

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Inter Parties

Review of: U.S. Patent No. 9,421,713
Title: ADDITIVE MANUFACTURING METHOD FOR PRINTING
THREE-DIMENSIONAL PARTS WITH PURGE TOWERS
Inventors: William J. Swanson, et al.
IPR Filed: December 17, 2024

**AMENDED DECLARATION OF GARY LARSON IN CONNECTION WITH PATENT
OWNER'S PRELIMINARY RESPONSE TO PETITION TO INSTITUTE *INTER
PARTES* REVIEW OF U.S. PATENT. NO. 9,421,713**

I, the undersigned, hereby declare and state that:

1. I am over the age of 18 years, of sound mind, and competent in all respects to make this Declaration.
2. I was a principal research engineer at Stratasys, Inc. ("Stratasys") and was employed at Stratasys, Inc. from 1991 to 2021.
3. I understand that a challenge has been filed against United States Patent No. 9,421,713 (the "'713 Patent"), which is entitled *Additive Manufacturing Method for Printing Three-Dimensional Parts with Purge Towers*. The front of the '713 Patent indicates that it was assigned to Stratasys, Inc. and filed on March 8, 2013. I understand the petitioner that filed the challenge has requested review of Claims 1, 2, 5-7, 9, 16, and 17 ("the Challenged Claims") of the '713 Patent.
4. I make this Declaration in connection with Stratasys's preliminary response to the petition for *inter partes* review of the '713 Patent.
5. Based on my experience and to the best of my knowledge, the three inventors listed on the front of the '713 Patent—William ("Bill") Swanson, Ronald Schloesser, and myself—conceived of and were involved with actually performing the Challenged Claims as part of Stratasys research and development efforts. Among other things, those efforts included a Stratasys

project to research and develop an automated, smaller-footprint (5x5x5 inch build volume) 3-D printer that was known as Solo within Stratasys. At the time, I was a senior applications engineer at Stratasys, Inc. where I worked on printer integration.

6. During research and development of the Solo printer, which was ultimately adapted for release to the public as the Mojo 3-D printer, Bill Swanson, Ronald Schloesser, and I tried to address the disadvantages related to “purge” operations in fused deposition modeling (FDM). A “purge” operation at that time conventionally involved moving a given print head to a purge station, such as a purge bucket, where it would extrude a strand of material. Purge operations were performed for a variety of reasons, including to free material adhered to the walls of the liquefier assembly, to verify that the print head can extrude the material, to remove any degraded materials or entrained gases in the print head, to bring the print head to a known operating state for printing the next layer, and to remove ooze that may hang from a nozzle of the liquefier assembly, among other reasons.

7. However, there were disadvantages with the conventional method of performing a purge operation, including that the use of a purge station generally required that a sufficient quantity of the material be extruded from the print head such that it had enough weight to fall away from the print head and into the purge bucket. Additionally, the purge station could take up a sizeable footprint of the 3-D printer, limiting the usable build volume and increasing costs, and the purge bucket would need to be periodically emptied, inhibiting the system from functioning in a fully automated manner. Furthermore, performing purge operations using purge buckets required the development of hardware and software for that purpose for a new concept like Solo, which was intended to operate in a fully automated manner.

8. By September 2010, during the research and early development of Solo, Bill Swanson, Ron Schloesser, and myself, addressed these disadvantages by conceiving of a purge operation that included printing one or more purge towers.

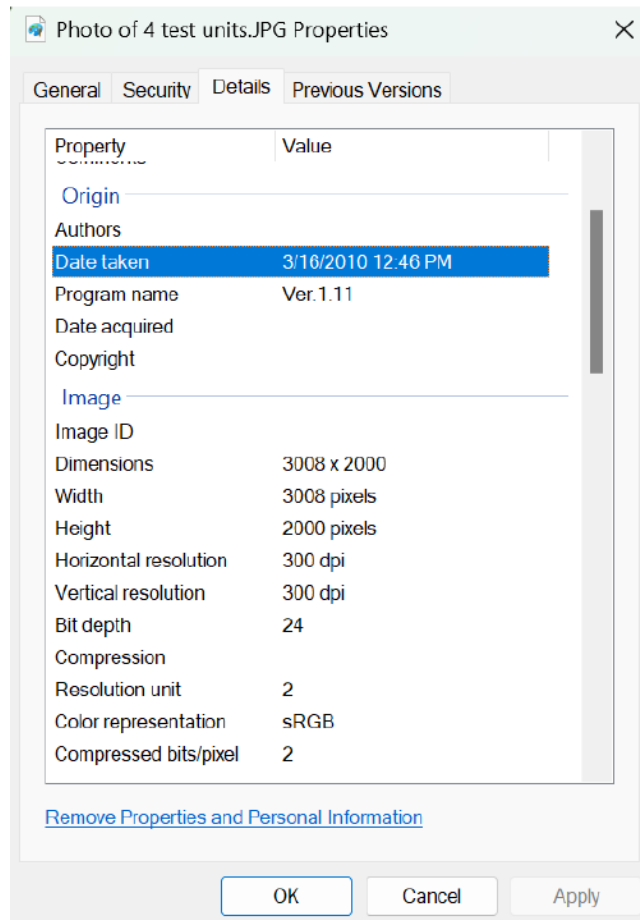
9. Thereafter, Bill Swanson, Ron Schloesser, and I, as well as others at Stratasys, continued to develop the Solo printer, including the development of creating a purge tower. This approach of using purge towers had the benefits of allowing each print head to achieve the desired functions of a purge operation without requiring the use or development of a separate purge station. This served to increase the useable build volume of the additive manufacturing system, reduced

the amount of part and support materials consumed during the purge operations, and allowed the system to operate in a fully automated manner. This also served to reduce part build time.

10. I will now explain various features of the Solo printer. The Solo printer was a 3-D printer (additive manufacturing system) that printed a three-dimensional part using FDM processes developed by Stratasys. A March 16, 2010, photograph of four prototype Solo printers in early development is shown below.



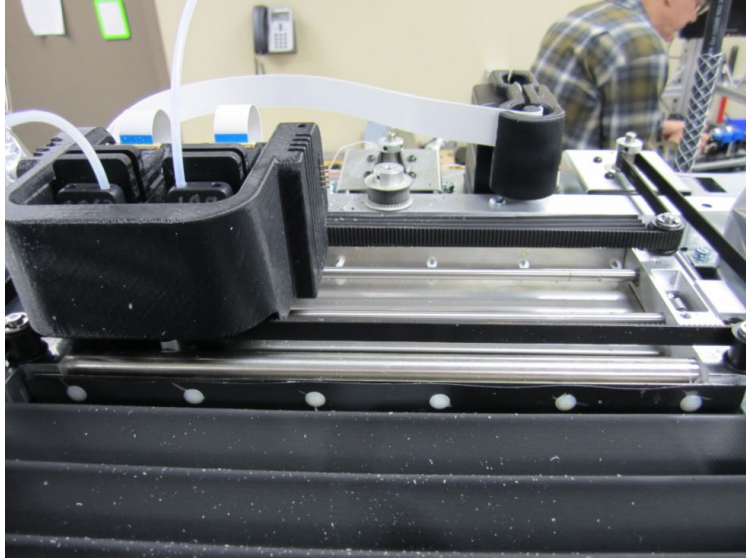
Ex. B (March 16, 2010, photograph showing four prototype Solo printer test units). In this early development photo, keyboards are shown sitting on top of the printers in front of the print heads. I recognize the printers in this photograph from my involvement in the development of the Solo printer and confirmed the date of the photograph from its file properties.



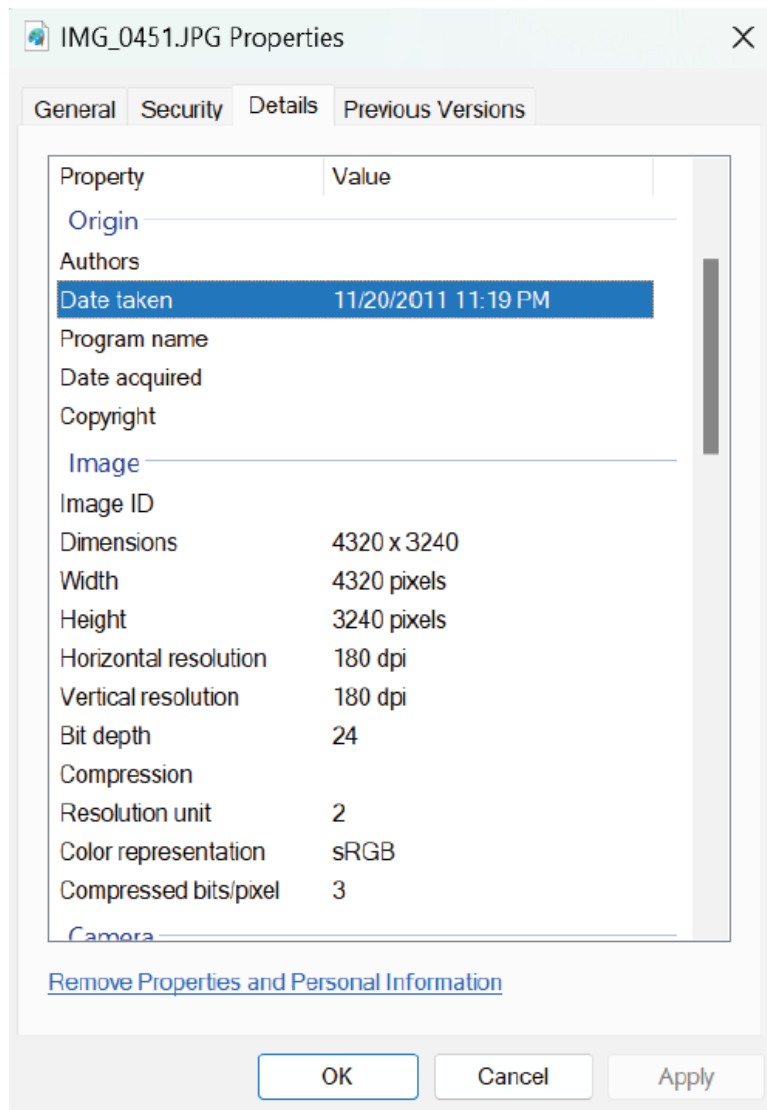
Ex. B at 2.

11. The Solo printer printed layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads and deposition lines using a layer-based, additive manufacturing technique known as FDM. For example, the Solo printer had a print head with a part material deposition line (the “Part Print Head”) and a second print head with a support material deposition line (the “Support Print Head”) to print the layers of the three-dimensional part and the support structure, respectively.

12. A November 20, 2011, photograph depicting Solo’s multiple print heads and deposition lines is shown below.



Ex. C (November 20, 2011, photograph showing Solo's print heads and deposition lines). Similar to the previous photograph, I recognize the Solo printer and multiple print heads and deposition lines from my work in developing the printer. Additionally, I confirmed the date from the file properties of the photograph.



Ex. C. at 2. Also, the Solo printer with multiple print heads shown in the photograph above resembles the printer illustrated in Figure 1 of the '713 Patent:

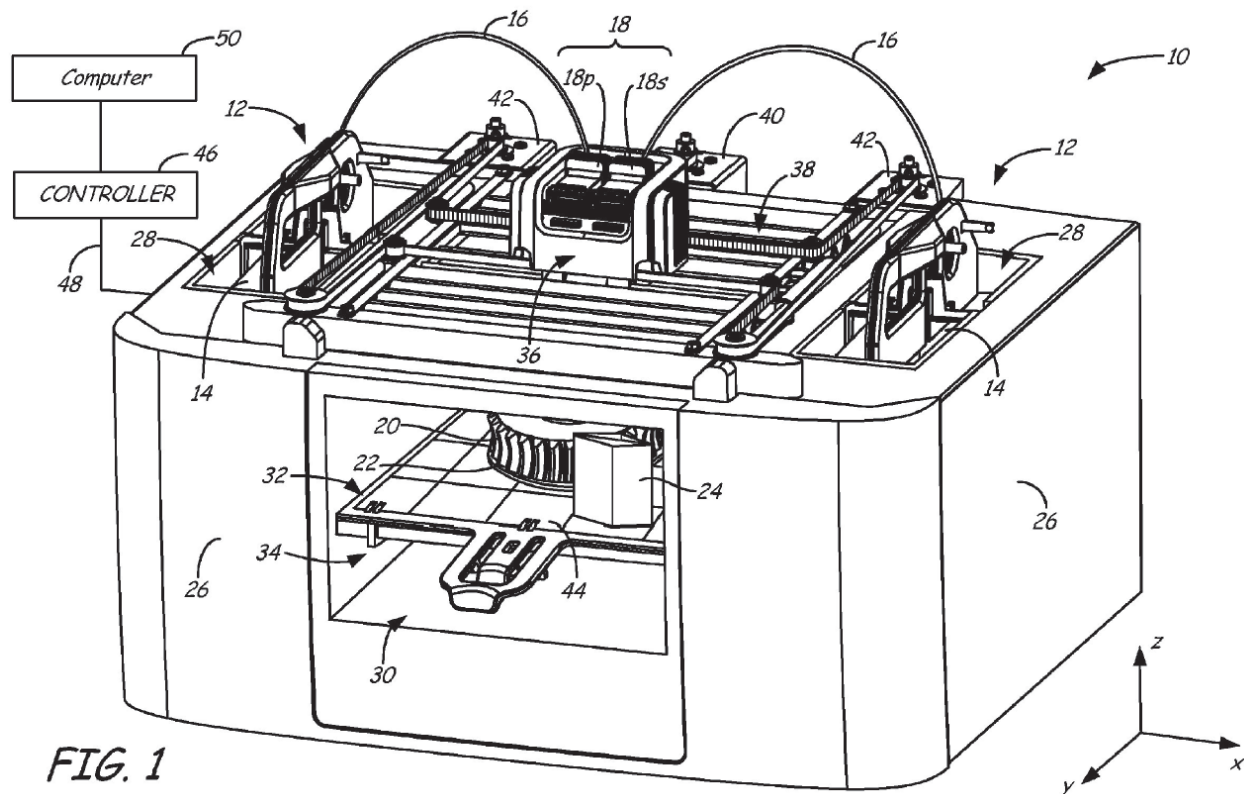


FIG. 1

Ex. D ('713 Patent), Fig. 1. Like the photo shown above, the printer illustrated in the figure has multiple print heads in a single assembly that is driven by a belt.

13. The Solo printer switched between stand-by modes and operating modes for the print heads and deposition lines in-between the printing of the layers of the three-dimensional part and the support structure. For example, the Part Print Head would be in the operating mode, where the liquefier assembly of the print head would be heated to its operating temperature, during which time it would print the part material layer. During that time, the Support Print Head would be in a stand-by mode, during which time it would not be printing material and it would be cooled down from its operating mode temperature to a stand-by temperature to prevent oozing. When the printing of the part material layer concluded, the Part Print Head would be switched to a stand-by mode and the Support Print Head would be switched to an operating mode.

14. The Solo printer performed a purge operation for each print head / deposition line switched to the operating mode. The purge operation comprised printing purge tower(s) in a layer-by-layer manner, where the layers of the purge towers were printed from the print head / deposition line switched to the operating mode. For example, when the Part Print Head / part material

deposition line was switched to the operating mode, the printer would perform a purge operation by printing a layer of a purge tower using the part material. Likewise, when the Support Print Head / support material deposition line was switched to the operating mode, the printer would perform a purge operation by printing a layer of the purge tower using the support material.

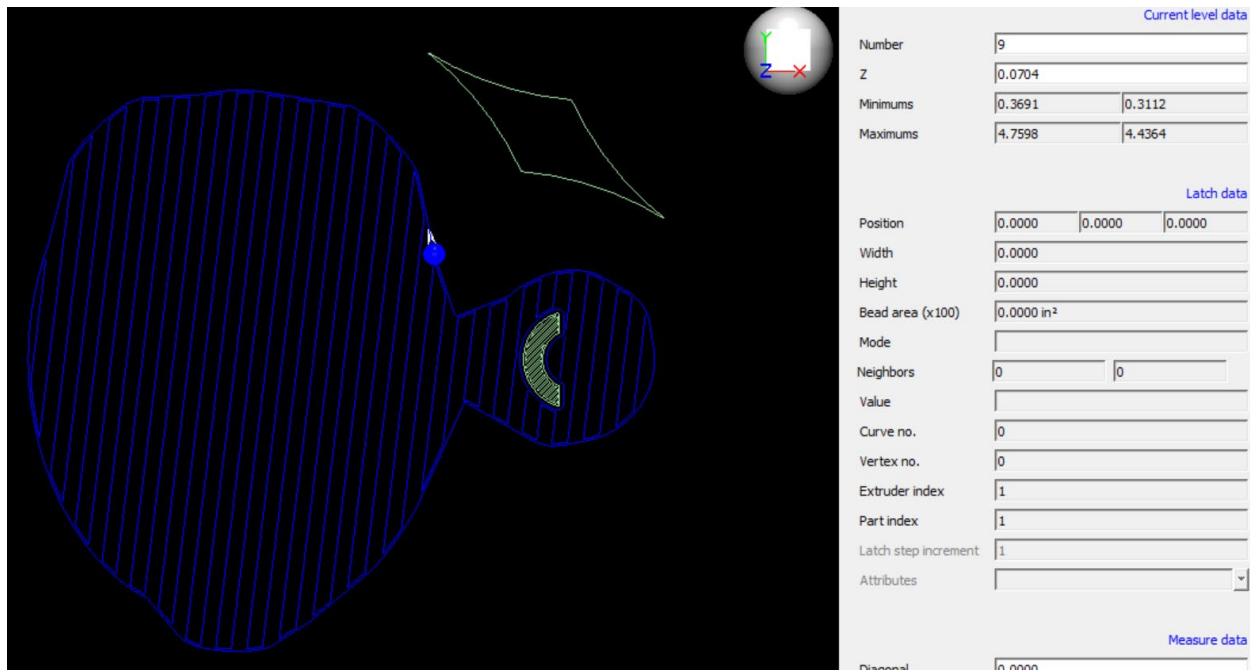
15. Bill Swanson, Ronald Schloesser, and I conceived of and were involved with actually making variations of the purge towers, including a single purge tower with alternating layers of part and support material, as well as two purge towers (one made of layers of part material, the other made of layers of support material), among other variations. For an example, I will reference the screenshots below taken of a graphical representation¹ of a coordinate machine binary (“CMB”) file, which is a representation of tool path instructions generated by Stratasys software, such as Insight™ or Control Center™. A Stratasys printer follows the generated tool path instructions to print 3-D part(s).

16. The information shown in the following screenshots is from Ex. E (July 5, 2011, packed CMB file). This CMB file was last modified on July 5, 2011 in conjunction with the Solo project. I recognize the shape of purge tower in this CMB file from my involvement in the development of the Solo printer and confirmed the date of this CMB file from its file properties, as shown below.

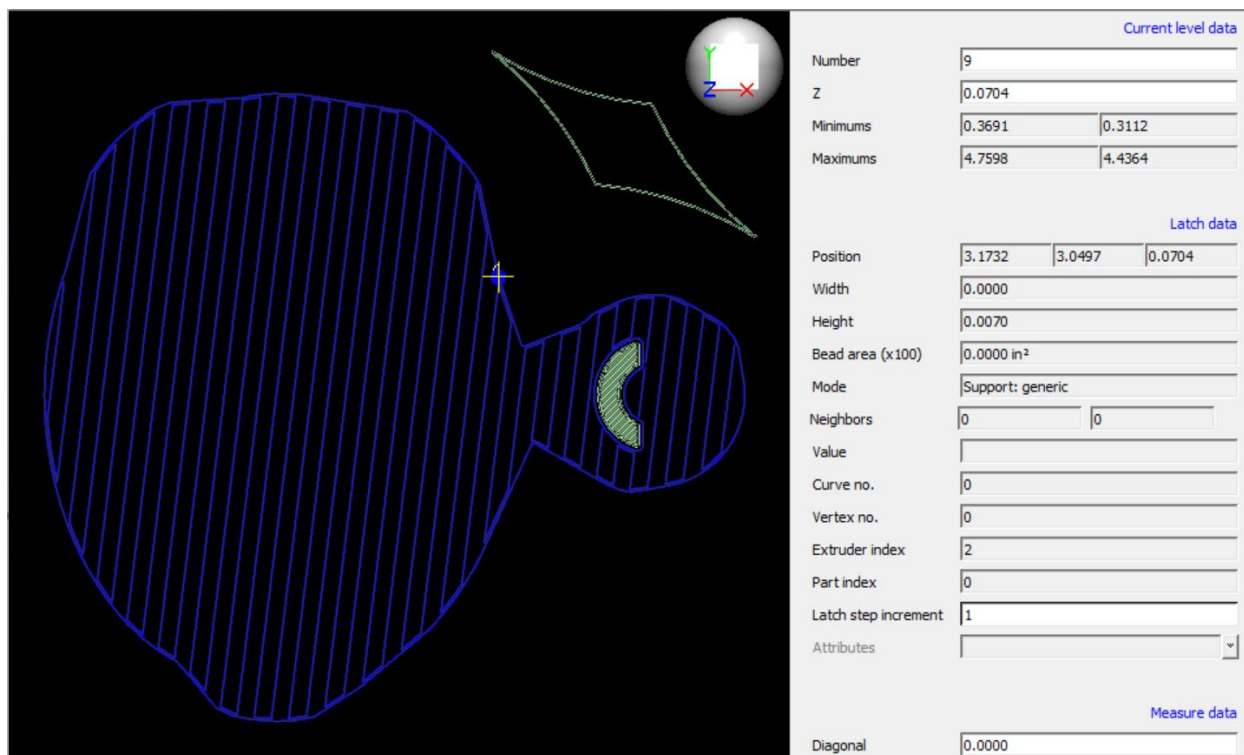
Name	Date modified	Type	Size	Date created
 Pack_338311575.cmb	7/5/2011 8:50 AM	CMB File	12,954 KB	3/20/2025 12:24 PM

Ex. E (July 5, 2011, packed CMB file) at 20. These screenshots depict a version of the purge tower constructed of alternating layers of part and support material:

¹ The CMB file is viewable in the graphical form shown in the screenshots in this declaration by using CMB Viewer, which is an application within Stratasys’s Insight™ software. The Insight™ software is free to download and available at <https://support.stratasys.com/en/Resources/Software-Download>. The screenshots of CMB file shown in this declaration are true and accurate representations of what I saw when I viewed the CMB file that I discuss in this declaration in CMB Viewer.



Ex. E (July 5, 2011, packed CMB file) at 8. As shown, the blue lines indicate support material, and the green lines indicate part material. While the screenshot above shows an “Extruder index” of “1” under the heading “Latch data,” this field and the rest of the fields under the “Latch data” heading are only populated with actual values when the view is latched to a particular point, which is not the case in the above image. When a specific point is selected, as shown in the image below by the white crosshair, the “Latch data” is populated. In the instance shown below, the first point in layer 9 of the CMB file (corresponding to curve no. 0 and vertex no. 0) is on the support structure and the “Extruder index” reflects that the extruder “2” is in use and the mode is “Support:generic.”

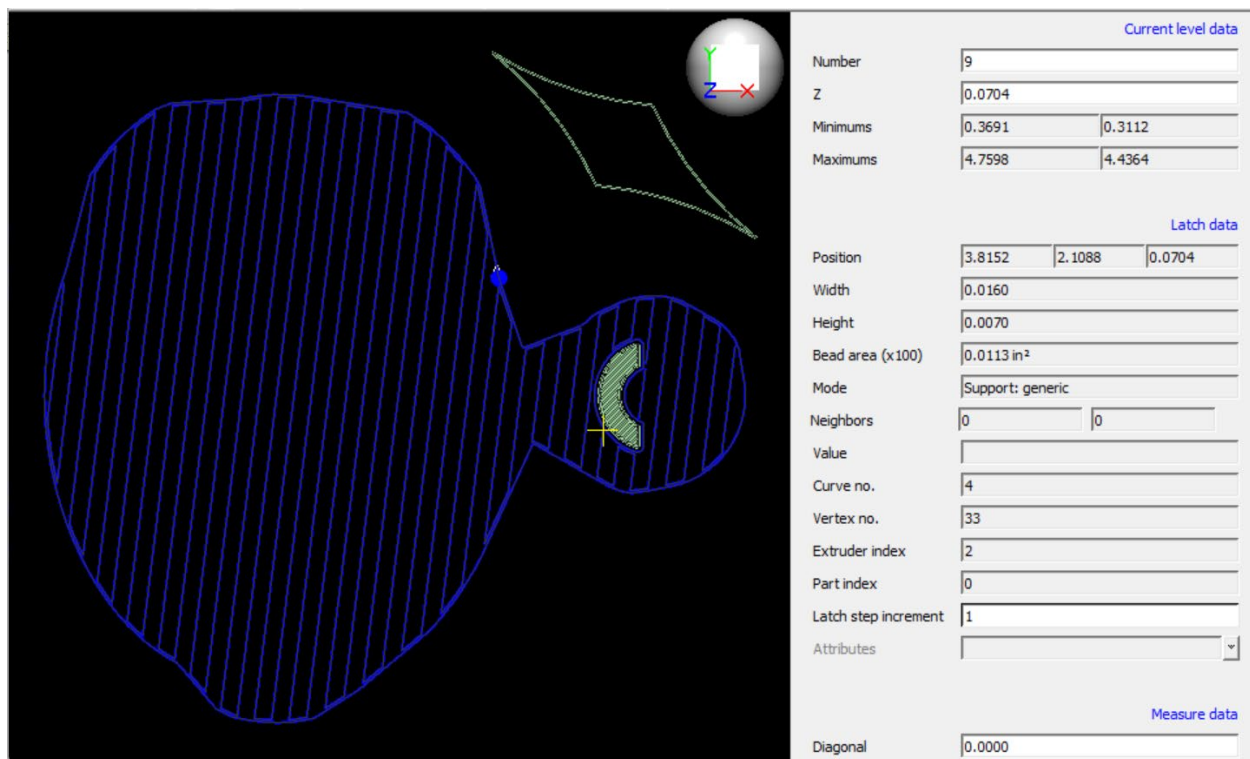


Ex. E (July 5, 2011, packed CMB file) at 21. Similarly, as shown below, when “Extruder index” is set to “2” on the information panel of the CMB file, the “Material” field indicates that the material is “SR-30,” which is a type of support material.²

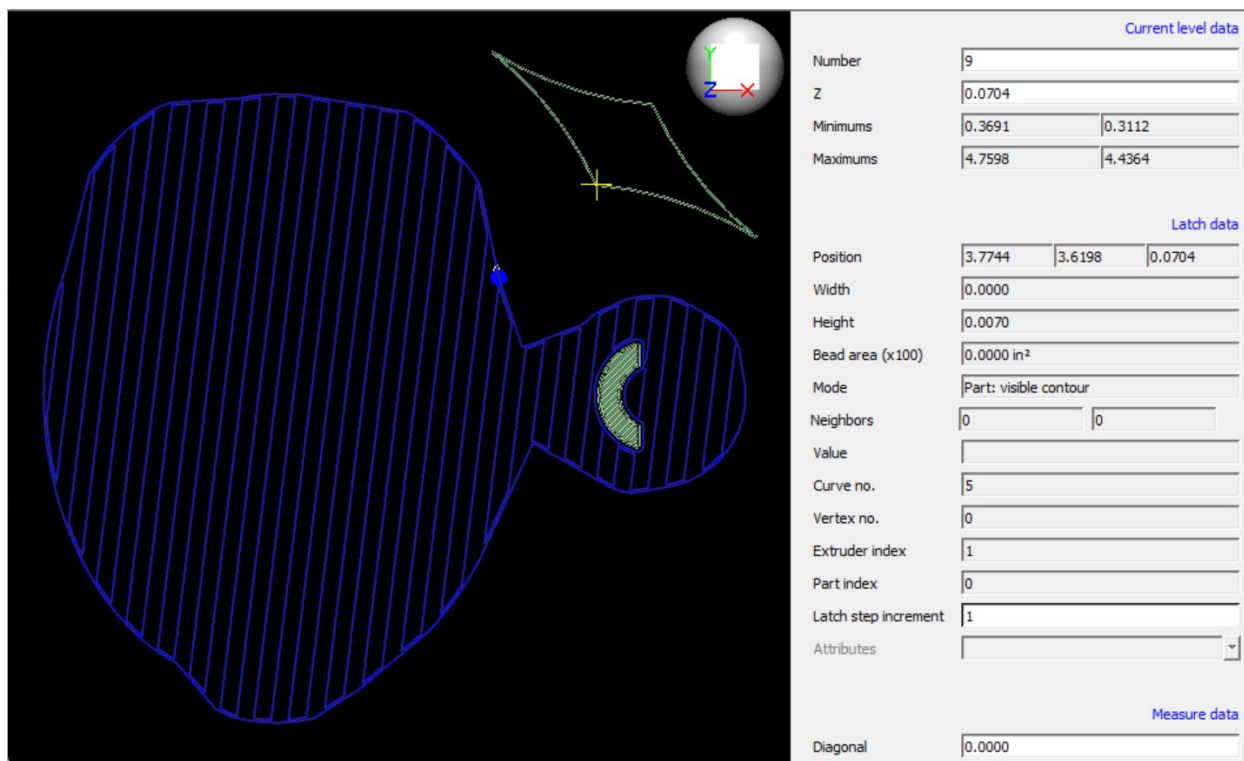
² The Stratasys website (<https://support.stratasys.com/en/Materials/FDM/FDM-Support-Materials>) lists types of Stratasys support material, including SR-30.

General			Internals	
Machine type	Fortus 400mc Large		Comment	Packed file written by Control Center!!!
Extruder index	2		Pack list	purge_part+support-11
Material	SR30		Versions	8.1 (4255) 8.9
Color	not specified		GUID	
Tip size	T12		Limits	
Volume	6.469729		Part width	0.0110 0.0600
Slice height	0.0070		Part area	0.0001 in ² 0.0004 in ²
Number of slices	607		Part aspect ratio	1.5767 8.5714
System mode	none		Support width	0.0121 0.0191
Part build style	none		Support area	0.0001 in ² 0.0001 in ²
Shrink factor (X Y Z)	1.000000	1.000000	Support aspect ratio	1.7244 2.7303
Has variable width				
CMB locked				
User name				
Embedded version				
System Serial#				

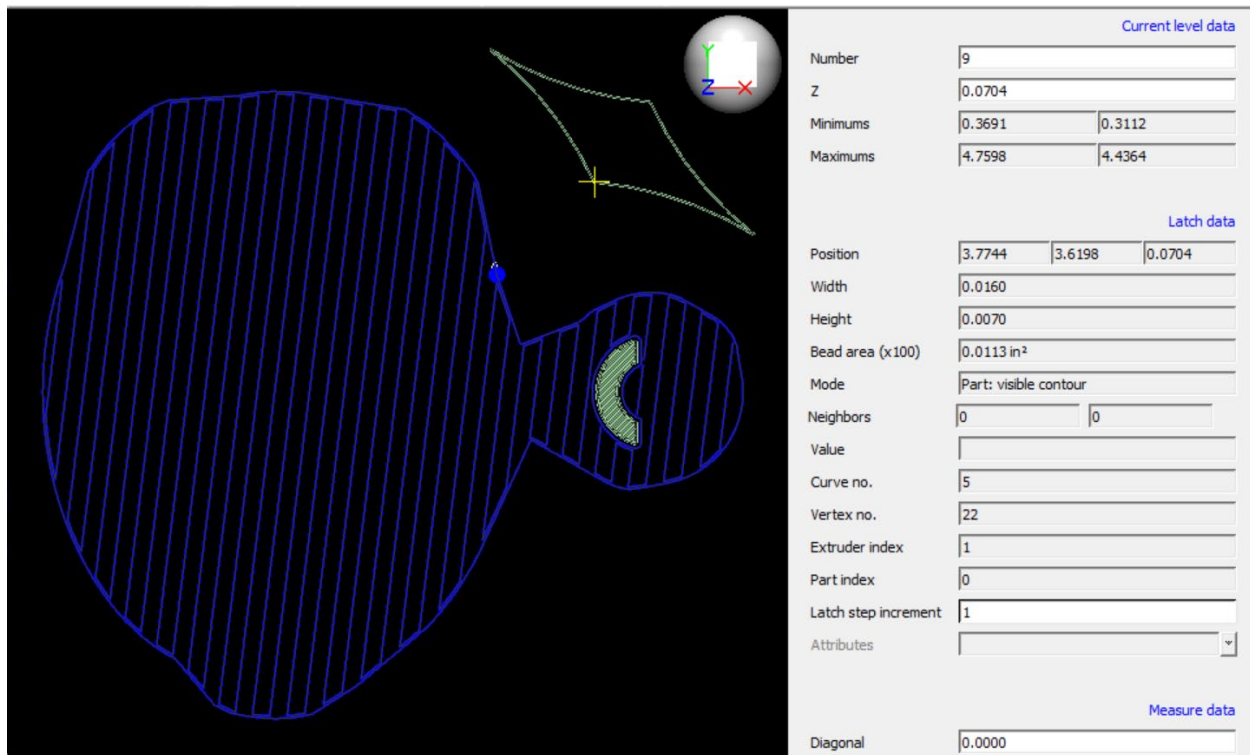
Ex. E (July 5, 2011, packed CMB file) at 50. In the image below, the final point of the support structure tool path in level 9 of the CMB file (corresponding to curve no. 4 and vertex no. 33) is shown.



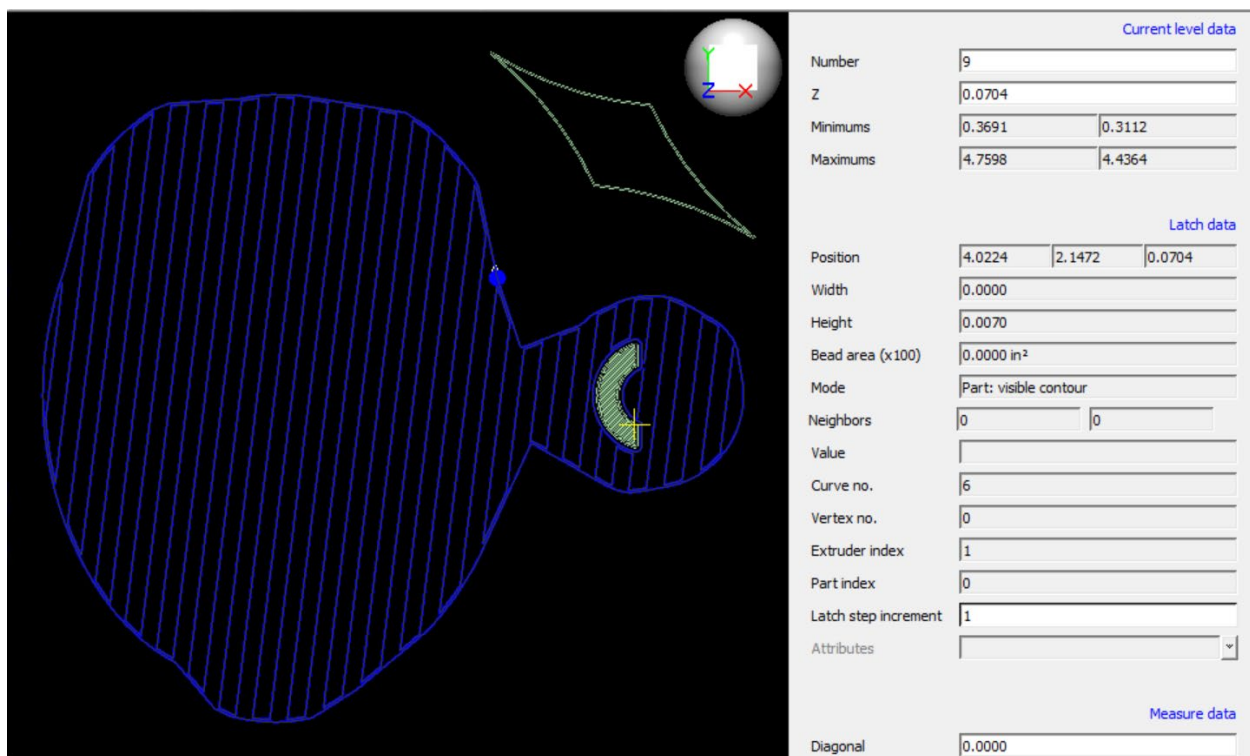
Ex. E (July 5, 2011, packed CMB file) at 22. The next point in level 9 of the CMB file (curve no. 5 and vertex no. 0) corresponds to the switch of the Part Print Head / part material deposition line to operating mode, whereby printing of the layer of the purge tower with part material is commenced.



