Novel and flexible method of generating aspheric glass moulds
Vichare, Parag; Sudin, Izman; Venkatesh, Vellore; Woo, Calvin; Murugan, Shree

Published in:
Journal of Machine Engineering

Published: 01/01/2005

Document Version
Publisher's PDF, also known as Version of record

Link to publication on the UWS Academic Portal

Citation for published version (APA):

General rights
Copyright and moral rights for the publications made accessible in the UWS Academic Portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

This is an Open Access item distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way.

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.
NOVEL AND FLEXIBLE METHOD OF GENERATING ASPHERIC GLASS MOULDS

The work described in this paper is about the efforts towards simplifying the lens making process. The different processes are studied by the author and a new process is developed for making glass moulds to produce aspheric lenses. The new process uses general purpose machine like vertical machining centre. Present process of generating these lenses utilizes special purpose machines, which are capable of producing the lenses of single geometry at a time. The setup time to make a lens of different geometry with these machines is the main bottleneck for the flexible production system. The potentials of the vertical machining centre have been exploded for its use to manufacture aspheric glass moulds. The process is giving better results with use of newly developed technique to generate aspheric surfaces. The resulting surface were showing the sign of partial ductile mode machining giving form error in the profile less than 2%.

1. INTRODUCTION

For an astonishingly large number of people in poor countries, uncorrected vision prevents them from doing the things some of us take care for granted, like reading street signs or comparing ads to decide which market has the best price. According to world health organization, as many as billion people need vision correction but will never get it. Eyeglasses are scarce in developing nations because they cost too much for the average person, some time more costly than average monthly income, causing just few peoples qualified to diagnose eye problems and then provide the proper corrective lenses. In addition to this today, the optical industry requires aspheric optics not only for the visible spectrum, but also for high power and short wavelength radiation (eg X-rays, etc). At these wavelengths, a great necessity exists for aspheric surfaces on brittle materials, presenting the challenge of producing such complex optics as quickly as possible and at the lowest possible cost.

The materials like glass are brittle, and the requirements for the surface roughness and shape accuracy of the lenses are extremely rigid. Traditionally several manufacturing processes are necessary to machine them. In the finishing process, loose abrasives are

* Faculty of Mechanical Engineering, University Technology Malaysia, Malaysia
usually used and manual operations are carried out by trial and error while repeatedly performing shape inspections. If the surface finish and profile accuracy is not good in the generation process, the finishing process time would be very long as the amount removed can be very large and finish machining would be time consuming. It has been long for manufacturer’s dream to automatically generate the aspheric surface with high degree of accuracy and low surface roughness. If the surface with high shape accuracy and low surface roughness can be obtained by means of automatic grinding operation, it may be good enough to eliminate or reduce polishing cycle time.

The researchers are continuously trying find out a means of manufacturing the aspheric lenses, which is cost effective and quite flexible. The work describe in this paper is an addendum to their work. The research work in this paper references to the previous attempts of generating aspheric surface by using cup wheel. The fundamental idea for using cup wheel is to make use of general purpose tooling instead of special purpose tooling for generating aspherics. The use of general toolings like cup wheel could give an opportunity to manufacturers being capable of producing optical products by using general purpose machine like VMC.

2. GENERATING ASPHERIC SURFACE METHODS

2.1 CONCEPT OF THE ZONE ASPHERIC GENERATION

Van Ligten and Venkatesh [1] developed a new technique for aspheric generation that makes use of cup wheel for generating aspherics. They used 4 and 5 axis vertical CNC machining centres that incorporate a tilting rotary table and its rotary motion.

![Fig. 1 Basic principle of grinding by zone (a) Cutting plane of paraboloid (b) Resulting cutting plane of paraboloid gives best arc contact of cup wheel with the truncated parabolic surface.](image)

The motion of the individual axis is dependent on one another. To remove material quickly and end up with the desired surface, the contact area between the grinding tool and the work piece should be as large as possible. Since only spheres and toroids permit the condition of full area contact, partial area contact, or line contact will be the best alternative. Thus, the method is based on a long line contact between the tool and the work piece during the first step of rough grinding. The profile of the grinding edge is circular in this case, but
not restricted to this shape, thus, forming a toroid. The important feature is that the grinding surface shape is axially symmetrical. It is now possible to drive the tool on the CNC-machine such that it is in line (or arc) contact with the work piece as it cuts the desired shape (Fig. 1).

