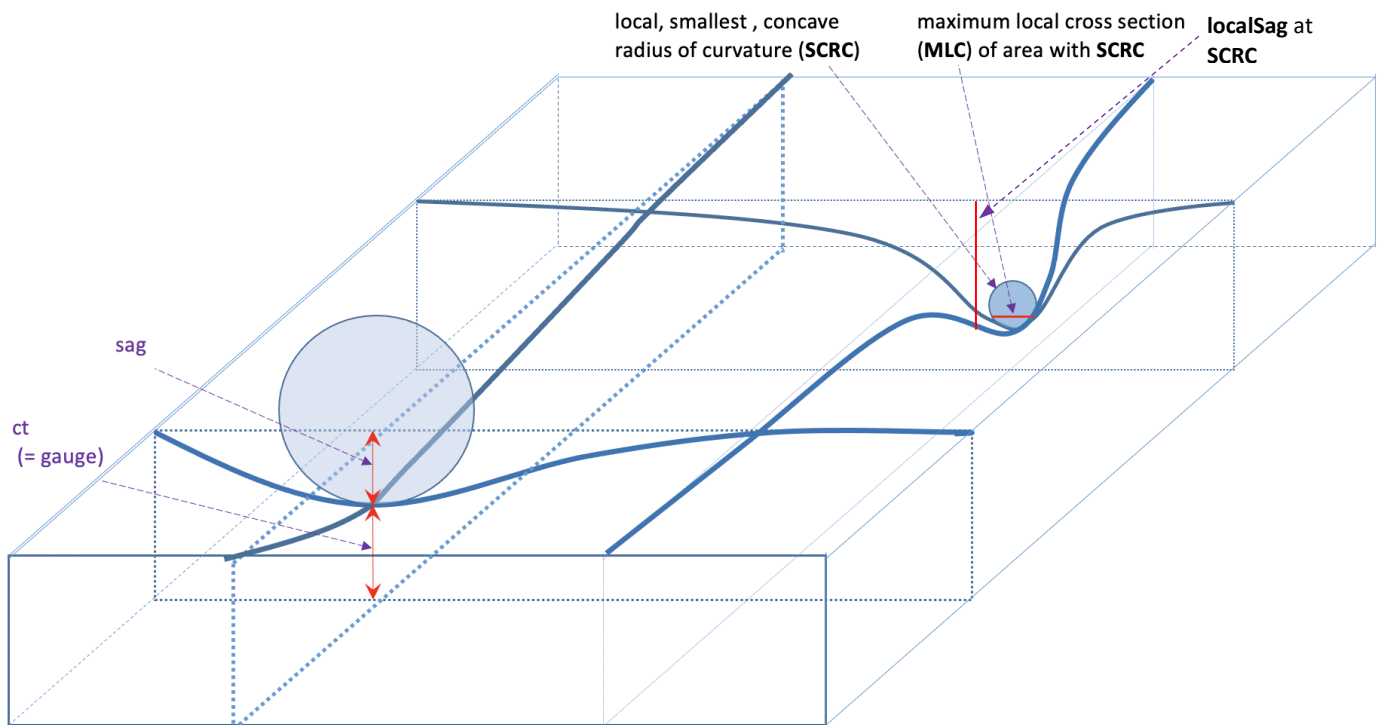
LEFT SIDE (side 1)

clearAperture Φe:
prot.chamfer (length):
coating (AR/special):
3/power(irregularity)
~~4/centering asccuracy~~, not applicable*: see FAQ*
5/
6/ (if > 10J/cm^2 = LIDT)
Sq surface roughness
smallest midSpatialWaelength:
sag

if freeform (YES/NO):
smallest radius of curvature
asphericity: *see FAQ*
radius of removal sphere: *see FAQ*
contains concave parts (YES/NO)?
smallest concave radius of curvature (**SCRC**)
MLC of **SCRC**
(Maximum Local Cross section (MLC) of the area with the Smallest Concave Radius of Curvature (SCRC))
localSag at **SCRC**
(local sagitta at the point z(x,y) where **SCRC** is located

MATERIAL:
if glass (YES/NO):
HK:
AR:
Alpha:

DIMENSIONS
"center thickness"**ct = gauge**
(for of-axis aspheres and freeforms: enter local minimum lens thickness = gauge as center thickness)
ct tolerance
lens diameter
diam tolerance

PRODUCTION ORDER
totalNumber pcs
batchSize pcs:

RIGHT SIDE (side 2):
any shape allowed

2.5. Prisms

Prisms generation is currently not covered by PanDao (see chapter 5, development stage).

