VARIABLE AND PROGRESSIVE POWER LENSES

4. Progressive Power Lenses

By A. G. Bennett*

A progressive power lens is one in which there is a continuous change of power over a pre-determined area, the power thus depending on the direction of the gaze. In some lenses of this kind, the change is continuous over the whole area of the lens; in others, the "progressive" area is designed to bridge the power gap between portions of uniform power for distance and near vision respectively.

The first progressive power lens, invented in 1907 by the Yorkshire-born optician, Owen Aves, is in a category of its own. Those devised subsequently can be put into one or other of the following groups:

Group A: lenses incorporating an aspherical surface of revolution.
Group B: lenses incorporating a surface of "elephant's trunk" construction.
Group C: lenses incorporating a "homastigmatic" surface.
Group D: lenses of concentric construction.
Group E: "Varilux" and similar lenses.
Group F: lenses of variable refractive index.
Group G: miscellaneous designs.

* Department of Ophthalmic Optics and Visual Science, The City University.

The Owen Aves lens

The patent specification covers both the design of the lens and machinery for producing surfaces of the type required. In fact, the combination of two surfaces of a special type was needed. One is a portion of a conical surface with its axis vertical and apex down; the other is a surface resembling a convex cylinder with its axis horizontal, except that in profile the curve is not a circular arc but one of increasing curvature from the top downwards. An example of such a curve is the portion GH of the ellipse shown in Fig. 21.

In combination, the surfaces were to be arranged as shown in Fig. 22. At every point on the vertical meridian MN of the conical surface the curvature would be zero vertically, but in the horizontal plane would increase continuously from M to N because of the tapering effect of the cone. There would

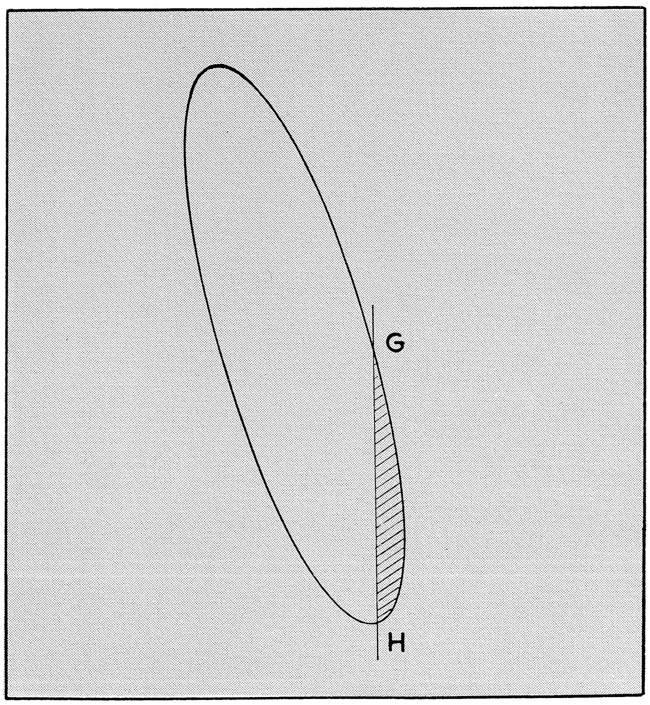

Fig 21 Vertical section of one of the surfaces employed in Owen Aves's progressive power lens

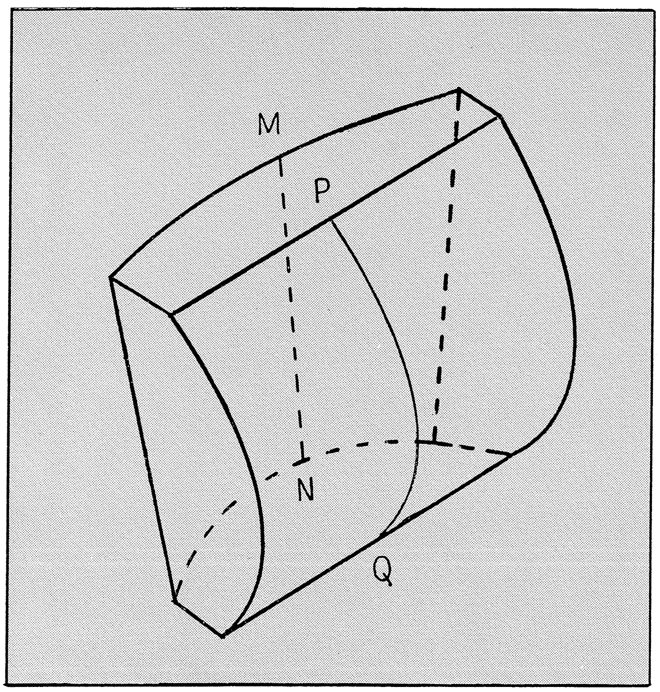

Fig. 22 Construction of the Owen Aves progressive power lens (thickness exaggerated for clarity)

thus be a progressive increase in horizontal power, say, from +2·00 D to +4·00 D. Similarly, at every point on the vertical meridian PQ of the other surface, the curvature would be zero horizontally but in the vertical plane would increase progressively from P to Q, corresponding to a power variation, say, from +2·00 D to +4·00 D.

The possibility thus arises that at every point on the vertical meridian of the lens, the horizontal curvature of one surface could be substantially matched by the vertical curvature of the other surface, resulting in continuously increasing plus spherical power from the top of the lens downwards.

An obvious drawback of this arrangement is that it does not lend itself very readily to the incorporation of a cylindrical element, especially at an oblique axis.

A curious episode

In 1913, a letter appeared in *The Optician* over the signature of H. Newbold in which the writer described how, in 1907, he had devised a "multifocal lens" using a combination of a conical and "an elliptical cylindrical surface" with their axes at right-angles. He said he had shown the explanatory papers to Mr A. B. Wells of the American Optical Company, who, in turn, had shown them to von Rohr at Jena. He went on to say that the papers had since been returned to him with the verdict that the idea was not practical. In conclusion, he stated: ". . . I have been granted a patent for a machine for working such or like curves of a similar nature—or, in other words, 'progressive curves' ".

A fortnight later there appeared a letter from Owen Aves in which he pointed out that the construction described by Newbold was identical with his own, for which he had been granted a patent in 1907. His letter concluded as follows:

"It may be interesting to your readers to know that I still have some of the lenses which I manufactured. The reason they were not put on the market at the time is that, as in Mr Newbold's case. I was told by various authorities that they were unpractical.

"I have not yet procured a copy of Mr Newbold's specification, and therefore cannot say more as to the commercial value of his patent, but it is at any rate interesting to know that someone was working along similar lines to myself at a time when I felt I was all alone."

Incidentally, the present writer, when he discovered it, read this letter with enormous interest because it was his first intimation that Owen Aves had actually made some lenses in accordance with his patent. This is, perhaps, the least known though not the least notable of his many achievements.

Unfortunately, recent efforts to trace one of these lenses have been unsuccessful.

In his rejoinder, Newbold acknowledged that he and Owen Aves had been thinking on identical lines as far as the lens design was concerned, but said that the machine which was the subject of his patent was different from Aves's. He said he could not offer to show it to Aves because foreign patents were pending.

Harry Newbold was a prolific inventor but the present writer has, to the best of his knowledge, examined all the British patents granted to him. The nearest approach is one dated 1912 for a machine producing solid bifocals with elliptical or shaped segments. It is most unlikely that this was the machine to which Newbold was alluding. The most probable explanation is that he obtained only a provisional patent for the progressive curve machine and did not complete it.

Group A: Aspherical surfaces of revolution

The use of an aspherical surface of revolution to produce the effect of progressive power has a special attraction from the standpoint of manufacture: it is much easier to produce than one devoid of axial symmetry. Hence it is not surprising that aspherical surfaces feature in a number of different constructions proposed from time to time. In fact, the first progressive power lenses to become commercially available incorporated one surface of this kind.

The "Ultifo" lens

According to Duke-Elder, progressive power lenses were introduced in 1922 by "Gowlland of Montreal" under the trade-name "Ultifo". The present writer has seen no other reference to these lenses in ophthalmic literature or trade publications. Detailed information concerning them would be greatly welcomed.

A search of the patent literature has brought certain facts to light, including another mystery. In 1914, a Henry Orford Gowlland of Montreal, Quebec, was granted a Canadian patent for a progressive power lens as shown in Fig. 23. The concave back surface of the lens formed part of a paraboloid, the surface produced by the revolution of a parabola about its axis of symmetry, XX. The convex front surface was spherical or toroidal according to the distance prescription. Because of the decreasing concave curvature of the paraboloidal surface from the top downwards, the effect would be a progressive addition of positive power as the gaze was lowered. Two British patents covering the same construction were granted to Gowlland in 1915. It seemed a reasonable assumption that the "Ultifo" lenses mentioned by Duke-Elder were based on Gowlland's Canadian patent of 1914.