In this method, the lenses are cut such a way that they are aspherical, that is neither flat nor spherical which allows the opticians to make lenses without distinct bifocal lines. The principle of the process is somewhat similar to the one used in producing spherical lenses. Instead of making the whole lens surface on spherical radius, many smaller portions of the work surface are ground in series of varying spherical radii of performed spherical lens surface (Fig. 2). The connection of these varying spherical radii along the workpiece surface forms desired parabolic shape. The mathematical expression of this work can be found in work of Tan [2], Russel [3]. They used FORTRAN programs to calculate tool path and write CNC program is necessary.

Two main FORTRAN programs make all the computations necessary to supply the CNC machining centre with a tool path. The first program calculates the tool coordinates that give the most line contact with the desired parabolic profile. A data file supplies this program with the desired parabolic profile focal length F, grinding tool tip radius R, and grinding wheel pitch diameter D. The second program generates CNC code for machining. The desired output values computed by this program are the X and Y axis movement and the inclination angle of the grinding tool.

2.2. EXPERIMENTAL SETUP AND RESULTS

Metal bonded wheels were initially used as these do not wear easily on radius work or on small areas of contact. Subsequently resinoid bonded wheels were used quite successfully. Metal bonded wheels gave better surface roughness and form accuracy. Resin bonded wheels produced brighter surfaces and form accuracy with more ductile streaks [4].

---

---

---
The finest grinding wheel parameters were chosen to get better surface quality. The grinding wheel used was of 10-30µm grit size. The grinding operation starts from the periphery of the workpiece and ends at the apex, or centre.

When the whole workpiece surface is ground, the desired parabola is formed and the line contact of the wheel on the surface can be seen during the last five grinding passes. As seen in Fig. 4.

It is found that the whole zone generation method has the following limitations:
- The resulting parabolic profile is a connection of several spherical arcs and not a continuous path
- Grinding process is interrupted to perform zone operation. New contact between wheel and workpiece of preceding zone may not be same with the adjacent zone.
The process is not suitable for developing a material removal model as its parameters get changed within the process.
- The process results in zone ringed appearance on ground workpieces
- As the process gets interrupted because of the zone concept, grinding wheel leaves the contact mark on each zone (Fig. 4).
- During the polishing material removal rate fluctuate within each zone.

In this method of generating aspheric the wheel axis always adjusted in perpendicular position to workpiece profile. The grinding path OA is plane curve in the YZ plane as shown in the Fig. 5. As wheel is programmed for zone generation, only one part of the wheel (point P_A) is used in this grinding process. Moreover, it is impossible to grind a deep or large workpiece due to machine travel limit.

3. REVISED METHOD OF GENERATING ASPHERIC SURFACE

It has been described in the above discussion, how aspheric surface generation by cup wheel is an economic method to produce aspheric lenses with optimum required qualities.
The main idea to use general purpose machine like VMC for aspharising is to reduce the cost of the final product. Extensive experimental works was done by Venkatesh et al [4, 5] to establish optimum grinding parameters for economical machining. Resin bonded wheel with smaller grit size was recommended to facilitate ductile machining with little expense in form accuracy as compared with metal bonded wheel.

The new method of generating aspheric profiles is based on the same concept but using more advanced technologies of CAD/CAM. The profile generated in the previous work was based on FORTRAN due to lack of sophisticated modeling methods. Use of continuous parabolic path modeling method eliminates the need for zone generation during profile grinding. The proposed grinding sequence does not involve raising the grinding wheel in between path as illustrated in Fig. 6 It is continuous path grinding with the latest “Unigraphics” CAD / CAM modelling tool. The whole grinding sequence is converted into simple 2D parabolic line path. The grinding wheel traces the continuous parabolic line profile to generate aspheric profile.[6]