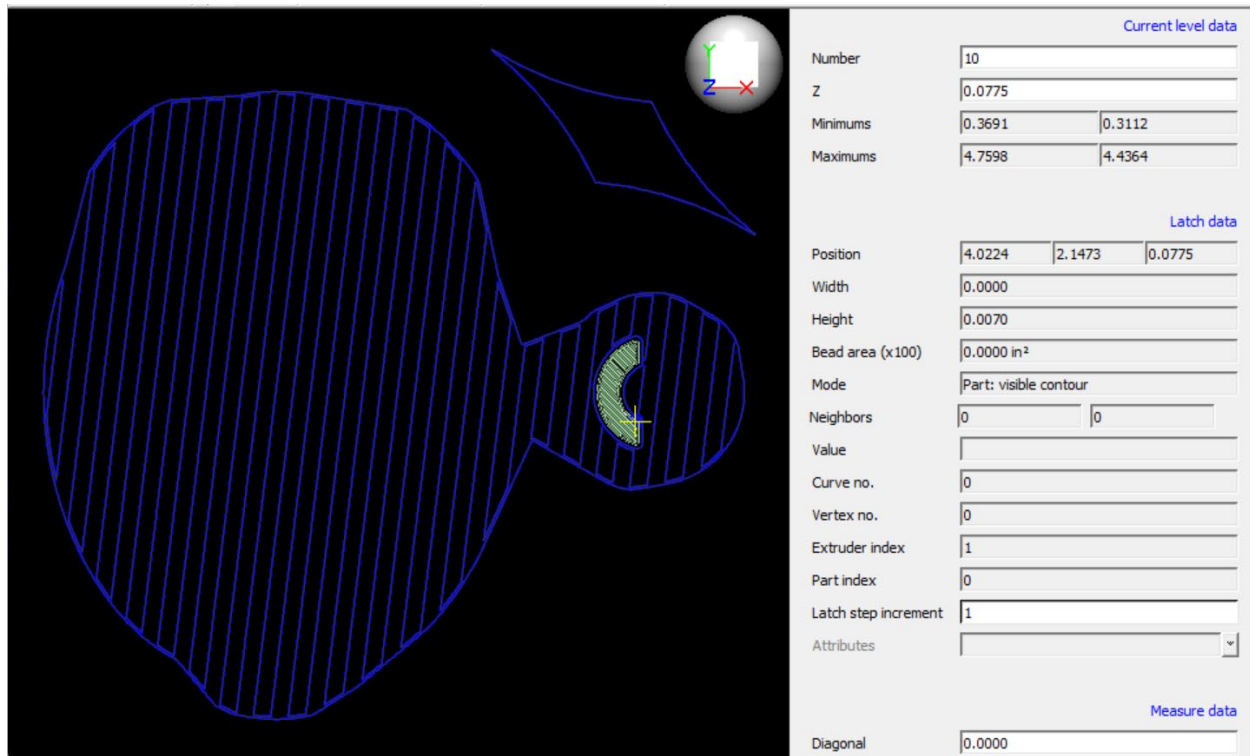
Ex. E (July 5, 2011, packed CMB file) at 23. Because the layer of the purge tower shown above is green, it is printed with part material. This is confirmed by the “Extruder index” of “1” as shown in the above image, as well as the mode being “Part: visible contour.” Printing of this layer commences until the final point of the purge tower layer (curve no. 5 and vertex no. 22), with the next point being the start of printing the three-dimensional part with part material (curve no. 6 and vertex no. 0) as shown in the below images.



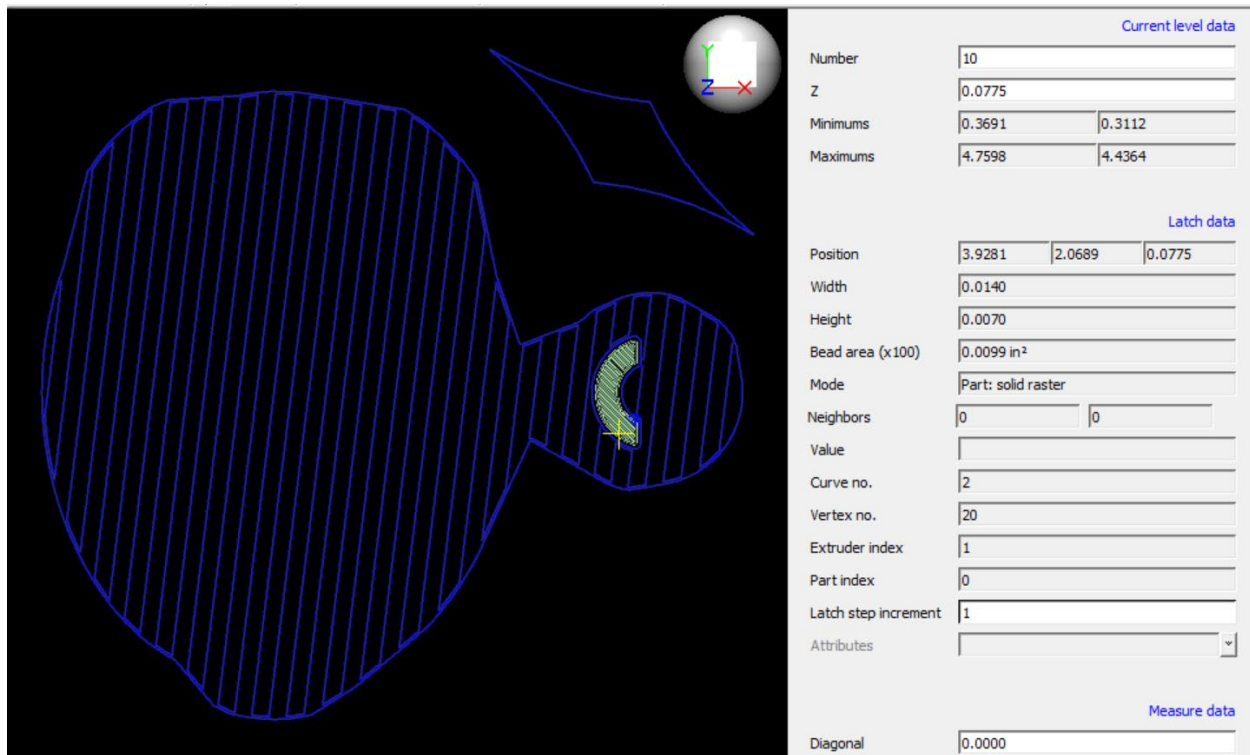
Ex. E (July 5, 2011, packed CMB file) at 24.



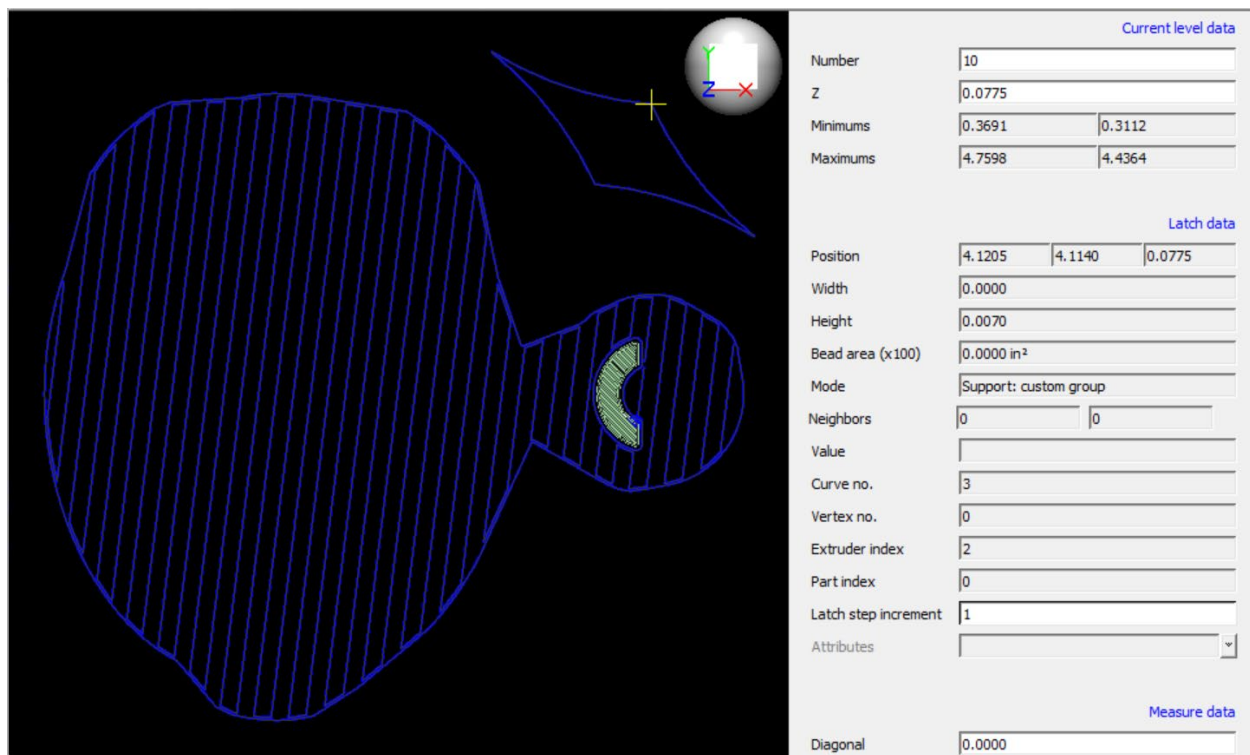
Ex. E (July 5, 2011, packed CMB file) at 25. As shown by the next two images, in the next layer of the CMB file (layer 10) the first point (curve no. 0 and vertex no. 0) is a continuation of the printing of the part material up until the final point of part material printing on CMB level 10 (curve no. 2 and vertex no. 20).



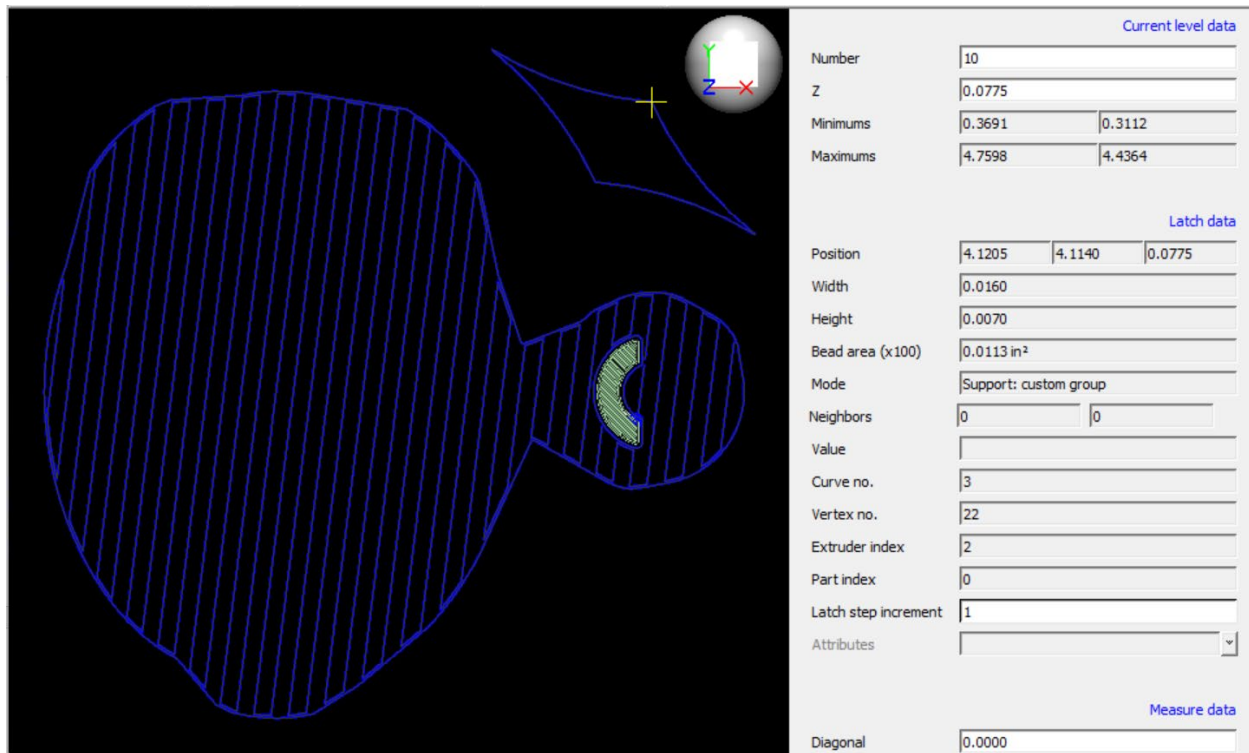
Ex. E (July 5, 2011, packed CMB file) at 26.



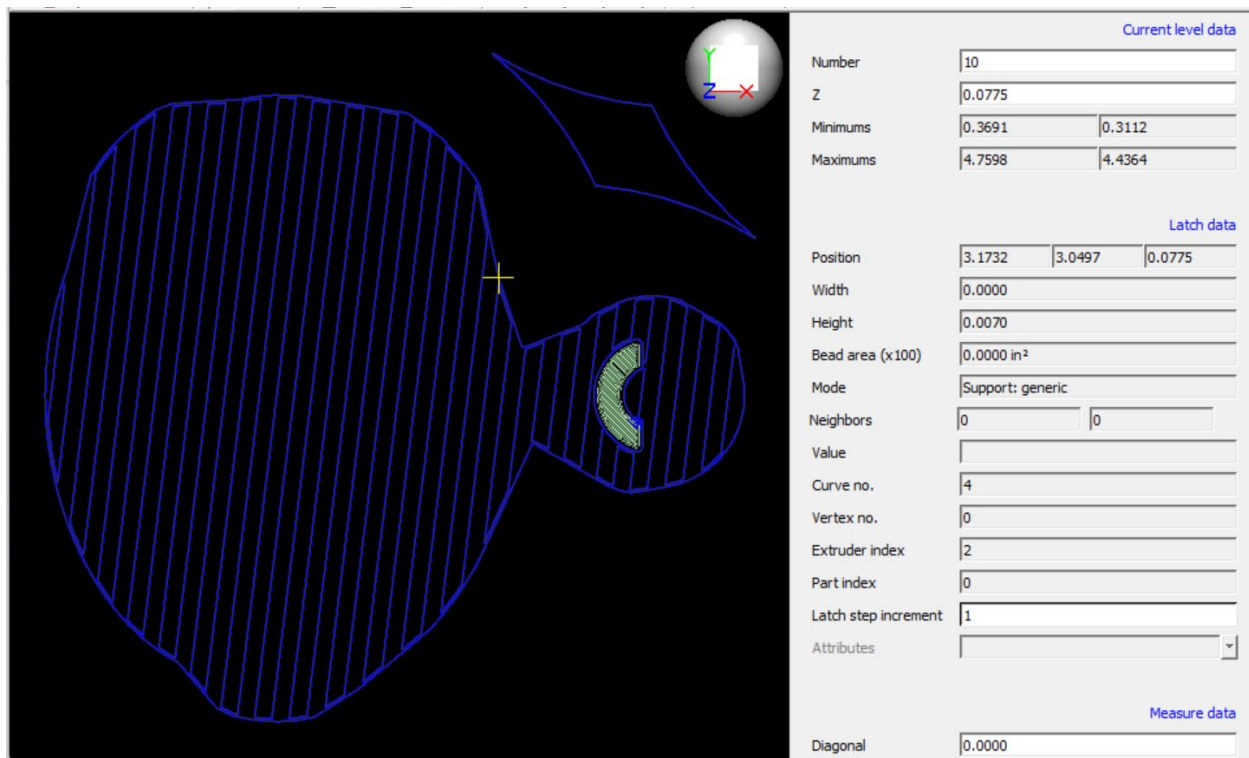
Ex. E (July 5, 2011, packed CMB file) at 27. As shown in the image below, the next point in level 10 of the CMB file (curve no. 3 and vertex no. 0) corresponds to the switch of Part Print Head / part material deposition line to stand-by mode and the switch of the Support Print Head / support material deposition line to operating mode, whereby printing of the layer of the purge tower with support material is commenced.



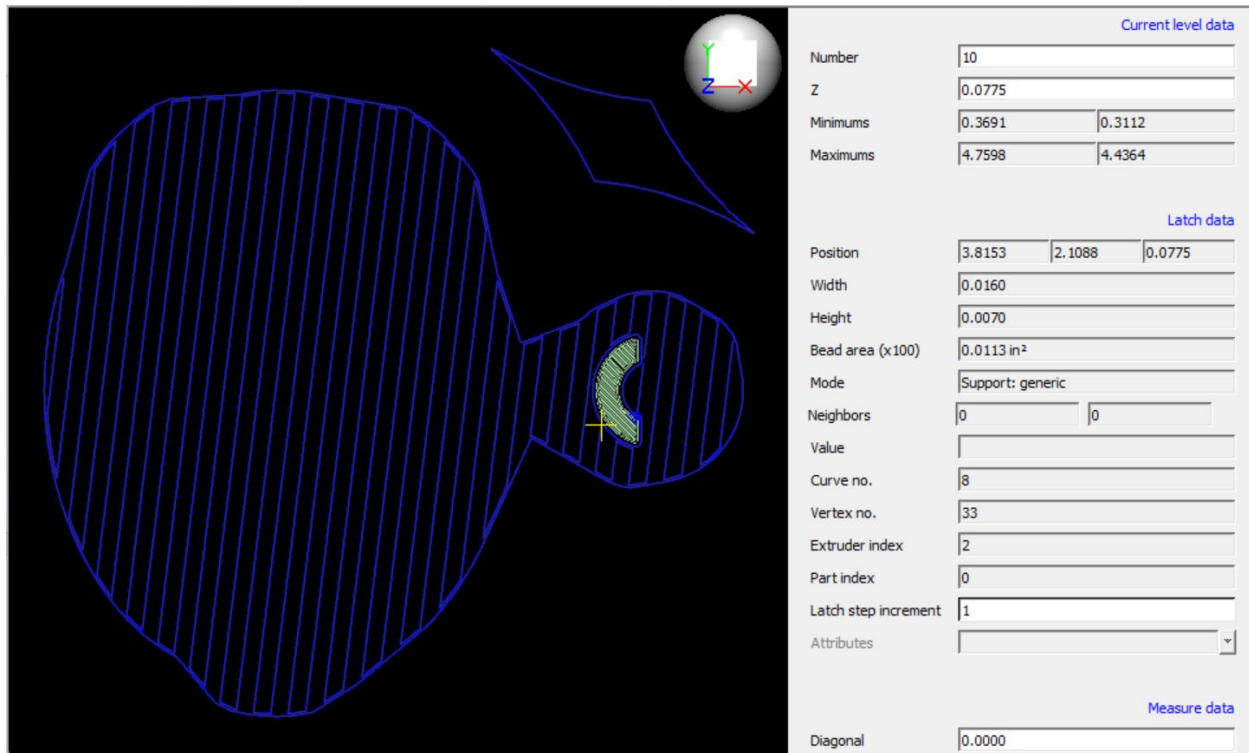
Ex. E (July 5, 2011, packed CMB file) at 28. That the blue lines of the purge tower correspond to support material is confirmed by the “Extruder index” being “2,” and the mode being “Support: custom group.” The printing of the layer of the purge tower with support material continues until complete (curve no. 3 and vertex no. 22), at which point the printing of the support structure commences (beginning with curve no. 4 and vertex no. 0 and ending with curve no. 8 and vertex no. 33), as shown in the images below.



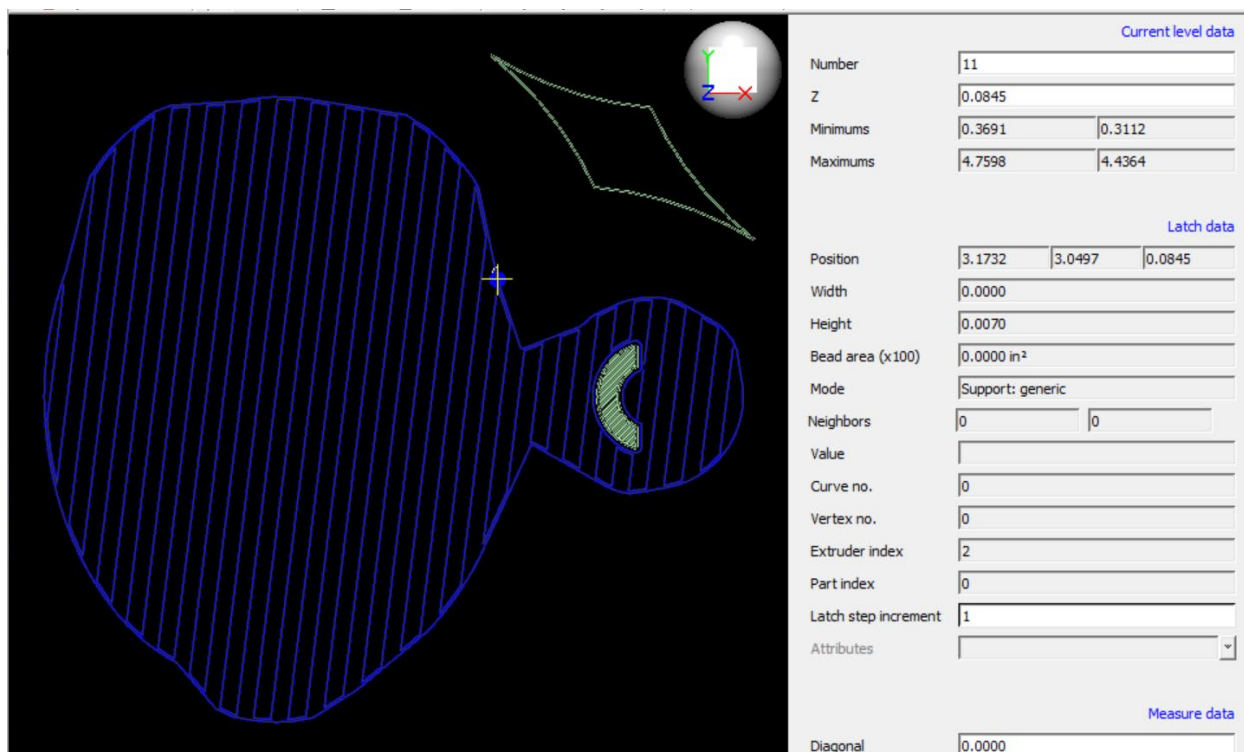
Ex. E (July 5, 2011, packed CMB file) at 29.



Ex. E (July 5, 2011, packed CMB file) at 30.



Ex. E (July 5, 2011, packed CMB file) at 31. This process is repeated for the other layers in the CMB file, as shown by the following layer (layer 11), where the layer of the purge tower is printed with part material, as indicated by the green lines.



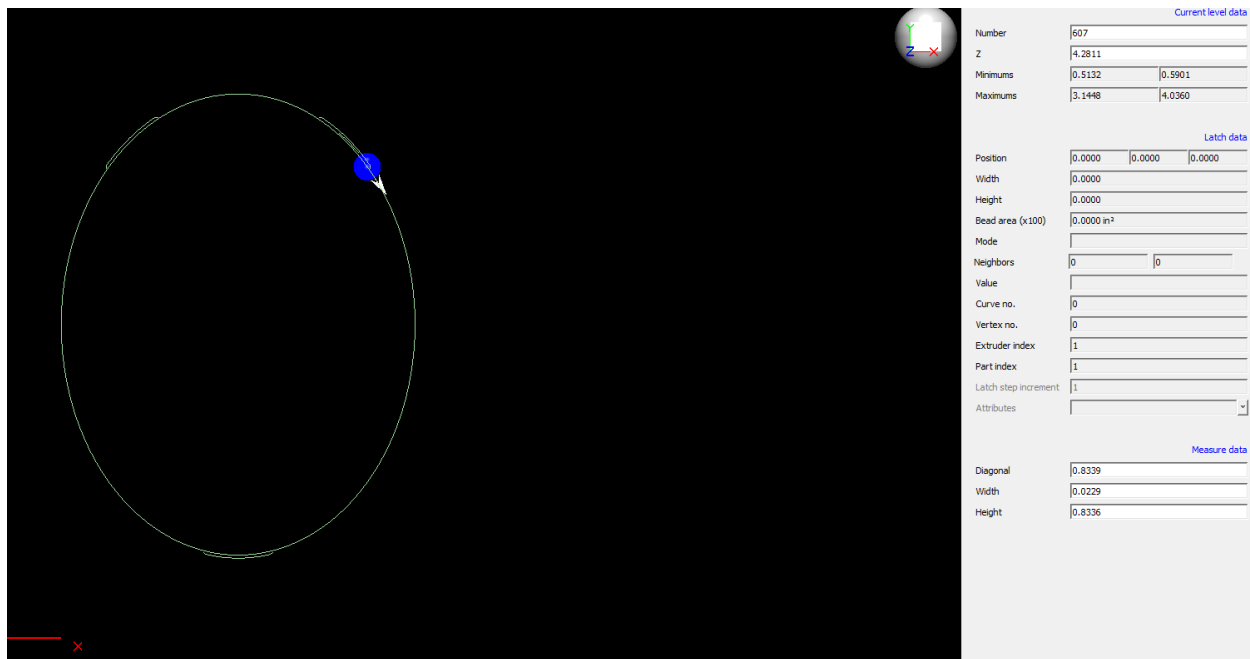
Ex. E (July 5, 2011, packed CMB file) at 32. The images above show that when switching the material being printed within each layer of the CMB file, each print head / deposition line (part and support material) begins with printing the layer of the purge tower followed by printing the respective layer of the part or support structure. I note that Exhibit E lists the “Fortus 400mc Large” under “Machine Type” in the file header, however early on in the Solo project development CMB files for the Fortus 400mc were repurposed for the smaller Solo printer.

76 Information on

General			Internals	
Machine type	Fortus 400mc Large		Comment	Packed file written by Control Center!!!
Extruder index	1		Pack list	purge_part+support-11
Material	ABS-M30		Versions	8.1 (4255) 8.9
Color	not specified		GUID	
Tip size	T12		Limits	
Volume	4.274194		Part width	0.0110 0.0600
Slice height	0.0070		Part area	0.0001 in ² 0.0004 in ²
Number of slices	607		Part aspect ratio	1.5767 8.5714
System mode	none		Support width	0.0121 0.0191
Part build style	none		Support area	0.0001 in ² 0.0001 in ²
Shrink factor (X Y Z)	1.000000	1.000000	Support aspect ratio	1.7244 2.7303
☐ Has variable width				
☐ CMB locked				
User name				
Embedded version				
System Serial#				

Ex. E (July 5, 2011, packed CMB file) at 2. Notably, the dimensions of the build space in Exhibit E align with the constraints of the Solo printer (5x5x5 inch build space) that was under development at that time. I also note that, as discussed above, the CMB file shows that when the “Extruder index” is set to “1” the “Material” type is “ABS-M30,” which is a type of part material.³ As shown by the screenshot below, the final layer of the three-dimensional part was printed with part material, as indicated by the green lines, on layer 607 (corresponding to height of just over 4 inches (i.e., Z=4.2811)).

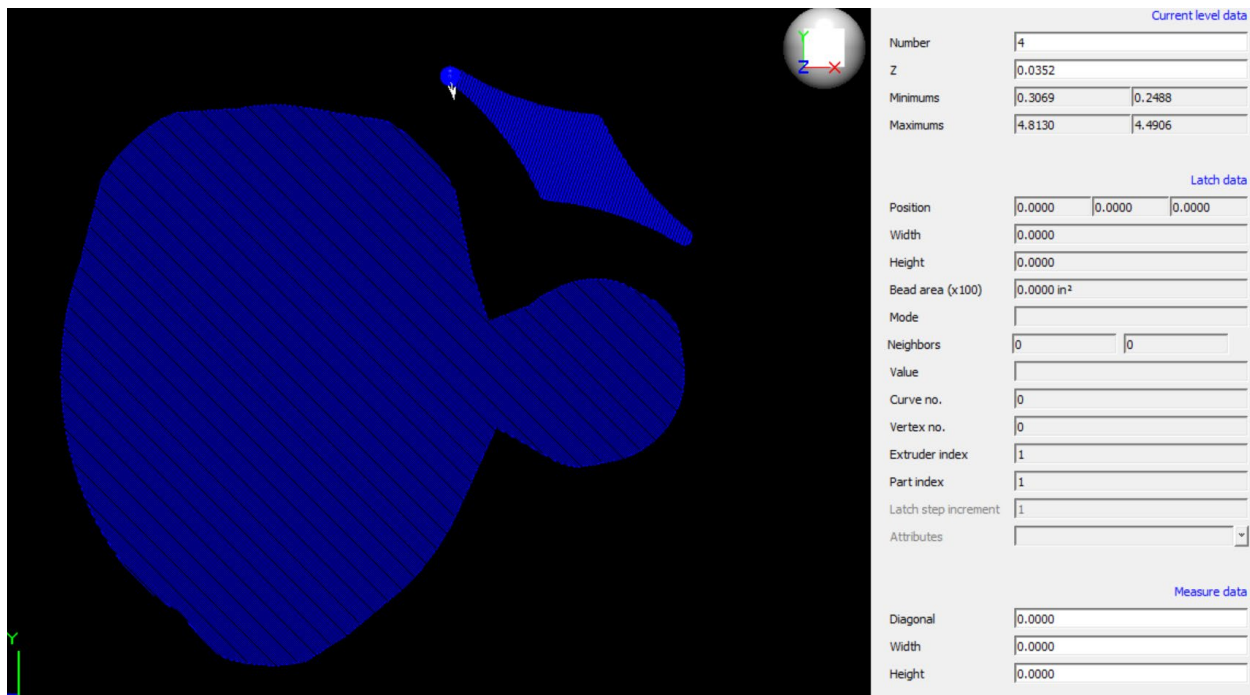
³ The Stratasys website (<https://www.stratasys.com/en/materials/materials-catalog/fdm-materials/abs-m30/>) lists types of Stratasys part material, including ABS-M30.



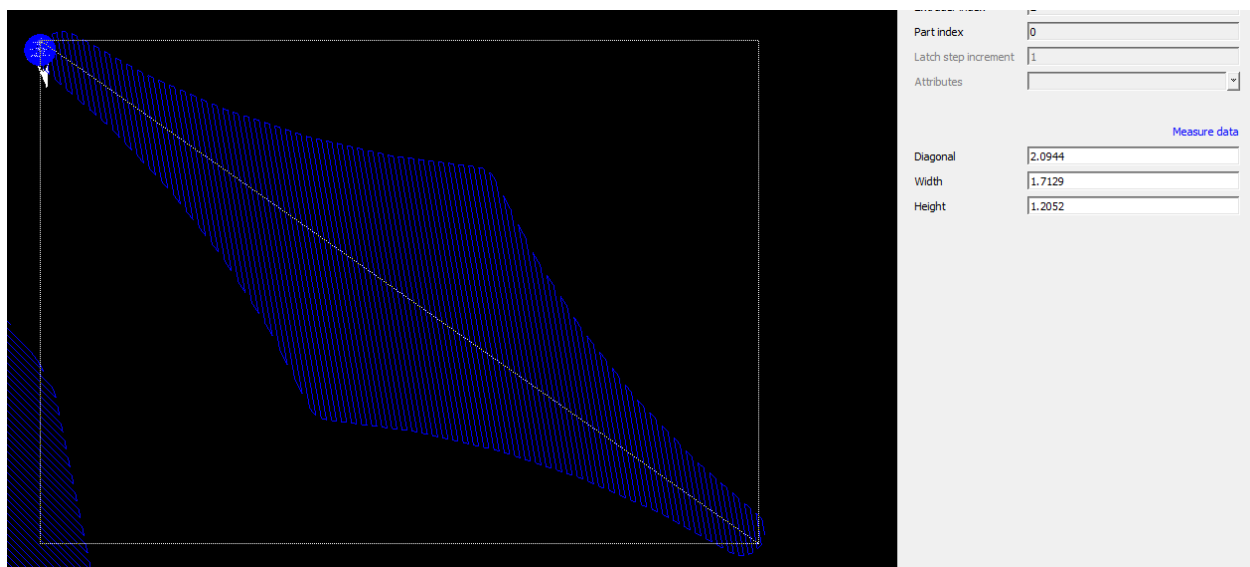
Ex. E (July 5, 2011, packed CMB file) at 19.

17. As noted, the Solo printer had multiple print heads and deposition lines, including a part material deposition line associated with the Part Print Head and a support material deposition line associated with the Support Print Head. Switching the deposition lines between the stand-by modes and the operating modes involved switching the part material deposition line from the stand-by mode to the operating mode; and switching the support material deposition line from the operating mode to the stand-by mode. The same process was also done in reverse for subsequent layers (i.e., the part material deposition line was switched to stand-by mode while the support material deposition line was switched to operating mode). This process is depicted in the screenshots above from Exhibit E.

