Freeform lenses

HOYA

Part 2

Paul Bullock describes the manufacturing process behind modern freeform lenses.
Module C14387, one general CET point for optometrists and dispensing opticians

What is freeform? This is a question I have put to many people, whether they be seasoned optical professionals in CET presentations or first-year optics students. The answers volunteered have been insightful, intriguing, derogatory and many other adjectives, but all different.

It is quite apparent that the term freeform has become an industry buzz-word that has led to much confusion. It is being embraced by the optical industry, but the term is still misunderstood in some instances.

Freeform surfacing is a wonder of modern technology; we now have the ability to manufacture lens designs that were inconceivable a decade ago. This technology is another milestone for the optical industry and only by having a clear understanding of the practical applications of this technology can we move forward as an industry to introduce it to the audience it deserves.

Freeform simply is a manufacturing process that allows the production of complex surfaces and designs with extreme precision.

The conventional method

The conventional lens surfacing process cannot produce the complex surface required for a progressive power lens (PPL). The process was designed to create simple spherical and toric surfaces which can be polished by rigid lap tools. A progressive surface does not have a consistent curvature and requires a flexible lap tool for polishing.

To overcome this restriction the complex progressive surface is cast into a semi-finished lens blank using a glass mould. A metal or ceramic dye is cut with the progressive lens design using a computer numerically controlled cutting tool. Heated glass is then slumped over the dye to reproduce the complex progressive design cut into the surface of the dye. There are two moulds for each lens blank, one for the front surface containing the progressive lens design and one for the back, a simple spherical curve. The moulds are mounted in a gasket, liquid lens monomer injected into the apparatus and the monomer heat polymerised. Once cured the resulting form takes the shape of the two moulds, a traditional semi-finished PPL blank.

This is known as the open and shut production method. Importantly, the accuracy of the lens is only equal to the accuracy of the moulds. This process is a highly repeatable method of production which yields consistent quality. The only drawback is shrinkage as the lens monomer goes through heat polymerisation. This process produces a power accuracy of approximately 0.06D. The semi-finished blanks would then have the distance prescription applied to the rear surface using traditional surfacing equipment. This equipment can only produce relatively simple surfaces because the surfacing tools they use can only produce a spherical or toric surface. For spherical surfaces, there is only one radius of curvature used in all meridians, for the cylinder surfaces (toric) there are two radii of curvature crossed at 90 degrees. These tools cannot create aspheric or complex progressive lens designs, hence the need to use pre-moulded semi-finished lens blanks.

As previously discussed in Part 1 (*Optician*, 09.07.10), the semi-finished lens blanks are available in a set number of base curves, each base curve covering a range of prescriptions.

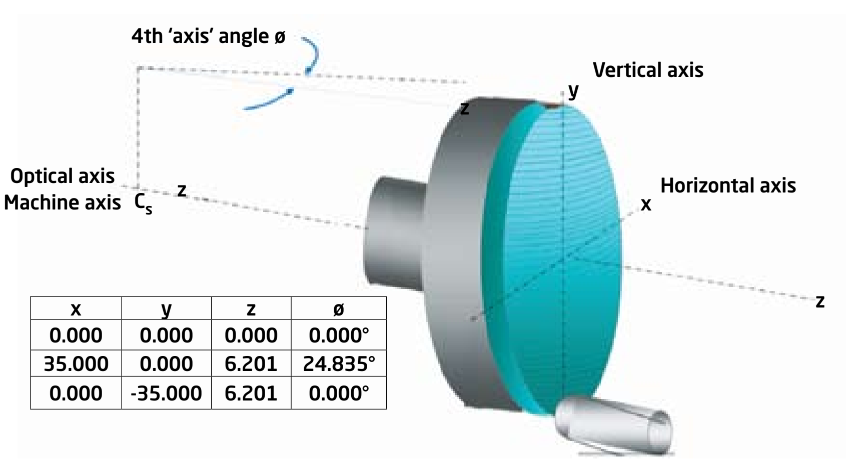
Advent of freeform technology

Freeform technology has been utilised in optical lens manufacture for approximately two decades. It first came into use manufacturing the moulds for PPLs.

Freeform was introduced to help improve the mould making technology which inherently improved the accuracy of the PPL. A freeform generator was used to directly cut the surface of the glass mould with the progressive design, rather than using the glass slumping process as previously described. This direct surfacing improved the power accuracy to approximately 0.01D.

This fact lends itself to a question. Because the mould is manufactured using freeform technology and the semi-finished lens blank cast from this mould, does this mean it is a freeform PPL? Does the use of a freeform generator on the mould equate to a freeform PPL?