2.6. CEMENTED OPTICS

How do I manage centering tolerances of cemented optical elements?

For cemented optics (e.g. doublets, triplets or quadruplets), the centering tolerance is often specified on the technical drawing of the cemented element rather than on the drawing of its lenses.

In this case, please input into PanDao the cemented element as if it would be one single lens. The two sides of this virtual lens are its outer surfaces of the cemented element (see below surface A and B of the triplet shown) and its center thickness is the sum of the center thicknesses of its individual lenses.

That way, PanDao copes with center grinding, circumference generation and multiple facets grinding of cemented optics.

Surface A   *Surface B*
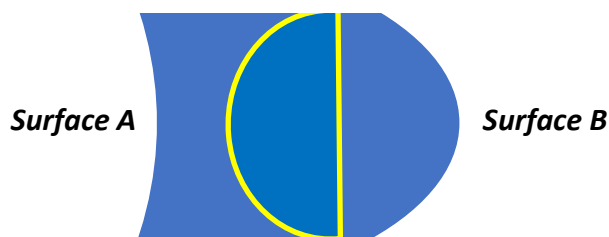
How do I determine cementing cost (assembly of lenses into cemented optical doublets, triplets etc.)?

This option will be available soon: it is currently in beta testing.

3. OUTPUT PARAMETERS

What are general boundary conditions for PanDao's output?

Tools and materials are available.

If you'll choose one of the input parameters "out of range", PanDao delivers an error message without counting this request.

What is the output of PanDao?

PanDao determines two optimized fabrication chains: (a) the most cost-efficient and (b) the fastest fabrication chain. In addition, PanDao informs about center grinding, testing, coating and material cost needed.

In general, there are three different possible answers given by PanDao:
  a) the two optimized fabrication chains as described and shown above,
  b) the two optimized fabrication chains together with a risk-alert,

  c) no fabrication chain possible for the lens data inputted; in this case, PanDao delivers the message "can't fabricate":

What should I do if my lens data generates the message "can't fabricate" or if unexpected responses are displayed?

Please proceed according to the following scheme when troubleshooting:

a) double check your input data
- Aspheres, off-axis aspheres and freeforms need a mid-spatial wavelength > 0.08 mm
- Options/Applicability: at least one of the three choices must be activated with a tick: "in industry", "RnD" and/or "university".
- Options/Level-of-Maturity: at least one of the two choices must be activated with a tick: "established" and/or "emerging technologies".
- Double check your 4/ centering tolerance
- General: Double check if you activated the tik for "Material suited for precision glass molding".
- Try to enable "emerging technologies" in the options/Level-of-Maturity" section.
- Double check if you selected the desired material.

b) load a stereotype product (from the scroll-down menu at the PanDao "specify your product" input page) and convert this data step by step into your lens data.

c) contact us at info@PanDao.ch and request a PanDao DesignToFabrication service for this lens: our experts will analyze your lens data and provide a detailed manufacturability report for this lens, including suggestions on which input data should be changed or optimized.

What is Prototype Batch Lead Time (PBLT)?

Prototyping Batch Lead Time (PBLT) is the minimum time needed to produce a first batch under the following boundary conditions: (a) using one fabrication chain only (production applied sequentially and not in parallel), (b) prototyping batch orders are classified with top priority and (c) taking industrial-realistic handover times of one day per production step into account.

Prototyping lead time is an information needed for the prototyping phase and therefore being displayed only for batch sizes smaller than 50 lenses.

Prototype batch lead time: 9.00 days

What is Serial Batch Lead Time (SBLT)?

Serial Batch Lead Time (SBLT) is the minimum time needed to produce a batch in serial production under the following boundary conditions: (a) using one fabrication chain only (production applied sequentially and not in parallel), (b) taking industrial-realistic handover times per production step into account and (c) applying a batch-controlled workshop manufacturing approach.

For the fastest production chain, it is assumed that the chain is optimally filled, the transfer times are minimized and the most complex production step determines the cycle rate.

Serial batch lead time: 3.9064 days

What is "most cost-effective fabrication chain"?