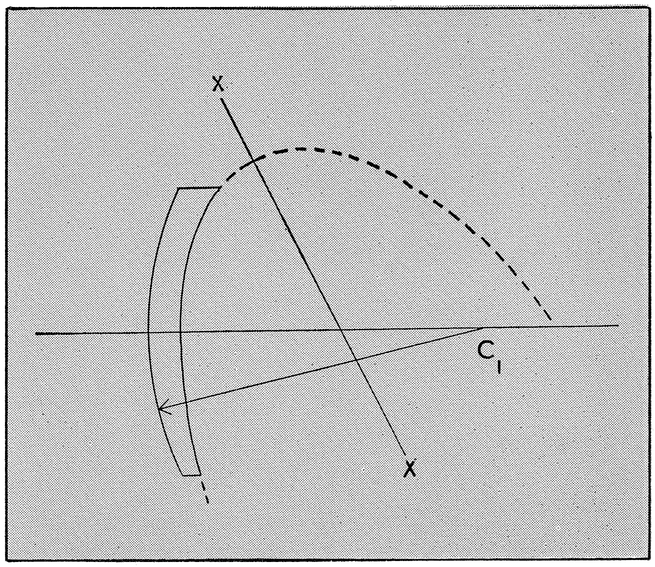

Fig. 23 The Gowlland progressive power lens, employing a concave paraboloidal surface

It was therefore with considerable surprise that the writer subsequently discovered that five years earlier, in 1909, a lens of identical construction had been patented in America by a certain Henry Orford, of Philadelphia. Furthermore, the claims as set out in the abridged Canadian specification are almost identical in wording to those in the earlier American patent. It would be too great a coincidence if Henry Orford of Philadelphia and Henry Orford Gowlland of Montreal were, in fact, two different persons.

Disadvantages of conicoidal surfaces

As we shall see, there are inherent drawbacks in every known method of producing lenses of progressive power. The disadvantages attaching to the use of paraboloidal and other aspherical surfaces of revolution can be deduced from Fig. 24.

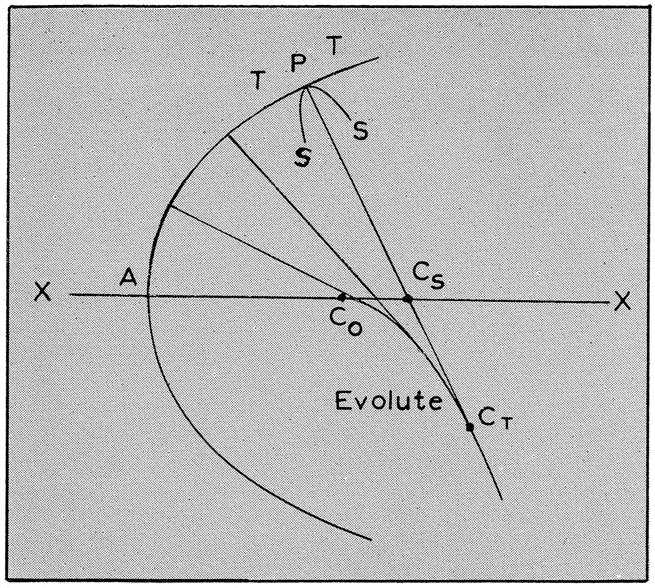

Fig. 24 Section of a conicoid, showing the sagittal and tangential centres of curvature (C_S and C_T) for the point P on the surface

The centre of curvature of a very small portion of the surface surrounding its vertex A is situated on the axis of revolution, XX, at the point C_O. All the normals to the surface in the plane of the diagram are tangential to a curve known as the "evolute". At any given point P on the surface, there are two principal curvatures in two mutually perpendicular meridians, the tangential (TT) lying in the plane of the diagram while the sagittal (SS) lies in a plane perpendicular to this and containing the normal to the surface.

In the tangential section, the centre of curvature C_T is situated on the normal at its point of contact with the evolute. On the other hand, the centre of curvature C_S in the sagittal section lies at the intersection of the normal with the axis of revolution. Because of this, the surface power in the tangential section is weaker than in the sagittal section, resulting in an unwanted astigmatic effect.

Table No. 2 shows the variation in surface power of a concave paraboloidal surface at points 10, 20, 30 and 40 mm below the vertex of the surface, the power at the vertex being —8·00 D for a refractive index of 1·523.

Table 2

Variable addition provided by a concave paraboloidal surface

Distance below vertex (mm)	Tangential surface power (D)	Sagittal surface power (D)	Effective addition (D)	Mean addition (S+C/2) (D)
0	−8·00	−8·00		
10	−7·72	−7·91	+0·28 D.S./−0·19 D.C. ax. V.	+0·19
20	−6·98	−7·65	+1·02 D.S./−0·67 D.C. ax. V.	+0·69
30	−6·01	−7·27	+1·99 D.S./−1·26 D.C. ax. V.	+1·36
40	−4·97	−6·82	+3·03 D.S./−1·85 D.C. ax. V.	+2·11

The axis of the minus cylinder remains vertical only within a narrow vertical band through the centre of the surface. On either side of this band the axis changes direction, passing always through the vertex of the paraboloid.

Subsequent patents

Despite the disadvantages just described—or perhaps in ignorance of them—aspherical surfaces of revolution have been employed in a number of patents subsequent to Orford Gowlland's.

One of the features of patent literature most surprising to a layman in this field is the extreme variation in the degree of detail disclosed. Some patent specifications are admirably explicit. Others are so vague and uninformative that it is impossible to discover what original feature, if any, is being protected.

For example, the progressive power lens construction patented in France by R. Gauthier as recently as 1958 employs one aspherical surface of revolution, but the specification is so vaguely worded that it would cover the aspherical lenses described by Descartes some centuries previously.

The two German patents granted to O. Schwarz in 1922 and 1953 (publication dates) for a progressive power lens with one aspherical surface are even more laconic and uninformative. The more recent one, which applies particularly to cataract lenses, makes the incredible claim that the lens is free from unwanted astigmatism, provides a field of view of 180 degrees, and is about only half the weight of a conventional cataract lens!

Group B: Elephant's trunk construction

The term "elephant's trunk" was applied by the writer some years ago to describe a progressive power surface of a radically different kind.

Imagine an elephant's trunk in its state of rest to be represented schematically by a cone, apex down. Now suppose the trunk to be bent backwards, as in the bun-into-mouth position, presenting in profile a convex curve of increasing curvature from the top downwards. An attempted three-dimensional view of the idealised surface in this position is shown in Fig. 25. It is not hard to visualise the possibility that, at every point on the median line MN, the horizontal curvature could be exactly matched by the vertical curvature.

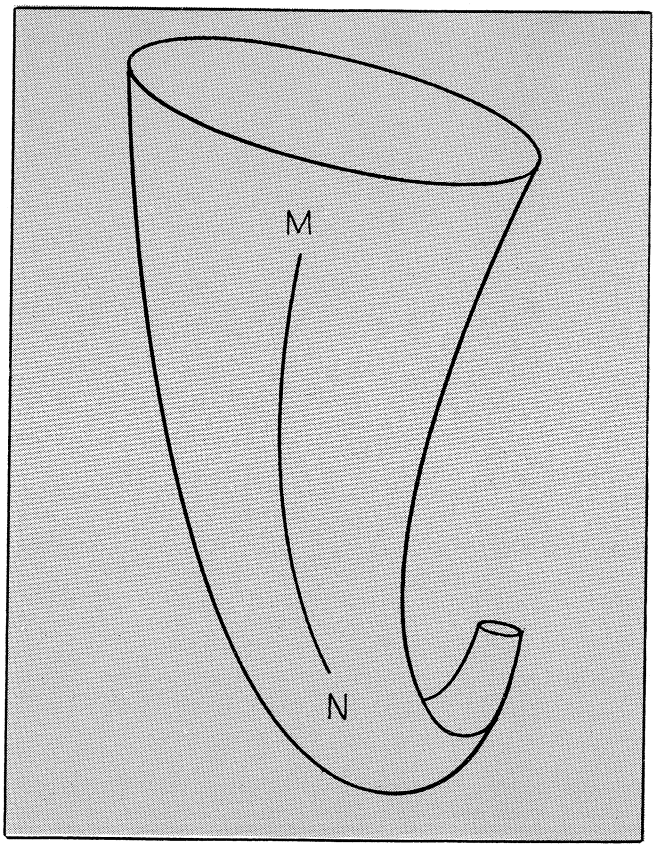

Fig. 25 The "elephant's trunk" surface

Volk and Weinberg have suggested that a surface of this kind can be considered as equivalent in effect to a combination of two surfaces of the type used in Owen Aves's design, with their meridians of zero curvature at 135° and 45°. In Fig. 26, these components are represented by A and B respectively. It is supposed that each provides a variation in power from

+6·00 D to +9·00 D. The sum of the two effects at various points on the surface is easily deduced and expressed as a sphero-cylinder in the manner shown in the diagram, which represents a map of the surface power.

