THE FREEDOM OF FREEFORM –
PART I
BASED ON A LECTURE GIVEN AT MAFO – THE CONFERENCE IN PARIS, OCTOBER 18, 2007

In the year 2000 the first two real FreeForm lenses had been introduced: ‘ImpressionILT’ by Rodenstock GmbH and ‘Gradal Individual’ by Carl Zeiss Vision AG. Eight years later almost everybody in the optic lens business is praising FreeForm lenses. Most companies now claim to produce FreeForm lenses. Even Essilor – in the last 15 years being a main advocate and strong promoter of conventional semi-finished progressive addition lenses – has changed the course and is offering FreeForm lenses now. The former refusal of measuring additional parameters of the patient has been finally given up with their latest progressive addition lenses.

By Prof. Dr. Peter Baumbach

What is so special with FreeForm lenses?
Let me first try to define the word ‘FreeForm lens’ as I understand it: A FreeForm lens consists of at least one FreeForm surface. The FreeForm surface can be on the front or on the rear side or on both sides. A FreeForm surface does not show any inherent mathematical limits other than at least 2 times continuous differentiability. A FreeForm surface is calculated and generated in the most flexible way according to State of the Art lens design philosophy after the order has been received from the optician or optometrist.

State of the Art lens design philosophy means that within the given mathematical limits an optical design is offered to the patient without any compromises to individual prescription and eye data, individual frame data, the individual task, and viewing habits.

Nearly 50 years after the successful introduction of the first progressive addition lens by Essel, named ‘Varilux 1’, one might seriously question how much room is left for future developments. In other words one could ask: How free a FreeForm lens today really is. In the following article some of the latest concepts of modern eyeglass optimization are explained. All calculations shown here are ‘real world’ calculations with a non-commercial eyeglass lens optimization program developed by the author.

SINGLE VISION LENSES
What are the advantages of using FreeForm surfaces in single vision lenses? This can be best demonstrated by an example calculated in the position of wear (see Figure 1).

The conventional single vision lens is not too bad at all: less than 1 Dioptrre cylinder error in the most important region, and a mean power error being less than 0.5 D. Nevertheless, with a FreeForm surface optimized for the individual prescription data these errors can be significantly reduced. Young people with high visual acuity and clear optical media will appreciate this.

Unfortunately, young people often do not have enough money to go for a FreeForm lens.

SINGLE VISION SPORTS GLASSES
Sports glasses must have a steep curvature irrespective of their actual optical power, typically 7 D. In the minus range this can be quite a challenge for the blank stock and the production machinery. Additionally, these lenses have to be tilted by 10° to 25° around the vertical axis and need large diameters.

What does it mean with respect to the optical performance? An example with the same prescription data as in Figure 1 is shown in Figure 2.

Here the optical differences between the conventional single vision lens and the FreeForm lens are even more pronounced. The optical design of the FreeForm lens in Figure 2 – characterized by the astigmatism and mean power error distribution over the lens area – is almost the same as the one in Figure 1 although the lens has been tilted by 20° and is made with a different spherical front surface in order to fit into the sports frame.

These are only two examples when a FreeForm surface can significantly improve vision. Prism correction and high power reading glasses are also excellent candidates for FreeForm optimization. The true object of preference however is the progressive addition lens (PAL).
PROGRESSIVE ADDITION LENSES

When considering progressive addition lenses the question immediately arises how flexible or free a FreeForm really is. From a lens designer’s standpoint one could say: A FreeForm is free enough to have some fun at least somewhere in the lens area but all delight is draconically monitored by a single fundamental mathematical law: the ‘Law of Minkwitz’.

\[
\frac{dA}{dx} = 2 \cdot \frac{dP}{ds}
\]

THE LAW OF MINKWITZ

Minkwitz’s law states that on an umbilic line every intended or unintended power change \( dP \) over an arc length \( ds \) will result in an increase of astigmatism \( dA/dx \) being two times the power gradient and perpendicular to it. This is illustrated in Figure 3.

So the basic drawback of any progressive surface – call it FreeForm or just progressive – is the limited width of the progressive zone and the addition related total amount of aberrations in the whole lens. And it seems that this fundamental law not only holds true for front or rear side progressives with or without umbilic lines. It seems to be valid for double progressives as well and even for gradient index lenses. Tough luck!

The progressive corridor itself can be ‘shaped’ in any desirable way. The fundamental law of curve theory, a part of differential geometry, proves that there exists a unique curve to every given curvature and torsion. Back to FreeForm this means that one can analytically calculate a single line on the progressive surface according to almost any given mean power distribution, astigmatism, and variable inset. Such a line is called the ‘main line’ or ‘main meridian’ of the PAL. The calculation itself leads to a differential equation of second order which has to be solved numerically by a Runge-Kutta method.

In the next 2 Figures (Fig. 4 and Fig. 5) a few examples are given. The main line on the rear surface was calculated according to the given prescription, thickness, and front surface curvature in the position of wear. Horizontally the main line was extrapolated by simple circles of varying radii. In a certain way this gives a modified Varilux 1 with perfect vision along the main meridian for any given prescription and inset, a ‘Varilux 1 Super’, in the position of wear.

In Figure 4 it is shown that we can easily achieve full correction for the straight view over any given inset, here 0%, 100% and 200% of a normal inset. In all cases the power increase along the main meridian is identical. The periphery is of course more than bad, because no attempt was made to use the highly praised freedom of FreeForm.
If we think back and imagine that Varilux 1 did not have an inset and was tilted instead the first PAL users had to live with more than 10 D of unwanted astigmatism in the periphery and very high binocular imbalances. This demonstrates once again the flexibility of the human visual system.