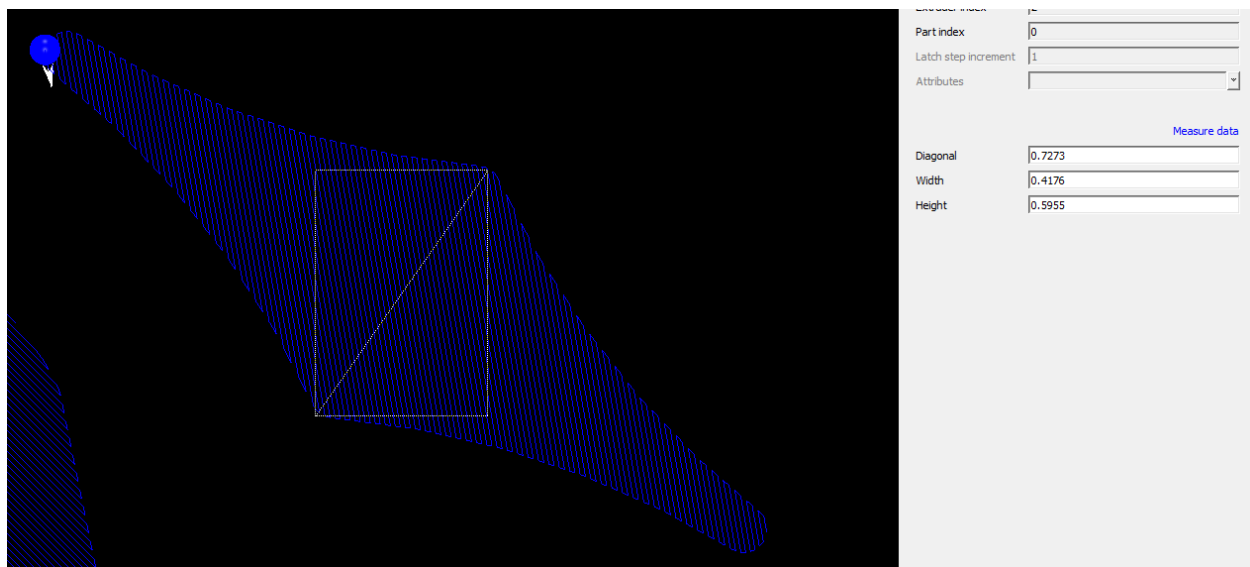
18. The Solo printer also printed the purge tower with a cross-sectional area that reduced in height along an axis that is perpendicular to a build plane. For example, the Solo printer printed a purge tower where the first few layers had a larger cross-sectional area to provide sufficient stability for the purge tower and then subsequent layers had a smaller cross-sectional area. The screenshots below of Exhibit E depict this relationship:



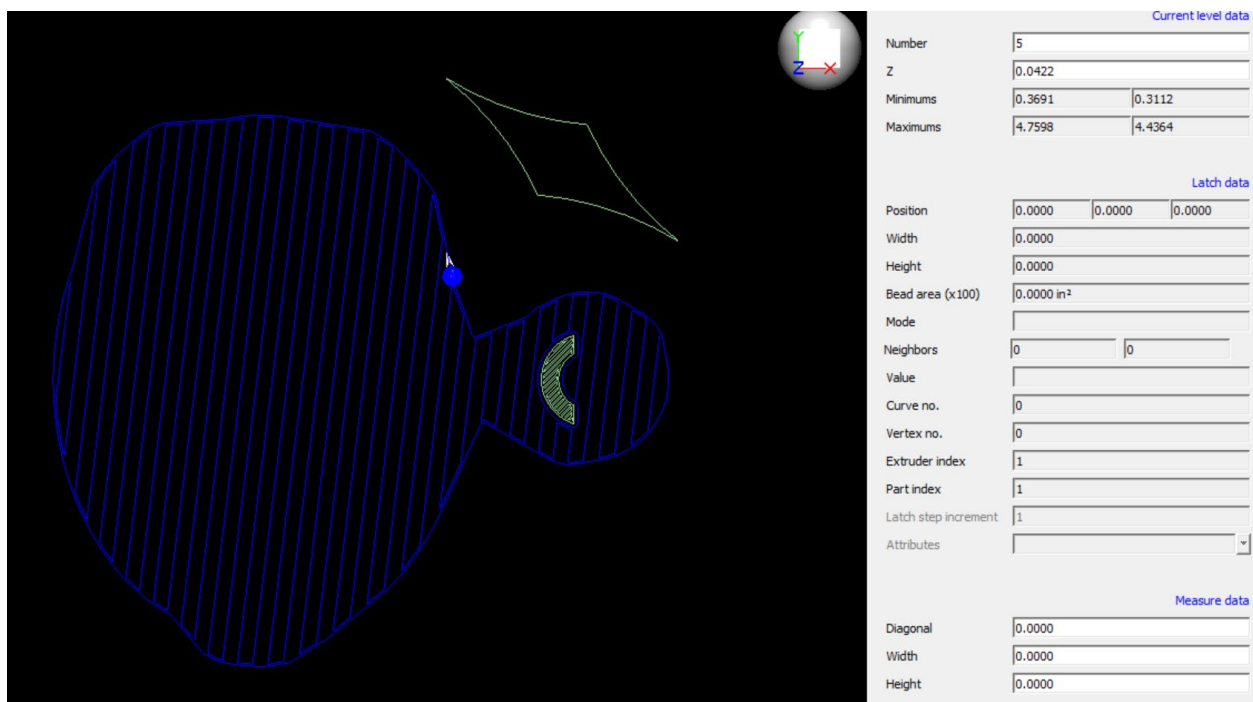
Ex. E (July 5, 2011, packed CMB file) at 3. As shown in layer 4, the blue lines indicate support material, and the blue filled-in diamond shape represents a layer of the purge tower. The blue-filled in diamond at layer 4 has a length of 2.0944 inches and a width of 0.7273 inches.



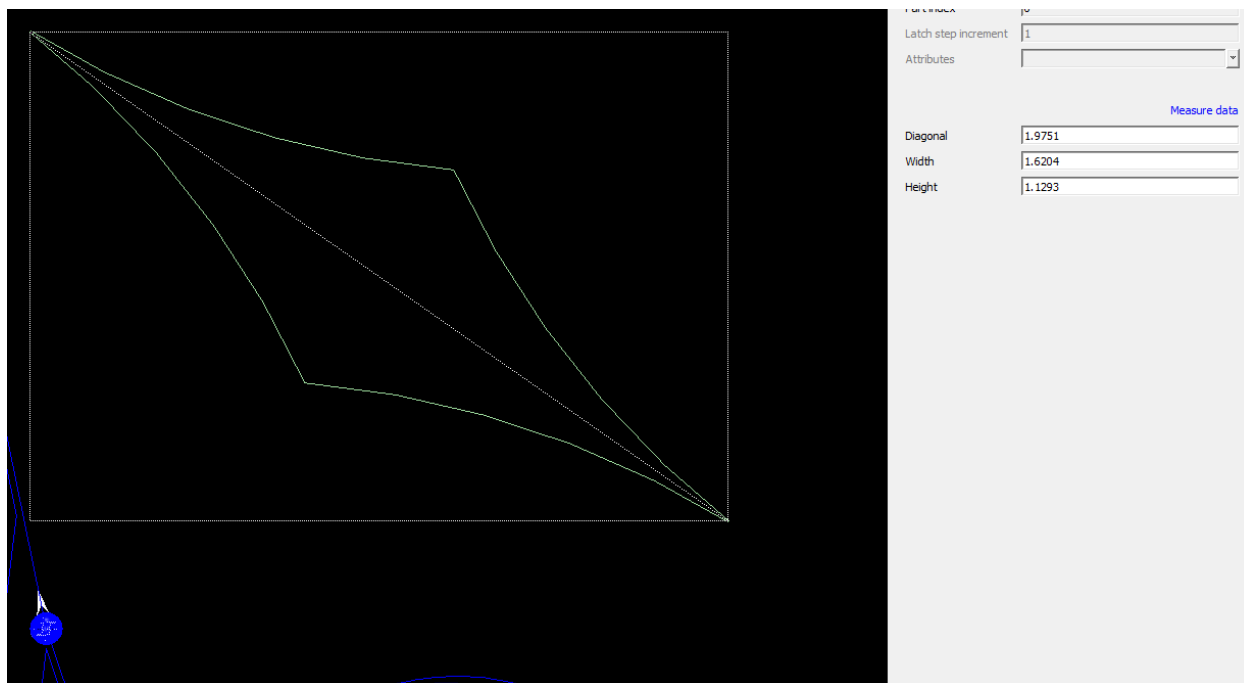
Ex. E (July 5, 2011, packed CMB file) at 5.



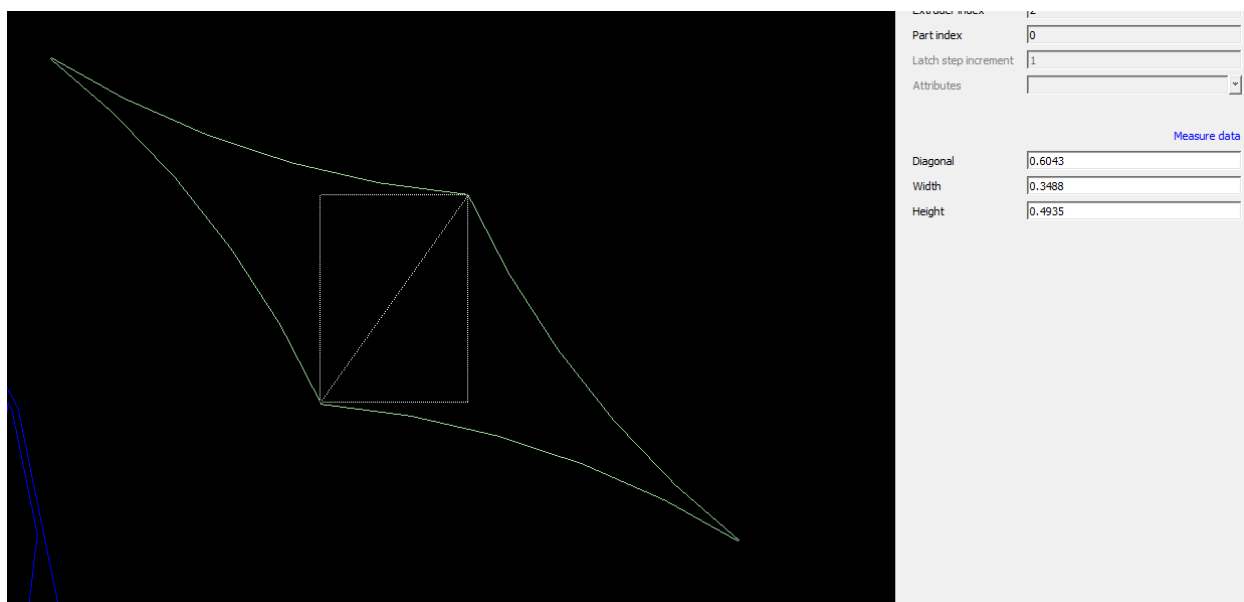
Ex. E (July 5, 2011, packed CMB file) at 5. Layer 5 is shown below:



Ex. E (July 5, 2011, packed CMB file) at 5. As shown in layer 5, which is above layer 4, the blue lines indicate support material, and the green lines indicate part material. The green diamond shape represents a layer of the purge tower, which has a smaller cross-sectional area than layer 4 shown in the previous image. For example, the green diamond shape at layer 5 has a length of 1.9751 inches and a width of 0.6043 inches.



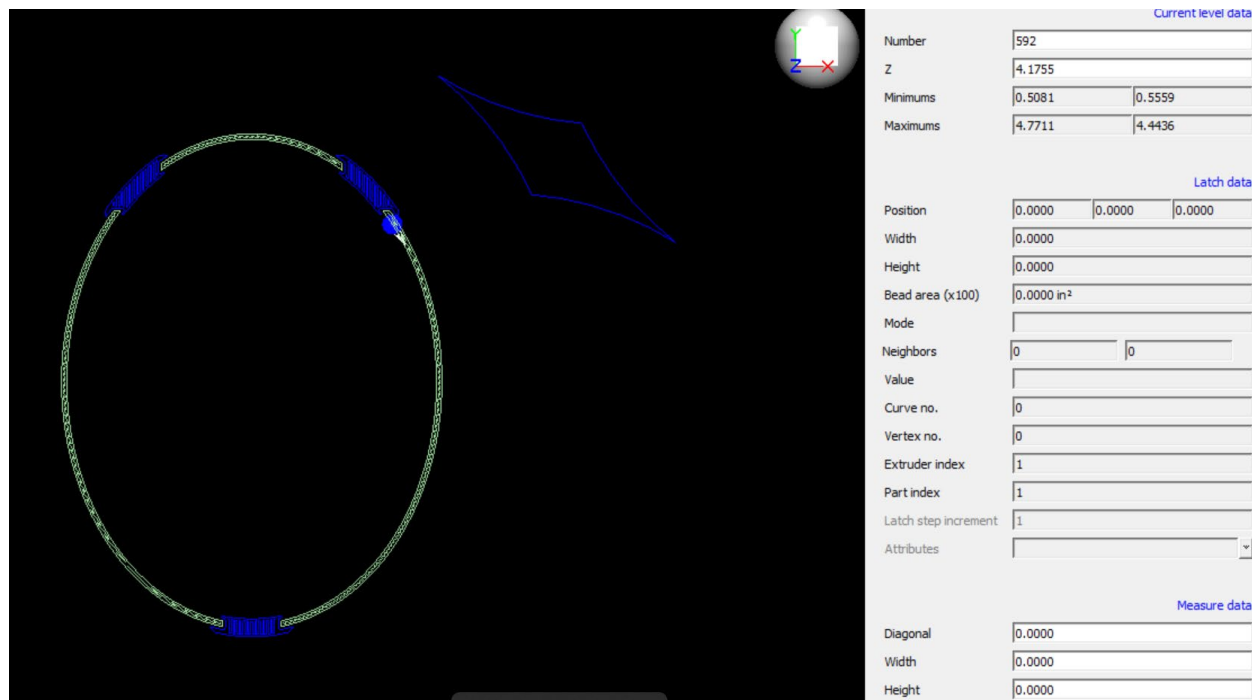
Ex. E (July 5, 2011, packed CMB file) at 6.



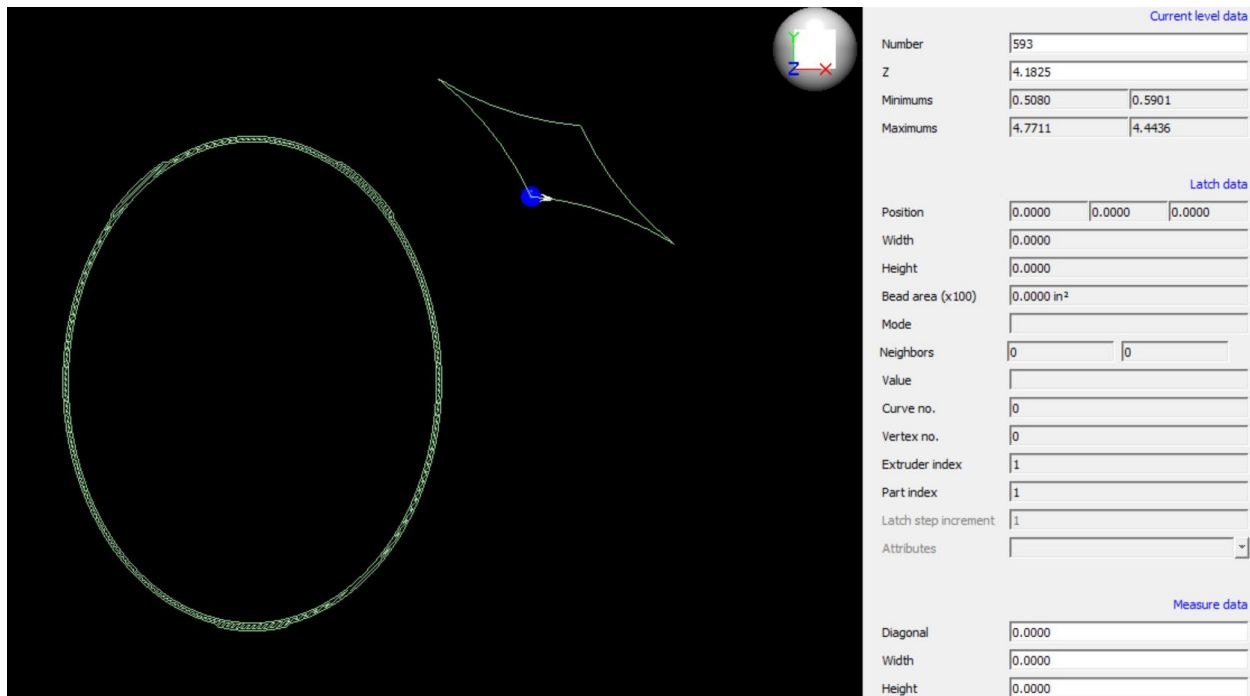
Ex. E (July 5, 2011, packed CMB file) at 7. These measurements are less than the length and width of the diamond shape at layer 4. The cross-sectional area shown in layer 5 is carried up through the rest of the layers of the purge tower (ending on layer 593).

19. The Solo printer also stopped building the purge tower at the highest layer at which there was a material change for the printed layers of the three-dimensional part and support

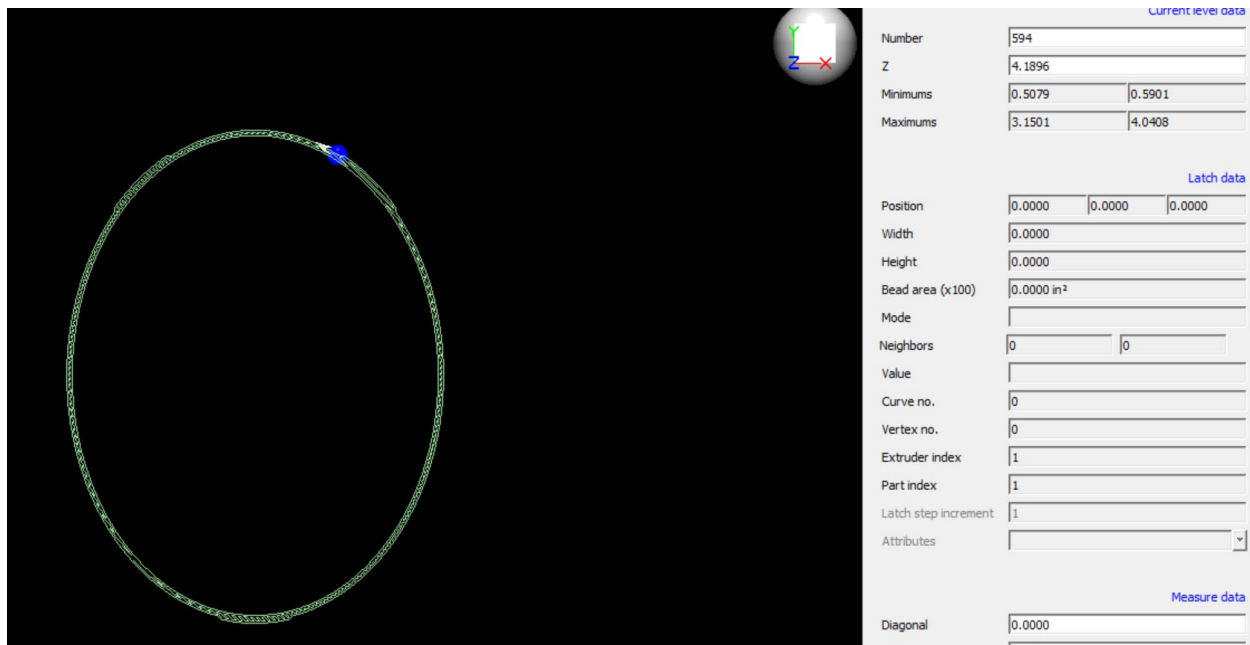
structure. The purge operations were performed when the relevant print head/deposition line went into operating mode. As such, there was no need to print additional layers of the purge tower after the last material change. The screenshots below of Exhibit E depict this process, showing that the last layer of the purge tower was printed on layer 593, which corresponded to the final change to part material:



Ex. E (July 5, 2011, packed CMB file) at 16. As shown in layer 592, the blue lines indicate support material, and the green lines indicate part material. The blue diamond shape represents a layer of the purge tower, corresponding to a switch to the printing of support material on this layer.



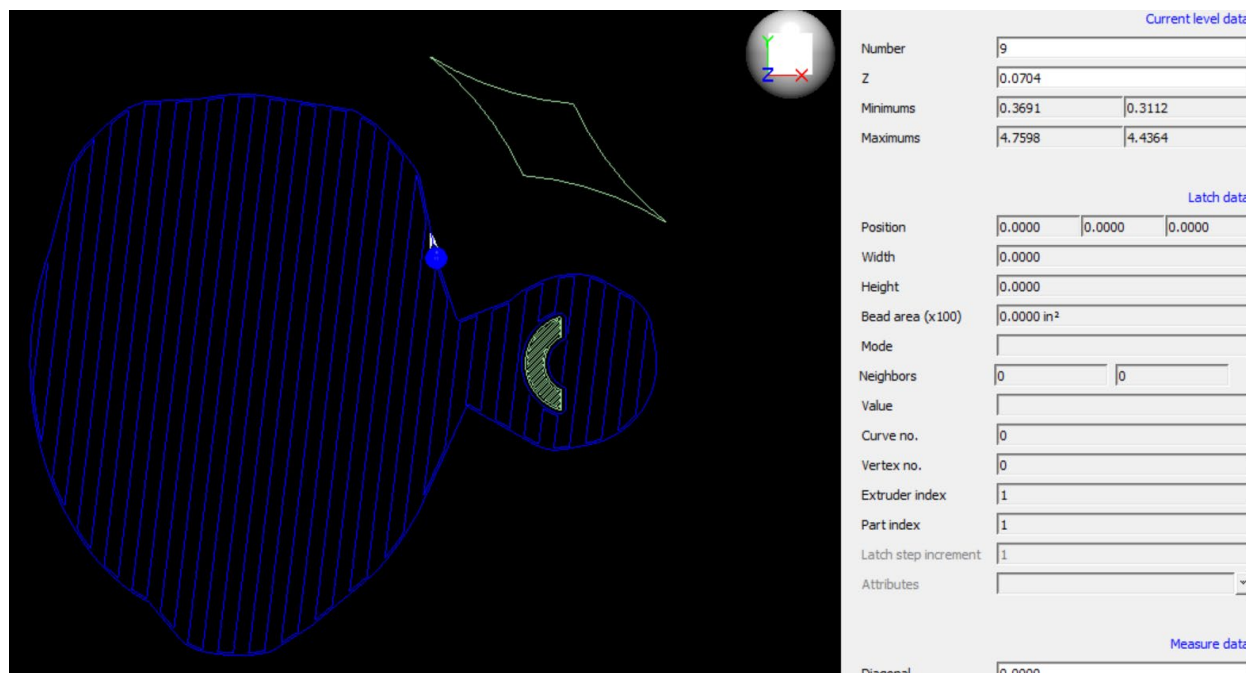
Ex. E (July 5, 2011, packed CMB file) at 17. As shown in layer 593, the green lines indicate part material. The green diamond shape represents a layer of the purge tower, corresponding to a switch to the printing of part material on this layer.



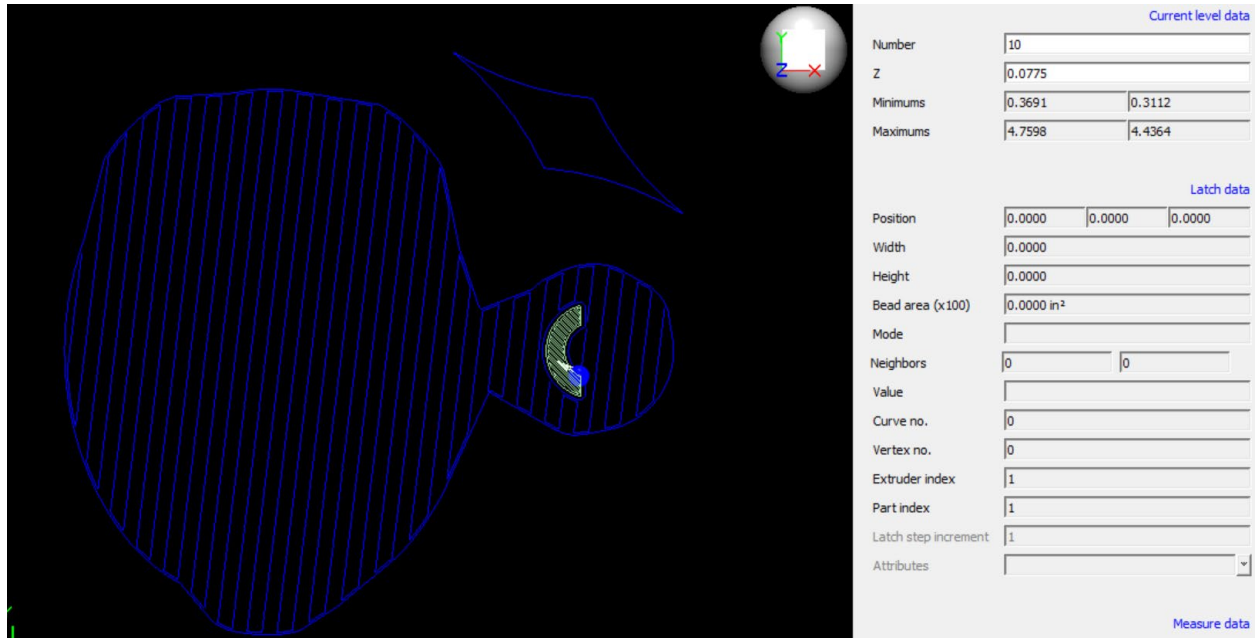
Ex. E (July 5, 2011, packed CMB file) at 18. As shown in layer 594, the green lines indicate part material. No layer of the purge tower is printed on layer 594 because there was no switch back

from part material to support material. No further layers of the purge tower were printed on layers 595-607 (the topmost layer) because all those layers printed only part material and no further material changes occurred.

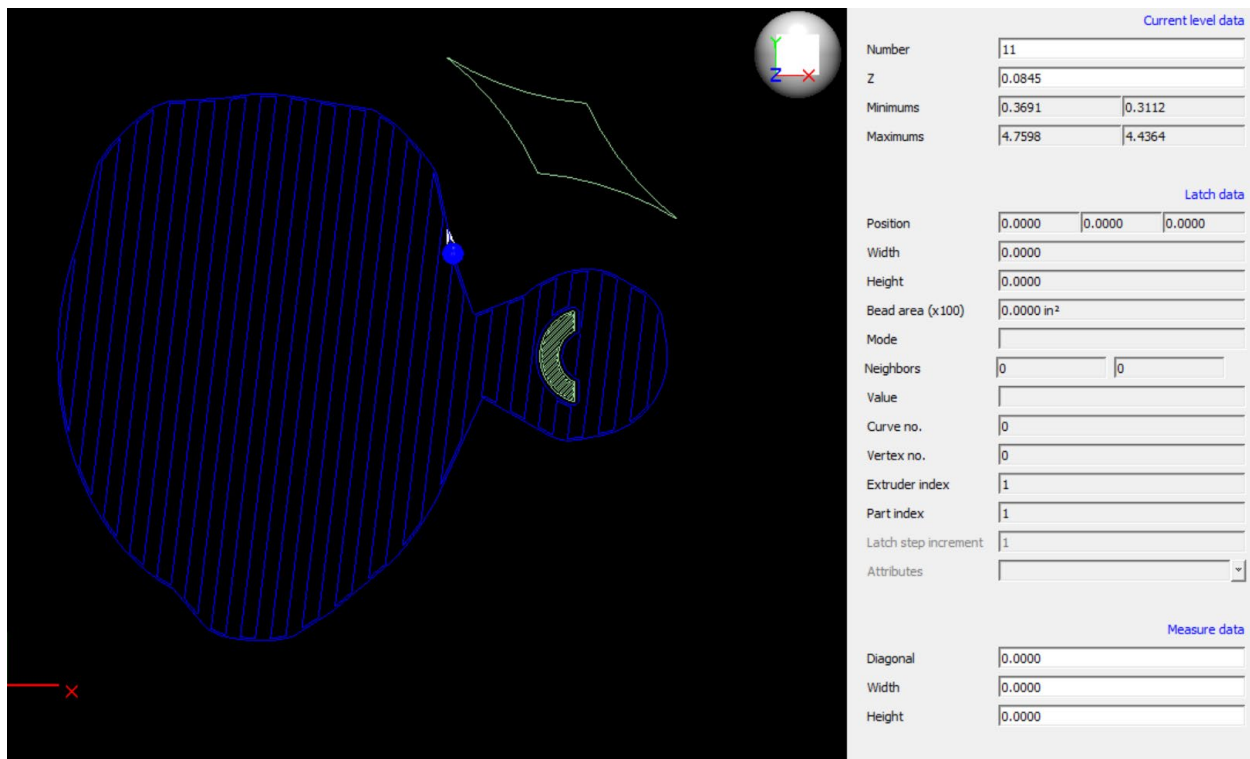
20. Software was used in conjunction with the Solo printer to generate tool path instructions for printing the layers of the three-dimensional part, the support structure, and the purge tower. The Solo printer used Stratasys software called Insight™ to generate the tool path instructions for printing the layers of the three-dimensional part and support structure. Additionally, I used Insight™ to generate the tool path instructions for printing the layers of the purge tower(s). These instructions were stored in coordinate machine binary (“CMB”) files I discussed above. I provided purge tower CMB files so others at Stratasys working on the development of the Solo printer could utilize the purge tower CMB files to print three-dimensional objects along with purge towers. These CMB files were packed together using Stratasys software called Control Center™ (an application within Insight™). The resulting combined CMB file contained the tool path instructions for the three-dimensional part, the support structure, and the purge tower(s). Resulting combined CMB files were used to print the three-dimensional part, the support structure, and the purge tower(s). An example of the tool paths from such a CMB file (Exhibit E) are shown below:



Ex. E (July 5, 2011, packed CMB file) at 8. As shown in layer 9, the blue lines indicate the tool paths for support material, and the green lines indicate the tool paths for part material. The green diamond shape represents the tool path for printing a layer of purge tower from part material.



Ex. E (July 5, 2011, packed CMB file) at 9. As shown in layer 10, the blue lines indicate the tool paths for support material, and the green lines indicate the tool paths for part material. The blue diamond shape represents the tool path for printing a layer of purge tower from support material.

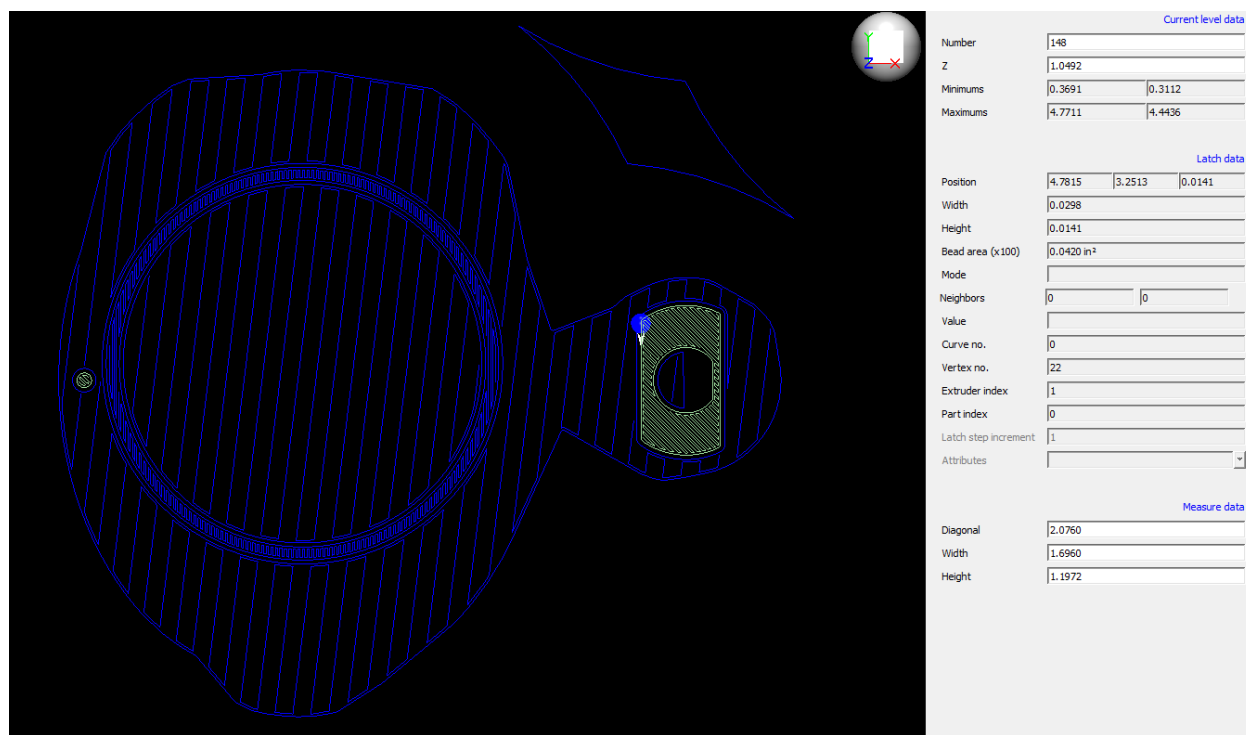


Ex. E (July 5, 2011, packed CMB file) at 10. As shown in layer 11, the blue lines indicate the tool paths for support material, and the green lines indicate the tool paths for part material. The green diamond shape represents the tool path for printing a layer of purge tower from part material. The blue tool paths surrounding the green tool paths in the above images of layers 9-11 correspond to the support structure. The green tool paths within the blue support structure correspond to the three-dimensional part. As I discussed, the diamond-shaped tool paths separate from the part and the support structure (alternating green and blue) correspond to the purge tower.

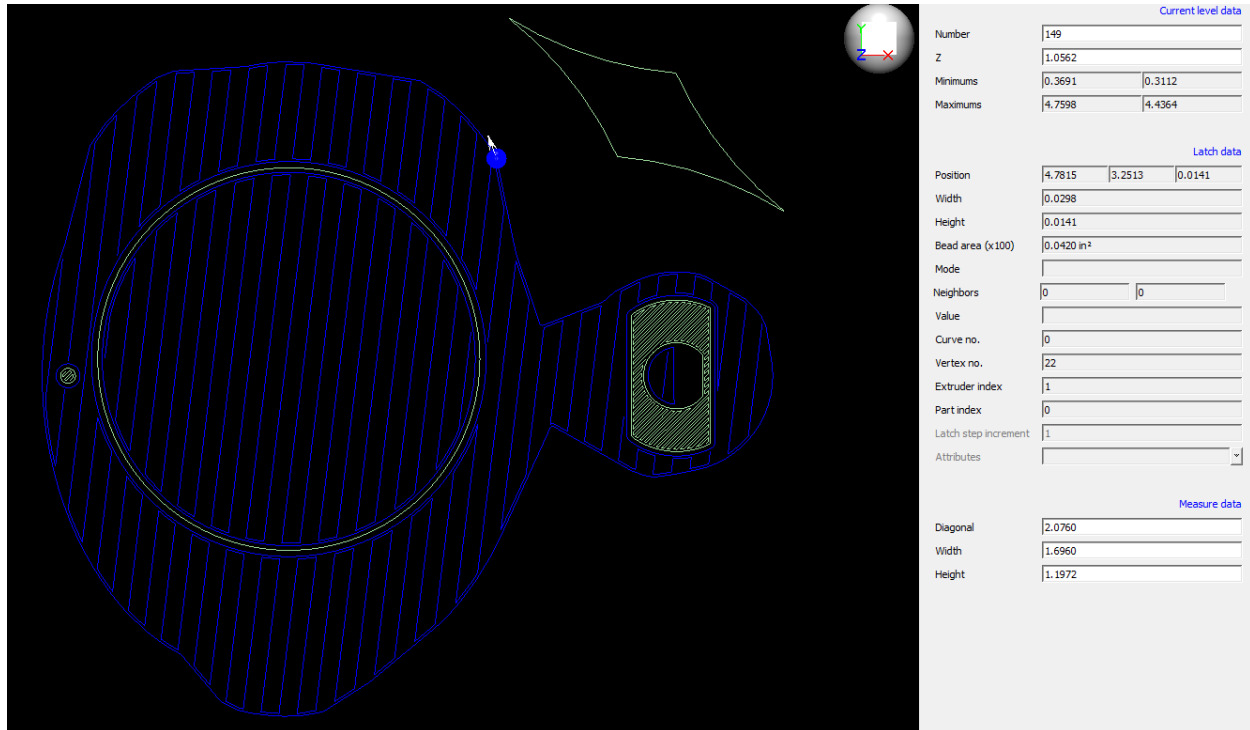
21. The tool path instructions for printing the layer of the purge tower(s) were generated prior to printing the layers of the three-dimensional part and of the support structure. As discussed above, I generated the CMB files with tool path instructions for printing the layers of the purge tower(s) using the Insight™ software. I then packed that purge tower CMB file into a single CMB file along with the CMB file containing the three-dimensional part and support structure using the Control Center™ software. The purge tower would be packed first in Control Center™ so that each layer would begin with printing the layer of the purge tower. The generation of the purge tower tool path instructions and the packing in Control Center™ was completed prior to printing the part and support structure. This order was necessary to use the purge tower during the printing

process, as the Solo printer used the single CMB file to perform the print operation of the purge tower, three-dimensional part, and support structure.