In a central vertical band the effect is substantially spherical, the power increasing from +6·00 D at the top to +9·00 D at the bottom. On each side of this central band there is an astigmatic effect, increasing in magnitude towards the edge of the lens. The maximum astigmatism is seen to be 3·00 D, equal in magnitude to the maximum spherical addition.

In fact, as Knoll found for an entirely different construction to be considered later, it seems to be a feature of several progressive power surfaces that the astigmatism at the worst point is of the same order as the maximum addition.

The writer was once informed by Mr R. C. Reid, founder of Stigmat Ltd., that Owen Aves had many years ago discussed with him the possibility of producing a progressive power surface shaped "like a snail's back". Though he chose a different anatomical analogy, there is little doubt that he had in mind a surface of elephant's trunk formation.

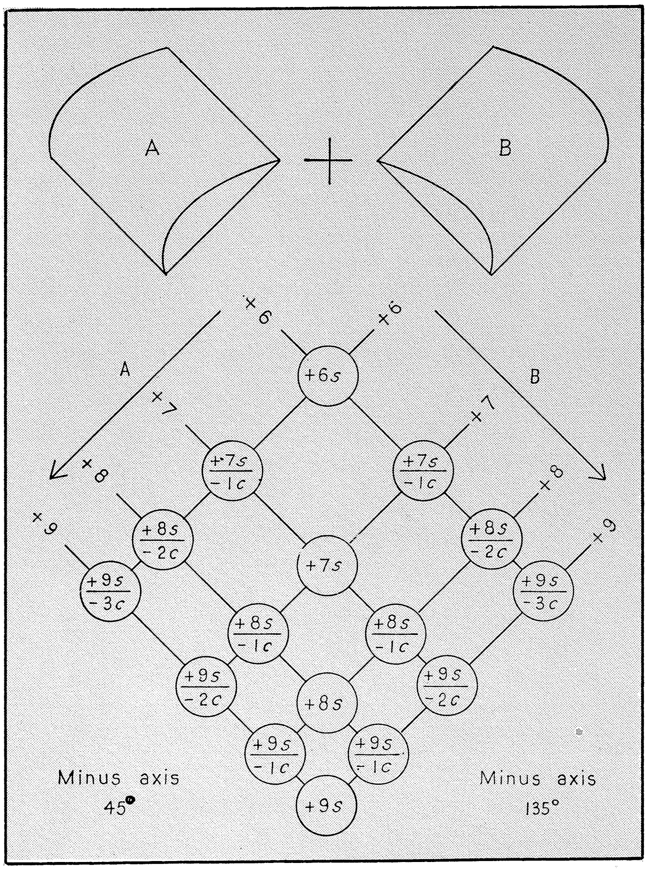

Fig. 26 Analysis of the surface power distribution of an elephant's trunk surface (based on the suggestion of Volk and Weinberg

Poullain and Cornet's patents

The use of such a surface seems first to have been suggested by Poullain and Cornet, who obtained a French patent in 1910. A point of particular interest in the specification is that it also covers a machine for grinding surfaces of this type.

An American patent was taken out in 1911 and this contains a number of interesting developments. For example, mention is made of a lens surface in which an elephant's trunk curve is worked over part of the area, merging into another portion of uniform curvature. The possibilities inherent in a combination of two surfaces of this complex construction are also explored. A significant omission in the American specification is the machine described in the original French version. It is merely stated that ordinary surfacing methods would not be suitable and that it would be necessary to have recourse to special machines.

Although the pioneer work of Poullain and Cornet does not appear to have been rewarded at the time, it has subsequently borne fruit in later developments.

Despite differences in terminology and approach, an American patent granted in 1938 to C. E. Evans appears to cover the same ground as Poullain and Cornet's American patent. The same can be said of the Belgian patent obtained in 1950 by R. and A. Fritz.

"Varifocal" lenses

A surface of elephant's trunk construction seems to have been employed in the "Varifocal" lenses which made their appearance in Italy during the 1950s. They were produced by the well-known firm of scientific instrument and ophthalmic lens manufacturers, Officine Galileo di Milano.

Apart from a trade pamphlet, little seems to have been published concerning these lenses and it is understood that they have been discontinued.

A feature of these lenses was that the power increased continuously from the top of the lens to the bottom, the addition being reckoned as the difference in power between two points 36 mm apart on a vertical median line.

In 1958, the writer had an opportunity of examining a pair of these lenses and was impressed by the excellent quality of their surfaces. Only a few very faint waves were discernible, the nature and direction of which helped to throw light on the geometry of the surface.

It was stated in the trade pamphlet issued by Officine Galileo that the lenses were of patented construction. No patent number was quoted, but it is probable that the reference was to an Italian patent issued in 1958 to A. Carini, of Milan.

Group C: Guy Bach's Homastigmatic surface

From the manufacturing point of view, a serious drawback of the elephant's trunk construction is that it is not a surface of revolution. If it could be replaced by a surface of revolution having broadly similar properties, manufacture would become much easier. A highly ingenious solution has been propounded on the following lines.

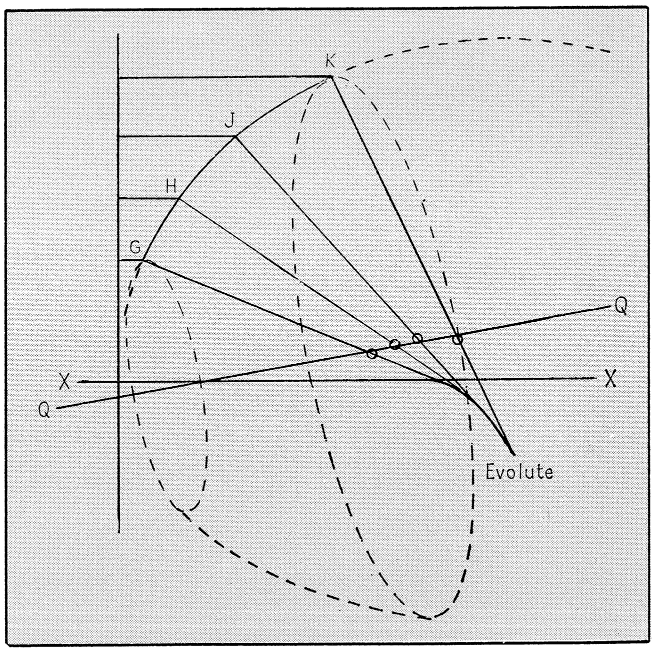

Fig. 27 Homastigmatic surface of the type originated by Guy Bach, produced by the revolution of the non-circular arc GK about the axis QQ

In Fig. 27, GK represents a portion of an ellipse with its major axis situated on the line XX. Revolution of the curve about XX as axis would produce an ellipsoidal surface, exhibiting progressive power and astigmatism of the type characterised by Table No. 2. Suppose, however, that the curve were to be rotated about another axis, QQ. In a tangential section (e.g., the plane of the diagram), nothing would alter. The tangential centres of curvature would remain on the evolute, at the points of contact with the normals to the curve. In the sagittal section, on the other hand, the centres of curvature would now be situated on QQ instead of on XX. There is thus a change of sagittal power at every point on the surface, and, therefore, a change in the amount of astigmatism.

If the astigmatism could be stabilised, instead of increasing continuously from the vertex outwards, we should have a surface of a type which the present writer proposes to term "homastigmatic". A surface of this kind would provide progressive power in a central vertical band, accompanied by an approximately constant astigmatic effect which could, however, be neutralised by the other surface of the lens.

A numerical example may be enlightening. The equation to any conic section may be written in the form

$$y^2 = 2r_0x - p\,x^2$$

in which r_0 denotes the radius of curvature at the vertex of the curve and p is a number related to the degree of peripheral flattening. At any point on the conicoid produced by the rotation of the conic about its axis of symmetry, the sagittal radius r_s is given by

$$r_s = \sqrt{r_0^2 + (1-p)^2}$$

and the tangential radius r_t by

$$r_t = r_s^3/r_0^2$$

In the original drawing reproduced as Fig. 27, the curve was part of an ellipse constructed from the equation

$$y^2 = 100x - 0{\cdot}8\,x^2$$

so that r_0 was 50 (mm) and p was 0·8. This radius corresponds to a surface power of 10·46 D if the refractive index is taken as 1·523.

The data presented in Table No. 3 were computed from these equations. The tangential radius at the points G, H, J and K is given in column (2) and the corresponding tangential surface powers in column (3). Column (4) shows the sagittal surface powers that would be needed to stabilise the astigmatism at 3·00 D and column (5) the corresponding sagittal radii of curvature. These lengths were marked off along the appropriate normals, thereby locating the desired sagittal centres of curvature, indicated by the small circles.

Although these centres lie on a curved line, it is possible to find a straight line such as QQ which passes very close to all of them. Consequently, if the curve GK were rotated about QQ, it would produce a reasonable approximation to a homastigmatic surface. Of course, the generating curve need not be limited to a conic.

