Synopsis of Technical Report:

Designing and Specifying Aspheres for Manufacturability

Jay Kumler
Published in Current Developments in Lens Design and Optical Engineering VI (2005)

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Introduction
This synopsis summarizes the asphere design guidelines which Jay Kumler provides in the report. The guidelines are listed for the ease of lens designers used. The reasons of these rules in details should refer the original report, and here I only leave the useful informations for designers to make decisions.

Summary of the asphere design guidelines
I list the useful asphere design guidelines for designers and briefly explain how the author comes out the rules of thumb. Some rules are added to my supplements.

✓ **For the choice of putting the aspheric surface on the Convex or Concave surface, if the radii of curvature for the surfaces being considered are shorter than the radius of polishing wheel, aspherize the convex surface.**

Explanation:
By geometric reason, the author points out a concave surface can not be polished by a polishing wheel that has larger radius than the vertex radius of curvature of the work piece; however, a convex surface is not constrained by this limitation.

Discussion:
From my knowledge, a convex asphere is usually harder to be tested than concave asphere. Though by the physical limitation of our current polishing machine we can only choose to aspherize the convex surface rather than concave surface, we should still compare *the cost* between *replacing another polishing wheel with smaller radius* and *building a reliable testing equipment for the convex asphere* to make the decision.

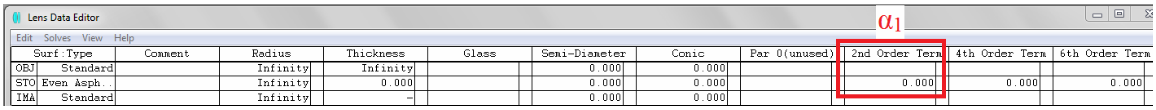
✓ **When you are optimizing aspheric coefficients, keep the first aspheric coefficient α_1 (the aspheric coefficient for the second order term r^2) equal to zero.**

Explanation:
An asphere is a rotationally symmetric optic whose surface profile (sag) is given:

$$sag\ \ Z(r) = \frac{cr^2}{1+\sqrt{1-(1+k)c^2r^2}} + \alpha_1\ r^2 + \alpha_2\ r^4 + \alpha_3\ r^6 + \alpha_4\ r^8 + \alpha_5\ r^{10} + \cdots\cdots$$

where c = curvature, inverse of radius; r = radial distance from the optical axis;
k = conic coefficient; $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ = aspheric coefficients

Optical design programs allow designers to optimize α_1, but the author points out *not* all computer controlled aspheric manufacturing equipment support the use of α_1 coefficient. Example of the use of α_1 in Zemax:



Surf:Type		Comment	Radius	Thickness	Glass	Semi-Diameter	Conic	Par 0(unused)	2nd Order Term	4th Order Term	6th Order Term
OBJ	Standard		Infinity	Infinity		0.000	0.000				
STO	Even Asph..		Infinity	0.000		0.000	0.000		0.000	0.000	0.000
IMA	Standard		Infinity	-		0.000	0.000				

- ✓ **Using higher order asphere is more manufacturable** (*retained*) **and with better performance than just using a conic section or adding an additional spherical element.**

Explanation:
The report gives an example and the tables of simulation results to support the argument. The analysis shows a higher order asphere has smaller transmitted wavefront error and smaller asphere departure which means less materials moved from the best-fit sphere. The author also points out higher order aspheres improve performance in fabrication with little or no increase in cost or complexity. The report concludes the use of higher order aspheres can improve the system performance and cost down for manufacturing process.

Some suggestions of optimizing higher order aspheres from the auther's observations:
- Design for *a larger aperture* than required for the clear aperture of the surface.
- Optimize *more field points* than the design for spherical surfaces.

Discussion:
The use of higher order aspheres should *be considered discreetly* because of the *testing issues* as following rules. The surface can only be made as accurately as the ability of measurement. The cost would raise since the testing equipment will be harder to build, so that *the use of a higher order asphere* is *not actually more manufacturable* than a conic section in the sense.

- ✓ **The higher aspheric surfaces are more difficult for testing than the surfaces which only used with conic sections.**

Explanation:
Though higher order aspheric surfaces can be tested by computer generated holograms (CGHs), CGHs are *expensive* and *unique* for each design of asphere. Also, the asphere departure is required *large enough* for the limitation of resolving power of CGH. Relatively, the pure conic surfaces can often be tested at its natural conic foci without custom null optics. The testing methods are provided in the report from Figure 3 to 6.

