2. Ophthalmic optics and progressive lenses, definitions and presentation of results

General

There are several good textbooks and publications on Ophthalmic Optics and Progressive Lenses, which give a clear insight into the optics of ophthalmic lenses, the physiology of vision as well as into the fundamentals of lens design,for example [1], [2], [3].
Therefore here I will only give a short list of the technical terms used in this publication and give some explanations and comments when necessary.

2.1 Definitions

The principal meridian

The first phase of calculating a new design is the definition of the main or principal meridian.

*Ideally the **principal meridian** of the progressive lens is the curve on the progressive surface where the wearer's line of sight intersects the surface, when the wearer looks at centrally situated objects at different distances. Along this principal meridian the power increases from far to near vision according to the power law required by the designer.*

For some lenses, at least for some of the first designs developped, the principal meridian was situated in a plane which was the symmetry plane of the surface geometry and turning the lens by 8 to 10 degrees nasally the progression was adjusted to the path of the converging eye.
The main drawbacks of such a construction is the loss of the horizontal symmetry necessary for high quality binocular vision.

The reference points for verification and fitting

The reference points for far- and near -vision as well as the fitting cross are situated on the main meridian.

Fig 1 shows as an example the characteristic permanent and stamped markings of a particular progressive lens illustrating the reference points for centering and control.

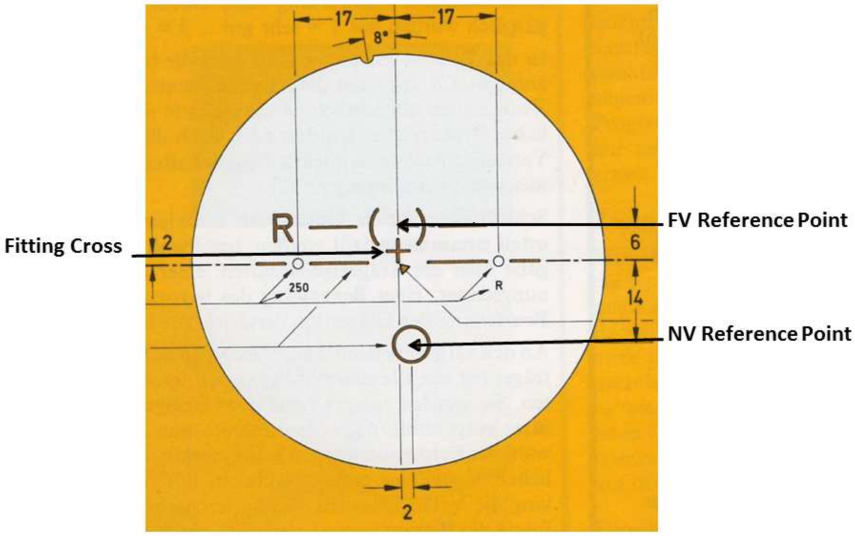

Fig 1: Example of characteristic markings of a progressive lens

One of the stamped markings labels the the ***far vision reference point****. In this point the far vision power is checked with a focimeter. If the lens is correctly manufactured the measured value deviates no more than 0.12 D from the ordered power (spherical* $power \leq 6\ D$*).*

The near vision power is controlled with the focimeter in the ***near vision reference point****. The difference of the power measurements in the NV -and the FV- reference points is the measured add power.The tolerance for the add-power (until add 4 D) is +/- 0.12 D.*

The power toerances are defined in the ISO standard ISO 8980-2.

The ***fitting cross*** *is used to position the progressive lens correctly in front of the eye of the wearer. Usually progressive lenses are centered so, that the fitting cross coincides with the center of the pupil when the subject, with normal head posture, looks straight ahead.*

The fitting cross marks the intersection of the surface with the wearer's principal line of sight when he observes distant objects. As the near vision portion should not be situated too low in the lens, for many designs the power increase starts about 2 mm (half diameter of the pupil) below the fitting cross.

Progression length

The choice of the power profile along the principal meridian can be done under different aspects. For example the designer takes into account primarily physiological considerations in order to achieve natural conditions for head posture and eye inclination or he targets specific geometry characteristics as a low level of aberrations in the periphery.