Major advantages of proposed method over Zone generation method are as follows:
In the zone generation method synchronized tilting movement of the rotary table with tool movement was programmed to keep points of contact fixed during profile generation. This synchronized movement of the rotary table is capable of generating accurate aspheric profiles only when the wheel is new. FORTRAN program takes into consideration the toroidal wheel profile and its toric radius to generate programs. Fixed contact point concept in this program accelerates local wear on the toric surface of the wheel. This would result in the creation of the flat land on the toric profile of the wheel. As this flat wear land increases, the resulting surface lacks the profile accuracy and the aspheric parameter “P” is the major factor that gets involved.
In the revised method the contact point between the workpiece and the toroidal cup wheel is allowed to vary within specific zone ($P_B$) on the toric surface of the cup wheel as shown in Fig. 7. Distributed contact between the workpiece and the cup wheel can be established by positioning the workpiece at a fixed angle of 20°. The toroidal cup wheel is programmed to trace the fixed aspheric profile without the changing tilting angle of the workpiece while machining. The impact of this alteration is to distribute the wear of the toroidal cup wheel throughout the specific area. [7]

4. EXPERIMENTAL SETUP AND PRELIMINARY RESULTS

The main objective of the research is to examine the potential of the CAD CAM method to generate the aspheric surface on the glass mould. The industrial survey was carried out to study the generation parameters. In mass manufacturing, the process of aspheric generation is more specialized. The use of specially designed machines and tools
make the process much concentric towards single design products. Some time the machines are not capable of producing the glass moulds of different geometries. Setting up a machine for the different design glass mould takes hours. This could be one of the main reasons for high cost of the lenses in the market.

The machining trials were planned to evaluate performance of new aspheric surface generation technique. Table 1 describes the detail generation parameter of aspheric glass mould for novel method, zone generation method and actual industrial setup.

Table 1 Different parameters used by industry, previous research & current work.

<table>
<thead>
<tr>
<th></th>
<th>Industry</th>
<th>Zone generation method</th>
<th>New method</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rough Grinding</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Machine</td>
<td>Aspheric Loh Generator</td>
<td>Fadal VMC</td>
<td>MAHOO CH700 VMC</td>
</tr>
<tr>
<td>Number of axis</td>
<td>2</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Workpiece angle adjustment</td>
<td>Manual</td>
<td>Servo Controlled (Angle is varied tangent to wheel for each zone programmed on FORTRAN)</td>
<td>Servo Controlled (Fixed and Programmed on UNIGRAPHICS)</td>
</tr>
<tr>
<td>Wheel movement control</td>
<td>Mechanical cam operated</td>
<td>Servo Controlled (programmed on FORTRAN)</td>
<td>Servo Controlled (Programmed on UNIGRAPHICS)</td>
</tr>
<tr>
<td>Fixture</td>
<td>Pneumatic holding</td>
<td>Mechanical chucking device</td>
<td>Mechanical Glue fixture</td>
</tr>
<tr>
<td>Lens diameter</td>
<td>60 mm</td>
<td>60 mm</td>
<td>50 mm</td>
</tr>
<tr>
<td>Work piece material</td>
<td>BK7</td>
<td>BK7</td>
<td>BK7</td>
</tr>
<tr>
<td>Work piece rotation</td>
<td>Not fixed</td>
<td>150rpm</td>
<td>250rpm</td>
</tr>
<tr>
<td>Wheel diameter</td>
<td>50 mm</td>
<td>101 mm</td>
<td>75 mm</td>
</tr>
<tr>
<td>Wheel abrasive</td>
<td>Diamond</td>
<td>Diamond</td>
<td>Diamond</td>
</tr>
<tr>
<td>Abrasive concentration</td>
<td>C40</td>
<td>30 to 60</td>
<td>C40</td>
</tr>
<tr>
<td>Grit size</td>
<td>150µm</td>
<td>10 to 30µm</td>
<td>150µm</td>
</tr>
<tr>
<td>Bond</td>
<td>Metal (Hard)</td>
<td>Metal and Resinoid (Hard)</td>
<td>Metal (Hard)</td>
</tr>
<tr>
<td>Grinding wheel RPM</td>
<td>12000rpm</td>
<td>5000rpm</td>
<td>6000rpm</td>
</tr>
<tr>
<td>Depth of cut</td>
<td>50 to 80 µm</td>
<td>25 µm</td>
<td>10 µm</td>
</tr>
<tr>
<td>Pressure on work piece</td>
<td>10Psi</td>
<td>Not applicable</td>
<td>Not applicable</td>
</tr>
<tr>
<td>Time</td>
<td>60 sec</td>
<td>30 min</td>
<td>150 sec</td>
</tr>
<tr>
<td>--------------</td>
<td>--------</td>
<td>--------</td>
<td>--------</td>
</tr>
<tr>
<td>Coolant</td>
<td>Miracol Castrol</td>
<td>Syn-Kool</td>
<td>Miracol Castrol</td>
</tr>
<tr>
<td>Tolerance</td>
<td>0 to 20 µm</td>
<td>Not available</td>
<td>+10 to -5 µm</td>
</tr>
</tbody>
</table>