Based on lens' input data given, PanDao determines **as standard output** the best fabrication chain in terms of causing minimum fabrication cost at maximum yield; this is also called the cheapest fabrication chain.

Please note, that he most cost-effective fabrication chain is not necessarily the fastest fabrication chain.

<div style="border:1px solid">Resulting most cost-efficient fabrication chain:</div>

What is the "fastest fabrication chain"?

In addition to the "most cost-effective fabrication chain", PanDao determines the "fastest fabrication chain": optimized for speed at reasonable risk while ignoring cost issues.

PanDao delivers information about both chains: the fastest and the most cost-effective: e.g. "...the "fastest chain" produces each batch 1.28 times faster than the "cheapest chain" at 2.9 times more cost.

<div style="border:1px solid">Resulting fastest fabrication chain:</div>

What is "chain uniqueness"?

This output parameter helps in the risk assessment of the most cost-effective fabrication chain determined. 'Chain uniqueness' informs about how many fabrication chains exist within a fabrication cost band of 20 % above (and including) the cheapest fabrication chain.

In the example below, there are two other manufacturing chains existing that do not cost more than 20% more than the optimal manufacturing chain and use other technologies.

Side 1:
- curve generator rough grinding
  - fabrication cost: 0.54€
  - block fabrication is used
- curve generator grinding
  - fabrication cost: 0.42€
  - block fabrication is used
- cnc full aperture polishing
  - fabrication cost: 0.65€
  - block fabrication is used

Cost 1.61€
Capability factor: 0.998
Chain uniqueness: 2

What is "chain capability"?

The 'chain capability' is a measure of the level at which the fabrication technologies must perform their duty in the best manufacturing chain.

At 'chain capability' 100 %, the chain has to be applied at state-of-the-art processing level.
Below 100%, tolerancing could be further tightened (up to capability = 100%) without the need of a technology change.

The chain in the example shown below has a 'Capability factor' of 99.8% (Capability factor: 0.988)

Side 1:
- curve generator rough grinding
  - fabrication cost: 0.54€
  - block fabrication is used
- curve generator grinding
  - fabrication cost: 0.42€
  - block fabrication is used
- cnc full aperture polishing
  - fabrication cost: 0.65€
  - block fabrication is used

Cost 1.61€
Capability factor: 0.998
Chain uniqueness: 2

What is the difference between the "most cost-effective fabrication chain" and the "fastest fabrication chain"?

The "most cost-effective fabrication chain" is the chain with minimum fabrication cost at maximum yield; it is not necessarily the fastest chain possible.

The "fastest fabrication chain" is the fastest possible fabrication chain optimized for speed at reasonable yield while ignoring cost issues.

Chain comparison:
During serial production, the fastest chain is 3.88 times faster than the most cost-efficient, but causing 1.06 times more cost.

How can I document PanDao's results?

You can save lens input data any time and reload later for further analysis by PanDao or by your optical design software. You can furthermore download a full PanDao report of your lens as a pdf file or a commercial summary as an Excel file; PanDao reports can be downloaded here:

Specify your Product:

Load/Store Products

Load from File   Clear all parameters   Load stereotype product:
                                                        Please select:

General Information

Side 1

Side 2

Options

Ask PanDao!   Dowload lens to file   Dowload report pdf   Dowload summary csv
                                                                Delete old csv entries

- "Download lens to file": the PanDao input data is downloaded into a json file and can be reloaded into PanDao any time.
- Download report pdf": a full report including cost and risk information as well as a management summary and literature references to all required optical fabrication technologies.
- "Download summary csv": download an Excel file with the cost details of your lens; You can use the "Delete old csv entries" button to write the cost information to a new Excel file: this allows you to combine the cost information for an entire objective into one file.

4. PanDao MASTER CLASS: specialities and tricks in optics fabrication

Tips and tricks for high level usage of PanDao.

4.1. General usage

The following is valid for the usage of PanDao with all three databases: "default", "company-owned" and "company specific".

Technology selection:	Technology selection:	Technology selection:
PanDaoDefault	CompanyOwned	CompanySpecific
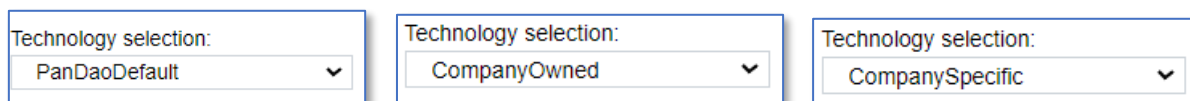
Production of off-axis aspheres customized?

