Freeform: optimise or individualise? Part 1

By Phil Gilbert FBDO

Competencies covered:
Dispensing opticians: Communication, Optical Appliances
Optometrists: Communication, Optical Appliances

It is nearly 15 years since Zeiss and Rodenstock introduced freeform-generated progressive lenses into the marketplace. In their infancy these lenses were looked upon as complex and expensive products, which many in both the industry and profession said would never catch on.

After having recently completed the 2014 ABDO publication, Ophthalmic Lenses Availability, it is evident that this production process has been adopted by all of the major manufacturers and is definitely here to stay. Not only has the freeform process been utilised for progressive lenses, but there is increasing use of the technology on every other type of spectacle lens, including an example of freeform bifocals.

To say that the technology took off very slowly in the UK is evident in the chart reproduced with data from the 2009 and 2014 Ophthalmic Lenses Availability (OLA) editions as seen in **Table 1**. Although freeform production had already been in evidence for nine years, there were only 43 freeform produced progressive lenses and three single vision lenses listed in 2009. Compare this to 2014 and the tide has changed dramatically, listing 247 progressive options and 69 single vision.

Most major lens manufacturers now supply the majority of their products using freeform production and this can be seen by the 474 per cent increase in freeform progressive offerings in comparison to the 77 per cent reduction in conventionally produced lenses. In reality, the production methods have reversed their roles completely in the space of only five years leaving conventional processing to a few entry level products from the major manufacturers, with the rest produced by smaller independent laboratories.

Industry benefits of freeform production

Freeform production has distinct benefits to all sectors of the optical industry and profession but, more importantly, there is a direct benefit to the spectacle-wearing public. This factor is the main consideration for all of us who work in optics, and understanding the production process and its benefits are paramount in helping the profession confidently recommend and dispense the vast array of products on offer.

With regard to the industry, prior to the introduction of digital freeform machinery it was necessary to hold large quantities of blanks that were pre-formed by casting in moulds. These semi-finished lens blanks had a finished optical surface on the front side and were boxed and stored in the warehouse according to their material type, blank size, thickness, progressive lens design, base curve

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This article has been approved for 1 CET point by the GOC. It is open to all FBDO members, including associate member optometrists. The multiple-choice questions (MCQs) for this month's CET are available on page 10 and **online.** Insert your answers to the six MCQs on the inserted sheet or online at www.abdo.org.uk. After log-in, go to 'CET Online'. Please ensure that your email address and GOC number are up-to-date. The pass mark is 60 per cent. The answers will appear in the November 2014 of *Dispensing Optics*. The closing date is 14 October 2014.

C-36374

F-F = Freeform	Clear		Photochromic		Polarised	
	2009	2014	2009	2014	2009	2014
S-V Plastic	96	109	83	76	25	27
S-V Glass	34	38	8	13		
F-F S-V	3	69	5	65	0	19
S-V Sport	0	9	0	4		
F-F S-V Sport	0	36	0	19	0	17
Bifocal Plastic	96	111	26	29	6	7
Bifocal Glass	33	27	16	11		
F-F Bifocals	0	6	0	9	0	1
Trifocal Plastic	14	19	2	5	1	1
Trifocal Glass	7	3	5	3		
Progressive Plastic	262	62	103	34	21	10
Progressive Glass	33	17	6	8		
F-F Prog Plastic	43	247	7	237	3	91
F-F Prog Glass	0	13	0	7		
Progressive Sport	0	6	0	3		
F-F Prog Sport	0	34	0	29	0	25
Degressive Plastic	19	15	0	0		
Degressive Glass	0	1				
F-F Degressive	0	20	0	6		
Prog Vocational	2	2				
F-F Prog Vocational	0	51	0	13		
Pre Presbyopia	0	8	0	5	0	3
F-F Pre Presbyopia	0	19	0	13	0	3
Totals	**642**	**922**	**261**	**589**	**56**	**204**

Table 1: Freeform lens designs in 2009 and 2014

and addition power, with the boxes barcoded for identification. Due to the number of semi-finished products required to fulfil orders, the warehouse of a large lens manufacturer could be vast and contain row after row of racking holding the various blanks awaiting final production, and laps for their production (**Figure 1**).