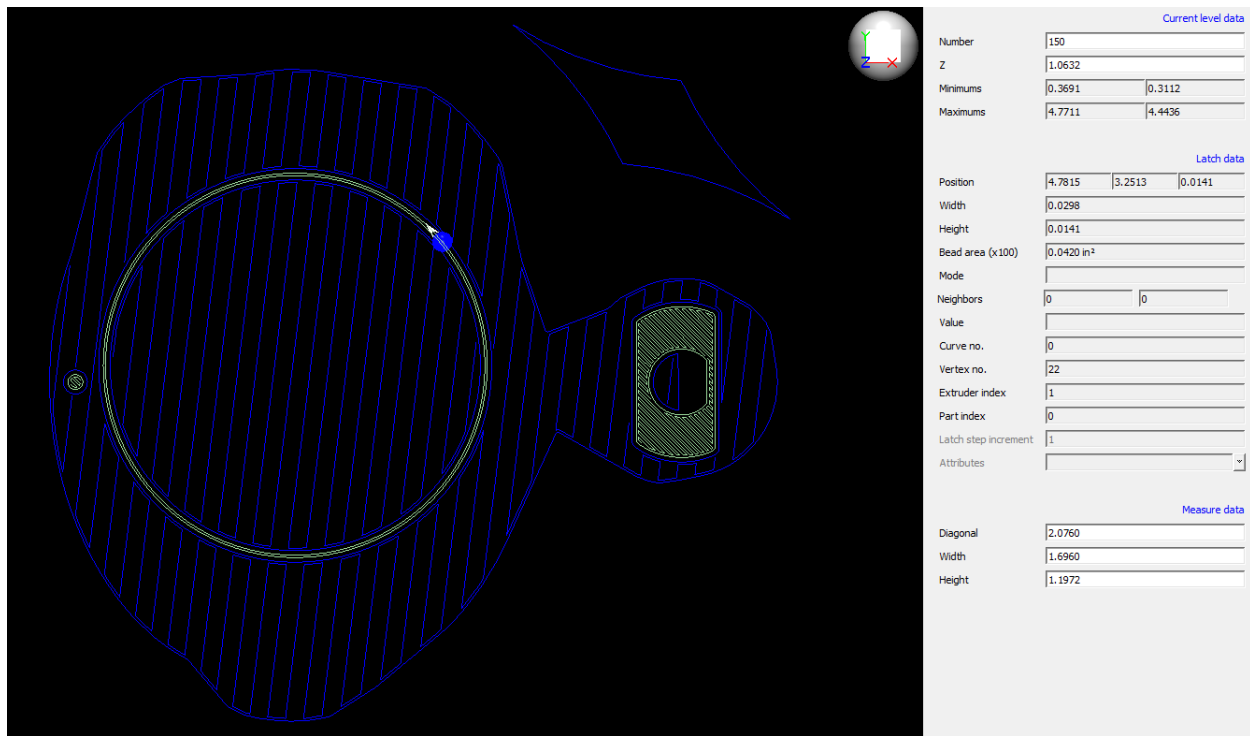
22. As discussed above, the Solo printer operated as a layer-based additive manufacturing system that alternated between printing layers of part and support material. For example, in some implementations, the Solo printer operated in the following series of steps: (a) printing a first layer of a support structure from a support material for the three-dimensional part; (b) printing a first layer of a purge tower from a part material; (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower; (d) printing a second layer of the purge tower from the support material; (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower. The Solo printer additionally repeated steps (b)-(e) to build successive layers of the three-dimensional part, support structure, and purge tower. An example of this process is shown by the graphical representations of Exhibit E shown below (depicting exemplary layers 148-152):



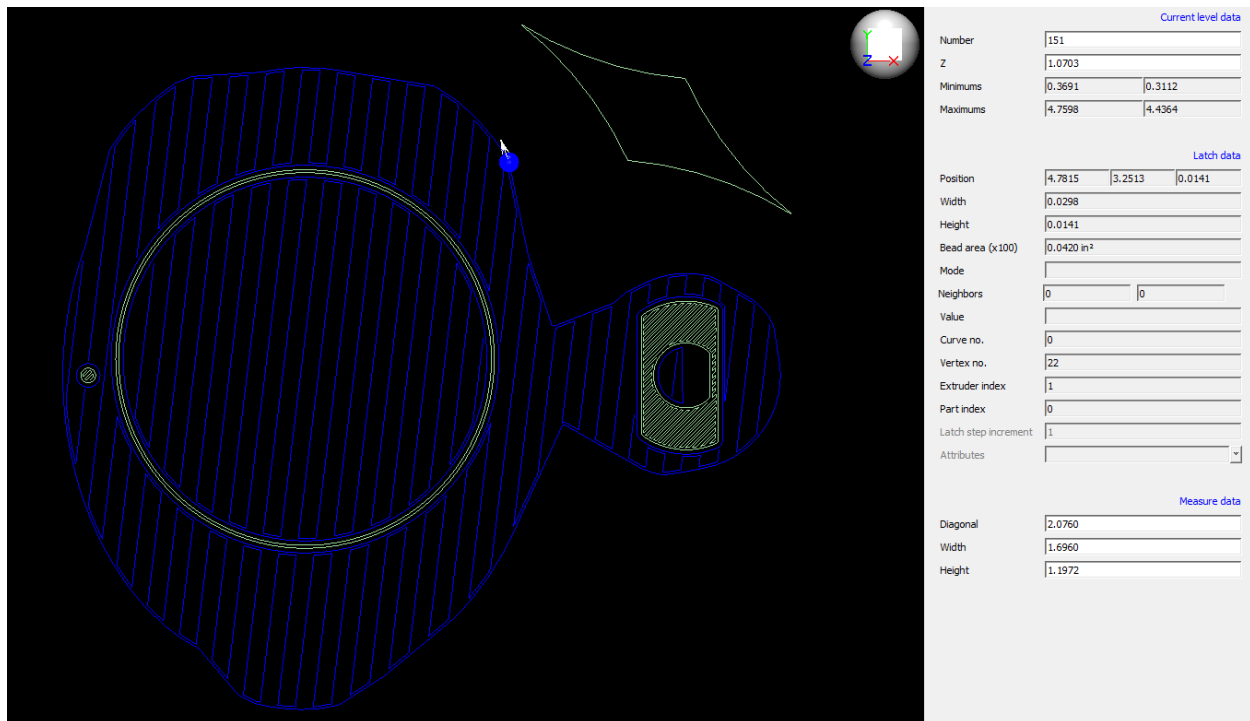
Ex. E (July 5, 2011, packed CMB file) at 11. As shown in layer 148, the blue lines indicate the tool paths for printing a first layer of a support structure from a support material for the three-dimensional part.



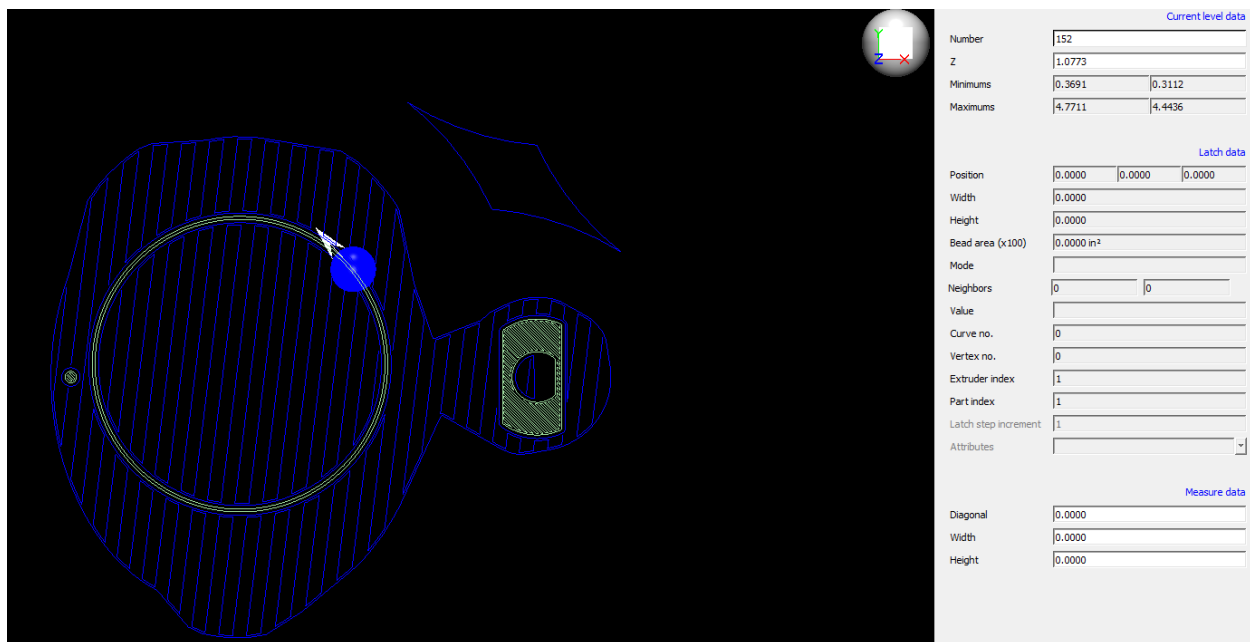
Ex. E (July 5, 2011, packed CMB file) at 12. As shown in layer 149, the green lines indicate the tool paths for (b) printing a first layer of a purge tower from a part material, and (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower.



Ex. E (July 5, 2011, packed CMB file) at 13. As shown in layer 150, the blue lines indicate the tool paths for (d) printing a second layer of the purge tower from the support material, and (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower. As shown in layers 151 and 152, the blue and green lines indicate the tool paths for repeating steps (b)-(e) described above to build successive layers of the three-dimensional part, support structure, and purge tower.



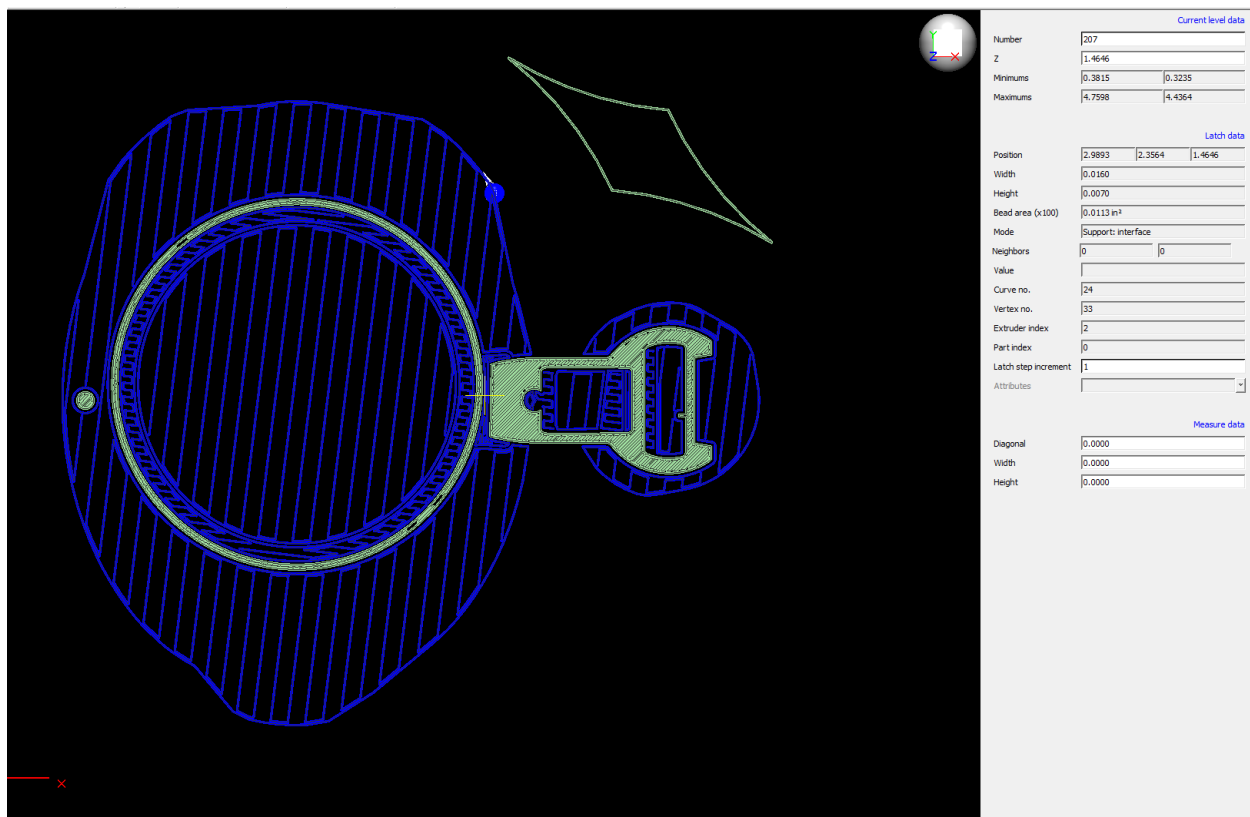
Ex. E (July 5, 2011, packed CMB file) at 14.



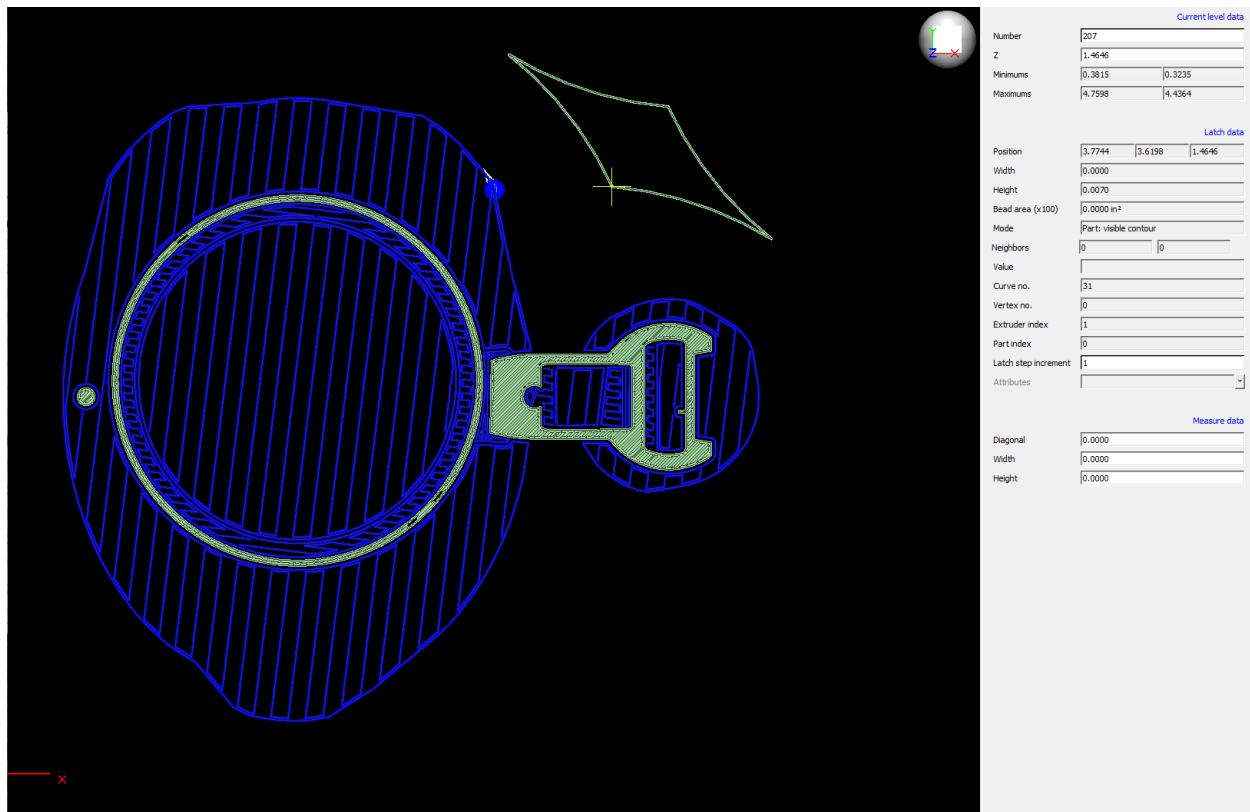
Ex. E (July 5, 2011, packed CMB file) at 15.

These series of steps are also shown by layers 207-210 of the CMB file. For instance, as shown in layer 207, the blue lines indicate the tool paths for (a) printing a first layer of a support structure

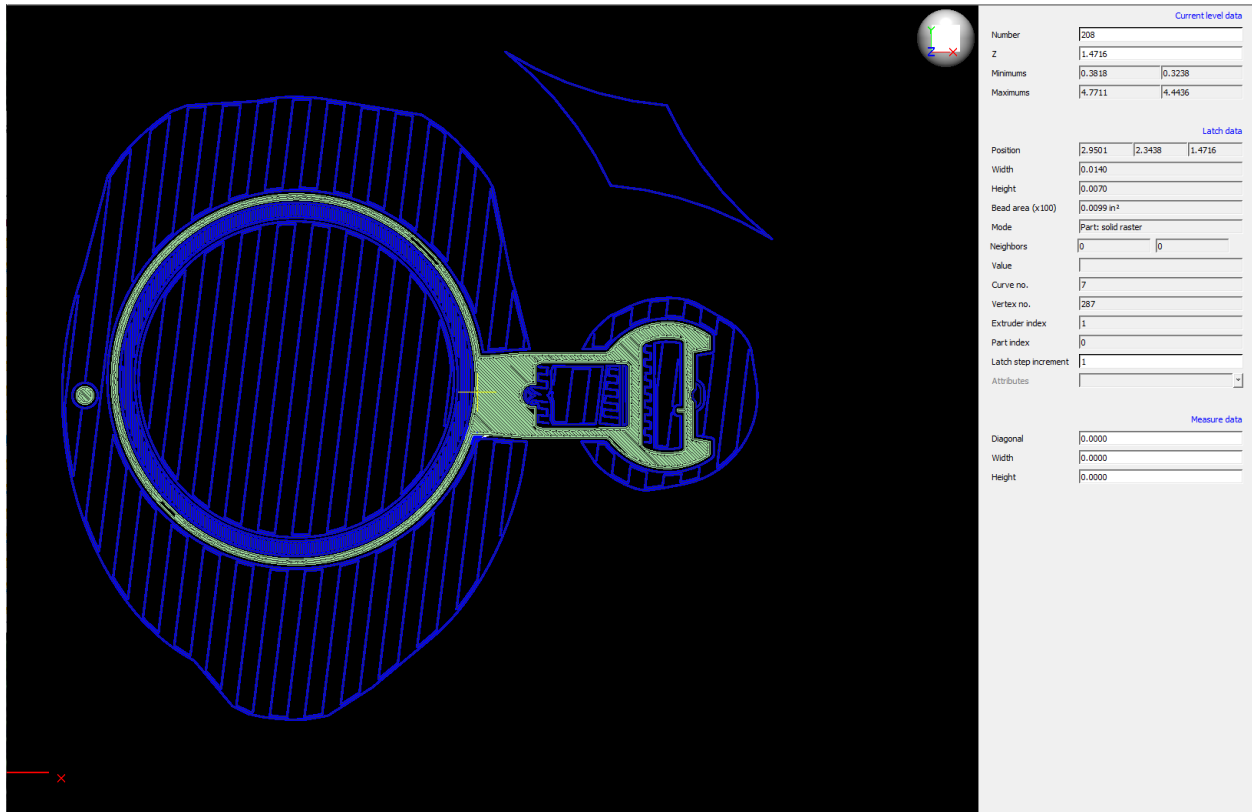
from a support material for the three-dimensional part; and the green lines in a diamond shape indicate the tool paths for (b) printing a first layer of a purge tower from a part material.



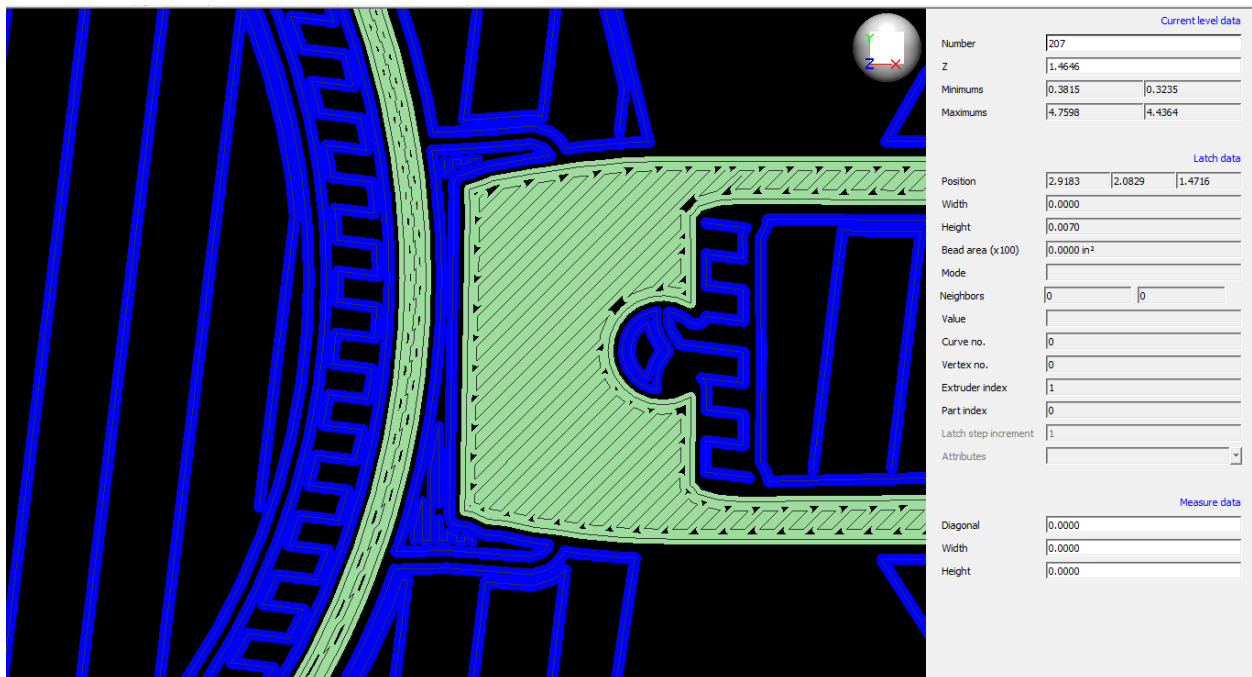
Ex. E (July 5, 2011, packed CMB file) at 33.



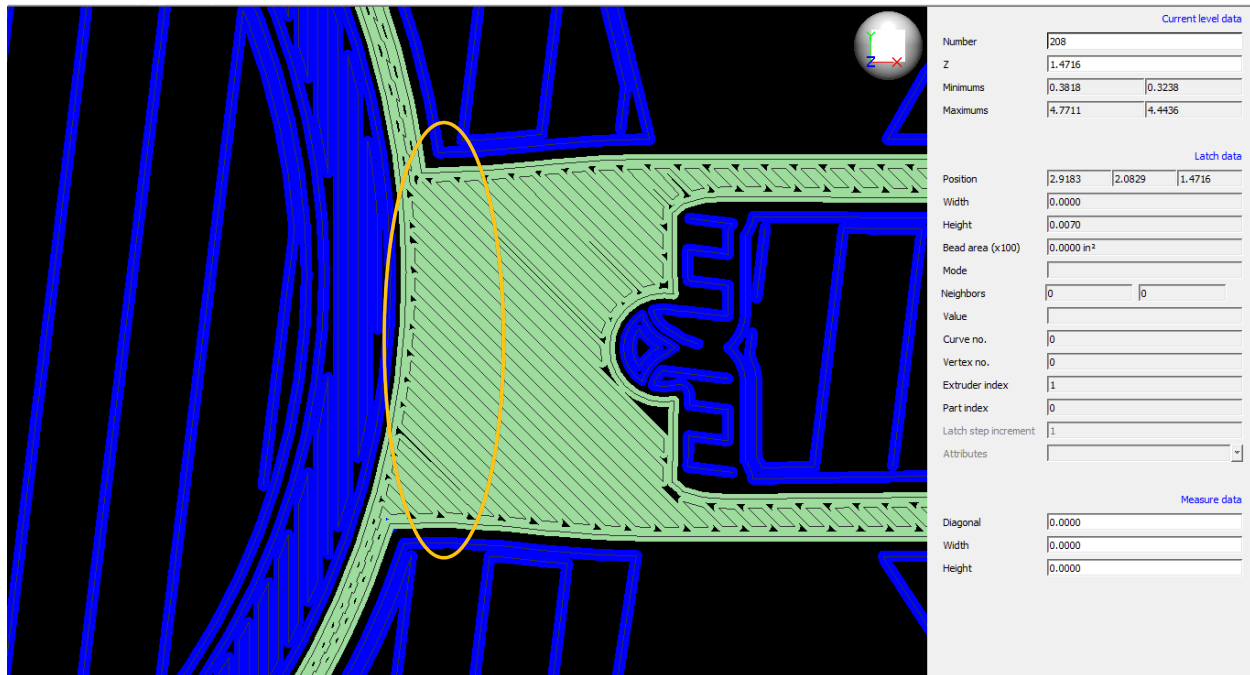
Ex. E (July 5, 2011, packed CMB file) at 34. As shown in layer 208, the green lines surrounded by the blue lines indicate the tool paths for (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower. The image below shows that the layer of the three-dimensional part near the center of the image in layer 208 is printed on at least a portion of the support structure in layer 207 where there was previously a gap between two portions of the part material (as seen above).



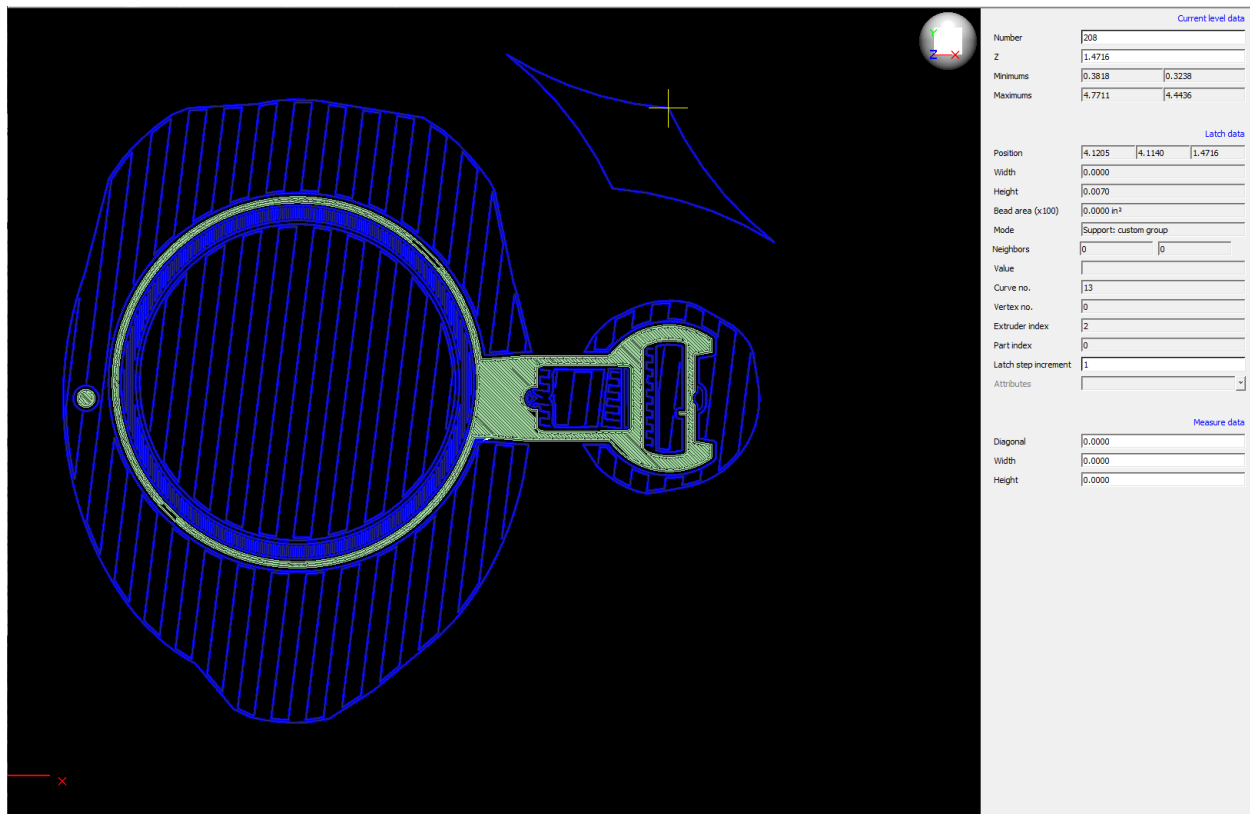
Ex. E (July 5, 2011, packed CMB file) at 35. Below is a close-up comparison between layers 207 and 208, which shows the printing of a layer of the part on the previous layer of the support structure:



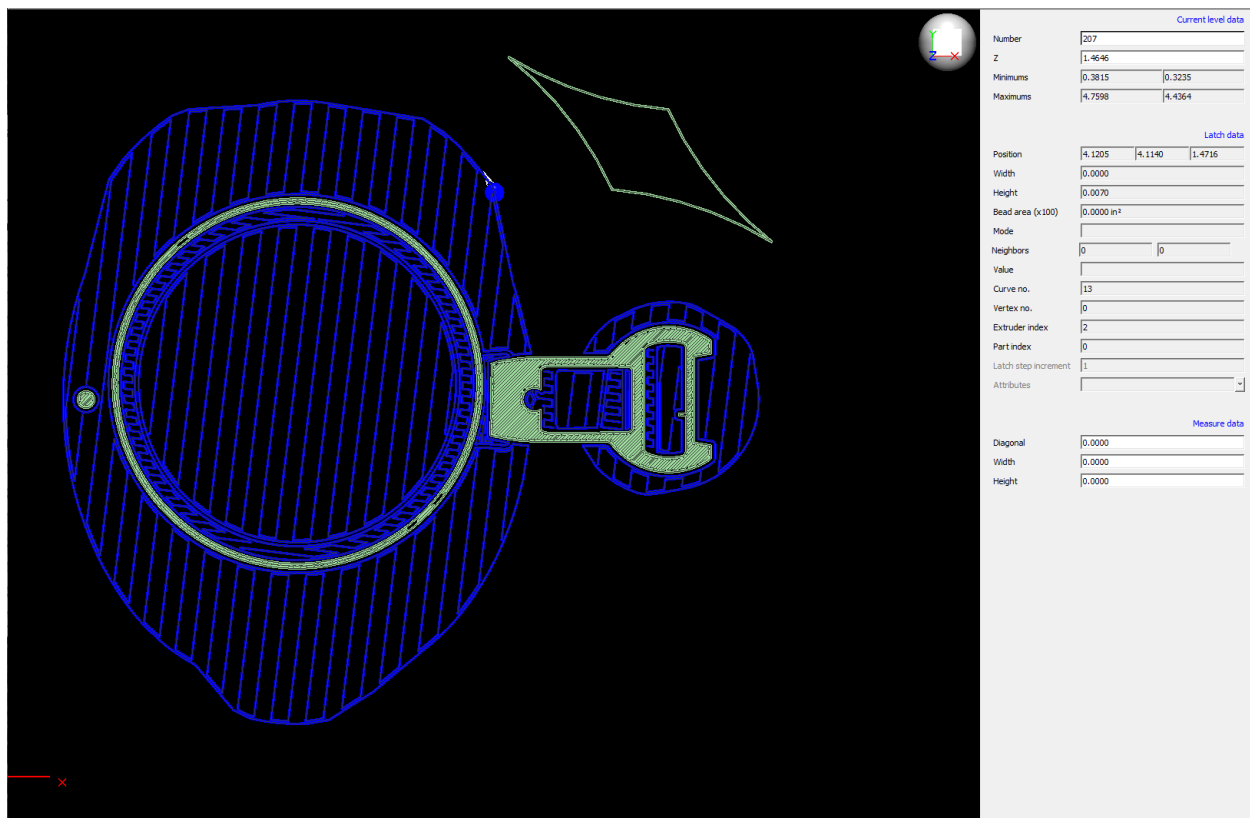
Ex. E (July 5, 2011, packed CMB file) at 36.



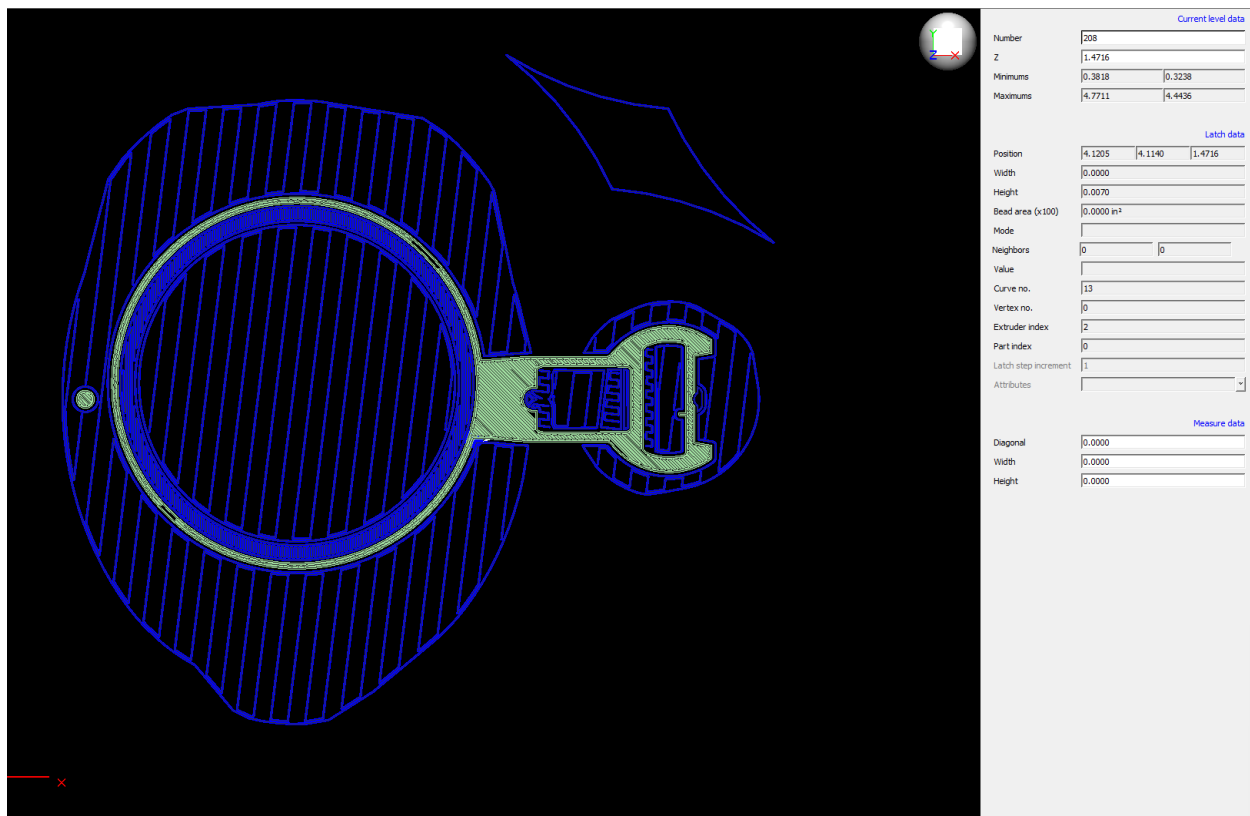
Ex. E (July 5, 2011, packed CMB file) at 37 (annotated to show part of the first layer of the three-dimensional part on at least a portion of the first layer of the support structure). As also shown in layer 208, the blue lines in a diamond shape indicate the tool paths for (d) printing a second layer of the purge tower from the support material.