Please note that there are two possible ways to generate off-axis aspherical optics and that the cost of both can be determined applying PanDao:

a) input of the lens as an off-axis aspherical element or
b) input of the lens as a freeform element.

Subsequently, you can choose the best variant for you taking cost and availability of technologies into account.

Side 1	Side 1
Global:	**Global:**
Shape:	Shape:
offAxisAspheres	freeforms

.

Production of a large number of small-diameter plano parallel plates?

There are two ways to determine the production of plano parallel plates:
a) input the plano parallel plate directly into PanDao.
b) Singling out of a big plate:
    i. Input a plano parallel plate into PanDao that contains a large number of the required small-diameter plano parallel plates. In this case, you need to determine the number "n" of the smaller plano parallel plates that can be drilled out of the bigger one (taking into account the wall thickness of the grinding cup wheel to be applied).
    ii. Subsequently you will need to determine the cost of singling out the eventual small plano parallel plates you want to generate. To that aim, you the center grinding cost of the direct generation of one smaller plano parallel plate as described in paragraph "a)" above.
    iii. Finally, the cost of one small plano parallel plate equals the cost for the generation of the bigger plano parallel plate (devided by the number of small parts contained) plus the drilling cost for singling.

Production of a large number of small-diameter optics with a convex, spherical side?

In case the combination of order size, tolerances and properties of the lens allow it, PanDao reports that the fabrication chain of the convex, spherical surface of this lens could possibly be replaced by purchasing a glass sphere instead:

Ask PanDao!	Download lens to file	Dowload report pdf	Dowload summary csv

Side 2: Instead of generating this side, a glass sphere can be purchased instead. If this is done, for the total fabrication cost subtract this side's cost from the total cost displayed below.

This would be appropriate if the PanDao manufacturing cost of this convex, spherical side plus the material cost would exceed the purchase price of the glass sphere.

All other costs that PanDao calculates (e.g. coating, the manufacturing costs of the second side, testing costs, center grinding, etc.) remain in place.

Optimization of lens specifications for minimal project risk?

Once PanDao has determined the optimal manufacturing chain for a lens, the design can be performance stabilized at the same cost. The most performance-relevant parameters are tightened with PanDao to such an extent that this does not cause any cost increase.

lens parameter	tolerancing level required by optical designer	tolerancing level possible without any higher fabrication cost or risk
surface roughness	3 nm rms	1 nm rms
decenter	5'	1'
scratch &dig	3*0.024	3* 0.024
shape accuracy	3/5(2)	3/4/(2)
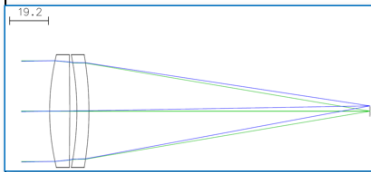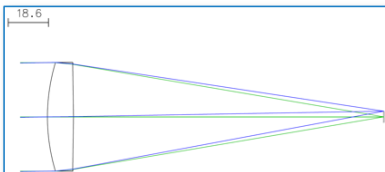
How can I use PanDao during supplier negotiations?