To give an idea of the quantities of lens blanks required, if you take an average progressive lens type in a single material it is not uncommon to require five different base curves, in 12 different additions, and all of these in right and left. This meant that for one progressive lens type in one refractive index, about 120 different semi-finished lens blanks were needed. In addition, they are available not only in clear material but also plastic photochromic, polarised and glass where the total can rise dramatically with regard to the number of different semi-finished blanks that had to be held in stock. Then add to this several other refractive indices and other lens types and designs within a manufacturer's range and you can fill a large warehouse very quickly.

With the introduction of freeform production, where more modern production techniques are employed, the need to keep warehouses full of semi-finished lens blanks is diminishing. In recent years, this has freed up space in many factories and reduced the need for large warehouse facilities. The look of surfacing laboratories has also changed over the years in relation to the equipment used and the process flows associated with it. No longer are surfacing labs the noisy, dirty places they were years ago (**Figure 2**). Today they are modern, cleaner and quieter with more utilisation of robotics, bar codes and computer chip technology.

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Figure 1: Lab laps awaiting production

Figure 2: Old surfacing equipment

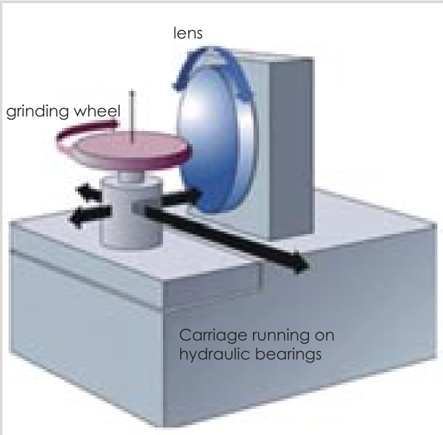


Figure 3: A two-axis generator

Figure 4: A freeform generator


Figure 5: A soft polisher

A new generation of generators

When using a conventional generator, the back surface of the semi-finished lens blank is left almost opaque and after removal it requires subsequent smoothing and polishing before it can be used as a finished spectacle lens. This requires the use of both smoothing and polishing pads, which are applied to the surfacing lap, and an allowance must be made to the lap with regard to pad thickness in order to maintain the correct curve. The simplest generators are two - axis machines that utilise a diamond impregnated grinding wheel to machine a spherical or toric lens surface, as shown in **Figure 3**.

The emphasis of a conventional two-axis generating process is on throughput and rapid removal of lens material. Any inaccuracy in the shape of the generated lens surface is ultimately corrected during the smoothing process by the rigid lap tool. In particular, the smoothing process with hard lap tools exploits the rotational or axial symmetry of spherical and toric lens surfaces, since these surfaces can be moved over the lap tool using a uniform rocking motion that produces relatively constant smoothing and polishing pressure over the lens blank. The use of hard lap tools during the smoothing and polishing processes, therefore, restricts the range of possible lens surface shapes to simple spherical and toric surfaces.

The tool used on a freeform generator is in principle a diamond tipped point, as can be seen in **Figure 4**. This has a three-axis capability which not only removes the surface material but the finished result, when the lens is taken off the generator, means that the lens is extremely smooth and clear and also very accurate with regard to power. This is termed 'cut-to-polish' technology. With this technology the lenses no longer need to undergo the aggressive smoothing and polishing required with conventional surfacing. They do, however, require final polishing and this is now undertaken by a soft pad polishing technique that is very gentle on the lens surfaces and does not alter the very accurate curves that were generated initially (**Figure 5**).

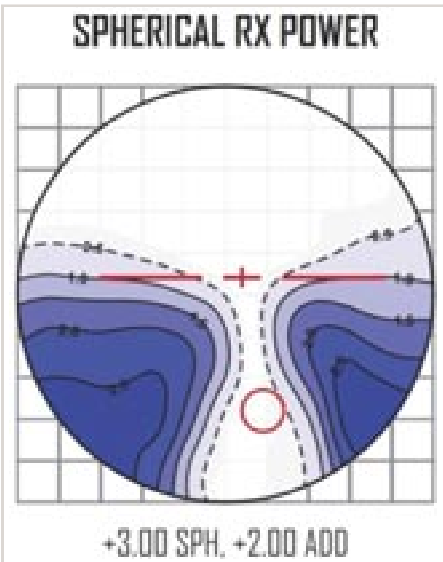
Due to the motion of the soft lap polishing process over a complex surface shape with varying curvature, dozens of polishing parameters must be carefully adjusted in order to ensure uniform polishing over the entire surface. Otherwise, errors from the desired surface shape may result, including unwanted waves. Although the process steps for final polishing are complex, the amount of time required to complete the process has been dramatically reduced – as has the actual surfacing time.