**Experimental setup**
- Picture: Not available
- Picture: Not available

**Comments**
- Fan shaped fins are clearly visible after rough grinding operation. Average fin width is about 0.5mm.
- The resulting surface is free from fan fin shape but different zone marks can be clearly seen with wheel contact line.
- The resulting surface is free from fan fin shape and no zone marks are appearing.

**Glass surface**
- Picture: Not available
- Picture: Not available

**Results (Ground)**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0.193 µm (Best result with 10-20 µm grit size and metal bonded wheel)</th>
<th>Not checked yet but expected better than zone generation by visual appearance.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface roughness Ra</td>
<td>Not checked but expected more than new method</td>
<td>42.97% (Best result with 20-30µm grit size and resinoid bonded wheel)</td>
</tr>
<tr>
<td>Shape accuracy (Error), aspheric parameter P</td>
<td>Not checked</td>
<td>25.79 % (Metal bonded wheel)</td>
</tr>
<tr>
<td>Waviness Wa</td>
<td>0.105 µm (Best result with 10-20 µm grit size, metal bonded wheel)</td>
<td>Not checked yet</td>
</tr>
</tbody>
</table>
Micrograph of ground surface | Not available | The partial ductile mode machining is reported | Partial ductile mode machined surface

The figure (aspheric parameter P) can be calculated by the following equation:
The general equation of parabola can be expressed as:

\[ Y = PX^2 \]  

(1)

Where \( P \) is parabolic parameter and (mm\(^{-1}\)) and

\[ P = \frac{1}{4F} \]  

(2)

Where \( F \) is the focal length of parabola (mm\(^{-1}\))

The aspheric surface parameters for the generated glass mould are shown in Fig. 8.

![Geometry of glass mould showing focal length and parabolic equation](image)

Fig. 8 Geometry of glass mould showing focal length and parabolic equation

Percentage error in the aspheric parameter \( P \) is calculated for the revised method and compared with the zone generation method. Fig. 9 and Table 2 represents the dramatic shoot in percentage error. Near the apex area aspheric profile is very closer to corresponding spherical curvature. Where the control of aspheric parameter \( P \) is very difficult to achieve. Small deviation from nominal value gives drastic error in this region as compared to the
same deviation near the periphery. Fig. 10 and Table 3 represents the resulting percentage error (%E) with 5µm deviation throughout the profile. The percentage error near the apex was the highest with zone generation method (42.9%) compared to the error with revised method (25.79%).

Table 2 Percentage error (%E) with a) Resin bonded wheel b) Metal bonded wheel with zone generation method c) Metal bonded with revised method