In Figure 5 it is shown that we also can calculate a main meridian with cylinders of different axes, here 0°, 45° and 90° of cylinder 1 Dioptre. For the straight view full correction is achieved in all cases. The power increase along the main meridian is identical and the periphery is bad for the reasons already given above. We can also calculate a main meridian with different astigmatism in the near and far zone for patients with a special near astigmatism.

The Law of Minkwitz allows us to construct a perfect main line, it limits the width temporally and nasally of this line, but gives us enough freedom to design the periphery of the PAL in a moderate way.

**Front Side or Rear Side Progressives**

First of all, there is no positive keyhole effect with rear side progressives, if we do not want to compare apples and oranges. The rear side progression is indeed closer to the eye but its length has to be reduced in order to allow the same positioning of the near zone with respect to eyes movement. In total the keyhole effect is almost fully compensated by the Law of Minkwitz. As a result the progression zone of a rear side progressive is not wider than progression zone of a corresponding front side progressive.

The magnification differences over the entire viewing zones of rear side progressives are slightly smaller compared to those of front side progressives. This has advantages in the periphery and disadvantages in the reading zone. Less magnification differences mean less distortion and less swim effect. Less magnification differences also mean smaller letters and could mislead the patients to want higher additions which would not be a good idea for obvious reasons.

Regarding the power and astigmatism distribution we can achieve almost the same design with both types of progressives (see Figure 6). It is all a question of setting the reference values in a common coordinate system.

**Double Progressives**

One could hope that double progressives are the solution for less aberration, wider viewing zones, and more design freedom. Unfortunately, this is not true because both surfaces are not independent of each other, and thickness is not an optimization parameter of arbitrary length. Spreading the addition over two surfaces does not significantly lower the total unwanted astigmatism in the near of the main meridian. Manufacturing costs and production complexity are higher anyway. I have not seen a double progressive design yet which could not be achieved by a combination of a sphere and a FreeForm surface as well. Examples which will prove the opposite are welcome at all times. At least one positive effect for the industry remains: Double progressives offer a way to bypass single surface FreeForm patents.

**Front Side Progressives**

Before the year 1995 the correction of presbyopic eye astigmatism was solved by front side progressives with toric rear surfaces. This is a good solution only for small eye astigmatism. In 1995 a new method was introduced: the correction of eye astigmatism by atoric rear surfaces. Zeiss Gradal HS OSD and Rodenstock Multigressiv 1 were the first examples of front side progressives with atoric rear surfaces (BTW reducing coma in the distance zone which was not hip at that time to speak about). Today lens manufacturers speak of ‘aberration
filters’ or ‘twin Rx technology’ which is basically the same idea and a now 13 old technology.

State-of-the-art correction of eye astigmatism is now done by either a standard progressive front surface and a FreeForm rear surface or a FreeForm progressive front surface and a standard spherical or toric rear surface. The FreeForm surface is adapted to the individual needs of the patient in both cases whereas the other surface can be a standard surface from stock.

In Figure 7 the advantage of a FreeForm cylinder correction is shown in comparison to a conventional cylinder correction. Except for politicians the natural viewing habit is not left or right biased. With an oblique cylinder axis it is difficult to achieve a well-balanced design temporally and nasally. While the conventional design is significantly changing with cylinder the FreeForm design retains perfect control of its basic design properties and provides natural eye movements even for this extreme prescription.

Placing the cylinder on the front surface would not be an appropriate solution for aesthetic and optical reasons. If the cylinder is on the rear surface one is obliged to manufacture two expensive surfaces in the lab. This is the reason why front side progressives are not very popular in the lab business compared to rear side progressives.

REAR SIDE PROGRESSIVES

The correction of the individual eye prescription by a superimposition of an atoric and progressive rear surface was first introduced by Seiko with the Super P-1 lens in 1997. Missing the position of wear concept and the influence of important individual parameters on the design this lens could not be categorised as a FreeForm lens.

Today state-of-the-art correction of individual eye prescription is done by a FreeForm rear surface combining both - the progressive and the atoric part of the correction in the most flexible way.

In Figure 8 the advantages of a FreeForm cylinder correction of a rear side progressive is shown. The optical design retains almost stable. Patients with astigmatism do not get an inferior correction than patients with a pure spherical presbyopia which is in a deeply democratic tradition.

PANTOSCOPIC TILT

One important individual parameter is the pantoscopic tilt of the lens. Until the year 2000 the optician had to pre-select frames with a pantoscopic tilt of 8° to 10° and a vertex distance of 12 to 15 mm in order to maximize the visual performance of the PAL. Progressive lenses in curved sunglasses were actually impossible. This changed totally with the introduction of the first individual PAL’s in 2000, Rodenstock ‘Impression’ and Zeiss ‘Gradal Individual’.

In Figure 9 the influence of different pantoscopic tilts on a conventional rear side PAL in the position of wear is shown. Without any pantoscopic tilt the near zone is very poor and the astigmatism in the periphery is way too high. With a too high pantoscopic tilt the optical quality of the distance zone degrades significantly. The addition also changes in a non tolerable way.

In Figure 10 the compensation of different pantoscopic tilts by a FreeForm rear surface in comparison of conventional rear side progressives in the position of wear (sph +2.5 D; cyl -1.0 D; A 135°; Add 2.0 D) with different pantoscopic tilts.
the position of wear is shown. In other words: The optical design does not change with the pantoscopic tilt and the patient may choose the frame for purely aesthetic reasons limited only by the overdraft agreement of his or her credit card.

Other examples of important individual (geometric) parameters of the patient are the working distance, the pupillary distance, the face form angle, and the vertex distance. Knowing these parameters in advance a FreeForm surface optimization will result in an optimal PAL for the patient.

LITERATURE

To be continued in the next MAFO issue