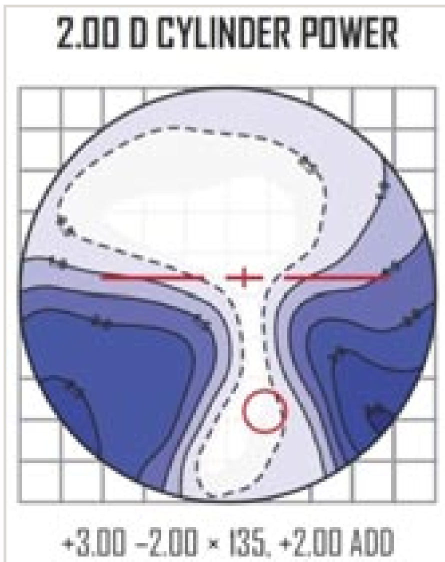
Freeform optimisation

Until the arrival of freeform generated products, both the optical professional and the spectacle wearer had to accept lens products that may or may not have been the best visually-performing products for some patients. Due to the restrictions that conventionally surfaced products posed, many aspects that we now take for granted were not available years ago leading to potential visual dissatisfaction for certain patients. Advances in production technology before the new millennium, although beneficial for some, amounted only to the choice between using a 'hard' or

Continued overleaf

Figures 6a and 6b: Impact of a 2D cylinder on a conventionally surfaced progressive lens





'soft' design for progressive lenses or latterly choosing whether to use a long or short corridor design.

Optimisation of the progressive design to take into account peripheral distortion or position of wear only became possible with the advent of freeform production. Many practitioners relied on manufacturers' published ISO cylinder plots that gave them an indication of the intended progressive design. These, however, were all based on plano with a +2.00D addition at which power many ISO plots looked very good but did not reflect the true design implications when 'real' prescription values were used in comparison. In **Figure 6** we can immediately see the impact that the introduction of a 2D cylinder can have on a conventionally surfaced progressive lens.

The optical effects of uncorrected lens aberrations are exacerbated in progressive lenses, which are already subject to optical limitations imposed by the surface astigmatism in the lateral blending regions of the lens design. As the prescription deviates from the ideal prescription associated with a given base curve design, oblique astigmatism interacts optically with the surface astigmatism of the progressive design, causing the viewing zones of clear vision to shrink and to lose clarity.

In **Figure 7** it can be seen how each base curve used in a conventional progressive is optimised for one and only one prescription. This optimal Rx (indicated in dark green) will have the maximum possible clarity for that curve. Aberrations increase as the Rx gets further from the ideal (through yellow orange and red), reducing clarity and increasing peripheral blur. Freeform surfacing technology allows the lens manufacturer to optimise the complex Rx surface for each individual prescription enabling every lens to give the maximum possible visual performance.

The production process of freeform surfaced lenses means that every lens produced by this method enables the manufacturer to introduce real time Rx optimisation into the design of the lens. This constitutes a large advance over the previous production methods using semi -finished blanks whereby any Rx optimisation could only be effected on the spherical and addition components.

Freeform is a production platform and it is important to be able to define the technology. With regard to the generation of power, one could define a freeform surface as an optically continuous surface, often of complex form with no symmetry, individually computed and manufactured for a specific prescription. As far as the method of production is concerned, freeform technology is a process in which freeform surfaces can be generated and polished to individual prescription; this is also known as direct or digital surfacing.

With regard to defining the machining of freeform surfaces, it can be said that for this kind of machining, the tool has to move in at least three axes simultaneously whilst processing the work piece. Sometimes five-axis milling machines are used to reach an optimised angle between it and the lens surface. It should also be noted that simpler surfaces that can be manufactured by conventional methods may also be produced by freeform technology, but these should not be termed freeform surfaces.