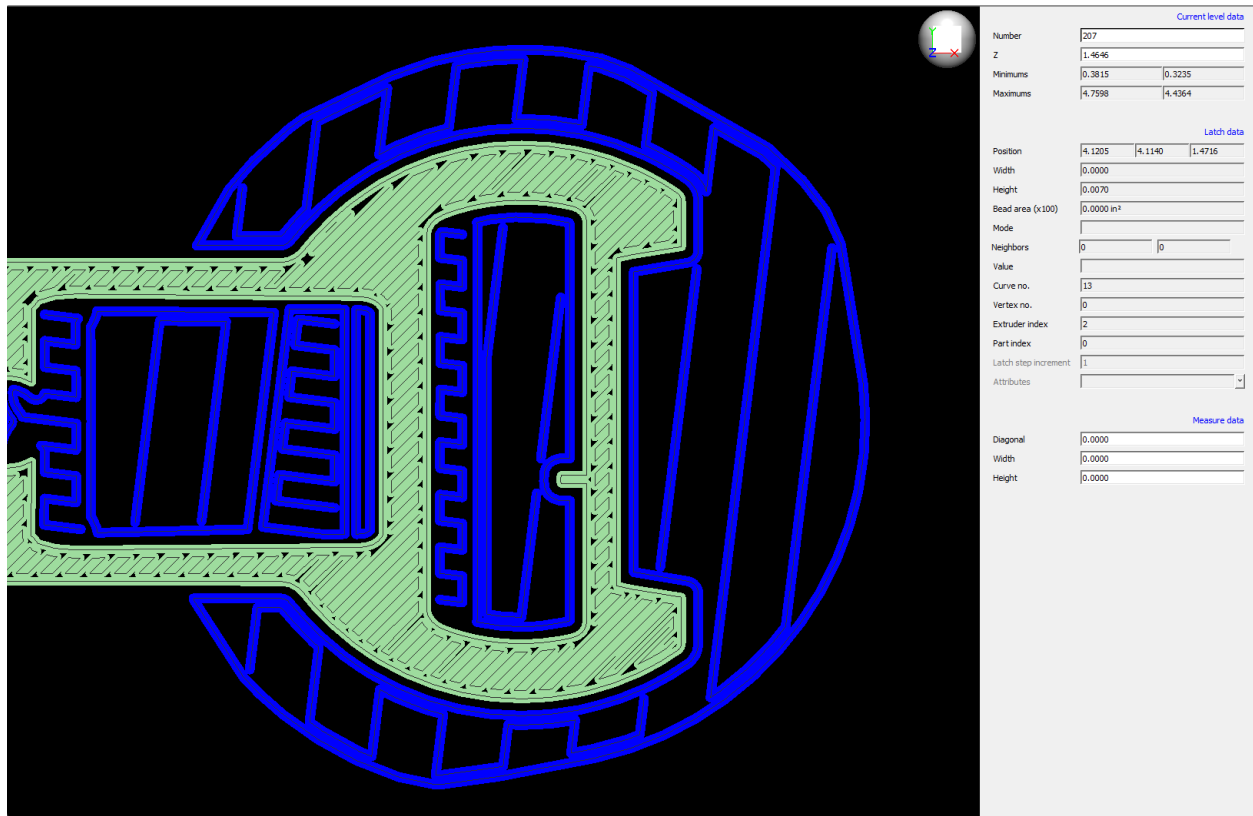
Ex. E (July 5, 2011, packed CMB file) at 38. As also shown in layer 208, the blue lines also indicate tool paths for (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower. The images below show that the layer of the support structure on the right-hand side of the image in layer 208 extends over and is printed on at least a portion of the three-dimensional part in layer 207.



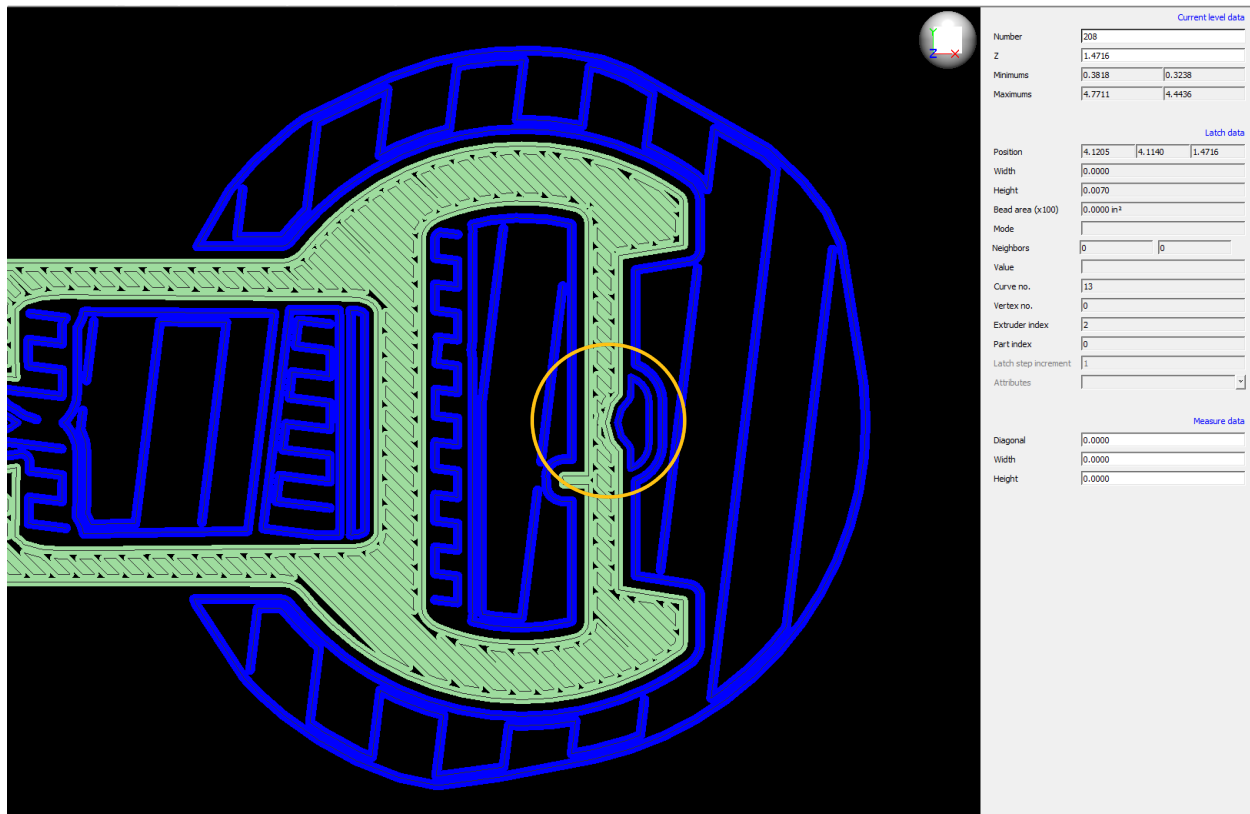
Ex. E (July 5, 2011, packed CMB file) at 39.



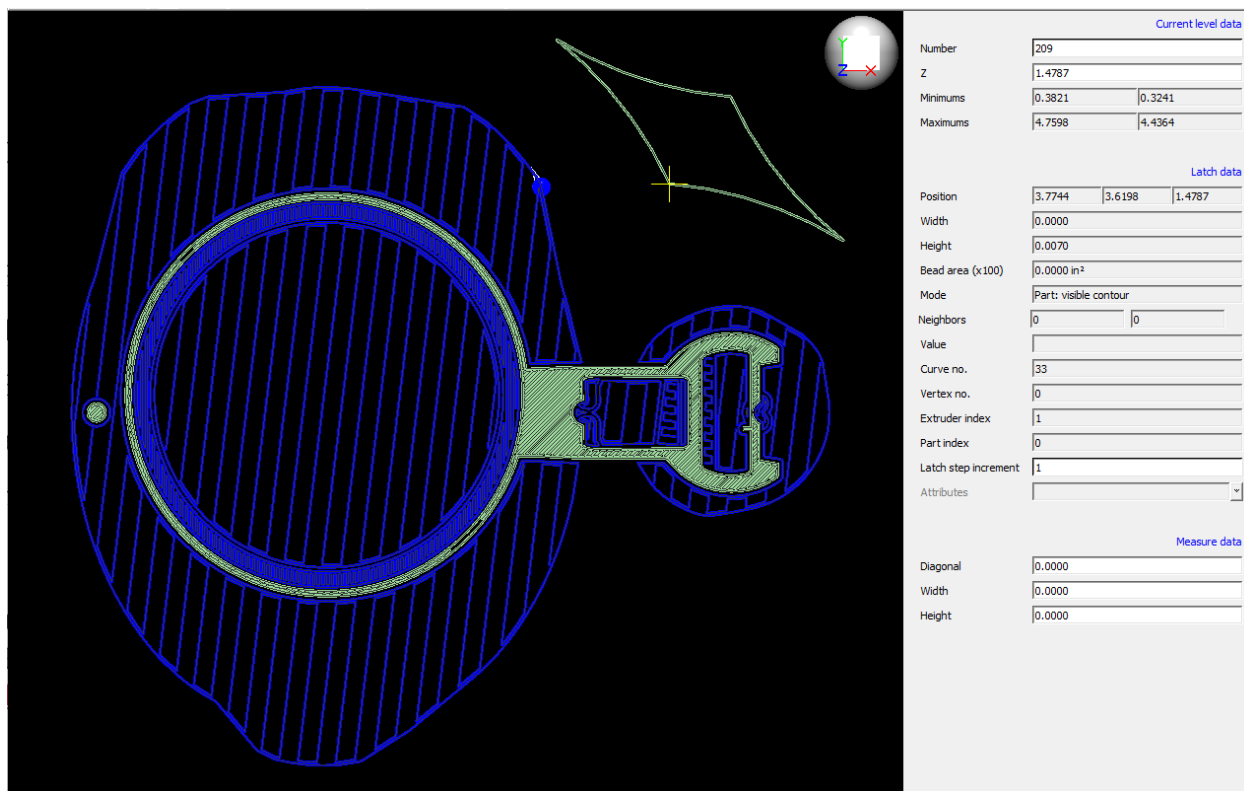
Ex. E (July 5, 2011, packed CMB file) at 40. Close-ups of this portion of layers 207 and 208 are shown below, depicting the printing of a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower.



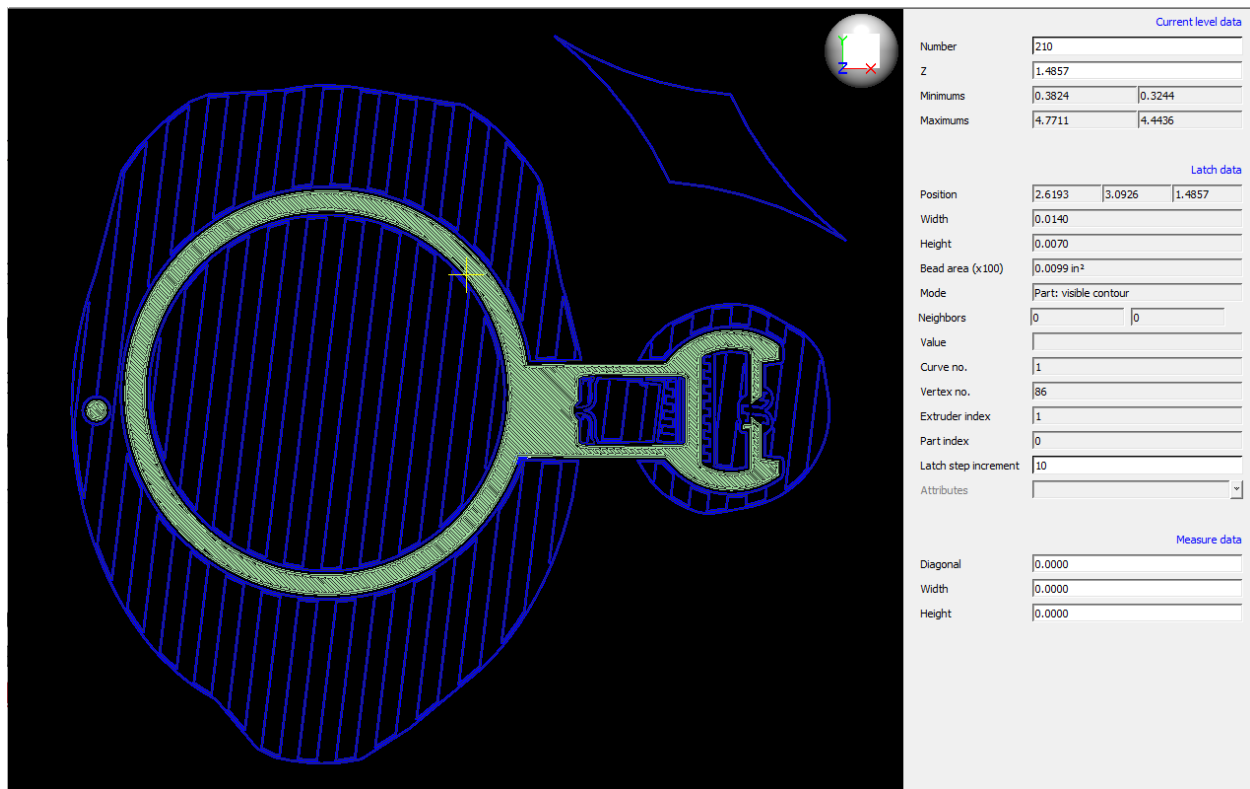
Ex. E (July 5, 2011, packed CMB file) at 41.



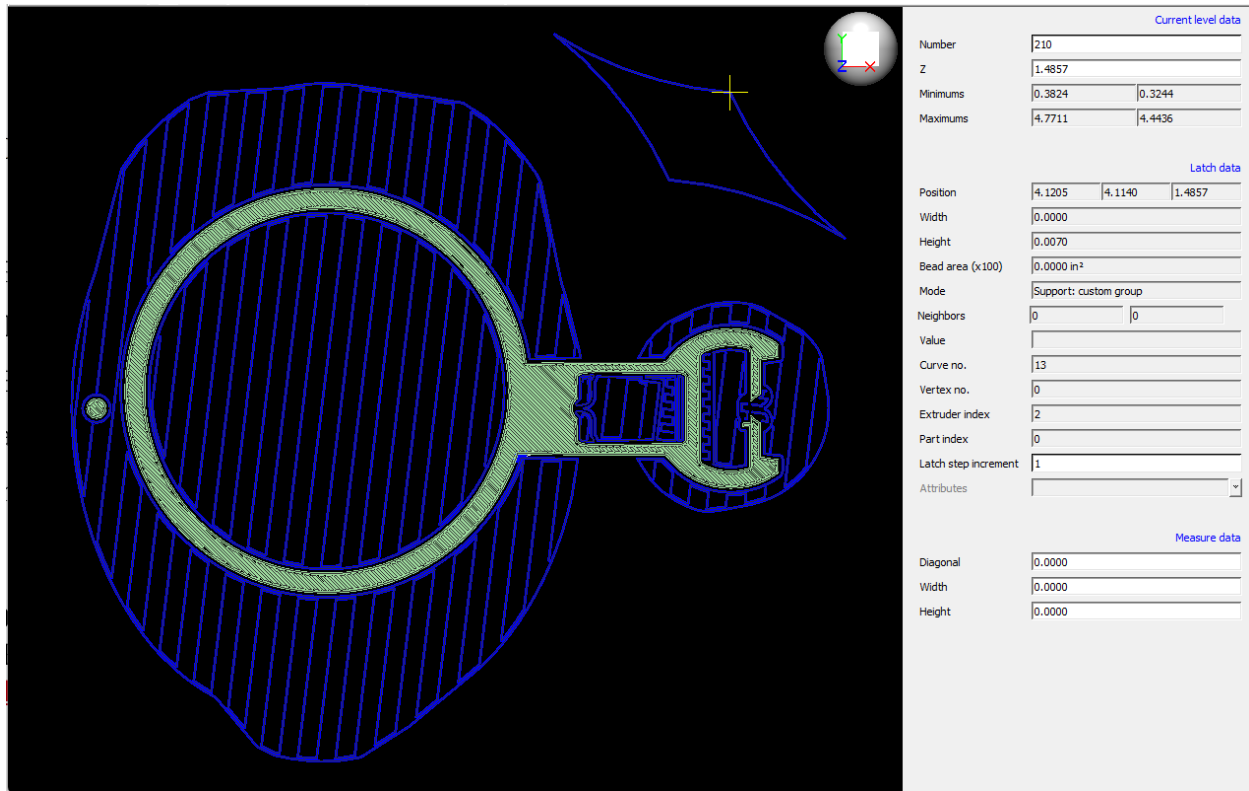
Ex. E (July 5, 2011, packed CMB file) at 42 (annotated to show part of the second layer of the support structure on at least a portion of the first layer of the three-dimensional part). As shown in layers 209 and 210, the blue and green lines indicate the tool paths for repeating steps (b)-(e) described above to build successive layers of the three-dimensional part, support structure, and purge tower. For instance, as shown in layer 209, the green lines in a diamond shape indicate the tool paths for (b) printing a layer of a purge tower from a part material.



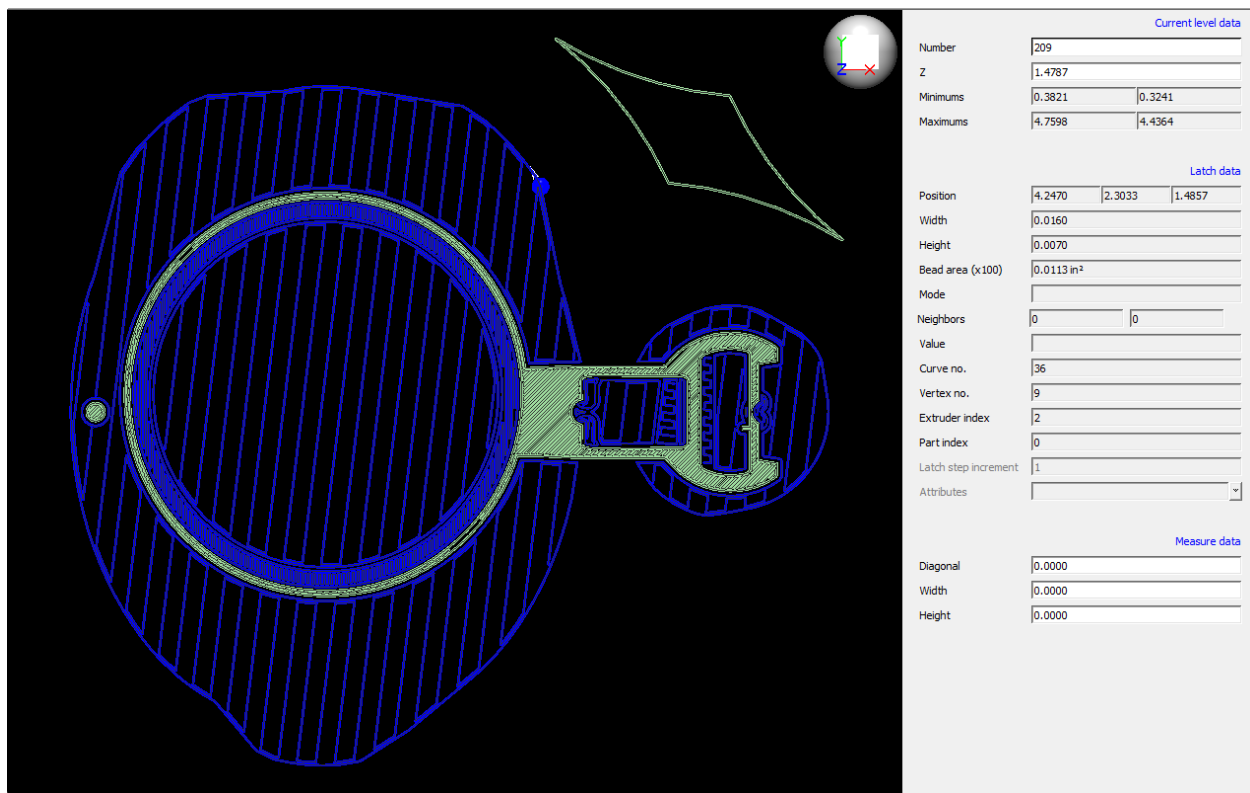
Ex. E (July 5, 2011, packed CMB file) at 43. As shown in layer 210, the green lines surrounded by the blue lines indicate the tool paths for (c) printing another layer of the three-dimensional part on at least a portion of the layer of the support structure from the part material after printing the layer of the purge tower. This is shown by the thickening of the green ring near the center of the image below.



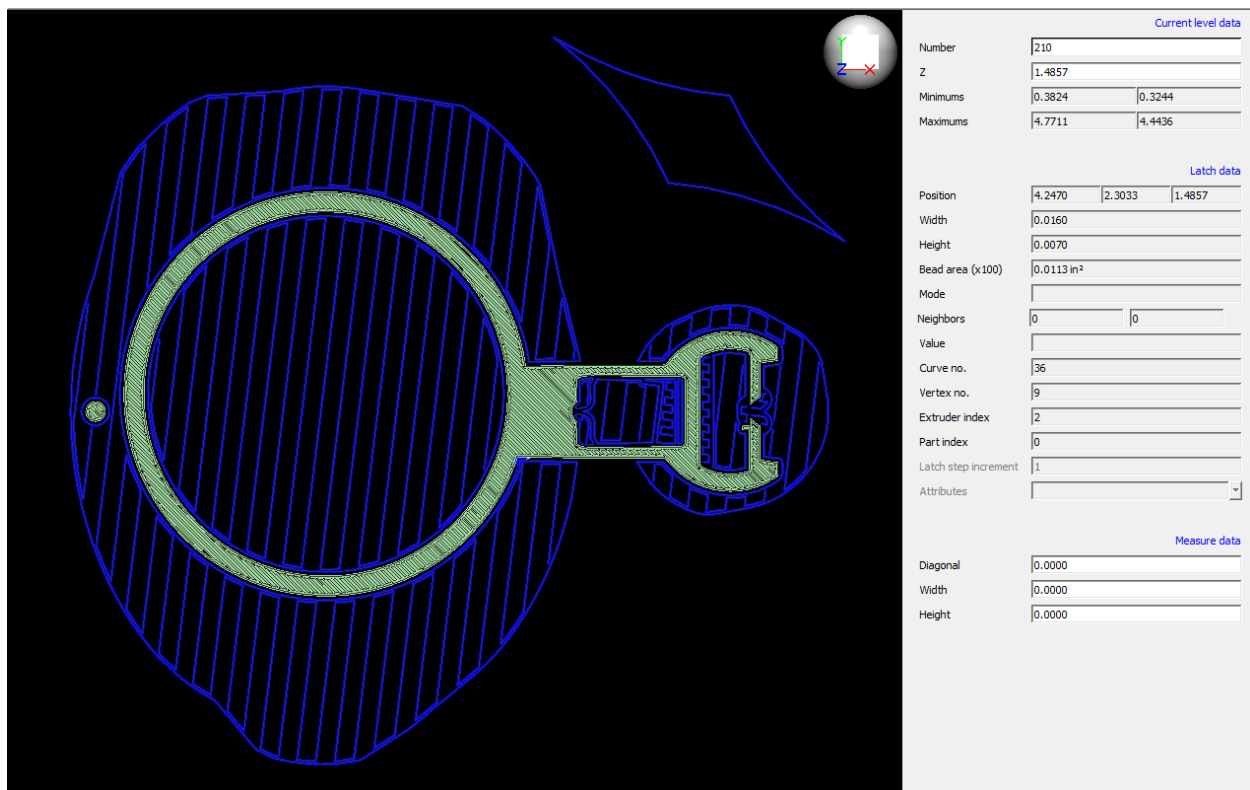
Ex. E (July 5, 2011, packed CMB file) at 44. As also shown in layer 210, the blue lines in a diamond shape indicate the tool paths for (d) printing another layer of the purge tower from the support material.



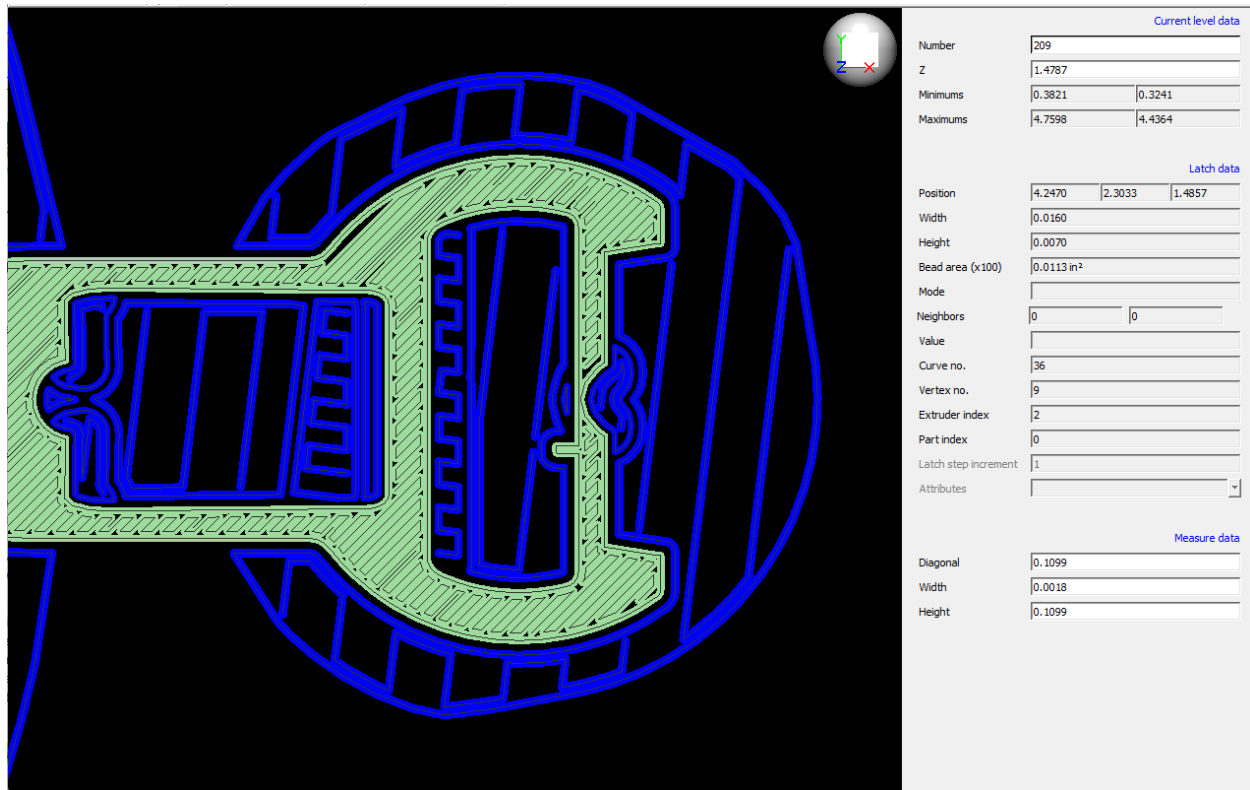
Ex. E (July 5, 2011, packed CMB file) at 45. As also shown in layer 210, the blue lines further indicate tool paths for (e) printing another layer of the support structure on at least a portion of the layer of the three-dimensional part from the support material after printing the layer of the purge tower. The images below show that the layer of the support structure on the right-hand side of the image in layer 210 extends over and is printed on at least a portion of the three-dimensional part in layer 209.



Ex. E (July 5, 2011, packed CMB file) at 46.



Ex. E (July 5, 2011, packed CMB file) at 47. Close-ups of this portion of layers 209 and 210 are shown below, depicting the printing of a layer of the support structure on at least a portion of the layer of the three-dimensional part from the support material after printing the layer of the purge tower.



Ex. E (July 5, 2011, packed CMB file) at 48.

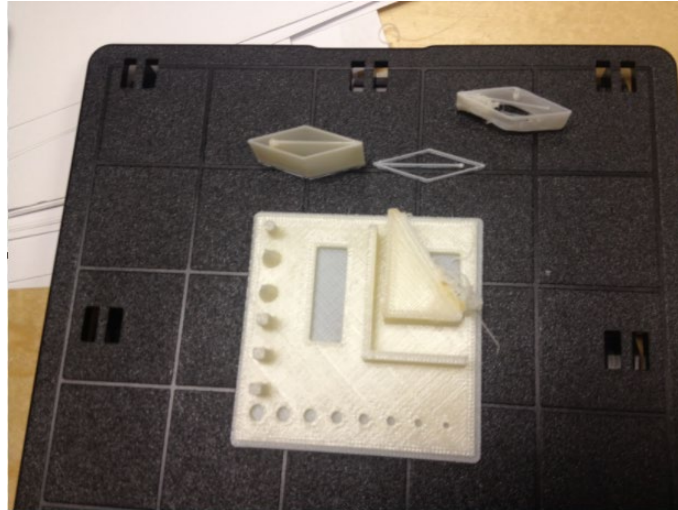


Ex. E (July 5, 2011, packed CMB file) at 49 (annotated to show part of the layer of the support structure on at least a portion of the layer of the three-dimensional part).

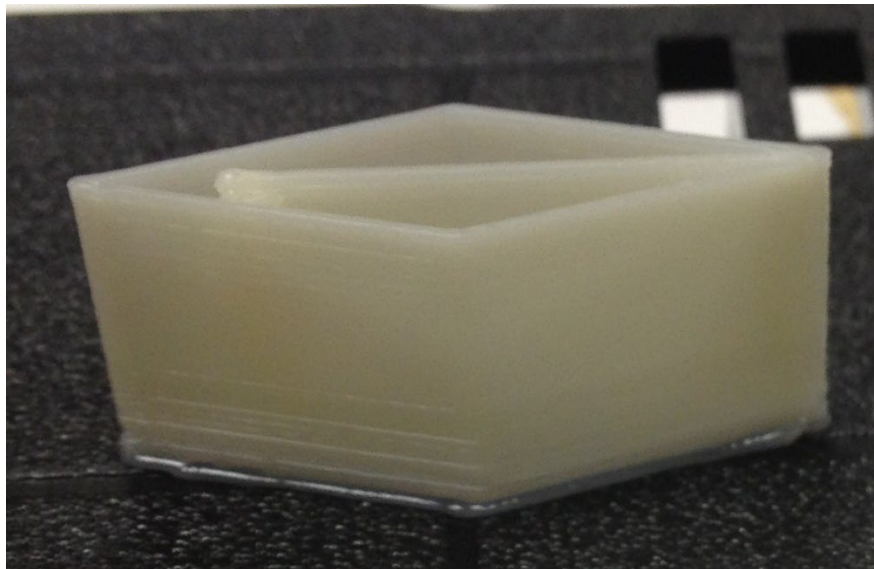
23. I have been asked whether the prototype of the Solo printer included the elements discussed above was used and shown to work for its designed purpose before September 21, 2012.

24. To confirm, a prototype of the Solo printer including the elements discussed above was used and shown to work for its designed purpose at least by November 20, 2011 (before September 21, 2012), at Stratasys's Minnesota facilities. In fact, as I have discussed above, the photograph of the Solo printer is from November 20, 2011. Ex. C. The named inventors, including Bill Swanson, Ronald Schloesser, and myself, printed purge towers and appreciated that the Solo development using the purge tower worked for its intended purposes discussed above. The development and testing of the Solo project was confidential and performed out of view of the public. Accordingly, the subject matter of at least Claims 1, 2, 5-7, 9, 16, and 17 of the '713 Patent was conceived of, actually used, by November 2011 (before September 21, 2012).

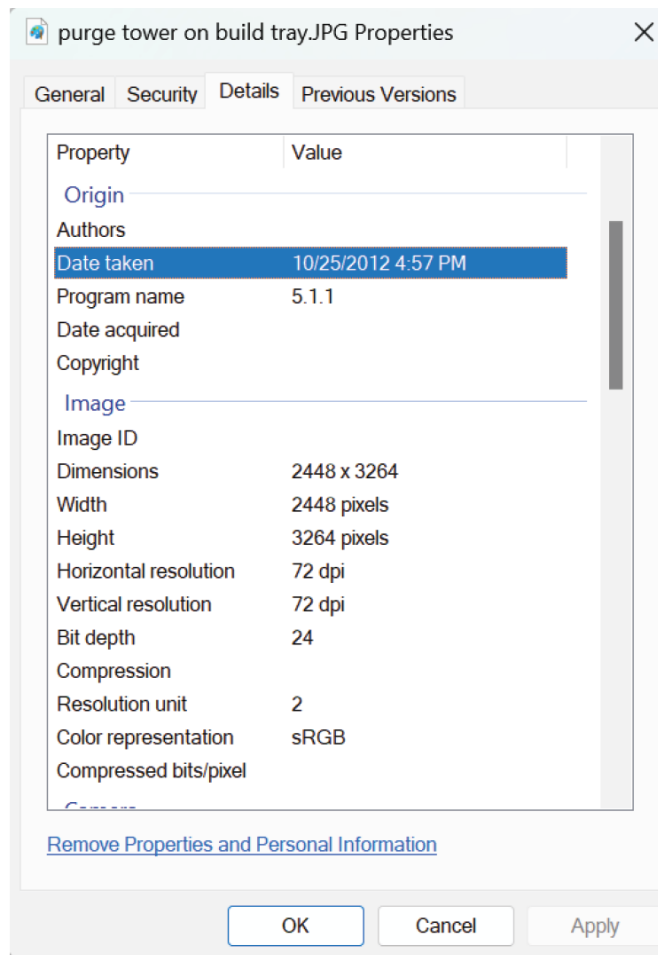
25. After November 2011, further research and development for the Solo project was conducted, including the printing and refinement of various other shapes of purge towers as shown by the October 25, 2012 photographs below:



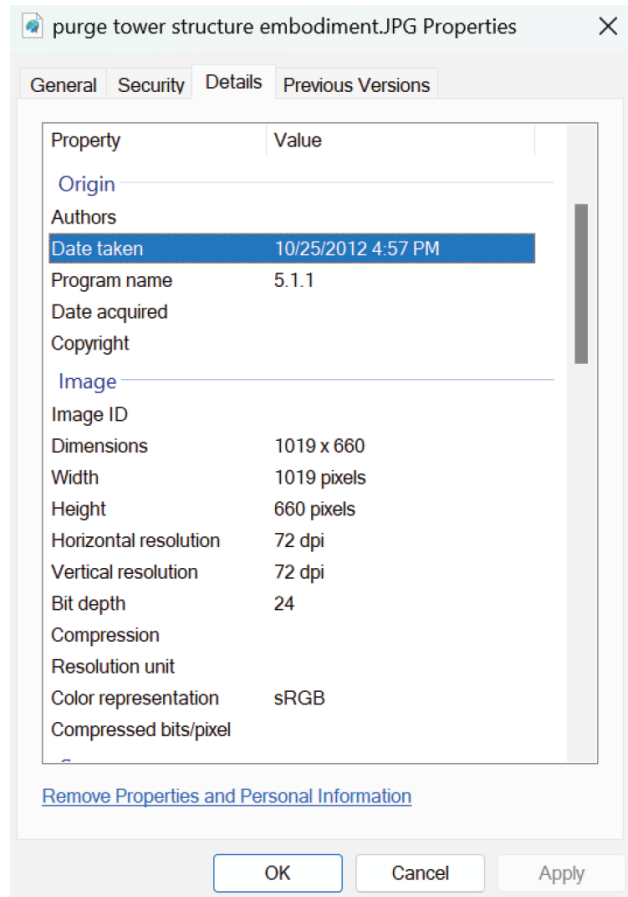
Ex. F (October 25, 2012, photograph showing build tray with purge towers).



Ex. G (October 25, 2012, photograph showing close-up view of purge tower). I recognize these photographs from my involvement in the development of the Solo printer and confirmed the dates of the photographs from their file properties.



Ex. F at 2.