Some manufacturers refer to products made in this manner as digitally moulded, digitally cast, freeform front surfaced and many other names and market them as such. The fact is that most semi-finished lenses are made from freeform generated moulds and have been for some time.



x	y	z	ø
0.000	0.000	0.000	0.000°
35.000	0.000	6.201	24.835°
0.000	-35.000	6.201	0.000°

Figure 1 Mathematical modelling of cutting tool coordinates

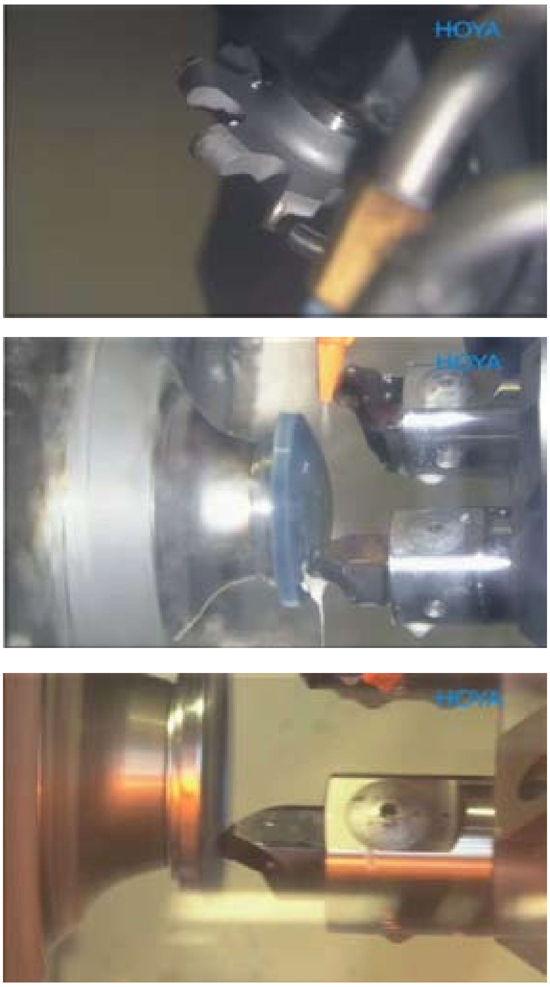


Figure 2 The three-stage freeform cutting cycle

The freeform generator

Freeform generators are multi-axis, computer numerically controlled (CNC) machines which rapidly translate the individual progressive design in the form of a point file to three-dimensional diamond cutting tools which remove material to create the surface. The combination of the point file, software control and pinpoint CNC surfacing accuracy means the freeform generator can precisely cut away material down to microns, thereby producing virtually any complex multi-curve surface.

Freeform surfacing begins by mathematically modelling the individual lens surface. The design is then translated into point file, a series of co-ordinates for the cutting tools along the x, y and z axis (Figure 1).

The lens blank then undergoes a three-stage cutting process (Figure 2):

- A multi-blade rough cutting tool
- A polycrystalline diamond smooth cutting tool
- A natural diamond high speed finish cutting tool.

After surface generation, the lens is then polished in a freeform polisher using a CNC dynamic, flexible lap tool. (Figure 3).

Freeform PPLs

Applying this technology to PPLs allows the lens manufacturer to overcome the restrictions of conventionally surfaced and cast PPLs.

The original design of the lens is still paramount. If a poorly designed lens is freeform manufactured, it remains a poor design; however, a well designed lens can be improved by utilising this technology.

Best form theory dictates a unique base curve for each specific prescription to reduce optical aberrations, but this is not economically viable due to the economics of mass production. So a best available fit is used. Conventional PPL designs are constrained by surfacing technology and parameters specific to the individual wearer. Frame and facial characteristics cannot be accounted for because the PPL has to be designed conforming to universal standard measurements. These constraints mean that the basic PPL design can only be varied slightly for each base curve and add power.

Freeform technology allows exciting possibilities for lens designers as it removes the constraints of traditional semi-finished lens manufacture and allows the direct surfacing of the extremely complex progressive lens surface directly onto the lens blank. This allows the opportunity to design a lens for every order, freeing us from the constraints of universal standard measurement and base curve restrictions. The lenses can now incorporate an infinite number of parameters specific to the individual prescription and frame fitting. It allows a unique PPL to be custom designed for each individual order and manufactured with the highest of precision.

Different types of freeform PPLs

There are many different freeform PPLs on the optical market, from many different manufacturers, each with their own interpretation of what the term means and what constitutes a freeform lens. Some lens manufacturers now have multiple freeform PPLs in their portfolios, and even within their own portfolio different manufacturing processes are employed, but all under the banner of freeform.

Figure 3 The CNC controlled flexiable lap tool

Some examples of these different types of freeform manufacture include:

- A semi-finished lens blank with a moulded progressive surface, cast from a freeform mould, and then utilising traditional surfacing for power (rear) surface
- A semi-finished lens blank with a moulded progressive surface, cast from a freeform mould, and then utilising freeform surfacing for the power (rear) surface
- Using a spherical lens blank, and then directly surfacing the progressive and power surface onto the rear surface using freeform surfacing
- Using a complete blank and then directly surfacing both lens surfaces with different elements of the progressive design and power surface using freeform manufacture.

As can be seen by this very generic and non-exhaustive list, the term freeform is used extensively to cover a wide range of manufacturing techniques, some with more credence to the term freeform and yielding superior optical performance than others.