Technological advantages

So what were the major technological advantages that came about with the introduction of digital surfacing that benefitted our patients, and what advances have been made since the introduction of this revolutionary production method?

The major advantages of digital surfacing have been twofold in that not only could lenses now be made more accurately, but also the manufacturing platform combined with enhanced computer processing power enabled a much higher degree of flexibility with regard to lens design. Early innovations linked to digitally surfaced lenses fell into the three categories as described below, and they were indeed revolutionary in comparison to their conventionally-produced predecessors.

The first digitally surfaced lenses were marketed with variations that allowed for the computer processing

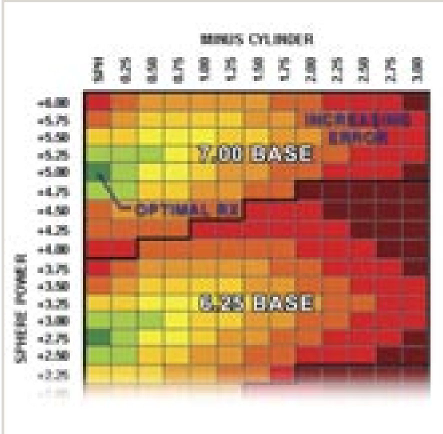


Figure 7: Base curves in a conventional progressive are optimised for one prescription only

capabilities at the time. These were:

- Freeform generated lenses taking into account the characteristics of the patient's frame
- Freeform generated lenses taking into account the patient's physiology
- Freeform generated lenses mathematically taking into account surface power distribution

These initial separate design capabilities have now, to a large extent, divided into either freeform Rx optimised designs or freeform individualised designs giving the profession the benefit of choice dependent on the degree of sophistication required by the patient. The International Standards body is currently working on a new Technical Report (TR 18476) in which much more information will be made available to all interested parties regarding the whole subject of freeform production.

So how far have we come over the last 14 years and what new factors have been introduced? One of the great strengths of the digital surfacing platform has been the ability to work every element of a progressive lens onto one surface. This means that the progressive design, the prescription and the addition are all incorporated on one surface with just a nominal spherical curve remaining on the opposite surface. Manufacturing using this form has the benefit of reducing both surfacing time and cost and many of the most popular freeform lenses are classed as back surface progressives.

The flexibility of the production platform has been a major influence in lens design and it has enabled manufacturers to incorporate the use of both lens surfaces if the power of the lens or the design warrants it. Of course, it is not necessary to only generate the back surface and some designs are classed as front surface progressives with a nominal curve on the back surface. Splitting curvature and power between both surfaces also has advantages, and a number of manufacturers do employ both surfaces either as standard or if the Rx and computer results dictate it.

Another milestone has been the ability to incorporate variable corridor lengths into the design of progressive lenses. Early attempts by manufacturers to design effective short corridor lenses proved somewhat difficult without compromising the performance of the intermediate area, but very quickly both standard and short corridor digitally surfaced progressives were offered by most major manufacturers. The next logical step was, therefore, the introduction of variable corridor lengths, a move pioneered by Zeiss in 2006. Many major manufacturers now offer this facility in their top-of-the-range digitally surfaced lenses and these can be measured and ordered manually in 1mm steps. Practices that have invested in digital measuring equipment can even order progression lengths in 1/10th mm steps from some manufacturers if required.

Patient adaptation

Patients changing from conventional progressives to freeform-generated products have been known to experience early adaptation difficulties and it is always wise to prepare patients in advance. This is mainly due to the fact that conventional progressive lenses were derived from semi- finished lens blanks with a fixed corridor and addition power on the front surface. The actual Rx was worked on the back surface but it was not Rx optimised. There was no change in curvature of the tool and no change in the frontal curves, inset or corridor length.

With freeform lenses, the curvatures are Rx optimised and are re-calculated for vergence, ray paths etc; this can lead to the need for a patient to adapt to the new form in comparison to their previous product. Verification or compensated powers are also very important with the advent of freeform progressive lenses, whether this is associated with the average or actual position of wear. This is due to a realisation that compensation for 'position of wear' is extremely important and factors such as lens tilt, vertex distance, and oblique refraction at near can result in effective power changes to the sphere and cylinder prescription components.