Ex. G at 2. The build tray shown in the first photograph above resembles the build tray illustrated in Figure 3B of the patent:

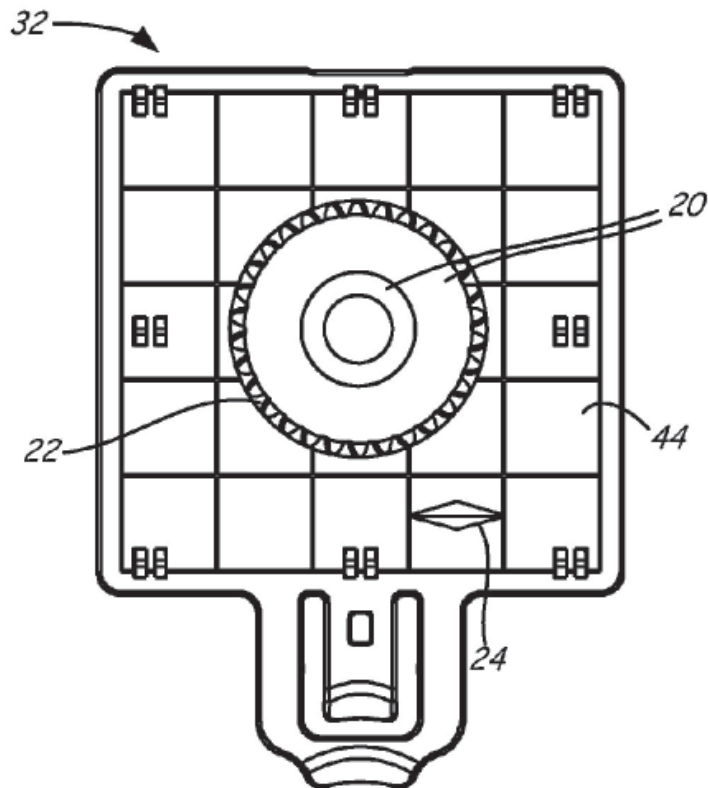


FIG. 3B

Ex. D ('713 Patent), Fig. 3B. In addition, the purge tower in these photographs resembles the purge tower illustrated in Figure 10 of the patent.

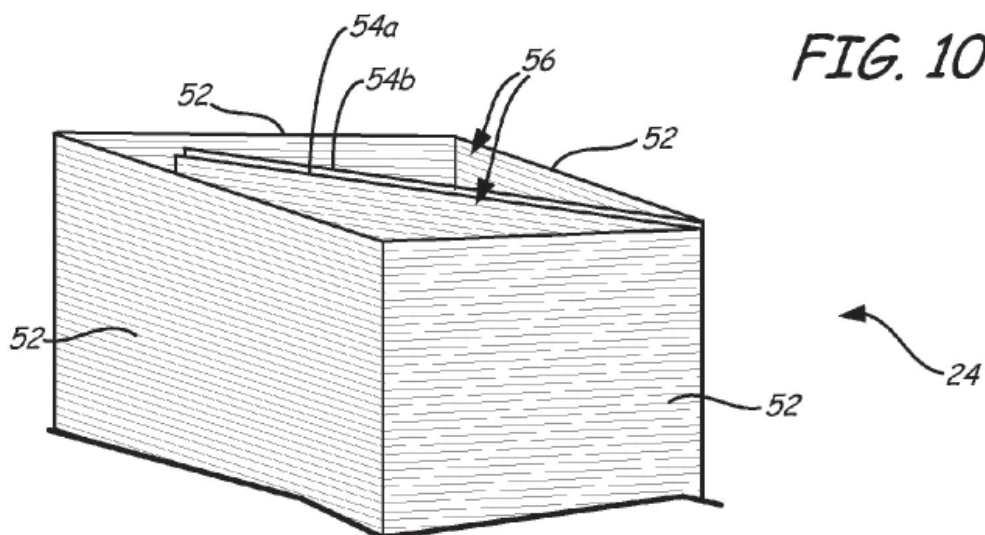


FIG. 10

Ex. D ('713 Patent), Fig. 10. Like the purge tower photograph shown above, the purge tower in Figure 10 has starting and ending points along an interior wall of the purge tower.

26. Exhibits B, C, and E contain description of the prototype Solo printer and of the files used by the Solo printer to print the parts, support structures, and purge towers described above. I have confirmed that all of the documents and information shown in Exhibits B, C, and E exactly match what was developed, tested and used in the early 2010s, by November 2011 and before September 21, 2012.

27. The document labeled Exhibit A is a claim chart comparing Claims 1, 2, 5-7, 9, 16, and 17 of the '713 Patent with the Solo system prototype and associated CMB files that were implemented, tested and used by November 2011 and before September 21, 2012. As shown in the claim chart, each limitation of these claims was conceived of by the named inventors and reduced to practice by November 2011 and before September 21, 2012.

28. The acts referred to in paragraphs 5 through 24 and in Exhibit A were carried out in the United States by November 2011 and before September 21, 2012.

29. Exhibits B, C, E, F, and G were made near the time of the date associated with the respective documents by someone with knowledge, and the records were all kept by Stratasy, Inc. in the ordinary course of business.

30. I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further, that the statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code.

Signed this 8th day of SEPTEMBER, 2025.

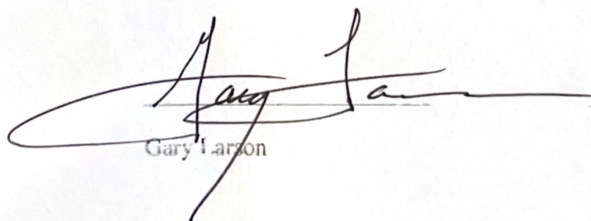
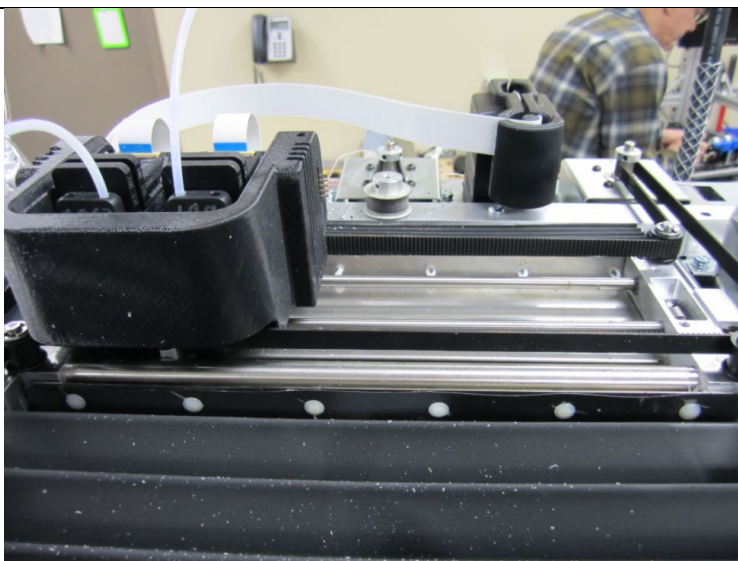

Gary Larson

EXHIBIT A

This claim chart shows, on an element-by-element basis, how the Solo printer system was designed and developed in 2010-2011—as evidenced by at least Exhibits B, C, and E, which show, among other things, the overall Solo printer architecture and function and use of purge towers—and actually reduced to practice each and every element of Claims 1, 2, 5-7, 9, 16, and 17 of the '713 Patent prior to at least September 21, 2012.

Claim	Conception/Reduction to Practice Evidence
<p>1. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:</p>	<p>The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to perform a method of printing a three-dimensional part with an additive manufacturing system, satisfying the preamble of claim 1.</p> <p>For example, the Solo printer printed a three-dimensional part using fused deposition modeling, which is an additive manufacturing process invented by Stratasys.</p>  <p>Ex. B (March 16, 2010, photograph showing four prototype Solo printer test units).</p>

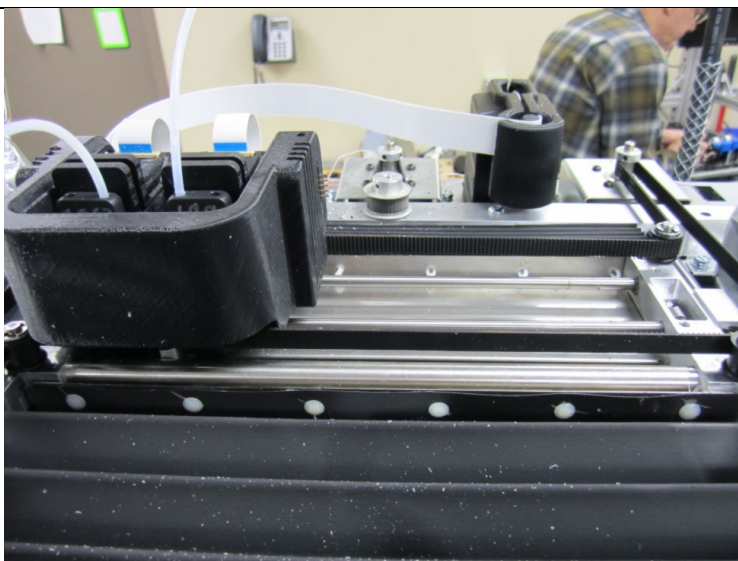


Ex. C (November 20, 2011, photograph showing Solo's print heads and deposition lines).

[1a] printing layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique;

The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to print layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based additive manufacturing technique, satisfying element [1a].

For example, the Solo printer had a print head with a part material deposition line (the "Part Print Head") and a second print head with a support material deposition line (the "Support Print Head") to print the layers of the three-dimensional part and the support structure, respectively. A November 20, 2011, photograph depicting Solo's multiple print heads and deposition lines is shown below.



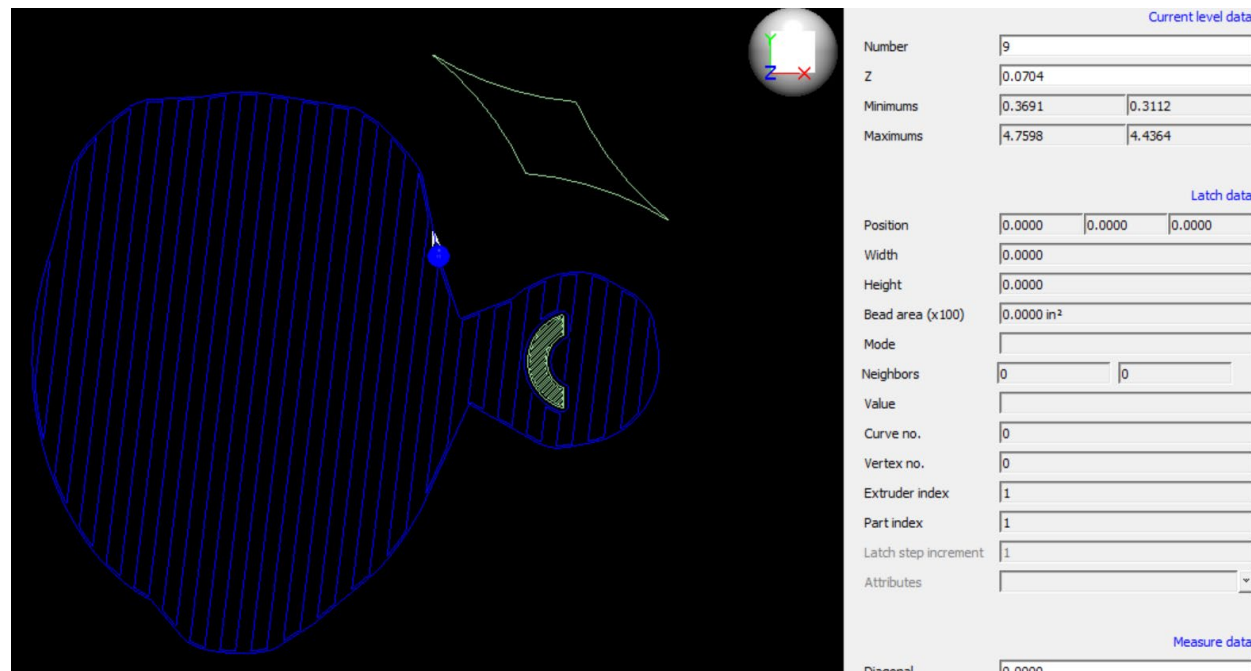
Ex. C (November 20, 2011, photograph showing Solo's print heads and deposition lines).

[1b] switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure;

The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, switched the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure, satisfying element [1b].

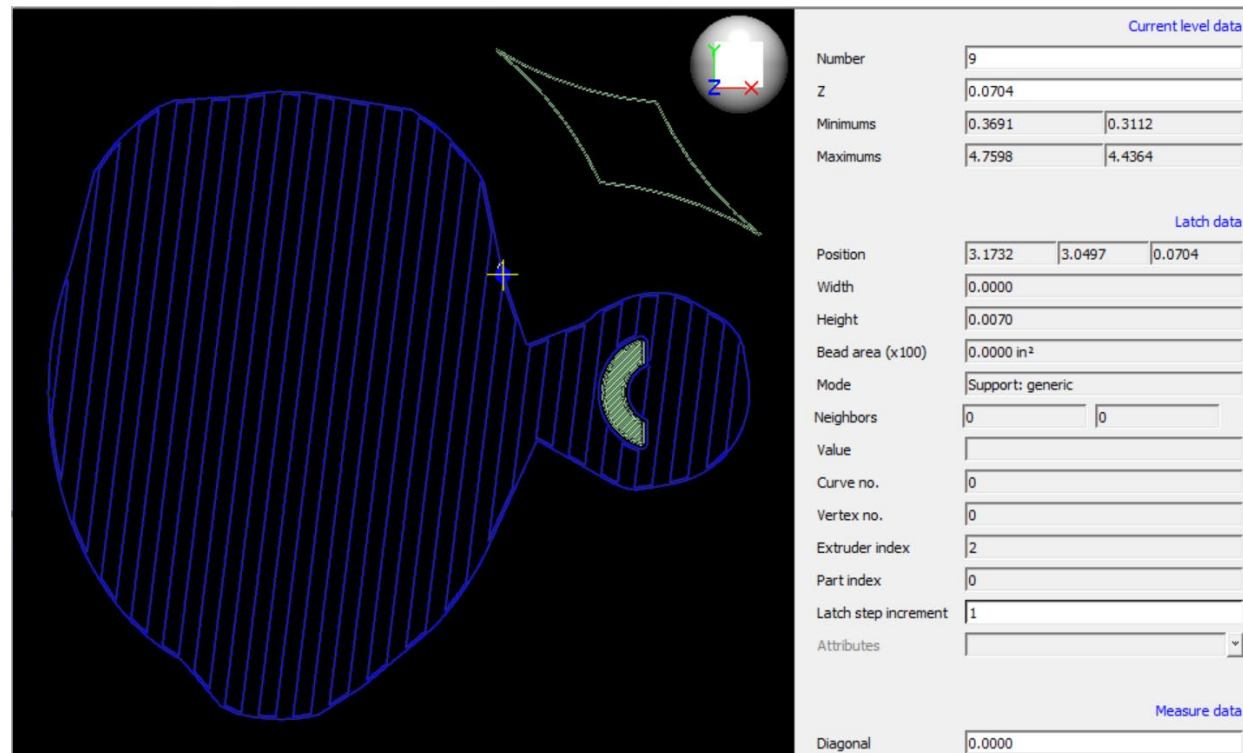
For example, the Part Print Head (and part material deposition line) would be in the operating mode, where the liquefier assembly of the print head would be heated to its operating temperature, during which time it would print the part material layer. During that time, the Support Print Head (and support material deposition line) would be in a stand-by mode, during which time it would not be printing material and it would be cooled down from its operating mode temperature to a stand-by temperature to prevent oozing. When the printing of the part material layer concluded, the Part Print Head would be switched to a stand-by mode and the Support Print Head would be switched to an operating mode. The screenshots below (and throughout this

claim chart) are taken from a graphical representation¹ of a coordinate machine binary (“CMB”) file, which is a representation of tool path instructions generated by Stratasys software, such as Insight™ or Control Center™. The information shown in the screenshots was created by at least July 5, 2011 in conjunction with the Solo project. These screenshots depict the layer-based additive manufacturing process used by the Solo printer, in which one print head / deposition line (e.g., Part Print Head) is in operating mode, while the other print head / deposition line (e.g., Support Print Head) is in stand-by mode:



¹ The CMB file is viewable in the graphical form shown in the screenshots in this chart by using CMB Viewer, which is an application within Stratasys’s Insight™ software. The Insight™ software is free to download and available at <https://support.stratasys.com/en/Resources/Software-Download>. The screenshots of CMB file shown in this chart are true and accurate representations of what I saw when I viewed the CMB file in CMB Viewer.

Ex. E (July 5, 2011, packed CMB file) at 8. As shown, the blue lines indicate support material, and the green lines indicate part material. While the screenshot above shows an “Extruder index” of “1” under the heading “Latch data,” this field and the rest of the fields under the “Latch data” heading are only populated with actual values when the view is latched to a particular point, which is not the case in the above image. When a specific point is selected, as shown in the image below by the white crosshair, the “Latch data” is populated. In the instance shown below, the first point in layer 9 of the CMB file (corresponding to curve no. 0 and vertex no. 0) is on the support structure and the “Extruder index” reflects that the extruder “2” is in use and the mode is “Support:generic.”

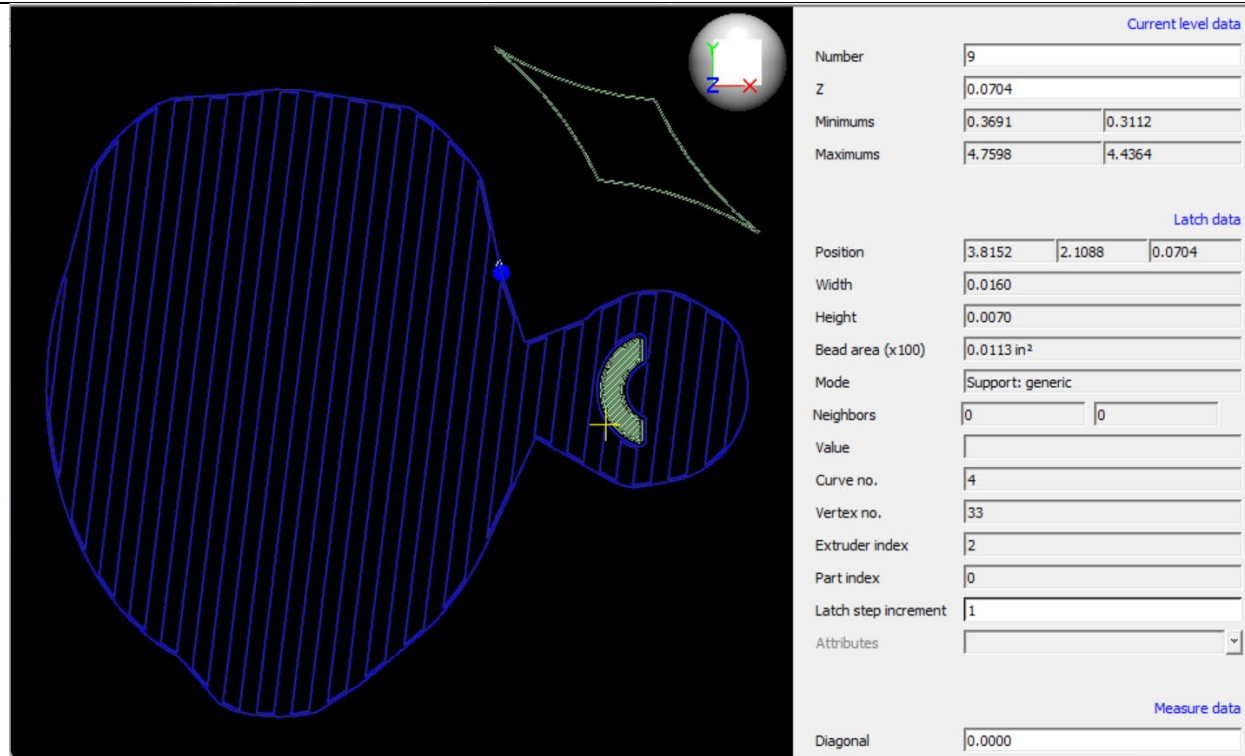


Ex. E (July 5, 2011, packed CMB file) at 21. Similarly, as shown below, when “Extruder index” is set to “2” on the information panel of the CMB file, the “Material” field indicates that the material is “SR-30,” which is a type of support material.²

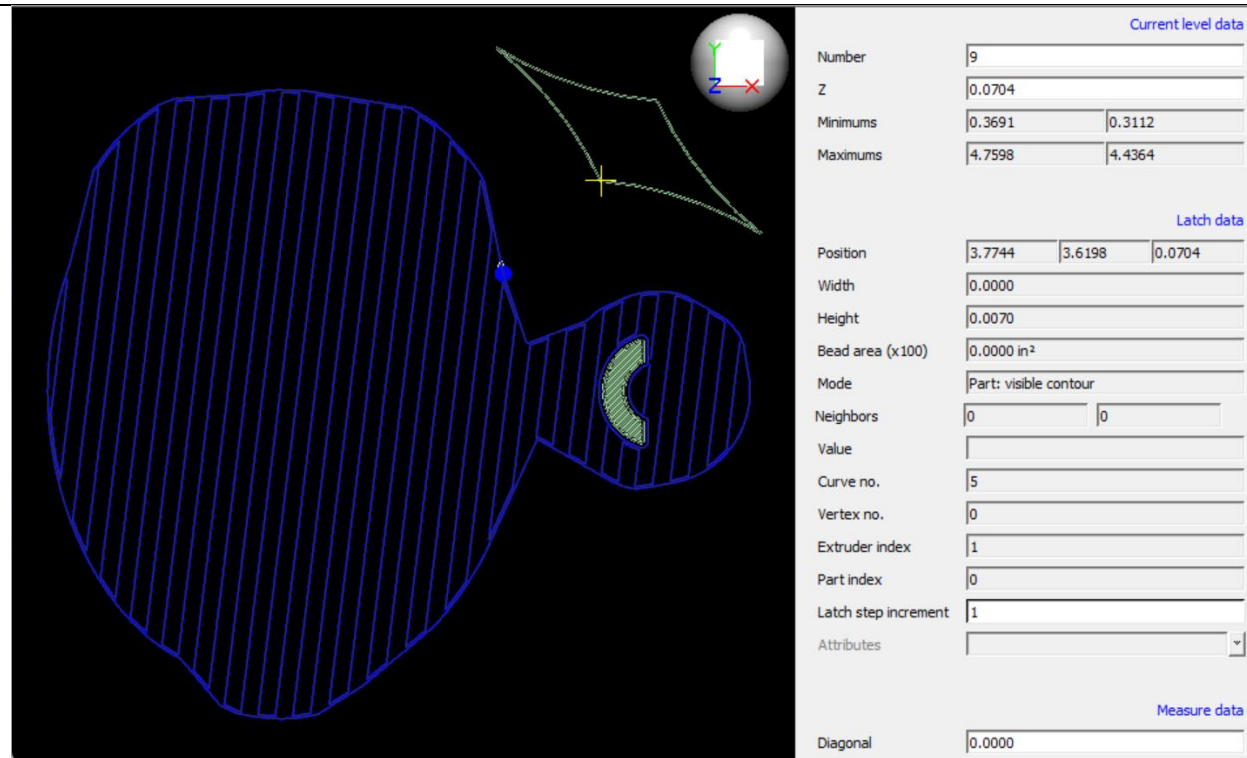
General			Internals	
Machine type	Fortus 400mc Large		Comment	Packed file written by Control Center!!!
Extruder index	2		Pack list	purge_part+support-11
Material	SR30		Versions	8.1 (4255) 8.9
Color	not specified		GUID	
Tip size	T12		Limits	
Volume	6.469729		Part width	0.0110 0.0600
Slice height	0.0070		Part area	0.0001 in ² 0.0004 in ²
Number of slices	607		Part aspect ratio	1.5767 8.5714
System mode	none		Support width	0.0121 0.0191
Part build style	none		Support area	0.0001 in ² 0.0001 in ²
Shrink factor (X Y Z)	1.000000	1.000000	Support aspect ratio	1.7244 2.7303
Has variable width				
CMB locked				
User name				
Embedded version				
System Serial#				

Ex. E (July 5, 2011, packed CMB file) at 50. In the image below, the final point of the support structure tool path in level 9 of the CMB file (corresponding to curve no. 4 and vertex no. 33) is shown.

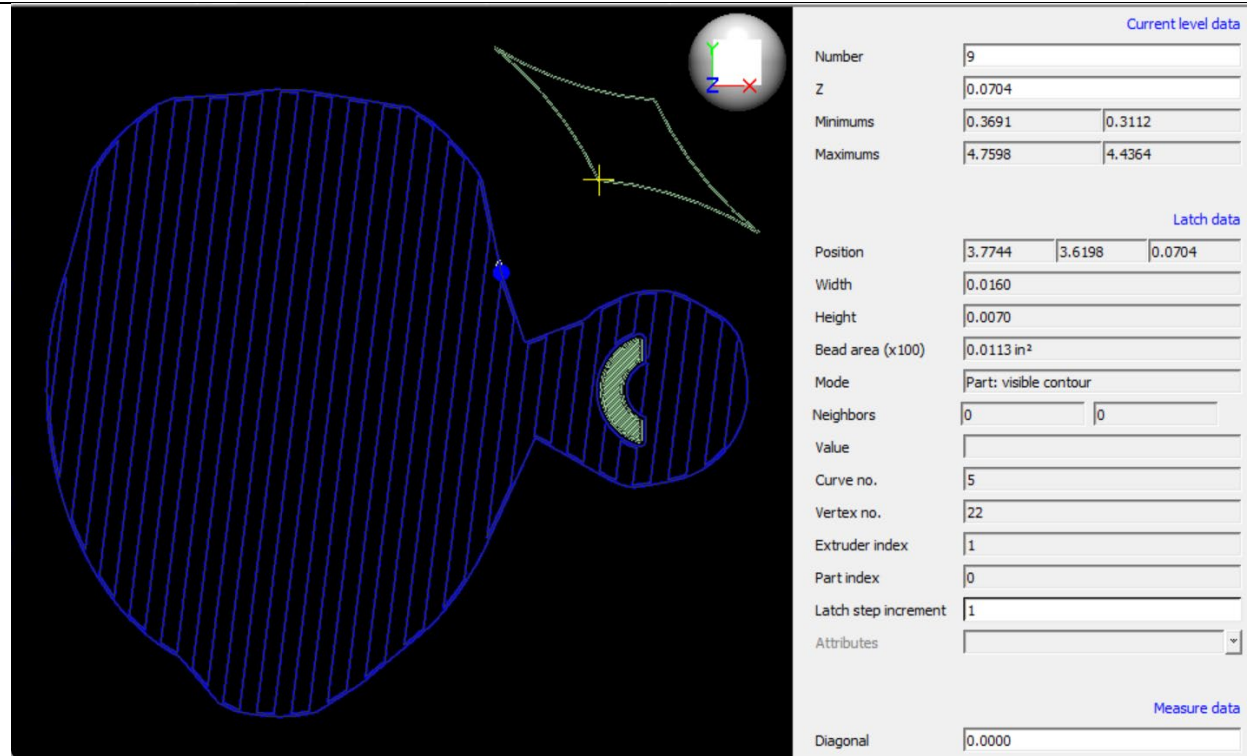
² The Stratasys website (<https://support.stratasys.com/en/Materials/FDM/FDM-Support-Materials>) lists types of Stratasys support material, including SR-30.



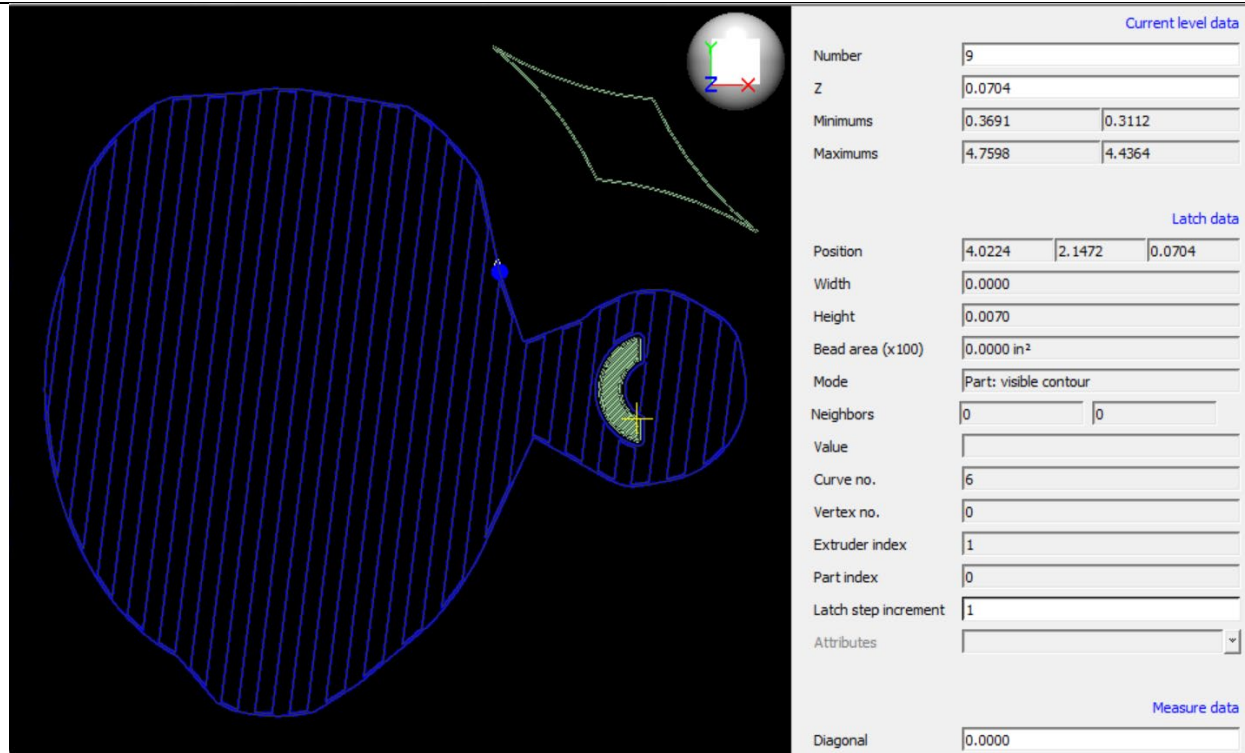
Ex. E (July 5, 2011, packed CMB file) at 22. The next point in level 9 of the CMB file (curve no. 5 and vertex no. 0) corresponds to the switch of the Part Print Head / part material deposition line to operating mode, whereby printing of the layer of the purge tower with part material is commenced.



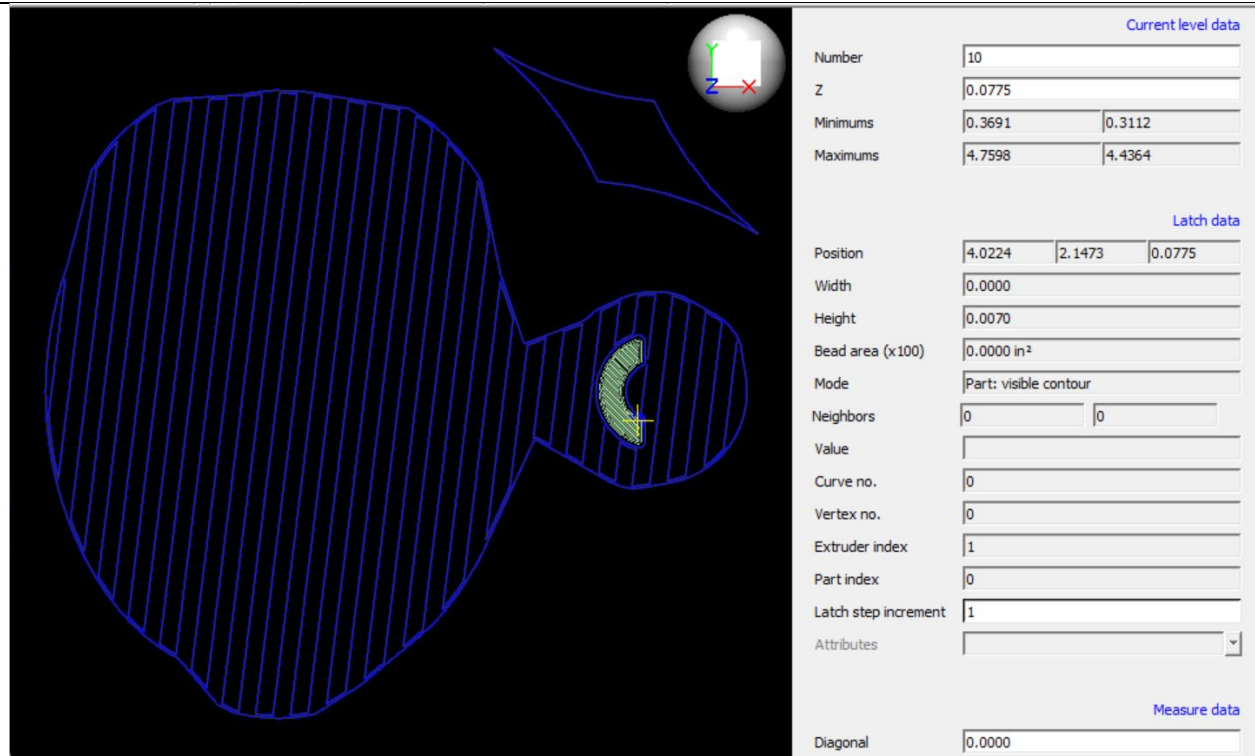
Ex. E (July 5, 2011, packed CMB file) at 23. Because the layer of the purge tower shown above is green, it is printed with part material. This is confirmed by the “Extruder index” of “1” as shown in the above image, as well as the mode being “Part: visible contour.” Printing of this layer commences until the final point of the purge tower layer (curve no. 5 and vertex no. 22), with the next point being the start of printing the three-dimensional part with part material (curve no. 6 and vertex no. 0) as shown in the below images.



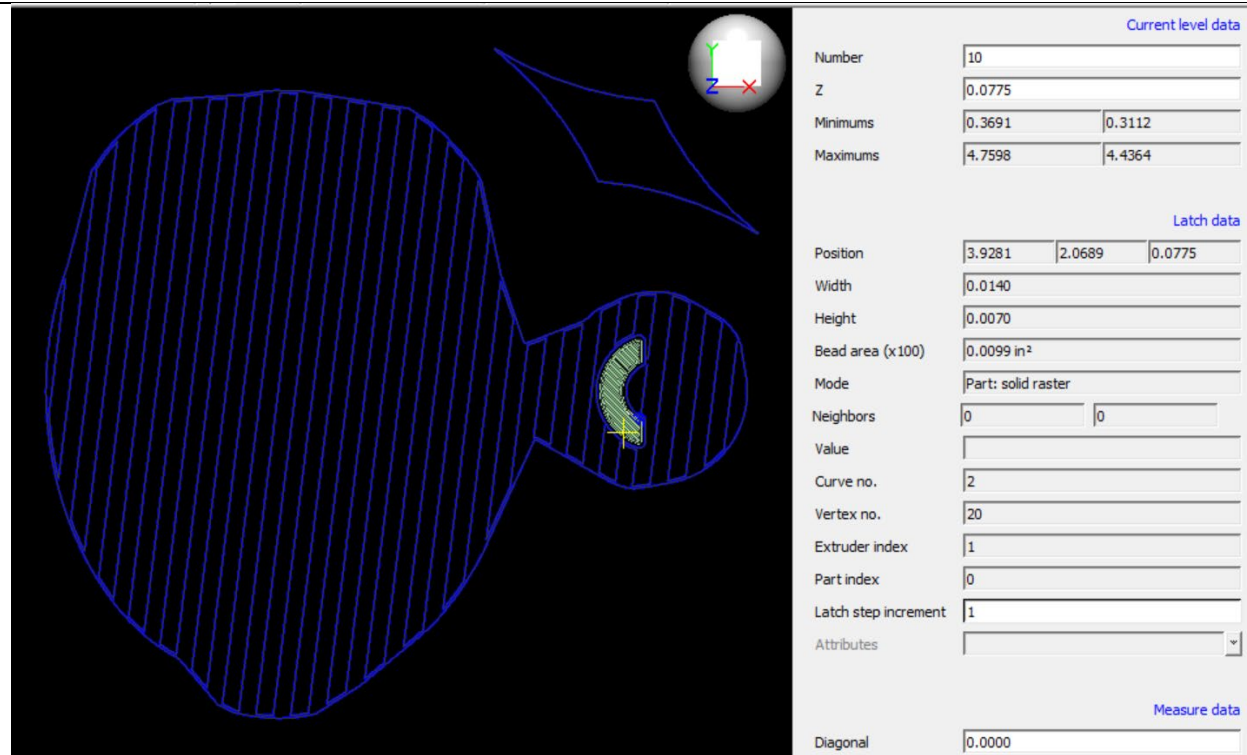
Ex. E (July 5, 2011, packed CMB file) at 24.