Table 3
Data used to construct a homastigmatic surface (see Fig. 27)

(1) Distance y (mm)	(2) Tangential radius (mm)	(3) Tangential power (D)	(4) Desired sagittal power (D)	(5) Corresponding radius (mm)
50	65·72	+7·96	+10·96	47·7
40	59·88	+8·73	+11·73	44·6
30	55·50	+9·42	+12·42	42·1
20	52·40	+9·98	+12·98	40·3

All plane sections through a homastigmatic surface containing its axis of revolution are identical. A number of such sections are indicated by broken lines in Fig. 28, in which the circle represents part of the homastigmatic surface of Fig. 27 used as the front surface of a progressive power lens. In addition to any prescribed cylinder, the back surface would have to incorporate a −3·00 D cylinder axis vertical. This would approximately neutralise the cylindrical effect of the homastigmatic surface in a vertical band surrounding the median line MN. Elsewhere on the surface, unfortunately, the axis direction of the front surface cylindrical effect is not vertical (as indicated by the broken lines in Fig. 28). In consequence, there is a residual astigmatic effect similar in kind and degree to that exhibited by a surface of elephant's trunk construction.

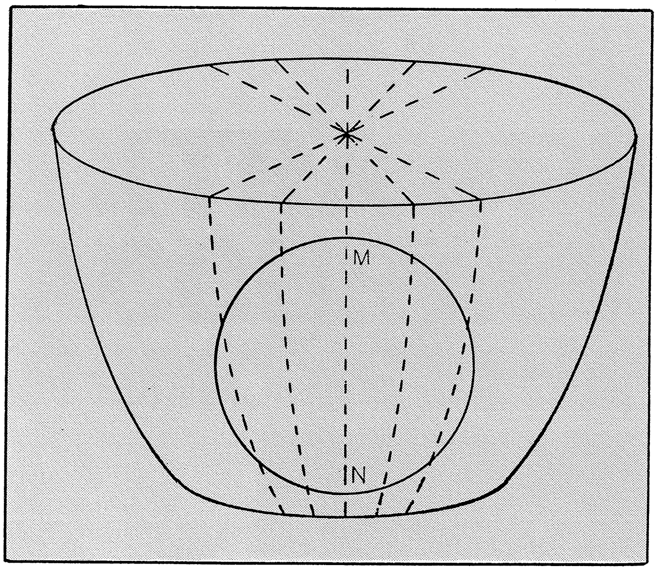

Fig. 28 Circular portion (median line MN) of a homastigmatic surface used for a progressive power lens, showing variation in axis direction from the median line outwards

The originator of this conception seems to have been Guy Bach, named as the inventor in a French patent issued in 1958 to Soc. Anon. des Manufactures des Glaces et Produits Chimiques de Saint-Gobain, Chauny & Cirey. This establishment, now known as Compagnie de Saint-Gobain, is understood to be willing to consider proposals from lens manufacturers interested in making such lenses under licence. The invention is also patented in Great Britain and certain other countries, but an application for an American patent was not granted.

The "Omnifocal" lens

In 1965 it was announced by House of Vision, Inc., of Chicago, that production of a range of progressive power lenses, to be named "Omnifocal", had commenced after 2 years of research and development. Distribution in the USA was to be undertaken by Univis, Inc., and the firm of Robinson-Houchin, Inc., of Columbus, Ohio, was named as one of the manufacturers.

The theoretical basis of these lenses had, in fact, been described some 3 years earlier in a paper by Volk and Weinberg in *Archives of Ophthalmology*. The principle does not appear to differ in essentials from the construction described in Compagnie de Saint-Gobain's patent. The authors refer to the progressive surface as "isostigmatic"—a term open to the objection that it does not convey the meaning intended. That is to say, the surface is not equally stigmatic but equally astigmatic.

It is understood that an application for an American patent was made in 1961 by Volk and Weinberg but has not so far come to fruition. A similar application, made in the name of J. C. Band, did, however, result in the grant of a British patent in 1966.

The patent specification includes a mathematical discussion of "isostigmatic" and related surface, and of manufacturing techniques.

(*to be continued*)

Variable and progressive power lenses

5. Conclusion

A. G. Bennett*

Group D: The concentric construction

One possible construction having the advantage of being a surface of revolution has occurred to a number of inventors. In its general arrangement the lens closely resembles a solid (one-piece) invisible trifocal of the concentric type, the intermediate portion being replaced by one of progressive power bridging the gap between distance and near. The essential features of the design are shown in Fig. 29 which is a section through a portion of the lens blank, drawn considerably out of scale in the interests of clarity. For the same reason, the illustration shows a flat lens form but it will be appreciated that a curved lens form would present the same essential geometrical features.

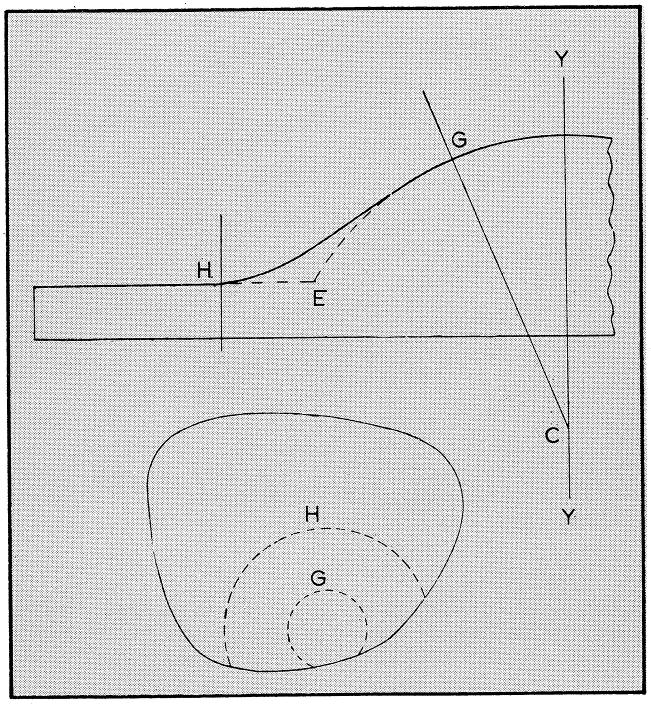

Fig. 29 The concentric type of progressive power lens. Upper figure: section through part of lens blank. Lower figure: front view of finished lens (on a smaller scale)

The central portion of the blank, the area in which the full near addition is operative, has its centre of curvature at C, situated on the axis of revolution of the blank, YY. The outer zone, corresponding to the distance portion, is plane and perpendicular to YY. If produced, these two surfaces would meet at E but are, in fact, separated by an intermediate zone of progressive curvature, extending from G to H. To present a continuous appearance free from dividing lines it is essential that the near and intermediate surfaces should share a common normal CG at their point of junction, and that the intermediate and distance portions should have a common normal at their point of junction H.

As the diagram makes clear, this latter condition is possible only if the intermediate surface becomes concave in the tangential meridian near its junction with the distance portion. In the sagittal section, however, the curvature remains convex because all the sagittal centres of curvature necessarily lie on the axis of revolution. Hence one would expect to find a negative addition combined with a strong plus cylinder immediately on passing from the distance to the progressive portion. This theoretical prediction has been confirmed by practical measurements reported by Knoll (1952).

The earliest patent based on this construction was probably granted in 1918 to A. E. Paige, of Philadelphia. In 1946, a patent for a lens of similar construction was issued to Howard D. Beach, a photographer, of Buffalo, New York. Lenses to this design were marketed in the USA by the Beach Lens Corporation.

The "Infinite Focal Lens", manufactured by the Franklin Optical Company, of Buffalo, New York, seems to be another member of this family. It has been described by Abbott. There are doubtless others.

An interesting member of this group is the lens patented in 1922 by Harold J. Stead of Geneva, New York—a well-known and greatly respected name in the American ophthalmic optical industry. In Stead's design, the intermediate band of progressive power is very narrow, and, in the admirably candid language of the patent specification, "is of non-optical character, of irregular and uncertain curvature . . .". Stead was under the impression that the eyes were "severely shocked" by an abrupt change of power from distance to near and vice versa, and that a gradual transition even of mediocre quality would be an improvement.

H. J. Birchall

The remarkable efforts of the late H. J. Birchall, for several years the managing director of Messrs. C. W. Dixey & Son Ltd, to develop a practical form of progressive power lens have never been publicised. Except to the handful of people directly involved, they are still unknown. The writer is delighted to have this opportunity of inviting a wider public acclaim for Birchall's pioneer work.

It was very largely a private venture, but Birchall nevertheless patented a number of different constructions, one of which might possibly have been developed into a commercial success. He was convinced that there was a future for progressive power lenses, and was encouraged by the reports of patients, friends, and colleagues for whom he made lenses to their own prescriptions.

In an unpublished manuscript dated December 14, 1944, Birchall summarised the progress he had made up to that time. It is a fascinating document. The writer frankly declared that his approach was practical, rather than mathematical, and commented: ". . . I have found it sufficiently difficult to work out a method by which such lenses could be economically produced at all and I am quite content that improvements in quality of surface and the correction of form defects shall evolve as a consequence of experience gained in their manufacture and use in ordinary everyday conditions."