Discussion:
The author points out a strong argument to stay with conic sections. The designers are needed to balance the ease of manufacturing and the accuracy of surface. The choice of two rules above depends on the fabrication skills and measurement abilities in the shop which designers should be familiar with.

✓ **Avoid the design of a steep aspheric slope.**

Explanation:
A steep aspheric slope will be hard to be tested if it exceeded the dynamic range of interferometer. Also the polishing footprint must get smaller and smaller to address steep aspheric slopes. The report gives a useful table for the slope limitations based on MRF polishing technology:

Table 3 - Practical limitations of aspheric figuring by polishing with MRF Technology (at Coastal)

Aspheric amplitude (MRF Polishing only from a polished spherical surface)	50 microns (demonstrated on 90 mm diameter surface)
Aspheric amplitude (aspheric generated and MRF polished)	950 microns departure over 45 mm diameter (see figure 8)
Aspheric slope (MRF only)	2 microns per mm as along as part is < 120 mm diameter
Surface figure accuracy	0.008 wave rms demonstrated on powered aspheres up to 50 mm in diameter
Accuracy of Surface slope	12 microradians peak to peak, demonstrated on space qualified parabolic mirrors 110 mm in diameter over off-axis subaperture[8]

✓ **Be aware of the limitations of the asphere size and thickness for manufacturing.**

Explanation:
The author points out many aspheric polishing machines have a *maximum diameter* and a *maximum thickness* which could be processed. The capabilities chart for QED MRF polishers is given from the report:

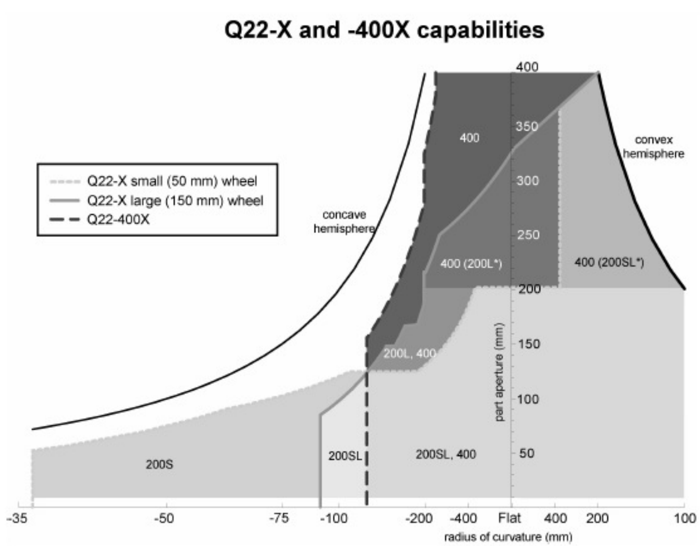


Figure 10 - Size capabilities of QED MRF machines (courtesy of QED)

Another consideration is maintaing *enough edge thickness or blank size* on asphere for fabrication. Asphere polishing methods require a blank margin of the work piece for the footprint due to manufacturing. The clear aperture of an asphere should be remained after fabrication.

✓ **Keep the surface accuracy requirements as loose as possible.**

Discussion:
If the aspheric surface figure accuracy can be larger than 1 μm, contact profilometry can be used, which eliminates the need for CGH or null lenses. Therefore, the use of higher order asphere will not limit by testing issue and will save significant cost when the performance could reach system requirement.

Other common rules for lens designers:

✓ **Use a non-staining optical glass.**

✓ **Use a higher index glass of similar dispersion.**

Conclusion:

The report provides the general notification for minimum cost and maximum manufacturability. The cost of producing Aspheres with enough accuracies are usually based on the difficulty of manufacturing and testing accurately. At the time the report was written, new reliable asphere testing methods are improved and make more possibilities for using higher order aspheres. Designers should always update the latest manufacturing and testing techniques and come out the set of rules of thumb for designing aspheric surface. Make good decisions by comparing the effects to balance the cost and system performance.

Reference:

J. Kumler, “Designing and Specifying Aspheres for Manufacturability”, in *Current Developments in Lens Design and Optical Engineering VI*, Proc. of SPIE 5874 (2005)