Lenses optimised for the 'as worn position' generally require small changes to the prescription as measured by a conventional focimeter. In these cases, a compensated prescription is provided for power verification purposes, which is printed separately, or alternatively on the lens packets. A compensated prescription is the prescription that is read in a focimeter if the lens is to provide the correct prescription for the wearer in its position of wear, and BS EN 21987:2009 states that the same tolerances as for non-compensated powers are applicable.

Also of note is the fact that when freeform lenses are read in a focimeter, the reading addition may appear to read differently to the actual ordered power and it is advisable to compare the addition with the one prescribed using the manufacturer's temporal micro engraving, as well as verifying the Rx against the compensated powers given. Further, it is a recommendation for the optometrist to always use a full subjective addition when prescribing, i.e. stronger rather than weaker if there is any doubt over which addition to use.

In conclusion, there are a wide variety of digitally surfaced lenses available now, ranging from basic entry level freeform surfaced lenses through to fully customised and individualised products requiring very accurate extra measurements. Even entry-level products that are digitally surfaced will give an improved visual performance over conventional products, particularly with regard to prescriptions with higher cylinder powers and prismatic corrections.

The ultimate, fully individualised products will continue to give our patients the best possible vision experience – particularly if they have chosen frames that have an unusual or difficult fitting. The impact of full individualisation will be expanded upon in Part 2.

With thanks to ABDO and Carl Zeiss Vision for the images reproduced in this article.

Further reading

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Phil Gilbert is a qualified dispensing optician with more than 40 years' experience. He currently works for Carl Zeiss Vision UK as an ophthalmic lens consultant. He is a committee member of BSI TC/172/WG3 Ophthalmic Lenses and the chairman of the Standards Panel of the Federation of Manufacturing Opticians. He has produced many articles for the benefit of educating ophthalmic professionals and is the editor of the ABDO College publication, Ophthalmic Lenses Availability, which lists and describes every spectacle lens available in the UK. ■

Multiple choice questions (MCQs) Freeform: optimise or individualise? Part 1

1. Which statement is true?
a. The term 'cut to polish' is used to describe the single process used to generate a finished lens surface using freeform technology
b. The design features of a conventionally generated progressive power lens surface can be accurately determined by observing isocylinder plots
c. Where prescribed astigmatism combines with the oblique astigmatism of a conventionally generated progressive design, areas of clear vision become constricted
d. Most base curves available for a traditionally generated progressive power lens will eliminate peripheral aberrations

2. Which option is correct? The definition of a freeform surface manufactured for a specific prescription is…
a. a progressive surface of complex form with no symmetry, individually computed
b. an optically complex, symmetrical surface specifically computed
c. any surface individually designed and generated by more than five-axes milling machines
d. an optically continuous surface, often of complex asymmetrical form, individually computed

3. The use of a 6.25 base curve for conventional progressives will provide the maximum clarity for which one of these prescriptions?
a. +3.00D sphere and up to -0.50 cylinder
b. +2.50 to +3.00 sphere with a -0.25 cylinder
c. +2.75D sphere
d. +5.00D sphere and up to -1.25 cylinder

4. Which option is correct? When the power of the near addition of a digitally-generated lens is measured with a focimeter, the measured value can appear…
a. up to 0.25D weak
b. up to 0.25D strong
c. to have an unwanted cylinder
d. uncompensated

5. Which option is correct? Hard lap tools for smoothing and polishing…
a. can only be used on spherical and toroidal surfaces
b. rectify under-compensation of surface power
c. can produce rotationally-symmetrical aspheric surfaces
d. provide a non-aggressive finishing process for digital surfacing

6. Which statement is true?
a. Entry level products that are digitally surfaced will tend to exhibit the same visual performance as conventional products
b. First generation short corridor lenses dispensed in relatively shallow frames provided ideal intermediate, distance and near zones
c. Traditional progressive power lenses were semi-finished with a fixed corridor and addition power on the back surface
d. The optimisation of a progressive design can only be accomplished using digital surfacing technology

The deadline for posted or faxed response is 14 October 2014. The module code is C-36374.

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