* Department of Ophthalmic Optics and Visual Science, The City University.

The manuscript also throws light on Birchall's two patents. The first of these, published in 1934, was for a progressive power lens having one surface of elephant's trunk construction, the lens being used either singly or, for certain purposes, in combination with other similar lenses. At this stage it must be admitted that the term "elephant's trunk", for which the present writer accepts responsibility, lacks precision. It covers a whole family of surfaces, the essential common feature being that at every point on a vertical median line, the horizontal and vertical curvatures are equal to each other though increasing continuously from the top downwards.

To define the surface more exactly it would be necessary to specify its equation in three-dimensional co-ordinates. Alternatively, one could specify the equation to the curve in a vertical section along the median line and the nature of sections in planes perpendicular to the median line.

Birchall's first patent did not specify the equation to the curve along the median line but made it clear that all sections perpendicular to it were circular. The patent specification included details of a machine for producing such surfaces.

The later patent, applied for in 1945 and obtained in 1948, embodies two significant developments. One is explained in Fig. 30, reproduced from Birchall's manuscript. Fig. 30(a) illustrates the appearance of a square grid viewed through a lens of Birchall's original construction. Birchall concluded that a better effect would be obtained by modifying the surface such that all sections perpendicular to the vertical median line decreased in curvature from the middle of the lens outwards. The appearance of a square grid would then be as illustrated in Fig. 30(b).

The second and more important development is summarised in Claim 2 of the patent specification, which covers a lens in which a progressive surface merges into a spherical surface at either or both ends. Fig. 31, also reproduced from the manuscript, illustrates the type of lens envisaged. Birchall remarks that "It is also possible to decentre the lower half of the lens gradually at the same time as the power is increased".

Birchall's untimely decease in 1952 unfortunately brought his work to an end. In paying tribute to his memory one should also recall the name of the late C. L. Winter, the gifted engineer who worked with him for many years.

Group E: Varilux and similar lenses

Varilux lenses, introduced by the Société des Lunetiers (Essel) in 1959, are the only progressive power lenses to have achieved a considerable commercial success. They are very much the creation of Bernard Maitenaz, who found in their development an ideal outlet for his outstanding talents as an optical designer, mathematician, and engineer.

Maitenaz has himself described the study and experimentation which preceded the final choice of lens design. Several different constructions were considered and rejected before the final decision was taken.

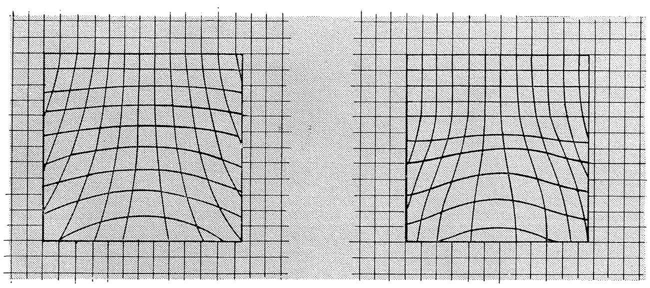

Fig. 30. Sketches reproduced from the late H. J. Birchall's unpublished manuscript: (a) Magnification effect of a lens made in accordance with his original patent. (b) Effect of a lens made in accordance with his later patent

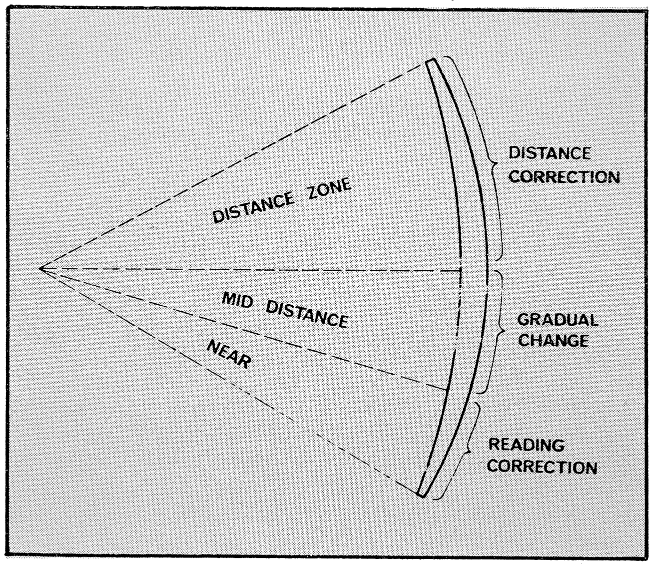

Fig. 31. Sketch from H. J. Birchall's manuscript showing a progressive power lens with areas of uniform power for distance and near

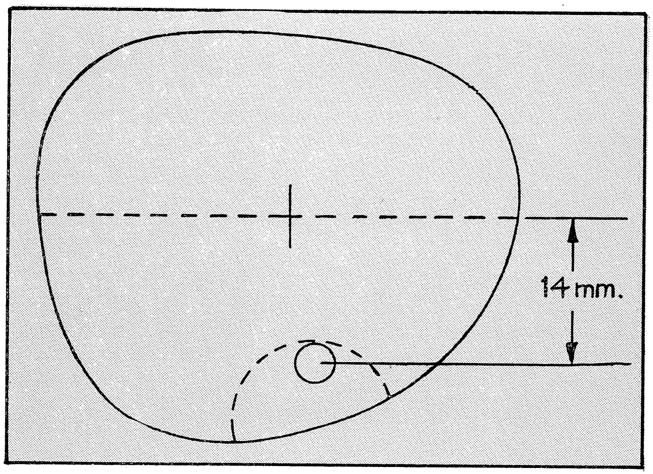

Fig. 32. The Varilux lens

As far as can be deduced from a study of the Essel patents and publications, and of Varilux lenses themselves, the construction of the operative surface is approximately as follows. The upper half, down to an invisible horizontal line of junction, is spherical. There is then a change to a surface of elephant's trunk construction having the same horizontal radius of curvature at the line of junction. To allow for the convergence of the eyes, the median line of this part of the surface is inclined downwards and inwards. At 12 mm below the horizontal line of junction the progressive surface merges into another spherical portion which has the curvature demanded by the full near addition. The diameter of this spherical area varies from about 20–21 mm to about 15–16 mm as the near addition increases. Its boundary is quite invisible and there is no image jump at the top.

The arrangement of the various portions of the lens is illustrated in Fig. 32. For purposes of verification of the near addition, a small circle with its centre 14 mm below the line of junction and 2·5 mm inwards from the distance optical centre is employed.

In a straight-top segment solid bifocal of the "Executive" type, the ridge increases in depth from the centre outwards. In a somewhat analogous fashion, the optical change at the horizontal line of junction of a Varilux lens becomes more marked and abrupt towards the periphery.

It generally takes the successful wearer up to a week or more to accustom himself to the peculiarities of Varilux lenses. Some of these are due to the construction of the lens itself but others are inherent in any surface of progressive power. For example, as objects are viewed in indirect vision through different portions of the lens, when the head is moved, there is an apparent undulation aptly termed by the French *balancement*. This is an inescapable consequence of the change in magnification inseparable from progressive power.

Accuracy in fitting all lenses of this type is essential. The distance of the pupil centre from the bridge of the nose should be measured for each eye independently, and any difference in the level of the pupils should be taken into account.

Ingenuity of a very high order is needed to produce such complex surfaces to an acceptable standard of quality. It is not the least of Maitenaz's achievements to have solved these daunting practical difficulties in addition to the theoretical problems of the lens design.

A plastics version of the Varilux lens, made from C.R.39, was introduced into Great Britain in 1966 under the trade-name "Variplas".

The "Zoom" lens, introduced a few years ago by the French firm Benoist Berthiot, appears to have a basic construction very similar to that of the Varilux lens, though differing in minor points of detail. It can certainly be regarded as belonging to the same category. This remark applies also to the "Gradal" and "Progressiv" lenses marketed in West Germany by Zeiss and Rodenstock respectively.

Group F: Variable refractive index lenses

One other possible way of producing a progressive power effect would be to use a lens material having a controlled local variation of refractive index. In 1963, J. R. Benford and C. H. Brumley, of Bausch & Lomb, Inc., applied for a United States patent for a lens embodying this idea. The application does not appear to have been granted but patents have been obtained in France and Great Britain, possibly in other countries as well.

The English and French patents make reference to an American patent granted in 1950 to H. H. Spiegel, of the Bell & Howell Company, Chicago. This covers the composition and thermal treatment of a molten glass batch so as to produce a variation in refractive index through at least a portion of the batch. It is claimed in the specification that the variation in refractive index is of the order of 0·012 over a length of 0·612 in. This is clearly insufficient to produce an effect of the magnitude demanded by a progressive power lens.

In the Bausch & Lomb patent, the construction shown in the drawing is a round-segment fused bifocal in which the segment varies in refractive index from 1·523 at the top to 1·665 at the centre. Other possible constructions are mentioned, but one wonders whether the technical means of realising so large an index difference over so short a distance are yet in existence.