During negotiations, the customer and supplier can review the optimal manufacturing chain, estimate cost and required technologies. In this way, additional cost become visible if a required technology is not available, as well as the cost impact of changes in tolerances and order size. This leads to a better understanding of each other and more efficient contracts that can be relied upon...
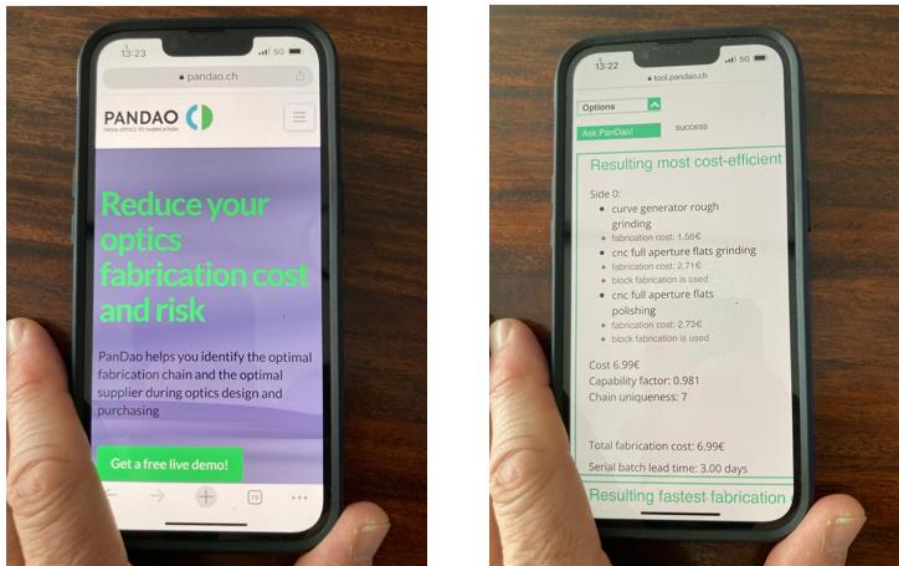
Comparison of competing optical designs?

In case two (or more) competing optical designs have been generated at similar optical performance levels, PanDao can be used to choose the one causing minimum fabrication cost (or fastest delivery times) at smallest manufacturing risk:

	focal length = 150, D = 50, NA = 0.1667, field = 5.2mm	
design	spherical doublet, N-SF57, HK520, AR1	aspherical lens K-PBK40, HK610, AR1
material cost	24.2 €	4.4 €
fabrication cost	18.61 €	32.25 €

How can I carry out optics life cycle analyses?

With PanDao, the entire cost lifecycle of a lens can be determined, from prototyping through pilot series to series production. PanDao recognizes when a technology change takes place and thus enables the optimization of order sizes for minimum costs.
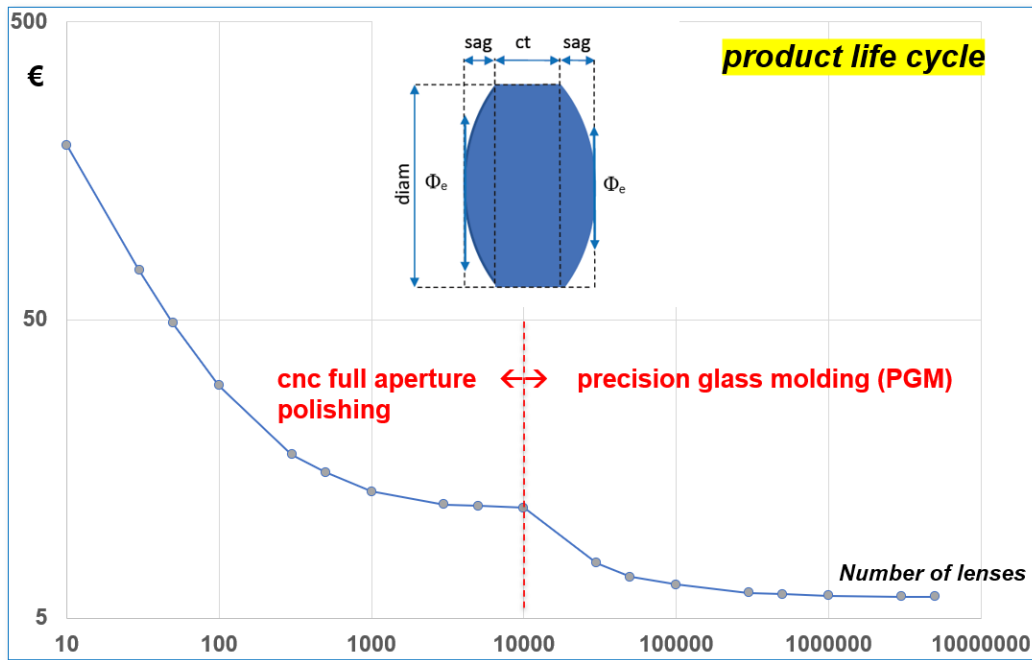
How do I determine the cost of a possibly competing chain that applies molding?

In case the optimal manufacturing chain is not molding, the costs of a possibly competing manufacturing chain which uses molding (precision glass molding (pgm) or injection molding) can be determined. For this purpose, the "Enforce Molding" field must be switched on in PanDao's options section:

4.2. Company-owned database

The following is valid for the usage of PanDao with the "company-owned" database.