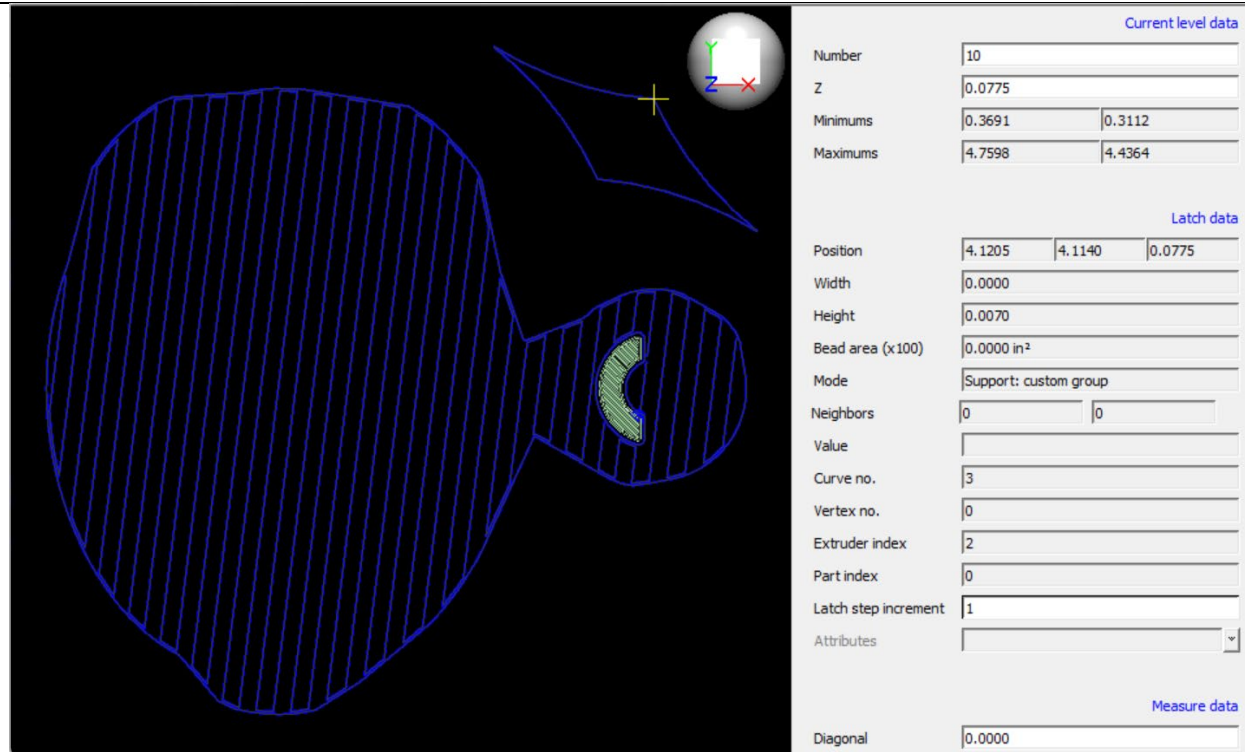
Ex. E (July 5, 2011, packed CMB file) at 25. As shown by the next two images, in the next layer of the CMB file (layer 10) the first point (curve no. 0 and vertex no. 0) is a continuation of the printing of the part material up until the final point of part material printing on CMB level 10 (curve no. 2 and vertex no. 20).



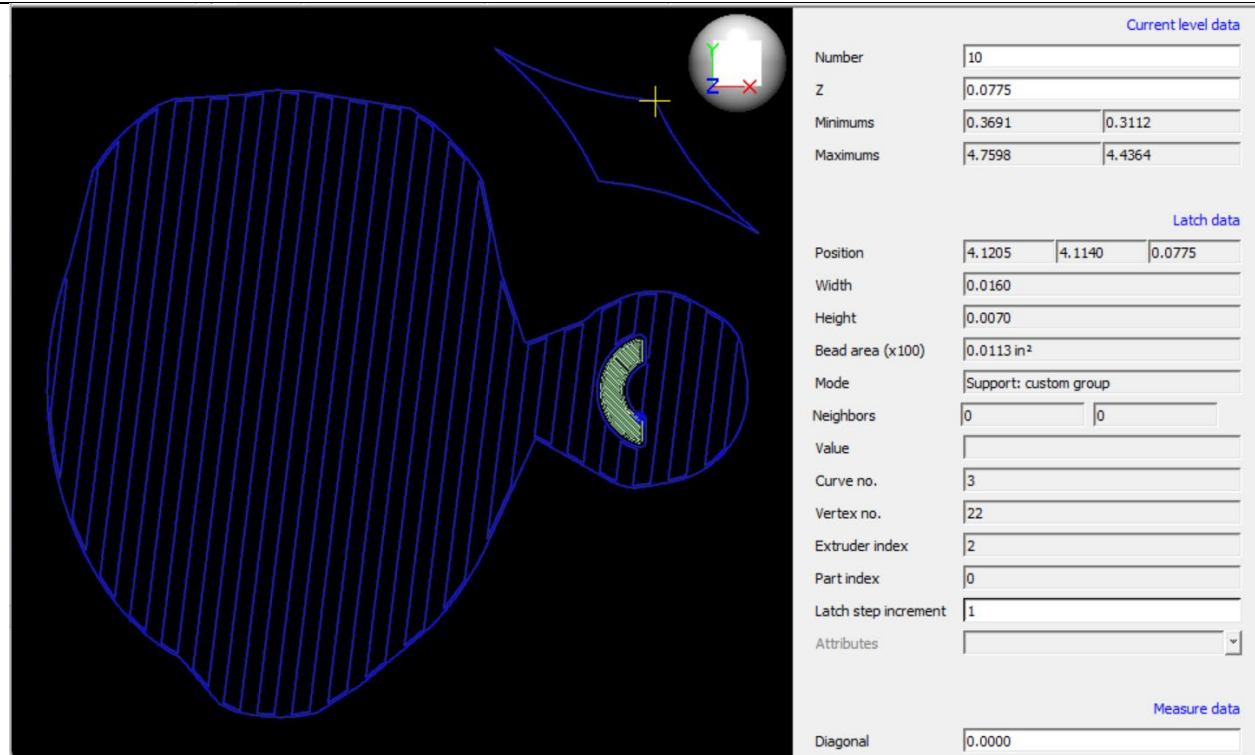
Ex. E (July 5, 2011, packed CMB file) at 26.



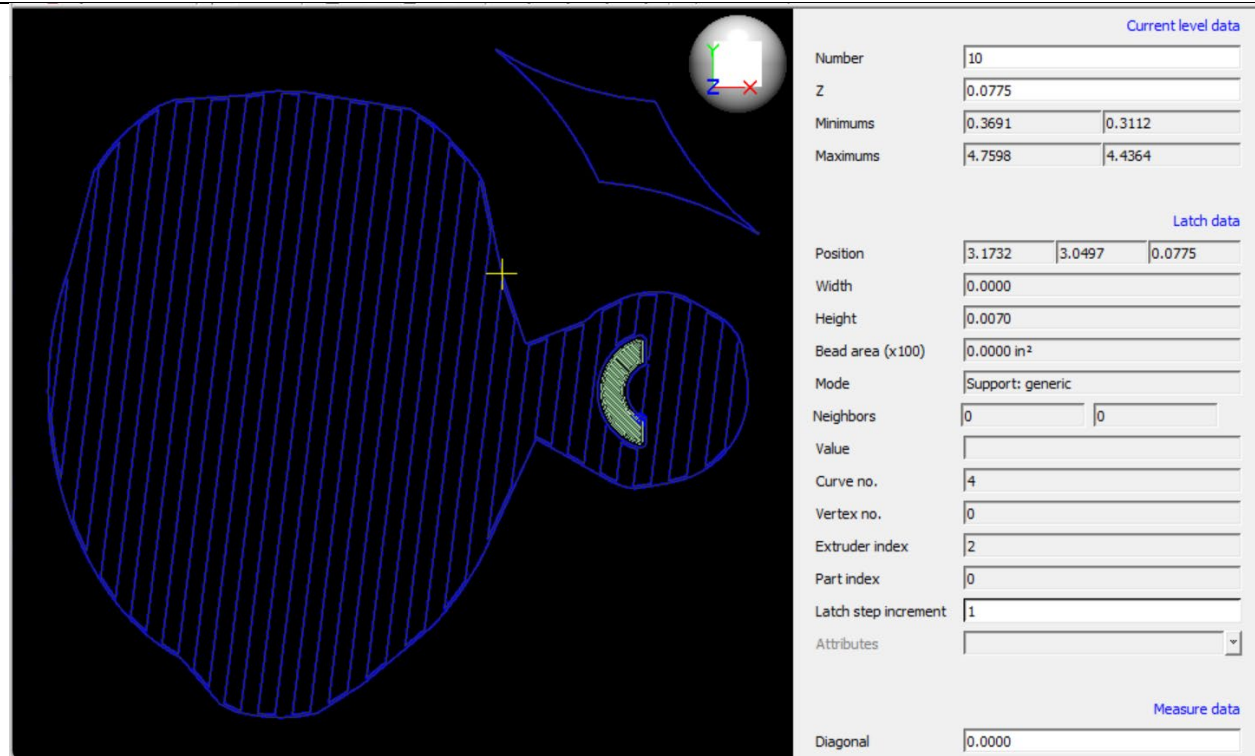
Ex. E (July 5, 2011, packed CMB file) at 27. As shown in the image below, the next point in level 10 of the CMB file (curve no. 3 and vertex no. 0) corresponds to the switch of Part Print Head / part material deposition line to stand-by mode and the switch of the Support Print Head / support material deposition line to operating mode, whereby printing of the layer of the purge tower with support material is commenced.



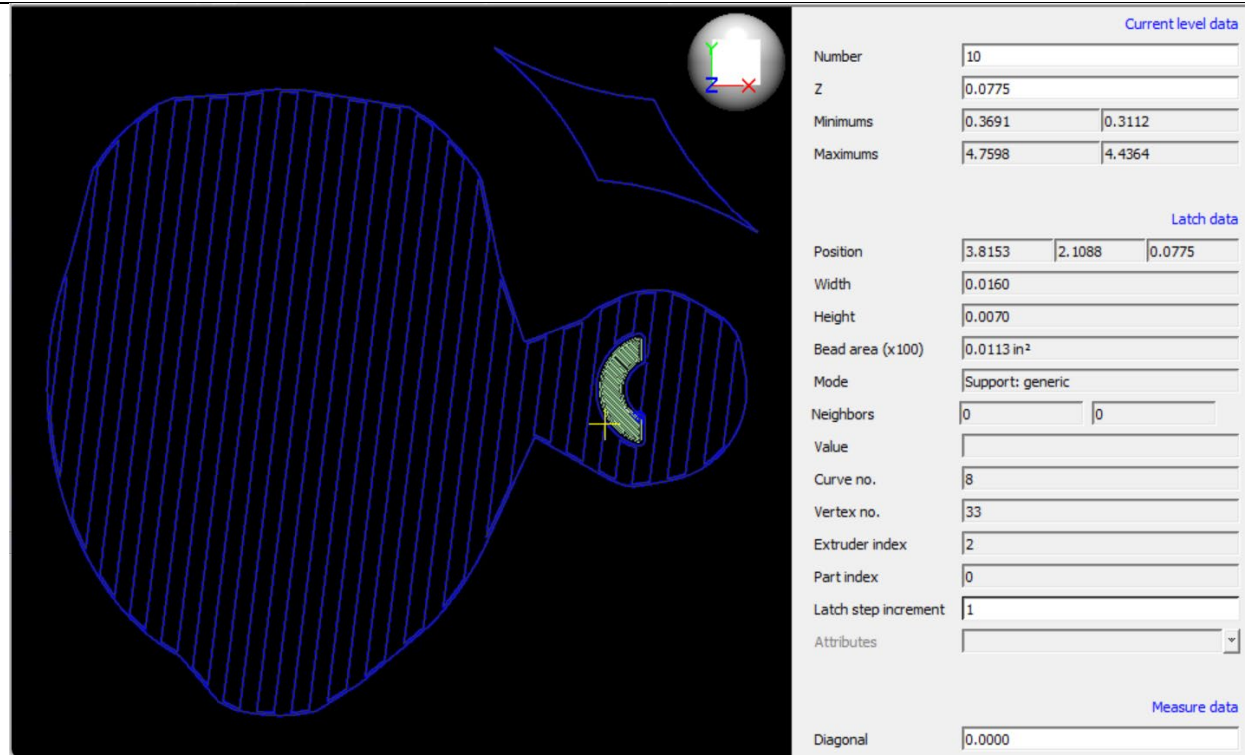
Ex. E (July 5, 2011, packed CMB file) at 28. That the blue lines of the purge tower correspond to support material is confirmed by the “Extruder index” being “2,” and the mode being “Support: custom group.” The printing of the layer of the purge tower with support material continues until complete (curve no. 3 and vertex no. 22), at which point the printing of the support structure commences (beginning with curve no. 4 and vertex no. 0 and ending with curve no. 8 and vertex no. 33), as shown in the images below.



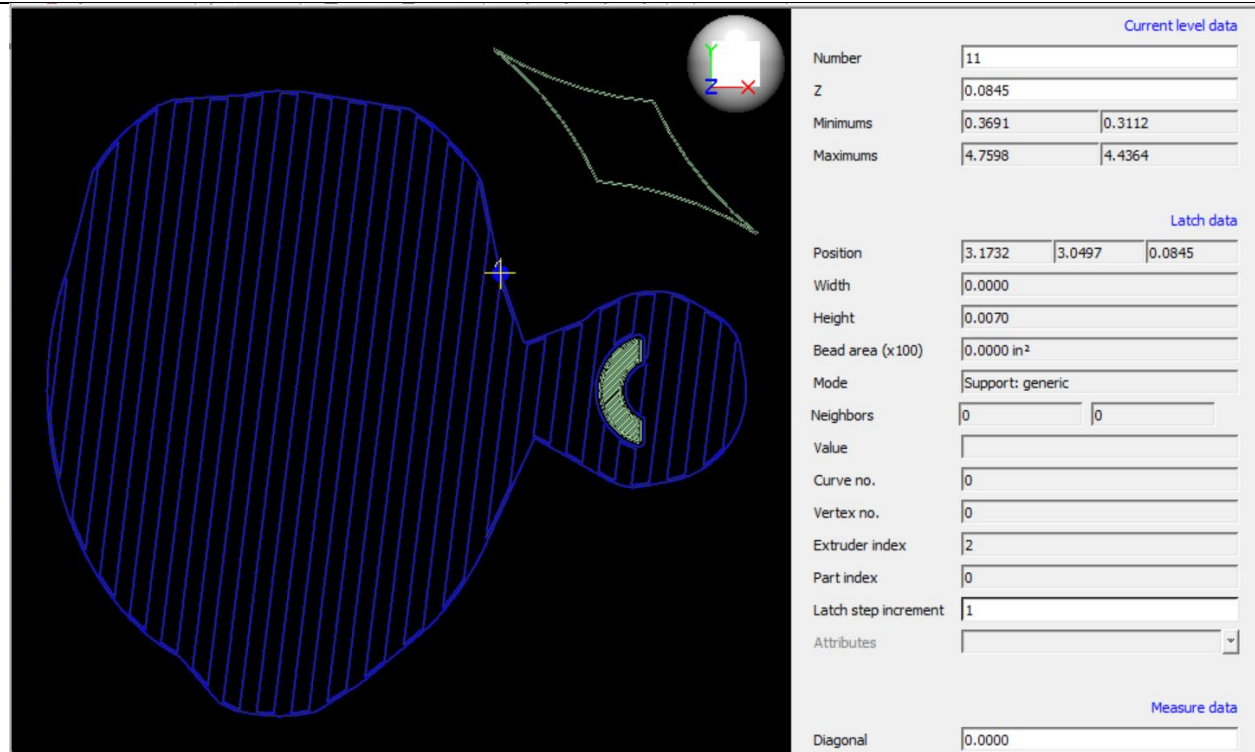
Ex. E (July 5, 2011, packed CMB file) at 29.



Ex. E (July 5, 2011, packed CMB file) at 30.



Ex. E (July 5, 2011, packed CMB file) at 31. This process is repeated for the other layers in the CMB file, as shown by the following layer (layer 11), where the layer of the purge tower is printed with part material, as indicated by the green lines.



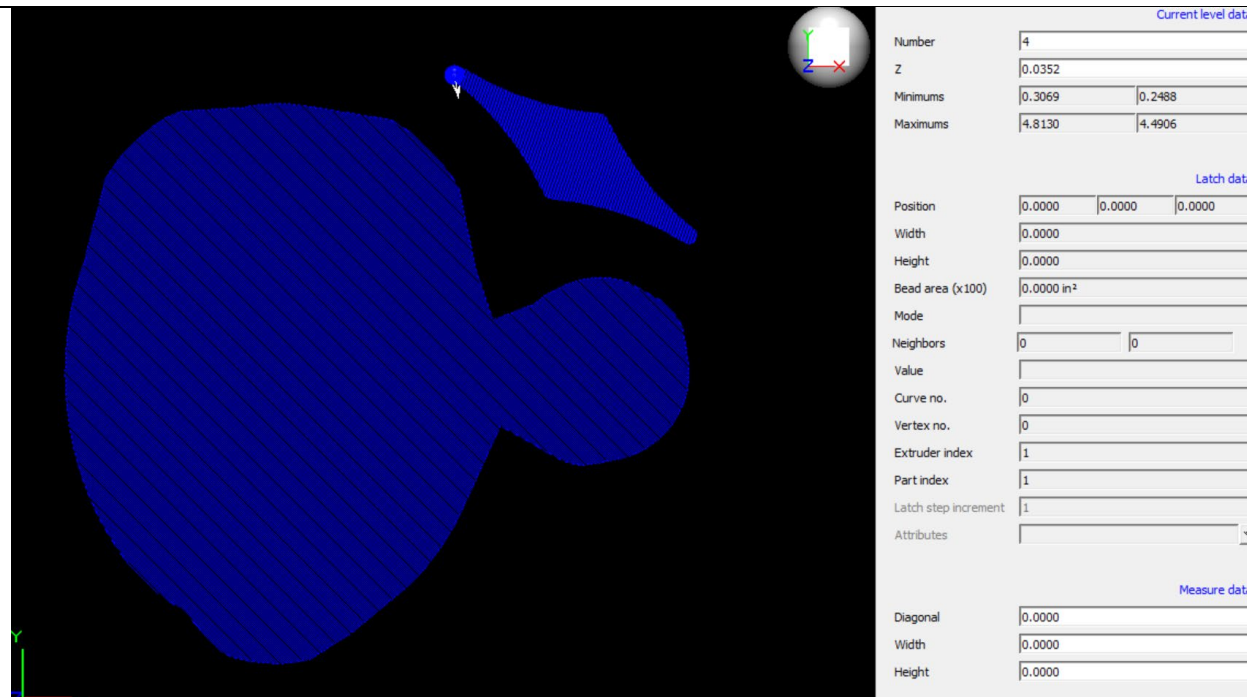
Ex. E (July 5, 2011, packed CMB file) at 32. The images above show that when switching the material being printed within each layer of the CMB file, each print head / deposition line (part and support material) begins with printing the layer of the purge tower followed by printing the respective layer of the part or support structure.

[1c] performing a purge operation for each print head or deposition line switched to the operating mode, the

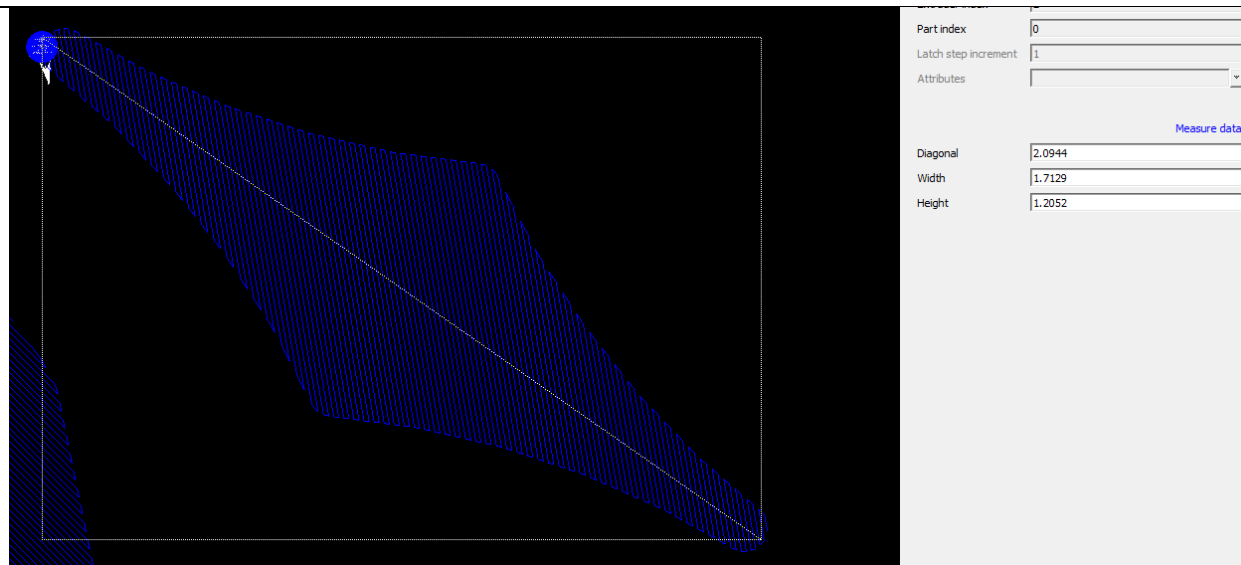
The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to perform a purge operation for each print head or deposition line switched to the operating mode, the purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode, satisfying element [1c].

<p>purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode.</p>	<p>For example, when the Part Print Head (and corresponding part material deposition line) was switched to the operating mode, the printer would perform a purge operation by printing a layer of a purge tower using the part material. Likewise, when the Support Print Head (and corresponding support material deposition line) was switched to the operating mode, the printer would perform a purge operation by printing a layer of the purge tower using the support material. The screenshots shown and described above for element [1b] depict a version of the purge tower constructed of alternating layers of part and support material according to the process of element [1c].</p>
<p>2. The method of claim 1, wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and wherein switching the deposition lines between the stand-by modes and the operating modes comprises:</p>	<p>The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to perform a method wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and wherein switching the deposition lines between the stand-by modes and the operating modes comprises switching the first deposition line from the stand-by mode to the operating mode; and switching the second deposition line from the operating mode to the stand-by mode, satisfying claim 2.</p> <p>For example, the Solo printer had multiple print heads and deposition lines, including a part material deposition line associated with the Part Print Head and a support material deposition line associated with the Support Print Head. Switching the deposition lines between the stand-by modes and the operating modes involved switching the part material deposition line from the stand-by mode to the operating mode; and switching the support material deposition line from the operating mode to the stand-by mode. The same process was also done in reverse for subsequent layers (i.e., the part material deposition line was switched to stand-by mode while the support material deposition line was switched to operating mode). This process is depicted in the screenshots shown above for element [1b].</p>

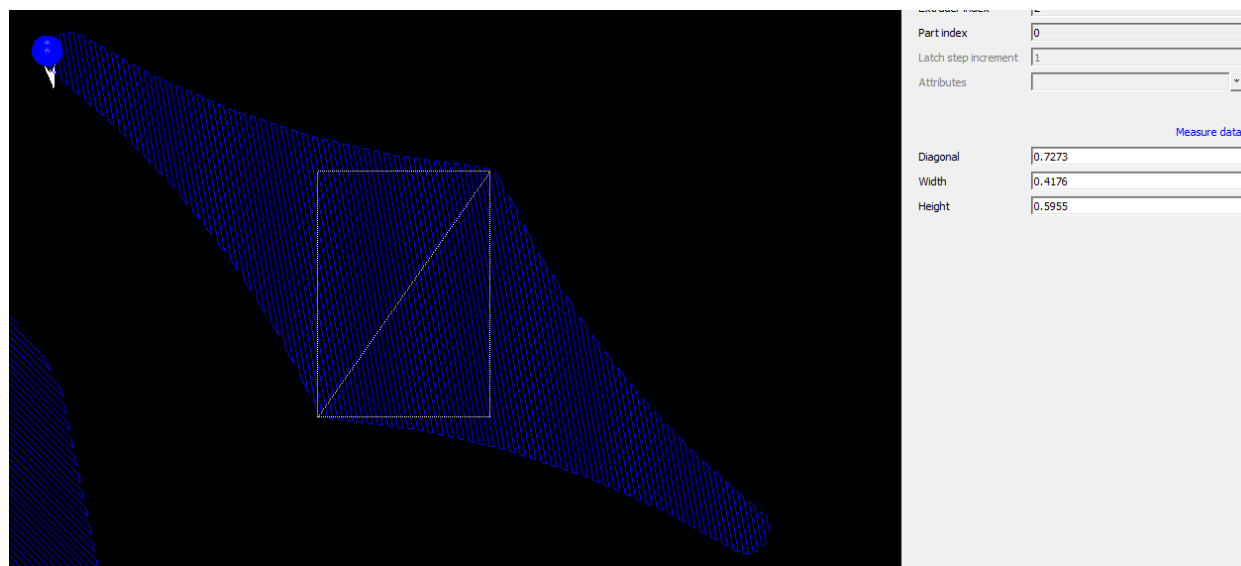
<p>switching the first deposition line from the stand-by mode to the operating mode; and switching the second deposition line from the operating mode to the stand-by mode.</p>	
<p>5. The method of claim 1, wherein the at least one purge tower has a cross-sectional area that reduces in height along an axis that is perpendicular to a build plane.</p>	<p>The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to perform a method wherein the at least one purge tower has a cross-sectional area that reduces in height along an axis that is perpendicular to a build plane, satisfying claim 5.</p> <p>For example, the Solo printer printed a purge tower where the first few layers had a larger cross-sectional area to provide sufficient stability for the purge tower and then subsequent layers had a smaller cross-sectional area. The screenshots below of Exhibit E depict this relationship:</p>



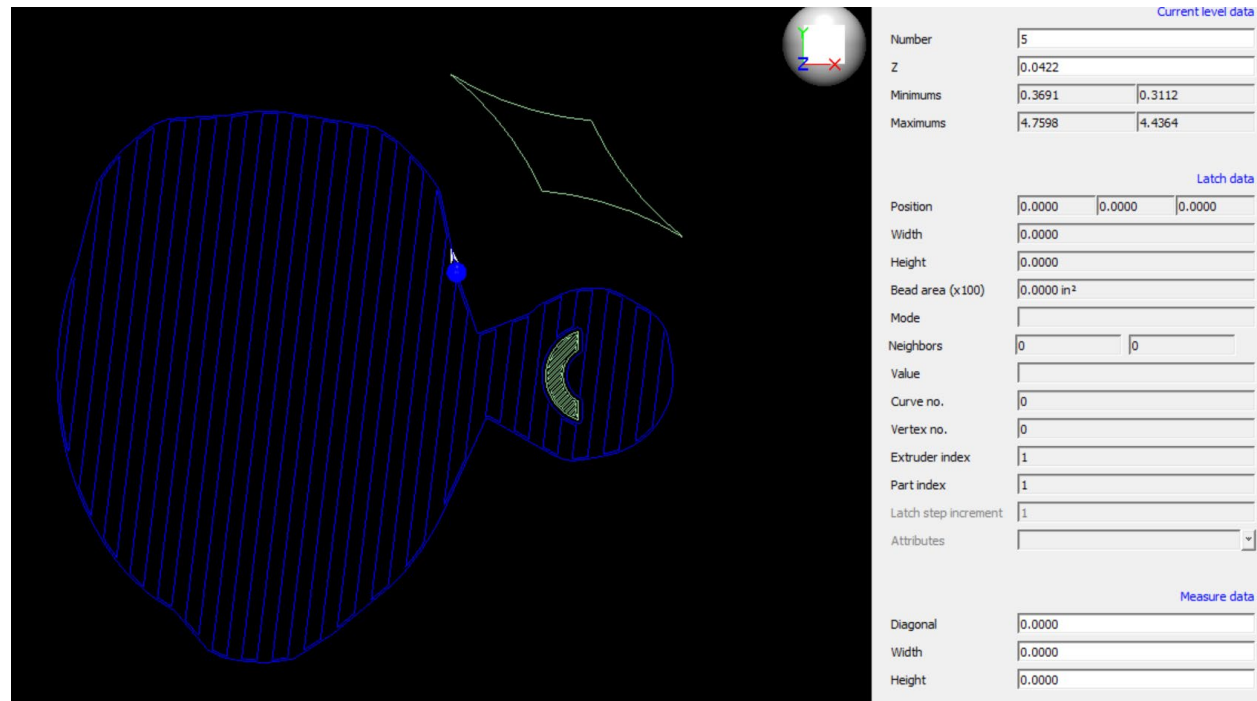
Ex. E (July 5, 2011, packed CMB file) at 3. As shown in layer 4, the blue lines indicate support material, and the blue filled-in diamond shape represents a layer of the purge tower. The blue-filled in diamond at layer 4 has a length of 2.0944 inches and a width of 0.7273 inches.



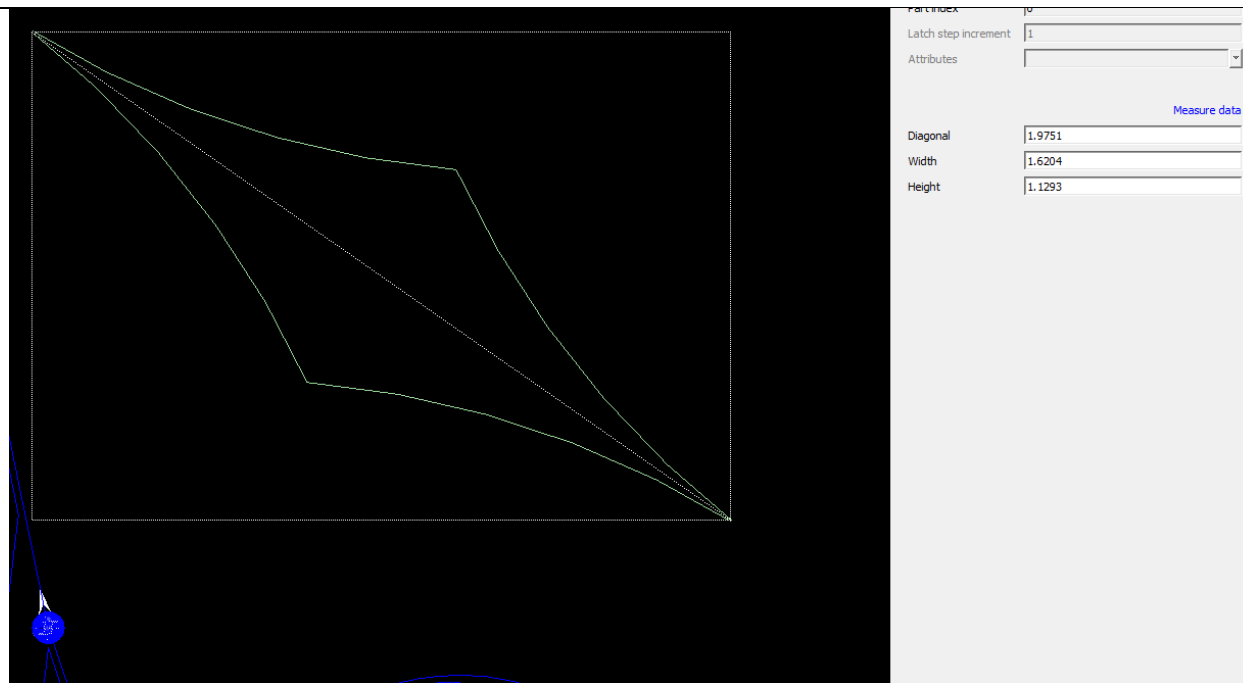
Ex. E (July 5, 2011, packed CMB file) at 4.



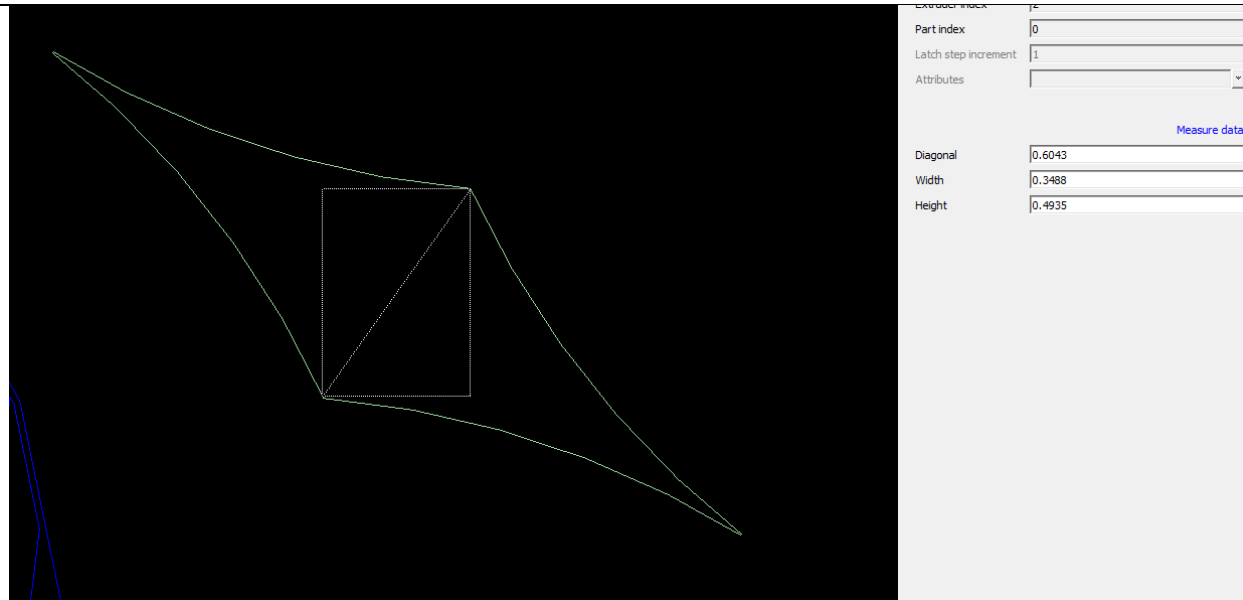
Ex. E (July 5, 2011, packed CMB file) at 4. Layer 5 is shown below:



Ex. E (July 5, 2011, packed CMB file) at 5. As shown in layer 5, which is above layer 4, the blue lines indicate support material, and the green lines indicate part material. The green diamond shape represents a layer of the purge tower, which has a smaller cross-sectional area than layer 4 shown in the previous image. For example, the green diamond shape at layer 5 has a length of 1.9751 inches and a width of 0.6043 inches.