An earlier Belgian patent based on variable refractive index in a different form was issued in 1961 to A. de Candt. This patent covers a large number of different constructions, some of them relating to contact lenses. A common feature is the introduction of a liquid, which can be changed, or two or more liquids of different specific gravity and refractive index, into the cavity of a hollow lens.

The earliest patent for a variable index construction was probably that granted in 1924 to L. W. Bugbee, of Indianapolis. The method he proposed was to make a fused bifocal in which the segment was composed of at least three different glasses of different refractive indices. Small nodules of each of these materials were to be arranged in concentric zones, the highest refractive index in the centre. In the fusing process they would unite to form a single segment indistinguishable in appearance from an ordinary fused segment. Bugbee's patent was assigned to the Franklin Optical Co. but does not appear to have borne fruit.

Group G: Miscellaneous designs

It now remains to describe a number of progressive power lenses which cannot be fitted into any of the categories already discussed.

In 1920, the same A. E. Paige who had previously obtained a patent for a concentric type of progressive power lens obtained a patent for another lens of ingenious construction but doubtful utility.

The lens was in curved form, the front surface being differently worked above and below a horizontal line. The upper half of the surface was spherical and the lower half toroidal, its shallower principal meridian being horizontal and of the same curvature as the spherical portion. For example, the upper part might have had a spherical power of +6·00D and the lower part a power of +6·00D horizontally and +8·00D vertically. There would be no obvious dividing line, and the effect would be that of a bifocal with a near addition consisting of a plus cylinder axis horizontal.

There is, of course, no element of variable or progressive power in this construction. It has been mentioned only because of its similarity to a later lens, claimed to have progressive power, patented in 1924 by Dr A. Estelle Glancy, of American Optical Company.

In Dr Glancy's invention, the lower half of the convex surface was not toroidal in the orthodox sense of that term, though its curvature did vary from a minimum in the horizontal to a maximum in the vertical. The precise form of surface envisaged was that generated by a circle, initially horizontal, rotating about a diameter but continuously decreasing in size until it was vertical and then gradually reverting to its original size as it again approached the horizontal. During this process, its vertex remains at the same fixed point.

Dr. Glancy's argument was that since this surface is truly circular in any oblique section, it must be free from astigmatism, and that the power varies in different meridians from a minimum in the horizontal to a maximum in the vertical.

It seems to the writer that this invention is based on a misconception. The surface described is fundamentally an astigmatic one, its departure from an orthodox toroidal surface being of a secondary nature. Like all astigmatic surfaces it has only two principal powers. The idea that there can be intermediate "powers" in oblique meridians of an astigmatic lens or surface has been shown by many writers to be fallacious.

Meyrowitz's fused bifocal

A novel approach is embodied in a patent issued in 1923 to E. B. Meyrowitz, founder of the international firm of dispensing opticians bearing his name. His idea was to make a fused bifocal with the contact surface of aspherical form, being more steeply curved at the vertex than at the periphery. To produce this surface he suggested that it be divided into a number of concentric zones, each worked with a slightly different spherical curvature. The polishing process, it was argued, would remove the dividing lines and merge the various zones into a continuous surface of the type desired.

J. H. Jeffree's patent

Unwanted astigmatism is the most common defect of progressive power surfaces. A number of designers have attempted to improve matters by using one surface of the lens to neutralise, if only to a partial extent, the unwanted astigmatism created by the other surface.

For example, in J. H. Jeffree's patent, obtained in 1957, two surfaces of progressive power are used in conjunction, each being more steeply curved in the horizontal than in the vertical meridian. A method of arriving at a preliminary design is explained but it is emphasised that much subsequent calculation may be necessary. According to this invention, either or both surfaces may be surfaces of revolution, in which case they would have some affinity with Bach's homastigmatic surfaces.

A. and R. Fritz's patent

A more recent Belgian patent by A. and R. Fritz also utilises two unconventional surfaces, rather in the manner of Owen Aves's construction but in curved form. This combination of surfaces would produce approximately the same optical effect as a single surface of elephant's trunk construction. There are no apparent advantages to offset the greater difficulty of production.

The Lau–Jaeckel–Riekher lens

A progressive power lens has been developed at the Institut für Optik und Spektroskopie (East Berlin) by Lau, Jaeckel, and Riekher. To the best of the writer's knowledge, this lens has not yet gone into regular commercial production but a number have evidently been made for clinical trials.

The original East German patent, granted in 1954 but published in 1959, is exceptionally uninformative. Little can be gleaned from the diagram, which is not even mentioned in the text, and the nature of the progressive surface is not disclosed. Although it is claimed that the unwanted astigmatism inherent in the progressive surface is neutralised, at least in part, by the oblique astigmatism due to the lens form, no data are put forward to justify this assertion.

The West German Auslegeschrift patent, published in 1969, is a little more informative, and a few further details can be pieced together from individual papers by Lau (1956), Jaeckel (1958), Mütze (1961), and Reiner (1967).

It would appear that the front (progressive) surface of the lens is a surface of revolution, the central portion of the generating curve being of progressive curvature and the surrounding portion circular. The two portions of the curve could meet without discontinuity at a common normal but the centre of curvature of the circular portion would necessarily be offset from the axis of revolution. This means that the distance portion of the surface would be unavoidably afflicted with unwanted astigmatism. On the other hand, there would be no unwanted astigmatism at the vertex of the generating curve, at which point the reading addition would reach its maximum value.

The Kanolt–Farrand lens

Another approach to the problem of reducing unwanted astigmatism is described in great detail in a patent issued in 1959 to C. W. Kanolt. Briefly, the principle is to divide the lens into a number of areas bounded by straight lines. Different curves are worked in these areas. Nevertheless the equations to the various curves are so chosen that there is no apparent discontinuity at any dividing line. Various possible constructions of this type are discussed, the performance of each being presented graphically in diagrams resembling contour maps. Fig. 33(a), for example, shows the variation in spherical power over the entire area of one of the Kanolt lenses, while Fig. 33(b) shows the amount of residual astigmatism in various areas of the same lens.

The patent rights have been assigned to the Farrand Optical Co., Inc., of New York. The writer is unable to say whether manufacture of these lenses has been undertaken or is contemplated, an enquiry addressed to the firm concerned having elicited no response.

Optical and clinical evaluations

A number of studies have been published in which progressive power lenses of various kinds have been evaluated from a wearer's standpoint. Though this aspect of progressive power lenses falls somewhat outside the scope of the present study, some of the more notable papers will be mentioned here.

One objective method of evaluation is to explore local variations in power, including any unwanted astigmatism inherent in the lens construction, with the aid of a specially adapted focimeter. This method was used by Knoll in 1952 to examine a central vertical band of a Beach lens. Ten years later, Knoll published the results of a similar study of Varilux and Varifocal lenses, together with the Younger Seamless Bifocal which does not purport to be a progressive power lens.

A more extensive exploration of a Varilux lens was made in 1961 by Reiner, using a large number of focimeter readings to construct a contour map showing the various degrees of unwanted astigmatism. In 1967 he published similar contour maps of Lau–Jaeckel–Riekher, Varilux, and Omnifocal lenses. In two subsequent papers, Reiner made a similar analysis of other progressive power lenses that had recently been introduced. A map of the dioptric power at various points on a Varilux lens, based on focimeter readings, was published by I. Bennett *et al.* in 1965.

Theoretical studies from different viewpoints of the nature of the retinal image obtained with progressive power surfaces have been published by Le Grand and Maitenaz, both in 1967.

A clinical evaluation of Lau–Jaeckel–Riekher lenses was included in a paper by Mütze presented in 1962. Clinical evaluations of Varilux lenses have been made by Bruens (1967 and 1968) and by Vesper (1964) who also included Lau–Jaeckel–Riekher lenses in the scope of his study. Many other papers on clinical experiences with Varilux lenses have appeared.

A suggested new design

So many ideas in this field have been put forward only to be forgotten that one more will make little difference. With no hope at all that it will ever be realised, the writer would like to end this review by presenting an idea of his own.