*When it is not defined particularly in the specific patent of the lens type under examination we use as **effective progression length** the vertical distance between the two surface points on the principal meridian where the optical power attains the values (FV-power +0.12 D) and (NV-power -0.12 D).*

As far vision and near vision power are usually the asymptotic values of the power profile the determination of points where the FV- and NV-power is attained is not possible without a tolerance. It makes sens to choose the ISO tolerances which are used to decide if the manufactured lens is acceptetd or rejected. Other definitions are possible.

Definition of optical power and aberration types.

The optical power of an ophthalmic lens is usually defined as **the back vertex power** and computed using the **surface powers** of the front -and back surface, the lens thickness d and the index of refraction n [1].

For all the calculations of this publication we consider only the progressive front surface which is sufficient to obtain our goal to analyze the optical quality of the progressive lens. This reflects the way how the first designs have been optimized . The optimum bending of the front surface for a specific range of optical power of the finished lens as well as the necessary front surface add power to measure with the focimeter the correct add on the finished lens were determined by trigonometric ray tracing through the thick lens.

As concerns the optical quality we consider surface astigmatism and distortion. It is true that ray tracing through the thick lens brings additional contributions, for example oblique astigmatism, but we neglect these contributions as being small.

*The **surface power** in a normal (orthogonal) section of a surface in point P is defined by*

$$D = \frac{(n-1)}{r}$$

wherein n is the index of refraction of the lens material and r is the radius of curvature of the normal section in the considered surface point.

So if K_1 and K_2 are the principal curvatures in the considered surface point *the **average surface power** is*

$$POW = \frac{1}{2} \cdot (n-1) \cdot \left(K_1 + K_2\right) = (n-1) \cdot H$$

with H as mean curvature (see chapter 3)

*and the **surface astigmatism** is defined by*

$$AST = (n-1) \cdot \left(K_1 - K_2\right)$$

For the index of refraction we use $n_e = 1.525$. Some of the first progressives were calculated with the index of crown glass, so it was adopted for all the computations.

*The **distortion** of an optical lens is the relative difference of the image size between the computation by ray tracing of the thick lens and the paraxial calculation. In this publication the distortion of the progressive lens is analyzed using the paraxial formula for the prismatic deviation.*

Thus the obtained results are an approximation describing the impact of the power variation of the progressive surface , neglecting the effects which describe the pincushion respectively barrel distortion of plus and minus single vision lenses.

Other definitions used

Z'	eye's center of rotation
b'	distance eye's center of rotation to back vertex of the lens
d	lens center thickness

2.2 Presentation of Results

Isopower-Lines

The mean surface power POW is depicted by isolines with 0.5 D difference between the isolevels.
The figure below shows the power increase across the surface for Varilux 1 with far vision power 6D and add 2.

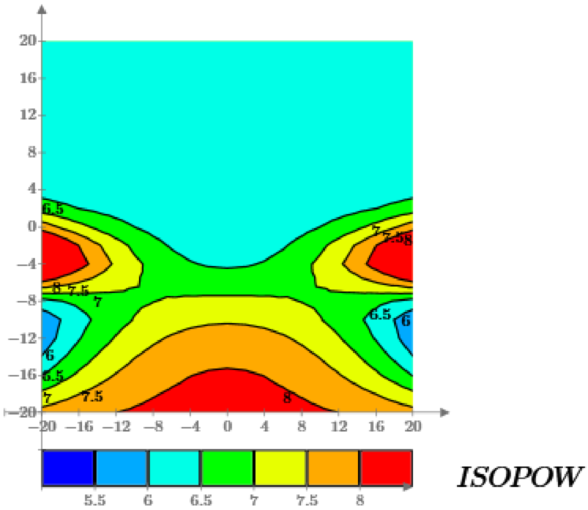

Fig 2: Isopower-lines

Isoastigmatism-Lines

The surface astigmatism is presented by isoastigmatism plots. The spacing between the lines is 0.5 D and the lowest level is =0.5D. The example below describes Varilux 1.