Freeform allows the lens designer to directly surface the progressive design onto the lens surface. However, a large proportion of freeform PPLs are still manufactured from moulded semi-finished blanks with the progressive element moulded in casting. The true benefits of freeform progressives can only be fully reached once the starting point of the lens is a true blank with no restrictions and the lens is designed for freeform manufacture. There are factors which make this method of manufacture difficult, which is why the majority of manufacturers do not produce PPLs using this method, but to use freeform technology to its full potential and to strive for the best optical performance, this method of manufacture must be adopted.

To manufacture a PPL from scratch, freeforming both sides of the lens, incorporating different elements of the progressive design onto both surfaces and integrating them together to achieve the best characteristics of both front surface PPLs with a fast, dynamic progression corridor and the wide fields of view enjoyed by the wearers ▶

of rear surface PPLs is not an easy undertaking. It requires a very complex mathematical modelling to generate the lens surfaces,[2] for each lens integrated together for best performance to create a dual surface PPL. In order to manufacture a dual surface PPL, the lens must go through two freeform cycles, one for the concave side and one for the convex side. This increases the machining costs and requires specialist equipment for concave and convex freeform generation and polishing.

Another difficulty is in offering a photochromatic plastic lens. The preferred type of photochromatic product by patients and optical professionals is an imbibed offering. Here the semi-finished lens blank, whether it be a semi-finished PPL to be freeformed on the rear surface, or a semi-finished spherical lens blank to be freeformed on the rear surface with the power and progression to become a PPL, has absorbed a layer of photosensitive dye into the plastic substrate. This becomes permanently embedded into the semi-finished lens surface at a uniform depth of between 150 and 200 microns. Because this process requires the lens to start from a semi-finished spherical or progressive blank, it is not possible to create a dual surface freeformed PPL with this imbibing technology as a fully freeformed, dual surface PPL does not start from a semi-finished lens blank of any type, rather a large 'puck' of lens material. The imbibition photochromic technology described is a proprietary, patented process developed and commercially introduced by Transitions Optical.

To overcome this issue a different type of photochromatic technology must be used. A spin-coating process can be used after the lens has been manufactured to apply a photochromatic layer. The photochromic technology is a proprietary, patented process developed and commercially introduced by Hoya.

Freeform lenses in practice

Freeform PPLs from some manufacturers often require additional fitting parameters, back vertex distance, face form angle, near working distance, pantoscopic tilt for example. Others use an average value for these measurements. By individually designing the lenses before manufacture we now have the ability to optimise the lens performance, compensating for the effects that these parameters have on the performance of the lens. This technology not only allows us the facility to optimise for the prescription and facial parameters but also for lifestyle and previous lens experience of the wearer. The ability to tailor make the lenses to the patient's requirements offers the dispenser the option the deliver the highest level of patient care with an individual solution to the wearer's visual requirements.

The personalised or individualised freeform lenses will often arrive in practice with a compensated prescription, usually described as a measured prescription (Table 1). This generally will differ slightly from the prescribed prescription. The compensated prescription is what you would read using a traditional manual or digital focimeter. The lens will have the correct power in position of wear for the patient, taking into account how the patient would wear it, with compensation for back vertex distance, pantoscopic tilt, frame form angle etc. As the measured position on the focimeter is the unnatural wearing position, you would not measure the prescribed power. A digital focimeter conforming to the infinity on axis principle will accurately read the very latest generations of freeform manufactured lenses.

The latest individualised lenses along with the design base theory will be discussed in the next article of this series.

TABLE 1

	Sph	Cyl	Axis	Add
Ordered power	+2.75	0.00	0	+2.50
Reference power Including wear parameters, lens thickness, design and material properties	+2.60	+0.12	89	+2.45
Measuring power The actual lens power that you may measure yourself	+2.64	+0.16	86	+2.48
ISO tolerance compliant Reference power minus calculated power	+0.04	+0.04	-3	+0.03

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MULTIPLE-CHOICE QUESTIONS – take part at opticianonline.net

1 What is the power accuracy of the open and shut production method?
A 0.01D
B 0.03D
C 0.06D
D 0.6D

2 What is the power accuracy of direct surfacing?
A 0.01D
B 0.03D
C 0.06D
D 0.6D

3 In freeform surfacing, how many cutting stages are there?
A 1
B 2
C 3
D 4

4 The final cutting stage relies on a tool made of which of the following?
A Quartz
B Diamond
C Multicrystal
D Iron

5 For an ordered power of sphere of +2.50DS for a freeform lens, which of the following best represents the measuring power from a traditional focimeter?
A +2.44DS
B -2.64DS
C +2.64DS
D +2.60DS

6 What is the thickness of embedded photochromic material resulting from the imbibation photochromic technology process?
A 100-150 microns
B 150-200 microns
C 250-500 microns
D 150-200mm

Successful participation in this module counts as one credit towards the GOC CET scheme administered by Vantage and one towards the Association of Optometrists Ireland's scheme.
The deadline for responses is September 9 2010