Every progressive power lens designed so far has been free from visible dividing lines. This is not an essential requirement. The great success achieved in recent years by straight-top segment solid bifocals has demonstrated that the presence of a visible ridge is tolerated if the lens is functionally efficient. The freedom from vertical image jump characteristic of these lenses means in practice that

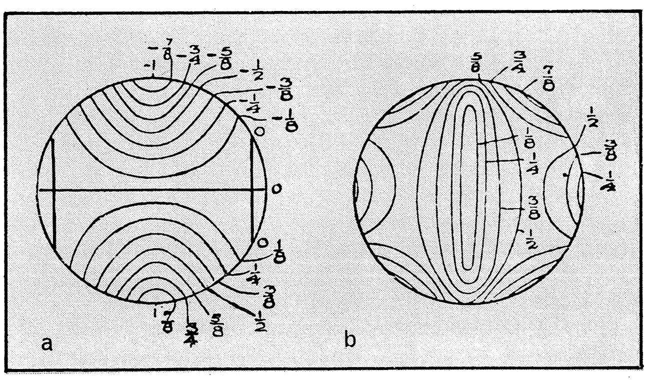

Fig. 33. One of the Kanolt–Farrand lenses: (a) Lines showing power variation in 1/8D intervals from −1·00D at the top to +1·00D at the bottom. (b) Lines showing areas of residual astigmatism in 1/8D steps

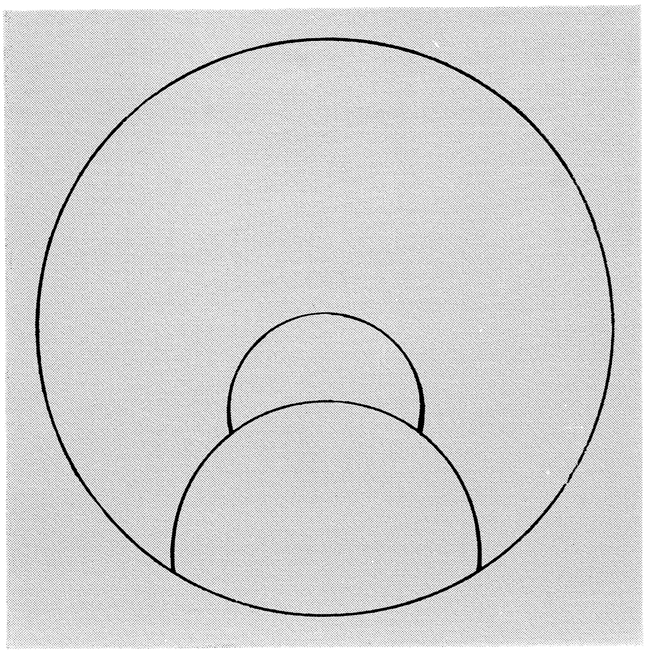

Fig. 34 The present writer's suggestion for a progressive power lens

the field of view appears to be just as continuous as with a progressive power lens.

With this in mind, the writer suggests a lens made as illustrated in Fig. 34. In principle it could be produced by taking a finished lens to the distance prescription and sinking in it a segment of about 20 mm diameter, ground at such an angle as to eliminate image jump at its top. The segment surface would be of elephant's trunk construction giving a progressive addition up to, say, +1·50D at 10 mm below the top.

To provide a reading portion of uniform power, a second segment of spherical curvature and of any desired power and diameter would then be ground into the lens, obliterating the bottom part of the first segment. This surface, too would be ground so as to eliminate image jump at the dividing line.

A lens so made would have no wasted areas of indistinct vision and would present no greater problems of adaptation than conventional trifocals.

The ideal correction for presbyopia would restore to the eyes' focusing that element of flexibility previously supplied by the crystalline lens.

Immense effort has been devoted by many people in various countries to the quest for this ideal lens. Many different avenues have been explored. It has been the aim of this paper to furnish a comprehensive account of the solutions propounded to date, and to promote a better understanding of the formidable problems to be surmounted. One hopes, also, that the account here given may serve as a stimulus to further thought and invention.

In preparing this study the writer greatly profited by earlier reviews, notably those by von Rohr (1916) and Graham (1942) but has subsequently gleaned much additional information, not generally known, from patent literature and other sources. Many gaps must nevertheless remain, and any reader who can help to fill them is requested to communicate with the writer or the Editor.

Acknowledgements

The writer is indebted to Prof. L. W. Alvarez, Dr B. M. Wright, and to several of the firms mentioned in this paper for their helpful replies to his inquiries. The directors of Messrs C. W. Dixey & Son Ltd were kind enough to allow him access to their files on the late Mr Birchall's patents.

The resources of a number of libraries were made available, and the writer greatly appreciates the assistance given by the Librarian and staff of the British Museum, the British Optical Association, the Institute of Electrical Engineers, the Institute of Ophthalmology, and the National Reference Library of Science and Invention (formerly the Patent Office Library).

A copy of Rudin's paper was kindly supplied by the Librarian of the Royal Society of Medicine and translated by Mrs H. Schlesinger.

Herr Ernst Hammon, of Optische Werke G. Rodenstock, Munich, must also be thanked for his assistance with Vol. 1 of the Central-Zeitung für Optik und Mechanik, published in 1880.

References

Abbott, A. N., "The infinite focal lens", *Optom. Wkly*, **44**, 417–418, 1953.

Alvarez, L. W., "Two-element variable-power spherical lens", U.S. Pat. 3,305,294 (1967).

Alvarez, L. W. and Humphrey, W. E., "Variable-power lens and system", U.S. Pat. 3,507,565 (1970).

American Optical Company, see Boeder, P. A. K., Glancy, A. Estelle and Gordon, R. L.

Anderson, T., "On a varying cylindrical lens", *Rep. Br. Ass. Advmt Sci.* (56th meeting), 520–521, 1886.

Aves, O., "Improvements in and relating to multifocal lenses and the like, and the method of grinding same", Brit. Pat. 15,735 (1907).

Aves, O., "Multifocal surfacing" (Correspondence), *Optn photogr. Trade J.*, **46**, 135, 1913.

Babcock, F. G., "Lens", U.S. Pat. 1,692,973 (1928).

Bach, G., see Manufactures des Glaces, etc.

Band, J. C., "Ophthalmic lens and method of making same", Brit. Pat. 1,032,541 (1966).

Bausch & Lomb Inc., "Ophthalmic lenses", Brit. Pat. 1,029,766 (1966).

Beach, H. D., "Lens", U.S. Pat. 2,405,989 (1946). See also Brit. Pat. 585,913 (1947).

Bell & Howell Co., see Spiegel, H. H.

Benford, J. R., see Bausch & Lomb Inc.

Bennett, I., *et al.*, "The Varilux variable power lens—a report and evaluation", *Opt. J. Rev. Optom.*, **102** (18), 47–57, 1965.

Bibard, R. A., "Lunettes accomodatrices pour le champ moyen de la vision", Fr. Pat. 628,316 (1927). See also Brit. Pat. 282,460 (1928).

Birchall, H. J., "Improvements in lenses and in their combination and arrangement in various instruments and apparatus", Brit. Pat. 413,670 (1934).

Birchall, H. J., Unpublished manuscript dated December 14, 1944.

Birchall, H. J., "Improvements in and relating to lenses", Brit. Pat. 596,655 (1948).

Boeder, P. A. K., "Variable power bifocal lens", U.S. Pat. 2,642,776 (1953).

Bruens, E., "Praxiserfahrungen mit Varilux", *Klin. Mbl. Augenheilk.*, **151**, 737–751, 1967.

Bruens, E., "Über die 'Verkehrstüchtigkeit von Varilux-Gläsern' ", *Klin. Mbl. Augenheilk.*, **152**, 598–599, 1968.

Brumley, C. H., see Bausch & Lomb Inc.

Bugbee, L. W., "Process of making fused bifocal lenses", U.S. Pat. 1,483,509 (1924).

Carini, A., "Lente a fuoco variabile", Ital. Pat. 572,275 (1958).

Chamboissier, A. D., "Lentilles hydrauliques et leur réalisation", Fr. Pat. 1,216,652 (1960).

Chiesa, R., "Brille", D.R. (German) Pat. 78,652 (1894).

Compagnie de Saint-Gobain, see Manufactures des Glaces, etc.

Cusco, Dr, "Système de lentille à foyer variable sans déplacement", Fr. Pat. 129,293 (1879).

Cusco, Dr, "Sur un instrument dioptrique destiné à l'étude de l'accommodation", *Annls Oculist.*, **81**, 181–183, 1879 (reprinted from *Bull. Acad. Méd.*, **8**, 261–264, 1879).

De Candt, A., "Dispositif optique à une ou plusieurs distances focales", Belg. Pat. 1,279,252 (1961).

Dixon, H., "Telescopes, microscopes, spectacles, etc.", Brit. Pat. 1,515 (1785).

Duke-Elder, W. S., "The Practice of Refraction", London, Churchill, 1928.