How can I determine fabrication chains which use only technologies available at my or my supplier's company?

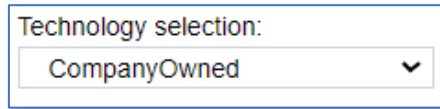If the company-owned database is being chosen in the options menu, PanDao determines the best fabrication chain for the limited custom list of company-owned fabrication technologies, only. These technologies are being applied at State-of-the-Art performance.

Determine the need for investment in new machineries by checking the difference between the PanDao results using "owned" and "default" databases.

The delta in fabrication cost for one lens if PanDao's default or PanDao's company-owned database is being applied can be used to determine the need for a possible investment project for buying and implementing a new technology.

Applying capacity management

Applying the omit and the enforced options it is possible to manage the capacity of technologies available at your company.

- **Omit Technologies:** In case one of the technologies contained in the optimal fabrication chain should be avoided: copy&paste the name into the "exclude Technology" field in the options and PanDao will determine the optimal fabrication chain without using this technology

- **Enforced OFTT:** select the technologies from your customized list of OFTTs that PanDao should enforce to be used for finding the optimal fabrication chain.

In this way, you can steer the capacities in your production department while taking into account the resulting additional costs.

4.3. Company's specific database

In this case, PanDao determines the best fabrication chain for the limited, customized list of company owned fabrication technologies, only. These technologies are being applied not at State-of-the-Art performance, but at the performance level defined by customer.
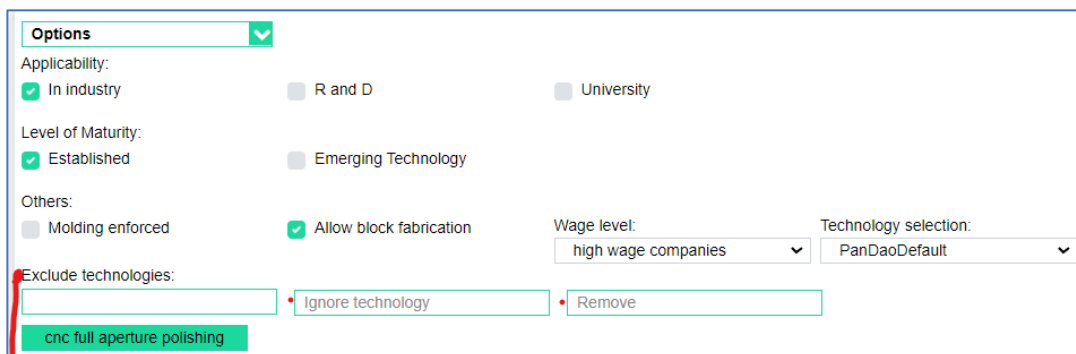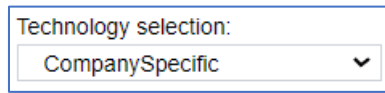
Technology selection:
CompanySpecific

How can I compare the performance of my machines with that of state-of-the-art machines?

Determine fabrication cost for a lens using the "company-specific" database and subsequently enforce PanDao to use the same fabrication chain for this lens using the "default" database. The difference in SBLT (serial batch lead time) and fabrication cost indicates the difference in performance of your machines with state-of-the-art machinery.

How can I determine of the need for replacement investments in machinery?

The delta in cost between the results of using PanDao "specific" and "default" databases is a measure for the difference of performance of the machines at your company to the current state-of-the-art and can be used to determine commercially the need of starting an investment project to buy new machines.

5. PanDao's development stage

In order to ensure PanDao's state of the art level, PanDao is regularly being updated: for more details, please consult the blog section at the PanDao webpage (www.PanDao.ch) and PanDao's LinkedIn page (www.linkedin.com/company/pandao-gmbh).