<table>
<thead>
<tr>
<th>X</th>
<th>%E</th>
<th>X</th>
<th>%E</th>
<th>X</th>
<th>Y</th>
<th>P</th>
<th>%E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.043</td>
<td>42.97</td>
<td>1.092</td>
<td>-35.09</td>
<td>1.092</td>
<td>0.003</td>
<td>0.002516</td>
<td>25.79</td>
</tr>
<tr>
<td>7.042</td>
<td>10.57</td>
<td>7.003</td>
<td>1.69</td>
<td>5</td>
<td>0.049</td>
<td>0.001960</td>
<td>-2.00</td>
</tr>
<tr>
<td>13.103</td>
<td>0.03</td>
<td>12.997</td>
<td>1.62</td>
<td>10</td>
<td>0.202</td>
<td>0.002020</td>
<td>1.00</td>
</tr>
<tr>
<td>19.035</td>
<td>0.63</td>
<td>19.122</td>
<td>1.93</td>
<td>15</td>
<td>0.452</td>
<td>0.002009</td>
<td>0.44</td>
</tr>
<tr>
<td>25.034</td>
<td>0.65</td>
<td>25.033</td>
<td>1.91</td>
<td>20</td>
<td>0.798</td>
<td>0.001995</td>
<td>-0.25</td>
</tr>
<tr>
<td>31.016</td>
<td>1.27</td>
<td>31.01</td>
<td>2.39</td>
<td>25</td>
<td>1.256</td>
<td>0.002010</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30</td>
<td>1.809</td>
<td>0.002010</td>
<td>0.50</td>
</tr>
</tbody>
</table>

Fig. 9 The percentage error (%E) in aspheric profile
Table 3 Percentage error in aspheric parameter with deviation of 5\( \mu \)m in vertical sag

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Y+5( \mu )m</th>
<th>P</th>
<th>%E</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.002</td>
<td>0.007</td>
<td>0.007000</td>
<td>250.00</td>
</tr>
<tr>
<td>5</td>
<td>0.050</td>
<td>0.055</td>
<td>0.002200</td>
<td>10.00</td>
</tr>
<tr>
<td>10</td>
<td>0.200</td>
<td>0.205</td>
<td>0.002050</td>
<td>2.50</td>
</tr>
<tr>
<td>15</td>
<td>0.450</td>
<td>0.455</td>
<td>0.002022</td>
<td>1.11</td>
</tr>
<tr>
<td>20</td>
<td>0.800</td>
<td>0.805</td>
<td>0.002013</td>
<td>0.62</td>
</tr>
<tr>
<td>25</td>
<td>1.250</td>
<td>1.255</td>
<td>0.002008</td>
<td>0.40</td>
</tr>
<tr>
<td>30</td>
<td>1.800</td>
<td>1.805</td>
<td>0.002006</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Fig. 10 The influence of 5\( \mu \)m deviation from the nominal value on percentage error through out the profile.

5. DISCUSSION

The main emphasize of this project is to verify the capability of the general purpose machines for manufacturing glass or silicon lenses. The application can be further extended towards manufacturing of toroidal and aspheric mirrors. The present trend of the general machine shops of die and mold manufacturers have not been diverted towards glass mould and lens manufacturing. The reason behind this fact may be the highly classified technology for lens manufacturing and lack of knowledge for machining the brittle materials like glass on general industrial platform. The main emphasize in this project has been given on the
general purpose accessories which are easily available in the market at low cost. The lens making industries are using highly specialized purpose machines like Loh aspheric generators for making aspheric lenses. The grinding wheels used in these machines are also specially designed for the typical geometry of the lens. Little variation in the lens geometry takes considerable time to set these special purpose machines. In addition to this, the machine meant for aspheric generation can not produce toroidal lenses if requirement arise.

Of course, generation of such optical components by using general purpose machines is also having some process limitations. The process would be dominantly dependent on the accuracy of the machine and its resolution. Most of the optical products like ophthalmic lenses are having bit liberal tolerances as compared to laser application mirrors. Typical manufactured product that could be produced by this method is the surface of the glass mould to manufacture plastic Fresnel lenses. These lenses are having verity of applications; some of are required high degree of accuracy such as lenses in the mobile camera whereas other could be bit liberal in tolerance such as binocular lenses. The main idea of the research is to cover-up such general purpose lens application by using the generate purpose machine for manufacturing.

6. CONCLUSIONS

1. The performance of the new aspheric generation method is evaluated.
2. New aspheric generation method appears to provide better results than zone method in this preliminary study.
3. The proposed method of machining can be transferred to a general manufacturing platform to promote lens manufacturing.

REFERENCES