Egoroff, N., "Modification de la lentille à foyer variable de M. Cusco", (Abstract), *J. Phys. théor. appl.*, **8**, 540, 1889.
Eilenberg, S. and Eilenberg, G., "Photographic apparatus", U.S. Pat. 1,771,844 (1930).
Evans, C. E., "Spectacle lens", U.S. Pat. 2,109,474 (1938).
Fagioli, O., "Lenti deformabili per variare con continuità la distanza focale, con particolare applicazione agli occhiali", Ital. Pat. 520,933 (1955).
Farrand Optical Co. Inc., see Kanolt, C. W.
Fritz, R. and Fritz, A., "Lentilles optiques", Belg. Pat. 493,058 (1950).
Fritz, R. and Fritz, A., "Lentilles optiques", Belg. Pat. 499,449 (1951).
Gariel, C. M., "La lentille à foyer variable du Dr. Cusco", *Séanc. Soc. fr. Phys.*, 57–61, 1880.
Gauthier, R., "Nouveaux verres pour la correction de la vue", Fr. Pat. 1,150,951 (1958).
Glancy, A. Estelle, "Ophthalmic lens", U.S. Pat. 1,518,405 (1924).
Gordon, R. L., "Lens", U.S. Pat. 1,269,422 (1918).
Gowlland, H. O., "Multi-focal lens", Can. Pat. 159,395 (1914). See also Brit. Pats. 3,776 (1915) and 5,583 (1915).
Graham, R., "Variable focus lenses", *Am. J. Optom.*, **19**, 437–443, 1942.
Graham, R. K., "Optical instrument", U.S. Pat. 2,269,905 (1942).
Grunberg, G., "Lentille à foyer variable", Fr. Pat. 1,117,690 (1956).
Jaeckel, G., "Die Mehrkreisevolvente als Hilfsmittel für die Berechnung asphärischer Brillengläser", *Optik. Stuttg.*, **15**, 606–611, 1958.
Jeffree, J. H., "Improvements in or relating to lenses", Brit. Pat. 775,007 (1957).
Jung, R. (Correspondence), *ZenZtg Opt. Mech.*, **1**, 192, 1880.
Kanolt, C. W., "Multifocal ophthalmic lenses", U.S. Pat. 2,878,721 (1959).
Kitajima, I., "Improvements in lenses", Brit. Pat. 250,268 (1926).
Kitchener, W., *The Economy of the Eyes*, London, Hurst Robinson, 1824.
Knoll, H. A., "The optical characteristics of Beach blended bifocals", *Am. J. Optom.*, **29**, 150–154, 1952.
Knoll, H. A., "The optical characteristics of so-called invisible bifocals", *Am. J. Optom.*, **39**, 538–542, 1962.
Lau, E., "Weiterentwicklung in der Brillenoptik", *Mschr. Feinmech. Opt.*, **73**, 325–327, 1956.
Lau, E., Jaeckel, G. and Riekher, R., "Brillenglas mit gleitender Dioptrienzahl", D.D.R. (East German) Pat. 17,853 (1959). See also West German Auslegeschrift 1,422,125 (1969).
Lauber, H., "Die Akkommodationsbrille", *Albrecht v. Graefes Arch. Ophthal.*, **89**, 401–407, 1915.
Le Grand, Y., "Image d'un point dans un verre progressif", *Revue Opt. théor. instrum.*, **46**, 229–233, 1967.
Lewis, R. W., "Lens and method of producing it", U.S. Pat. 2,263,509 (1941).
Luce, L. E., "Magnifying and condensing device", U.S. Pat. 2,051,791 (1936).
Maitenaz, B., "Variable power lenses", *Int. opt. Congr., 1961*, 533–545, 1962.
Maitenaz, B., "Neue Forschungen über die Anwendung der neuen progressiven Oberflächen als Korrektionshilfsmittel", *Augenoptiker*, **17** (7), 8–14, 1962.
Maitenaz, B., "Fünf Jahre danach . . .". *Augenoptiker*, **19** (8), 22–25, 1964.
Maitenaz, B., "Four steps that led to Varilux", *Am. J. Optom.*, **43**, 441–450, 1966.
Maitenaz, B., "Variplas, the plastics version of Varilux", *Ophthalmic Optician*, **6**, 909–913, 927, 1966.
Maitenaz, B., "Image rétinienne donnée par un verre correcteur de puissance progressive", *Revue Opt. théor. instrum.*, **46**, 233–241, 1967.
Manganotti, R., "Lenti e specchi sferici a fuoco regolabile", Ital. Pat. 469,768 (1952).
Manufactures des Glaces et Produits Chimiques de Saint-Gobain, Chauny & Cirey, "Systeme optique", Fr. Pat. 1,159,286 (1958) and Fr. Pat. of Addition 72,175 (1960). See also Brit. Pat. 876,798 (1961).
Meyer, J., "Doppelbrille", D.R. (German) Pat. 248,851 (1912).
Meyrowitz, E. B., "Lens for eyeglasses and spectacles", U.S. Pat. 1,445,227 (1923).
Mitchell, F. B., "Improvements in optical lenses and the like", Brit. Pat. 258,325 (1926).
Mütze, K., "Das Mehrstärkenglas mit gleitender Wirkung", *Süddt. OptZtg*, **16**, 254–258, 1961.
Mütze, K., "Über die Verträglichkeit der Mehrstärkenbrille mit sich stetig ändernder Wirkung nach Lau-Jaeckel-Riekher", *Augenoptiker*, **17** (6), 14–17, 1962.
Newbold, H., "In the year 1970" (Correspondence), *Optn photogr. Trade J.*, **46**, 88–89, 1913.
Newbold, H., " 'Multifocals' in the year 1907" (Correspondence), *Optn photogr. Trade J.*, **46**, 142, 1913.
Newbold, H. and Williams, W. R., "Improvements in bi-focal lenses and apparatus for their manufacture", Brit. Pat. 5,441 (1912).
Officine Galileo di Milano, *Lenti oftalmiche varifocal* (trade pamphlet), Milan, no date.
Ohmart, E. C., "Device for reflecting and refracting radiant energy", U.S. Pat. 504,890 (1893).
Orford, H., "Manufacture of lenses for spectacles or eye-glasses", U.S. Pat. 943,449 (1909).
Paige, A. E., "Multifocal optical element", U.S. Pat. 1,271,359 (1918).
Paige, A. E., "Multifocal optical element and method and means for making the same", U.S. Pat. 1,351,785 (1920).
Poullain, A. G. and Cornet, D. H. J., "Perfectionnements dans les verres de lunetterie et moyens de les réaliser", Fr. Pat. 418,583 (1920). See also Brit. Pat. 16,698 (1911) and U.S. Pat. 1,143,316 (1915).
Reiner, J., "Brillengläser mit gleitender optischer Wirkung", *Süddt. OptZtg*, **16**, 114–118, 1961.
Reiner, J., "Brillengläser mit gleitender (progressiver) optischer Wirkung", *Klin. Mbl. Augenheilk.*, **151**, 239–248, 1967.
Reiner, J., "Ein neues Brillenglas mit gleitender Dioptrienzahl", *Klin. Mbl. Augenheilk.*, **152**, 594–598, 1968.
Reiner, J., "Ein verbessertes Brillenglas mit gleitender (progressiver) Wirkung", *Klin. Mbl. Augenheilk.*, **157**, 556–560, 1970.
Ritzmann, K., "Linse mit veränderlicher optischer Wirkung", D.R. (German) Pat. 628,774 (1936).
Rudin, V., "Akkommodiruyushchie ochki", *Vêst. Oftal., Kiev*, **29**, 246–247, 1912.
Schaller, D. G., "Vorrichtung zur Scharfeinstellung elastischer und fester Objektive photographischer Kameras mittels eines Sucher-Prismas", D.R. (German) Pat. 258,963 (1913).
Schröder, H., (Correspondence), *ZenZtg Opt. Mech.*, **1**, 169, 1880.
Schwarz, O., "Linienschleifschablone zur Herstellung einer Schleifschale", D.R. (German) Pat. 352,758 (1922).
Schwarz, O., "Augenglas, insbesondere Star-Augenlinse für akkommodationslose Augen", German Pat. 871,076 (1953).
Societe Industrielle et Commerciale des Ouvriers Lunetiers (Cottet. Poichet. Tagnon & Cie), "Systèmes optiques à puissance localement variable", Fr. Pat. 1,095,375 (1955) and Fr. Pats. of Addition 67,060 (1957) and 67,669 (1958). See also Brit. Pats. 790,310 (1958) and 816,338 (1959).
Spiegel, H. H. "Method of producing optical glass of varied refractive index", U.S. Pat. 2,511,517 (1950).
Stead, H. J., "Bifocal lens and method of manufacturing the same", U.S. Pat. 1,413,945 (1922).
Steinmark, H., "Lenses and lens systems of variable power", Brit. Pat. 644,898 (1950).
Vesper, G., "Erfahrungen bei der Verordnung von Brillen mit gleitender Brechkraft verschiedener optischer Systeme", *Klin. Mbl. Augenheilk.*, **144**, 240–246, 1964.
Volk, D. and Weinberg, J. W., "The Omnifocal lens for presbyopia", *Archs Ophthal., N.Y.*, **68**, 776–784, 1962.
von Rohr, M., "Über Bifokal-und andere Brillen zur Unterstützung des Altersauges", *Z. ophthal. Opt.*, **4**, 85–122, 1916.
Wagner, R., "Über Linsen stetig veränderlicher Brechkraft, sowie akkomodierende Brillen", *Z. Biol.*, **104**, 315–319, 1951.

A note on patents

Inventions are frequently patented in more than one country. The above references give the title and details of the original patent. The number and date of the corresponding British patent is given whenever known but details of patents taken out in additional countries are given only if mentioned in the text. The data quoted is that of publication, which is not necessarily the date on which the patent came into force.