	PanDao	**development stage**
input	lens data according to ISO10110 standard and number of lenses to be produced	(a) read-in directly from your optical design software's output, (b) use a PanDao stereotype lens or (c) type in manually
taking into account	various materials	Glasses (covering a.o. glass catalogues of CDGM, Hoya, Ohara, Schott and Sumita), crystals, metals (magnetic and non magnetic, glass ceramics, ceramics, PMMA, PC, COC, SG95, UV hardening polymeres, CR39, Zeonex, binderless tungsten carbide (WC), SiC, fused silica, silicon, germanium, CaF2, Zerodur
	all existing optical fabrication techniques	currently appr. 360
	processing cost	ok
	operator cost	ok
	tooling and mounting cost	ok
	uptime and downtime of machines	ok
	job setup time on the machine	ok
	company's commercial settings: bank interest and loan payback times, salaries, wage level, etc.	PanDao offers the selection of three companies wage levels for fabrication cost calculations. In addition, it is also possible to input one's individual commercial parameters
output	using 360 technologies: determination of optimal optics fabrication chains, e.g. the most-cost efficient chain and the fastest chain	ok
	center grinding cost of single elements and of cemented elements: taking eight different center grinding technologies into account	ok
	material cost	ok
	coating cost	ok
	testing cost	ok
	cementing cost (e.g. doublet)	***not yet***: currently in final beta testing
	fabrication risk analysis	ok
	manufacturing chain quality assessment	ok
	cost impact analysis	ok
included	optics with any combinations of flat, spherical, cylindrical, freeform, off-axis aspherical or aspherical surfaces	ok
	maximum number of optical surfaces	two
	prisms	***not yet***: currently under development
	lens facet stages and protective chamfers	ok
	non-circular lens perimeter shapes	ok
	clear apertures	from 0.3 mm to 1.5 m
	surface quality	from IR to EUV optics
	order's batch size	from prototyping to mass production

optional	using technologies available <u>at your or your supplier's company</u>: determination of optimal optics fabrication chains, e.g. the most-cost efficient chain and the fastest chain	ok
	capacity steering tool for your workshop's technologies	ok
currently excluded	overhead cost	this strongly varies from department to department and company to company and is typically a corporate secret
	prisms, acylinders, cemented optics, wedge plates, beam splitters, glass-spheres, GRIN lenses, nanomere materials, consumer glass (e.g.: bottles, windows, pipettes), mechanical components, glass fiber, lithography or on-chip optics, diffractive optics, meta-surfaces and holograms.	not yet included…

6. PanDao's references

Along our trail towards harmony between optics designers and optics manufacturers, PanDao carries out research, holds webinars, gives invited university lectures and publishes scientific papers together with collaboration partners around the globe.

PanDao sincerely thanks all co-authors for invaluable discussions, support and friendship: Prof. Daewook Kim, University of Arizona, USA, Prof. Jens Bliedtner, University of Jena, Germany, Prof. Irina Livshits, University of St.Petersburg, Russia, Prof. Jyrki Saarinen, University of East Finland, Finland, Mrs. Olga Resnik and Mr. Yosi Arazi, JOYA Team, Israel, Prof. David Walker and Prof. Guoyu Yu, Huddersfield University, UK.

Since PanDao was founded in 2019,
>   we published
>   - 2 full journal papers,
>   - 3 invited conference papers,
>   - 7 contributed conference papers,
>   - 2 white papers at PhotonicsViews journal (Wiley publishers),
>   - 2 book chapters to standard works in Optical Technologies,
>
>   we gave
>   - 8 webinars
>   - 2 tutorials at Optical Design and Fabrication conferences
>   - 8 invited university lectures in USA, UK and Germany.

Webinars
- 2021: PhotonicsMedia, BayernPhotonics, Zemax Envsision, EPIC new product release
- 2022: PhotonicsMedia, EPIC new product release, interview and Webinar with Dr. Jose Pozo (CTO Optica (OSA))
- 2023: Zemax

Tutorials:
- 2021: EOSAM21 conference, Rome, Italy
- 2022: EOSAM22 conference, Porto, Portugal
- 2023 June: "Optical Design and Fabrication (ODF)" congress, Quebec City, Canada
- 2023 September: EOSAM23 conference, Dijon, France

University lectures
- 2021:University of Rochester (USA), University of Arizona (USA), University of Huddersfield (USA), EAH Fachhochschule Jena (Germany)
- 2022: University of Rochester (USA), University of Arizona (USA), University of Huddersfield (USA), EAH Fachhochschule Jena (Germany)
- 2023: University of Rochester (USA), University of Arizona (USA), University of Huddersfield (USA), EAH Fachhochschule Jena (Germany)

