Specifying Diffractive Surfaces

PRECISION-OPTICAL ENGINEERING

DM 003

Application Note

Technical data sheet DM 001 discussed the requirements and equations for defining an aspheric optical surface. Aspheric surfaces, however, may be further modified by the addition of diffractive elements. These are essentially ‘high efficiency’ zone plate profiles, formed from a precisely defined set of annular areas that are diamond machined on to a lens element during the surface fabrication process. Used primarily in medium wavelength infrared systems (MWIR) and long wavelength infrared systems (LWIR),diffractive surfaces are routinely used to correct for chromatic aberration, thereby removing the requirement for at least one expensive colour correcting component.

The profile generates a wavelength or ‘chromatic’ dispersion effect through the process of diffraction and the amount of ‘dispersion’ introduced depends upon the spacing and configuration of the annular zones machined on to the surface. This parameter can be varied, thus providing the design engineer with a valuable additional tool to obtain the best and most economical optical solution.

A key benefit for diffractive elements is that they may effectively be superimposed over a conventional aspheric contour to create a single hybrid profile. Thus where an aspheric has already been prescribed in a system, no further manufacturing costs are incurred if it is augmented by a diffractive.

The procedure superimposes a "saw tooth" profile on the aspheric surface, as illustrated in Figure 1.

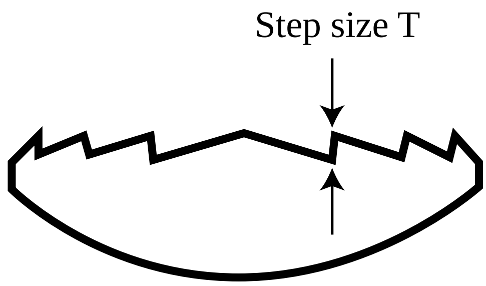

Figure 1

The additional surface profile is given by:

$$Z_{DOE} = T\,(N(h) - \text{Integer } N(h))$$

Where Z_{DOE} is the sag of the diffractive optical element, T is the binary depth, N is the number of zones and h is the height above the optical axis, as specified in the equation for a non-diffractive aspheric surface.

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The equation for the binary depth (or step size) is:

$$T = m\lambda/n\text{-}1$$

where λ is the design wavelength (e.g. 10.6 microns), m is the diffractive order (usually 1) and n is the refractive index at the design wavelength. Step size is shown in Figure 1.

N(h) is the number of zones for a given value of h, where:

$$N(h) = C_1h^2/\lambda + C_2h^4/\lambda + C_3h^6/\lambda\text{... etc}$$

To get an approximate idea of the number of zones, this can be simplified to:

$$N(h) = C_1h^2/\lambda$$

C_1, C_2 etc are coefficients determined by some optical software providers. There are alternative ways of describing the diffraction function by, for example, a mathematical phase function in the form of optical path difference (OPD). Whatever form of software is used, the outcome in terms of as manufacturing requirement is a series of surface zones with a step size of $T=m\lambda/n\text{-}1$.

Specifying diffractive surfaces for manufacture

All the information required for aspheric surfaces should be supplied as described in data sheet DM 001. It is also important to supply a Sag Table quoting a range of values of Z for the aspheric part and the diffractive part versus h as illustrated in the table below:

h	z (aspheric)	z (diffractive)	z (total)
5	0.09656	-0.00017	0.09639
10	0.38678	-0.00069	0.38609
15	0.87227	-0.00157	0.87070
20	1.55575	-0.00278	1.55297
25	2.44116	-0.00136	2.43980
30	3.53371	-0.00027	3.53344

Note that z (diffractive) never exceeds the step size, or binary depth, of $T=m\lambda/n\text{-}1$.

Further benefits of diffractive surfaces

P-OE has used diffractives, in combination with standard refracting materials, to produce systems that are both well balanced chromatically and insensitive to changes of environmental temperature ('athermalised'). This allows for considerable cost savings since it permits the avoidance of expensive processor driven servo -systems which would otherwise be needed to maintain image focus.

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