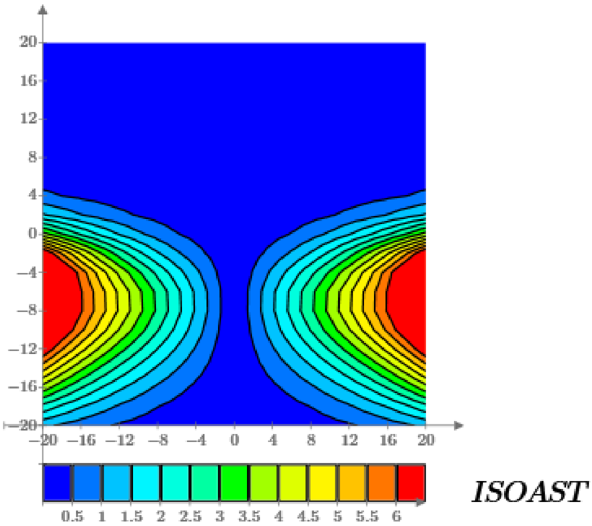

Fig 3: Isoastigmatism-lines

Distortion

The distortion of objects by the progressive lens will be illustrated by the deformation of a rectangular grid in 1m distance from the lens.The deformation of the verticals and horizontals are shown in 2 separated graphs as in Fig 4a and 4b (for the example Varilux 1).

In Fig 4a is x the coordinate of the distorted vertical in the grid plane, z0 the z-coordinate of the intersection point of the line of gaze with the progressive surface. In Fig 4b is z the coordinate of the distorted horizontal in the grid plane, $\xi 0$ the x- coordinate of the intersection point of the line of gaze with the progressive surface.

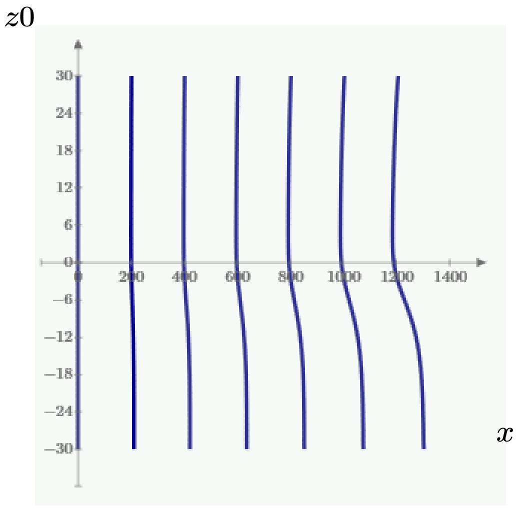

Fig 4a

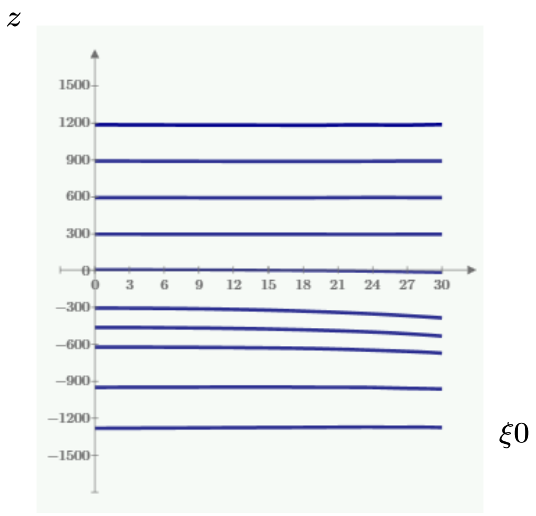

Fig 4b

References

1. Mo Jalie: Ophthalmic lenses and dispensing. Elsevier, 2008

2. Darryl Meister: Fundamentals of progressive lens design. Vision Care Product News, vol. 6, no. 9, 2006 or on www.opticampus.com

3. Dieter Kalder: Gleitsichtgläser 1 and 2. WVAO Bibliothek, vol. 16 and vol. 19, 2008