Papers
[1] **book chapter** Oliver Faehnle, Irina Livshits, Jyrki Saarinen, Daewook Kim and Jens Bliedtner, " Modulation optischer Fertigungsketten?", Jahrbuch für Optik und Feinmechanik 2020, Herausgeber: Dr.-Ing. Wolf-Dieter Prenzel, ISBN978-3-00-068425-8, OPTIK-Verlag Dr. Prenzel, Gorlitz, Deutschland, 67., 2022
[2] **book chapter** O.Faehnle, " Optikfertigungskettendesign" in Jens Bliedtner, Günter Gräfe, «Optiktechnologie», book, Hanser, ISBN 978-3-446-42466-1, 2022
[3] **Invited conference paper**: O.Faehnle, Rolf Rascher and Marco Tinner, "Next step in Optics Fabrication: moving from machining to processing", 12. Wetzlarer Herbsttagung "Moderne Optikfertigung», Wetzlar, Germany, September 2022
[4] O.Resnik, O.Faehnle and Y.Arazi, "Dynamic optimization of optical design process by means of producibility modulations", EOSAM22 conference on "Optical system design tolerancing an fabrication", European Optical Society (EOS), Porto, Portugal, September 2022

[5] **Invited conference paper**: O.Fähnle and I.Livshits, "Modeling of Optical Fabrication Chains during Optics Design", International Conference on Optics-photonics Design & Fabrication (ODF), JSAP (The Japan Society of Applied Physics), Sapporo, Japan , August 2022

[6] O. Faehnle, "Develop and apply innovative methods and tools", PhotonicsViews, 18: 1-1., https://doi.org/10.1002/phvs.202170401, 2021

[7] M.Tinner, I.Livshits and O.Faehnle, " Producibility analyses during the optical design stage", DGaO Tagung, Bremen, Germany 2021.

[8] O.Faehnle and I.Livshits, "Optical Fabrication Chain Modeling", SPIE conference on "Optical System Design", Madrid, Spain, 2021

[9] O.Fähnle, Rascher, R. and Tinner, M., Optical fabrication chain design. PhotonicsViews, 18: 43-45. https://doi.org/10.1002/phvs.202100051, 2021

[10] O.Faehnle and I.Livshits, "Manufacturing risk management in optical design", EOSAM21 conference on "Optical system design tolerancing an fabrication", European Optical Society (EOS), Rome, Italy, September 2021

[11] I.Livshits, A.Petukhov, J.Saarinen, O.Faehnle, "Supervised Machine Learning in Relation to the Simplest Classification of Optical Systems", "Optical Design and Fabrication" conference, Taiwan 2021

[12] **Invited conference paper**: O.Fähnle and I.Livshits, "Optical Fabrication Process Modeling", OSA's Optical Fabrication and Testing conference (OF&T), part of the Optical Design and Fabrication congress (ODF), Rode Island, NY, USA , June 2021

[13] O.Faehnle, E.Langenbach and I. Livshits, "Balancing optical system design and optical fabrication chain design", SPIE conference on "Precision Optics Manufacturing", Deggendorf Institute of Technology, Deggendorf, Germany, April 2021

[14] **Journal paper:** I.Livshits, T.Tochilina, O.Faehnle and S.Volkova, "Design strategy and management of aberration correction process for lens with high complexity index", Scientific and Technical Journal of Information Technologies, Mechanics and Optics, 2021, vol. 21, no. 1, pp. 40–51 (in Russian). doi: 10.17586/2226-1494-2021-21-1-40-51, **2021**

[15] **Journal paper:** I.Livshits and O.Faehnle, "Producibility analysis of a lens system during the optical design stage", Scientific and Technical Journal of Information Technologies, Mechanics and Optics, ISSN 2226-1494 (print), ISSN 2500-0373 (online), St. Petersburg, Russia, doi: 10.17586/2226-1494-2020-20-5-625-633, No.5 2020

[16] M.Tinner, O.Faehnle and I.Livshits, "PanDao fabrication cost impact analysis software tool for optical designers", EOSAM20 conference on "Optical system design tolerancing an fabrication", European Optical Society (EOS), due to CoronaVirus: "proceedings only", https://doi.org/10.1051/epjconf/202023803014, September 2020.

For frequently updates on PanDao's activities and updates:

- read our blog entries: https://pandao.ch/blog/
- watch our YouTube channel: https://www.youtube.com/channel/UC318X9TJZWs2xeTjzeE40zg
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