Ex. E (July 5, 2011, packed CMB file) at 6.



Ex. E (July 5, 2011, packed CMB file) at 7. These measurements are less than the length and width of the diamond shape at layer 4. The cross-sectional area shown in layer 5 is carried up through the rest of the layers of the purge tower (ending on layer 593).

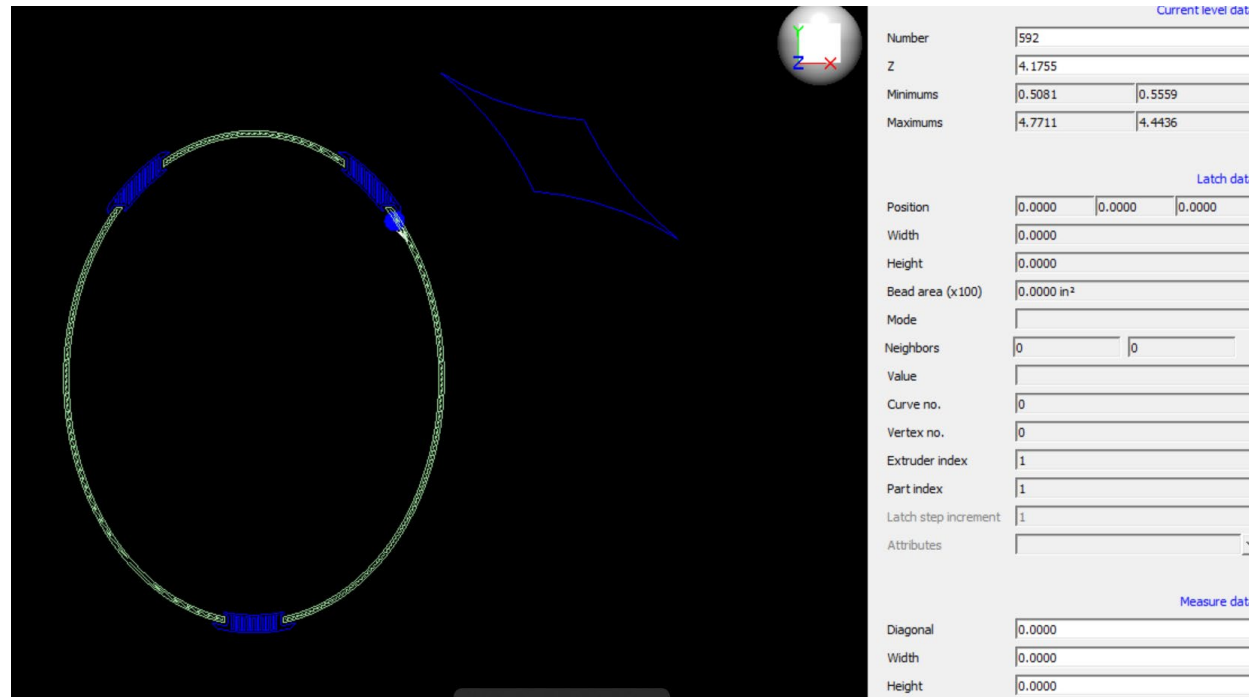
6. The method of claim 1, wherein the at least one purge tower is stopped at a highest layer at which there is a material change for the printed layers of the three-

The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to perform a method wherein the at least one purge tower is stopped at a highest layer at which there is a material change for the printed layers of the three-dimensional part and support structure, satisfying claim 6.

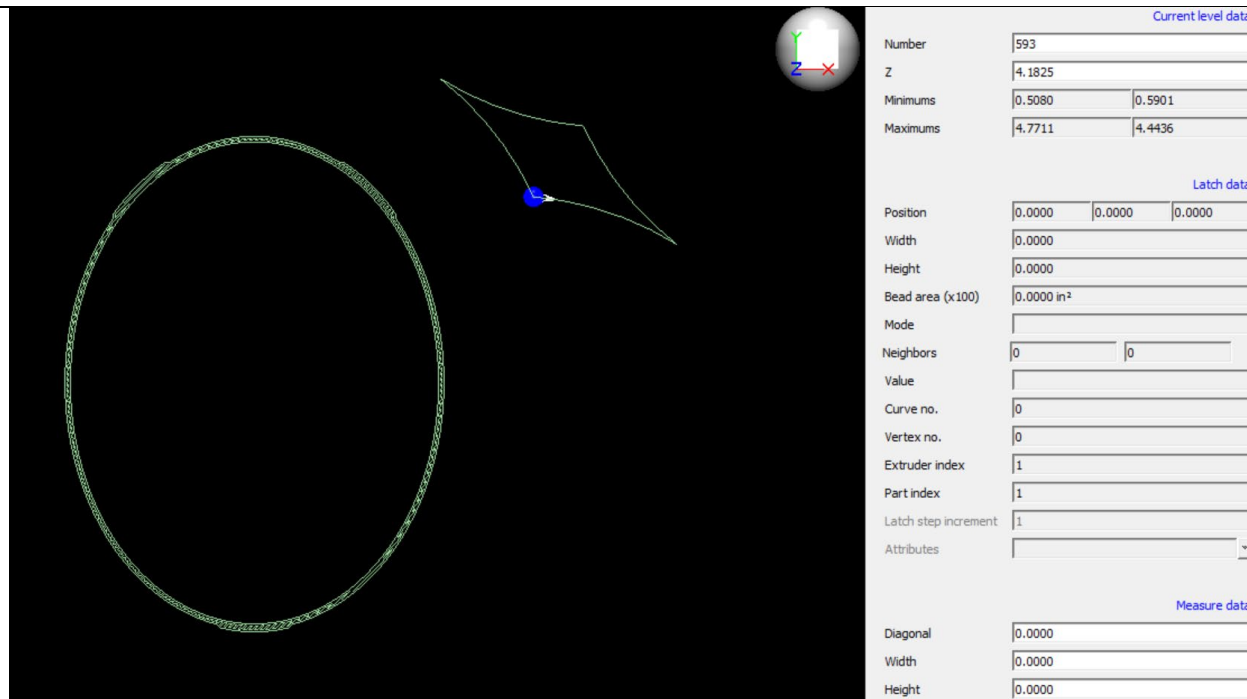
For example, Solo printer stopped building the purge tower at the highest layer at which there was a material change for the printed layers of the three-dimensional part and support structure. The purge operations were performed when the relevant print head/deposition line went into operating mode. As such, there was no need to print additional layers of the purge tower after the last material change. The screenshots below of

dimensional part and support structure.

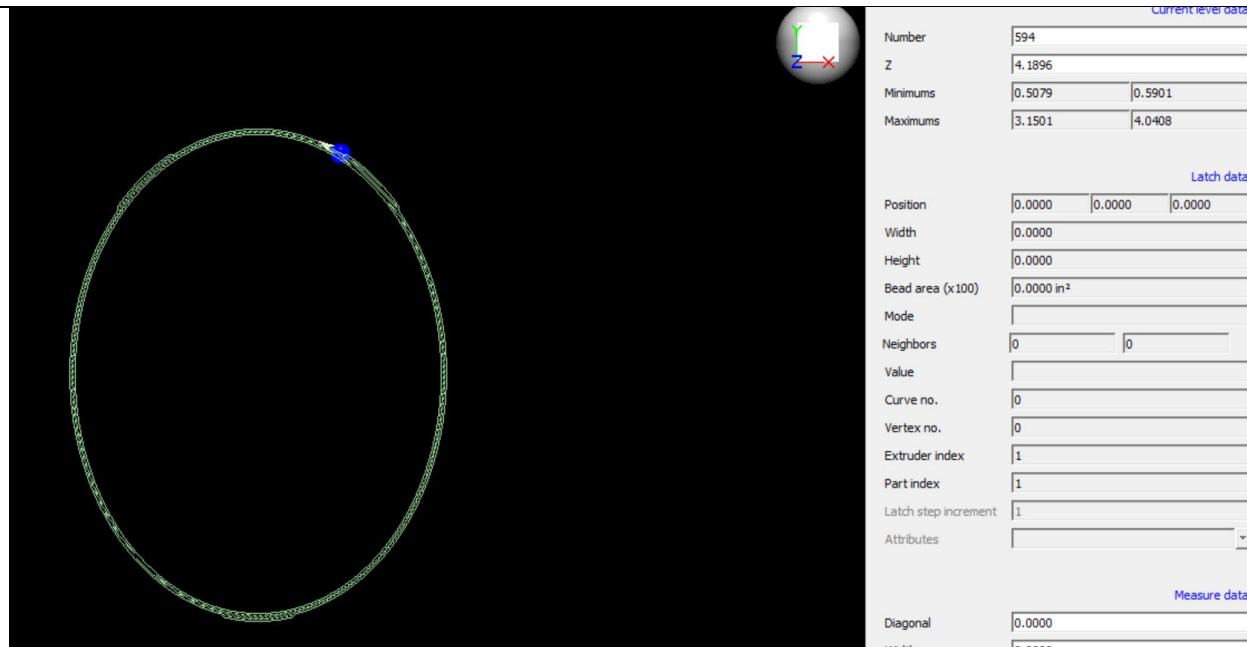
Exhibit E depict this process, showing that the last layer of the purge tower was printed on layer 593, which corresponded to the final change to part material:



Ex. E (July 5, 2011, packed CMB file) at 16. As shown in layer 592, the blue lines indicate support material, and the green lines indicate part material. The blue diamond shape represents a layer of the purge tower, corresponding to a switch to the printing of support material on this layer.



Ex. E (July 5, 2011, packed CMB file) at 17. As shown in layer 593, the green lines indicate part material. The green diamond shape represents a layer of the purge tower, corresponding to a switch to the printing of part material on this layer.



Ex. E (July 5, 2011, packed CMB file) at 18. As shown in layer 594, the green lines indicate part material. No layer of the purge tower is printed on layer 594 because there was no switch back from part material to support material. No further layers of the purge tower were printed on layers 595-607 (the topmost layer) because all those layers printed only part material and no further material changes occurred.

7. The method of claim 1, and further comprising:

[7a] generating tool path instructions for printing the layers of the three-

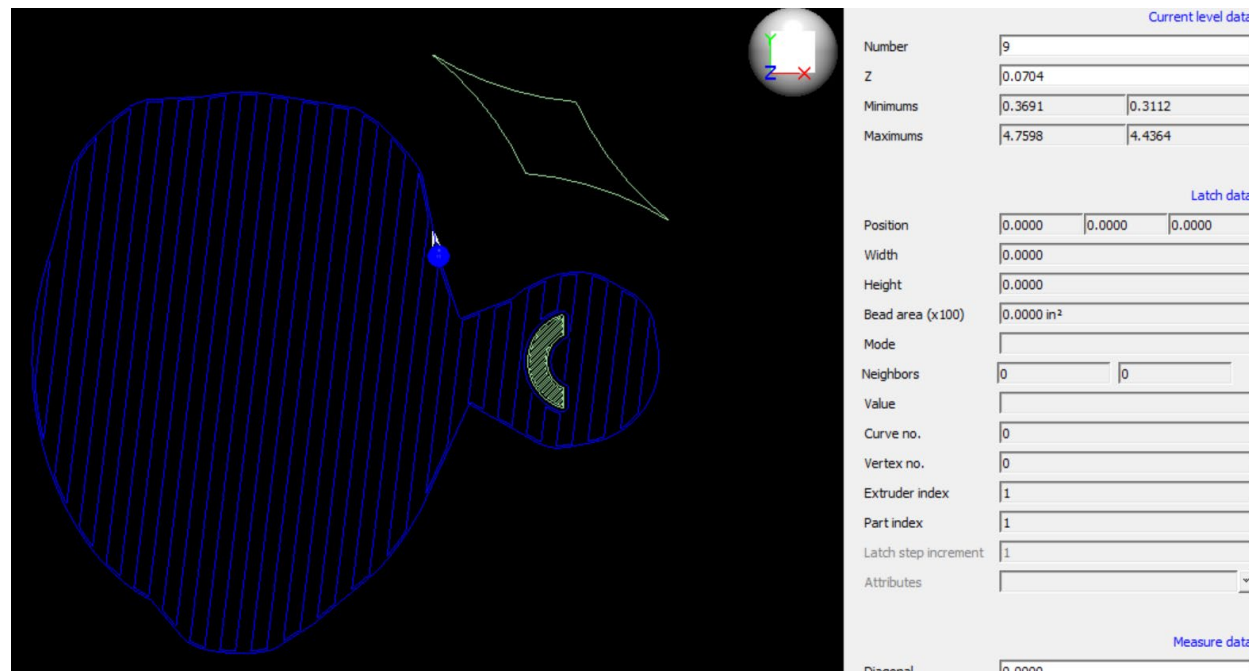
Software used in conjunction with the Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to generate tool path instructions for printing the layers of the three-dimensional part and of the support structure and was also used to generate tool path instructions for printing the layer of the at least one purge tower, satisfying claim 7.

For example, software was used in conjunction with the Solo printer to generate tool path instructions for printing the layers of the three-dimensional part, the support structure, and the purge tower. The Solo printer used Stratasys software called Insight™ to generate the tool path instructions for printing the layers of the

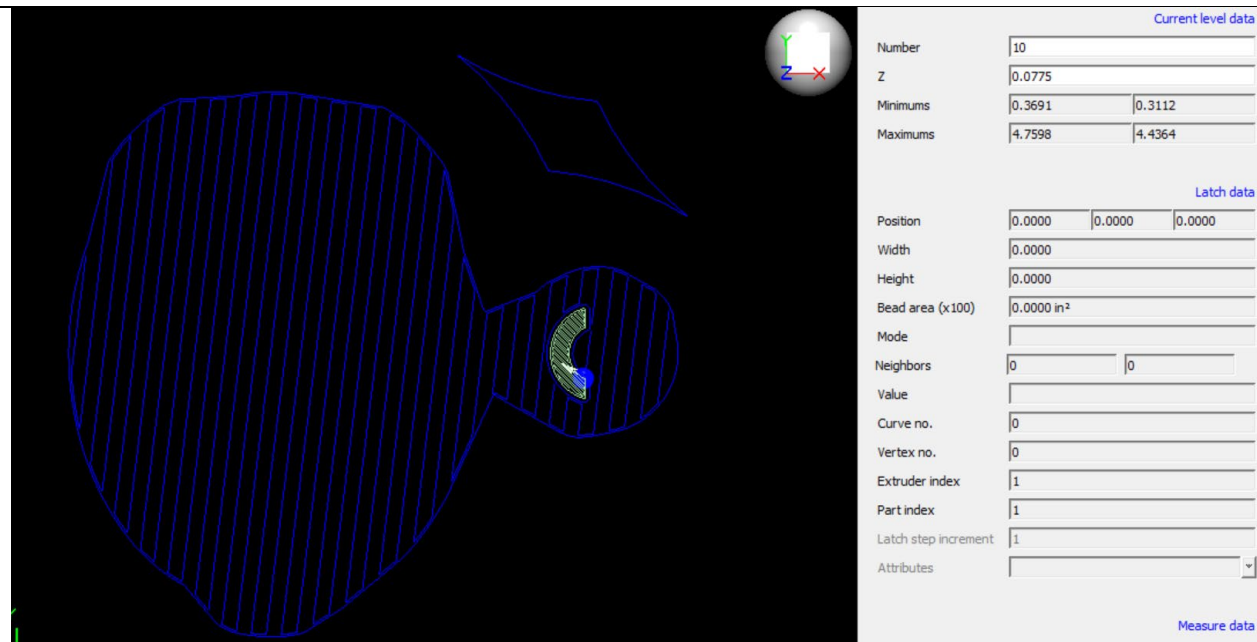
dimensional part and of the support structure; and

[7b] generating tool path instructions for printing the layer of the at least one purge tower.

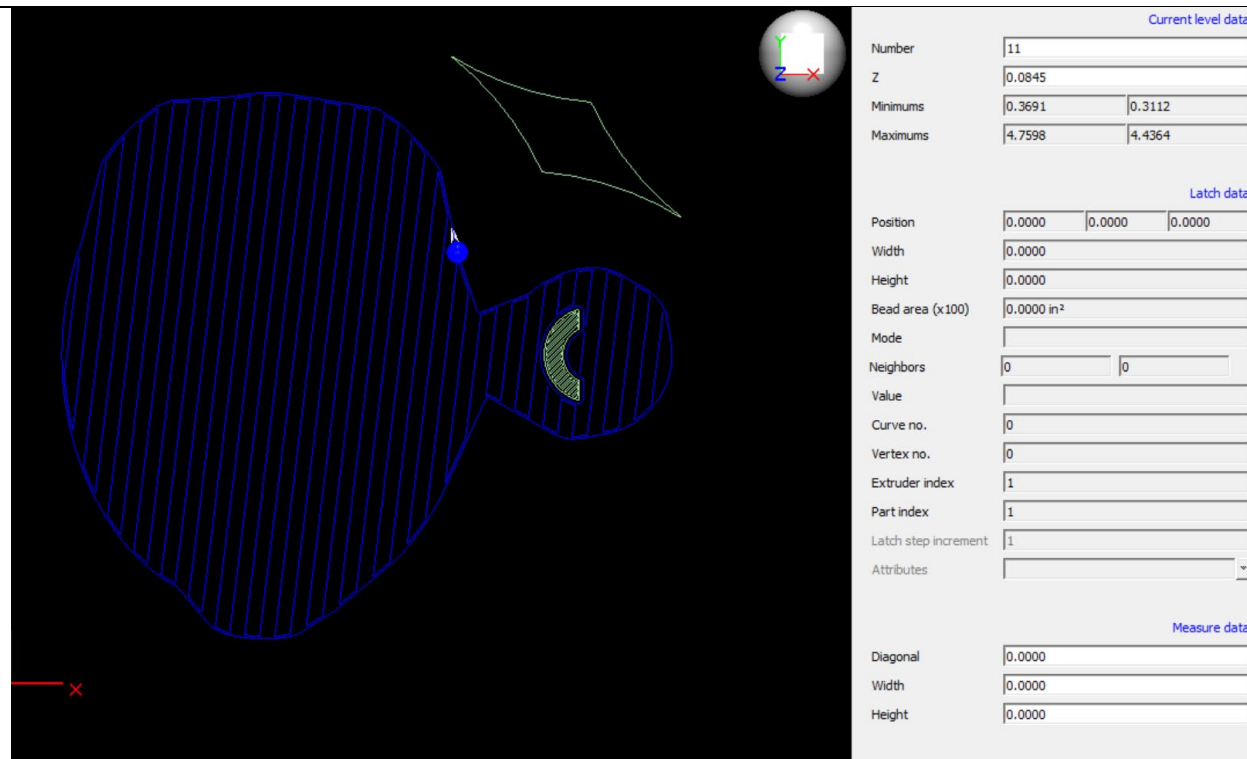
three-dimensional part and support structure. I also used Insight™ to generate the tool path instructions for printing the layers of the purge tower(s). These instructions were stored in coordinate machine binary (“CMB”) files I discussed above. These CMB files were packed together using Stratasys software called Control Center™ (an application within Insight™). The resulting combined CMB files contained the tool path instructions for the three-dimensional part, the support structure, and the purge tower(s). The resulting combined CMB files were used to print the three-dimensional part, the support structure, and the purge tower(s). An example of the tool paths from such a CMB file (Exhibit E) are shown below:



Ex. E (July 5, 2011, packed CMB file) at 8. As shown in layer 9, the blue lines indicate the tool paths for support material, and the green lines indicate the tool paths for part material. The green diamond shape represents the tool paths for printing a layer of purge tower from part material.



Ex. E (July 5, 2011, packed CMB file) at 9. As shown in layer 10, the blue lines indicate the tool paths for support material, and the green lines indicate the tool paths for part material. The blue diamond shape represents the tool paths for printing a layer of purge tower from support material.



Ex. E (July 5, 2011, packed CMB file) at 10. As shown in layer 11, the blue lines indicate the tool paths for support material, and the green lines indicate the tool paths for part material. The green diamond shape represents the tool path for printing a layer of purge tower from part material. The blue tool paths surrounding the green tool paths in the above images of layers 9-11 correspond to the support structure. The green tool paths within the blue support structure correspond to the three-dimensional part. As I discussed, the diamond-shaped tool paths offset from the part and the support structure (alternating green and blue) correspond to the purge tower.

9. The method of claim 7, wherein the generating of the

Software used in conjunction with the Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to generate the tool path instructions for printing the layer of the at least one

<p>tool path instructions for printing the layer of the at least one purge tower is performed prior to printing the layers of the three-dimensional part and of the support structure.</p>	<p>purge tower prior to printing the layers of the three-dimensional part and of the support structure, satisfying claim 9.</p> <p>For example, the tool path instructions for printing the layer of the purge tower(s) were generated prior to printing the layers of the three-dimensional part and of the support structure. As discussed above for claim 7, I generated the tool path instructions for printing the layers of the purge tower(s) were generated by using the Insight™ software and packed into a single CMB file along with the CMB file containing the three-dimensional part and support structure using the Control Center™ software. The purge tower would be packed first in Control Center™ so that each layer would begin with printing the layer of the purge tower. The generation of the purge tower tool path instructions and the packing in Control Center™ was completed prior to printing the part and support structure. This order was necessary to use the purge part during the printing process, as the Solo printer used the single CMB file to perform the print operation of the purge tower, three-dimensional part, and support structure.</p>
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16. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:

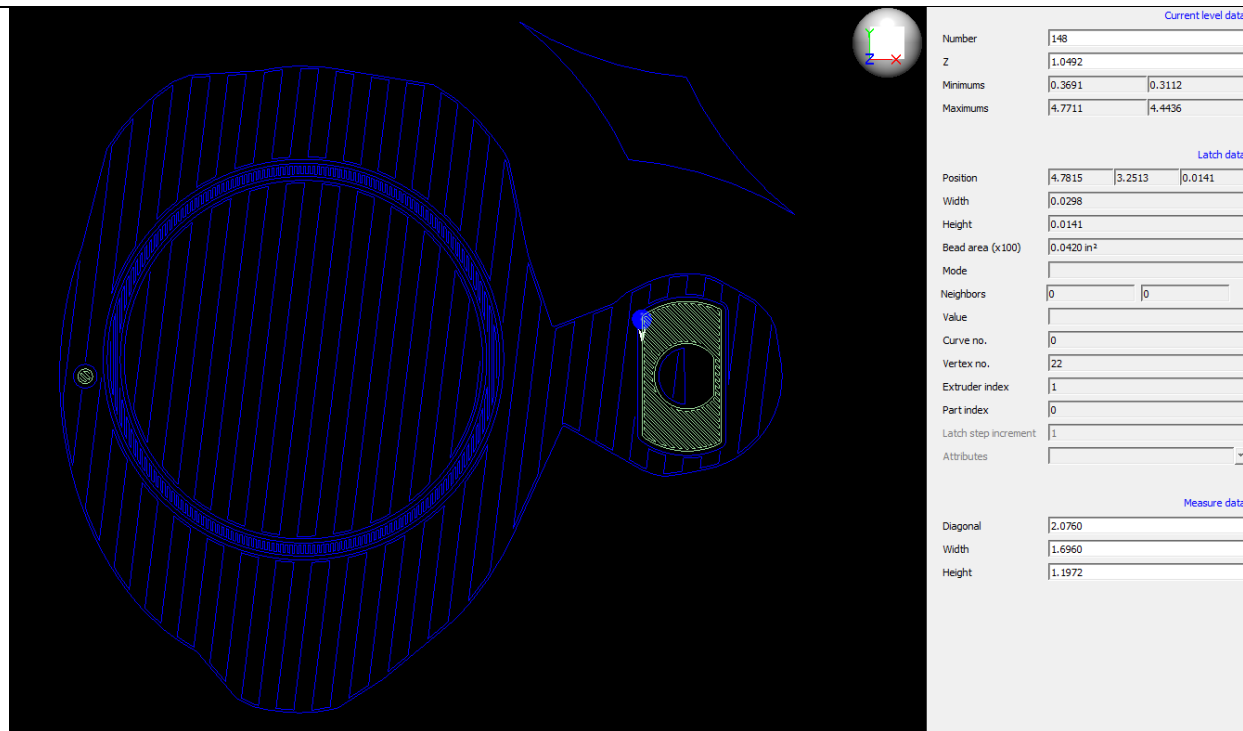
The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to print a three-dimensional part with an additive manufacturing system, satisfying the preamble of claim 16.

For example, as described above for the preamble of claim 1, the Solo printer was used to print a three-dimensional part using fused deposition modeling, which is an additive manufacturing process invented by Stratasys.



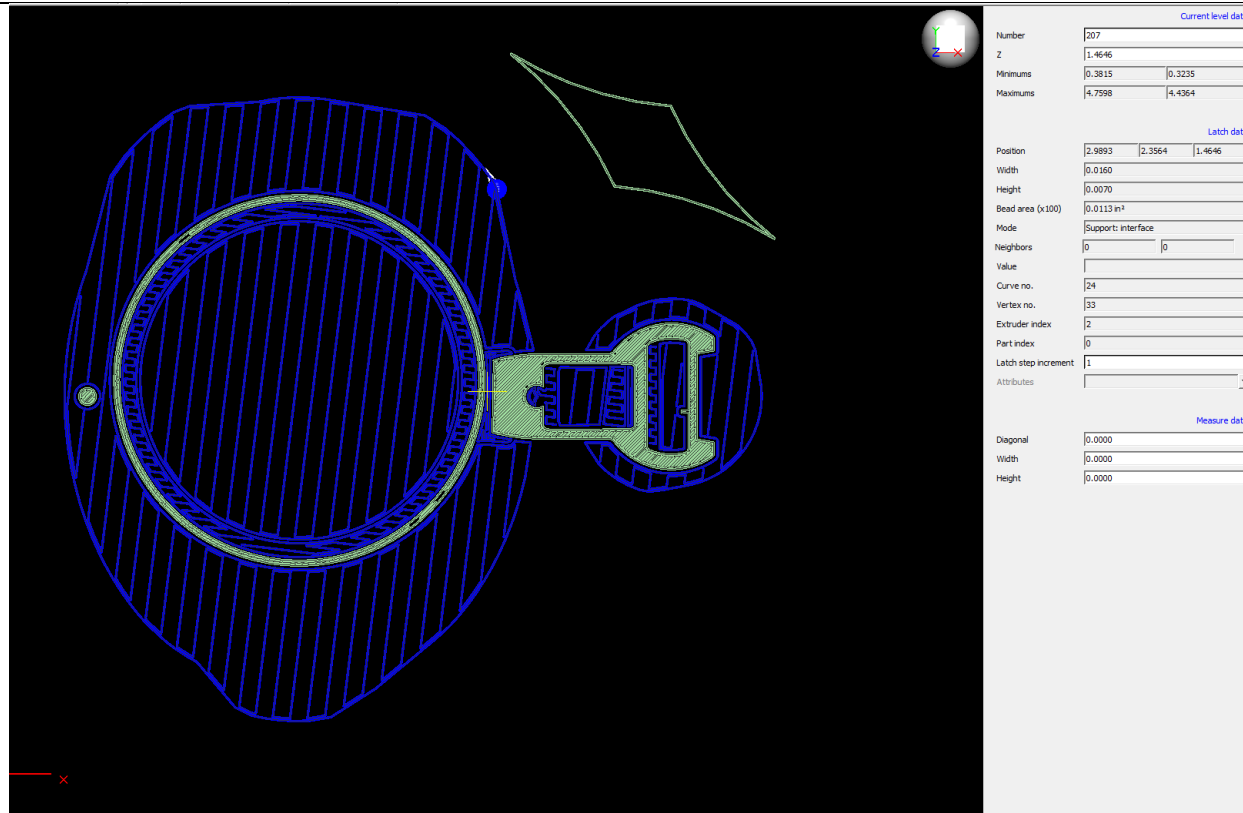
Ex. B (March 16, 2010, photograph showing four prototype Solo printer test units).

	<div data-bbox="835 191 1581 747" data-label="Image"> </div> <p data-bbox="499 771 1640 803">Ex. C (November 20, 2011, photograph showing Solo's print heads and deposition lines).</p>
<p data-bbox="201 857 474 1144">[16] (a) printing a first layer of a support structure from a support material for the three-dimensional part;</p>	<p data-bbox="499 857 1881 974">The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to print a first layer of a support structure from a support material for the three-dimensional part, satisfying element [16a].</p> <p data-bbox="499 1023 1917 1144">For example, the screenshots below of Exhibit E depict this process. Shown below is layer 148, where the blue lines indicate the tool paths for printing a first layer of a support structure from a support material for the three-dimensional part.</p>



Ex. E (July 5, 2011, packed CMB file) at 11.

As another example, layer 207 also depicts this element, as shown below:

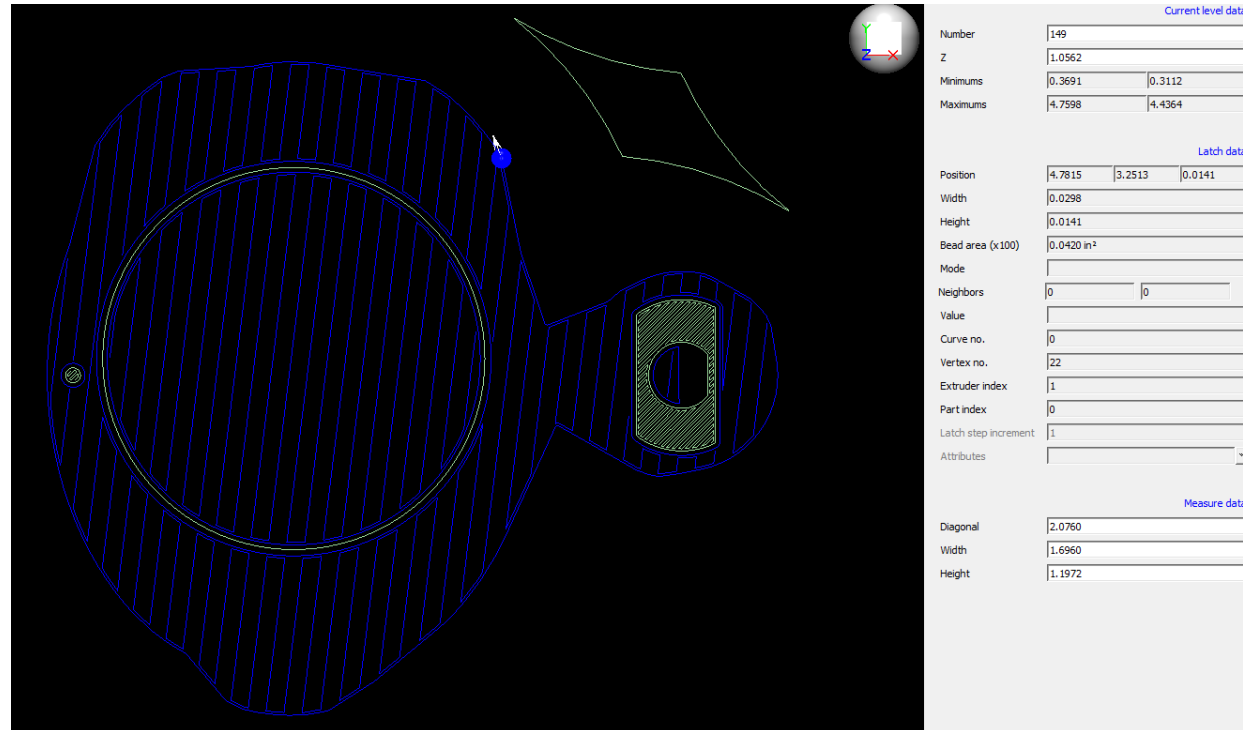


Ex. E (July 5, 2011, packed CMB file) at 33. As shown above in layer 207, the blue lines indicate the tool paths for printing a first layer of a support structure from a support material for the three-dimensional part.

[16] (b) printing a first layer of a purge tower from a part material;

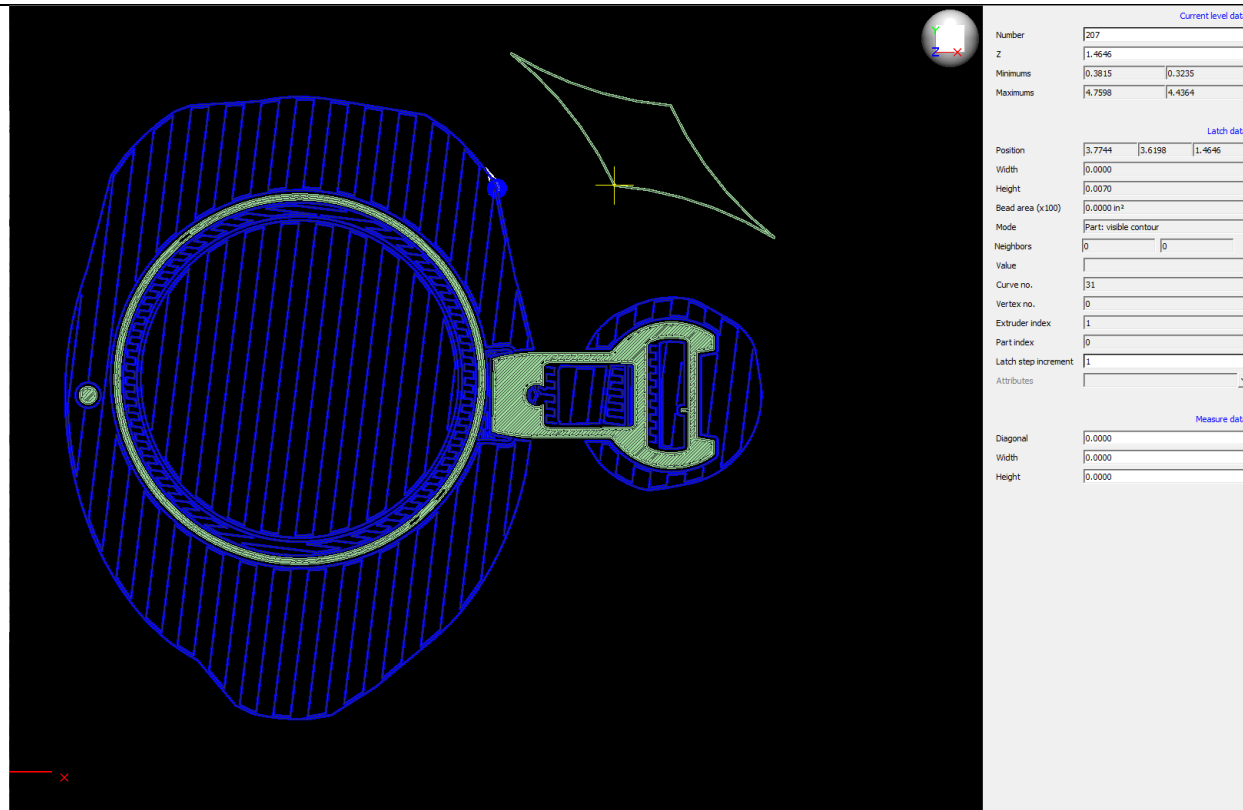
The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to print a first layer of a purge tower from part material, satisfying element [16b].

For example, the screenshots below of Exhibit E depict this process. Shown below is layer 149, where the green lines (in a diamond shape) indicate the tool paths for (b) printing a first layer of a purge tower from a part material.



Ex. E (July 5, 2011, packed CMB file) at 12.

As another example, layer 207 also depicts this element, as shown below:



Ex. E (July 5, 2011, packed CMB file) at 34. As shown above in layer 207, the green lines (in a diamond shape) indicate the tool paths for (b) printing a first layer of a purge tower from a part material.

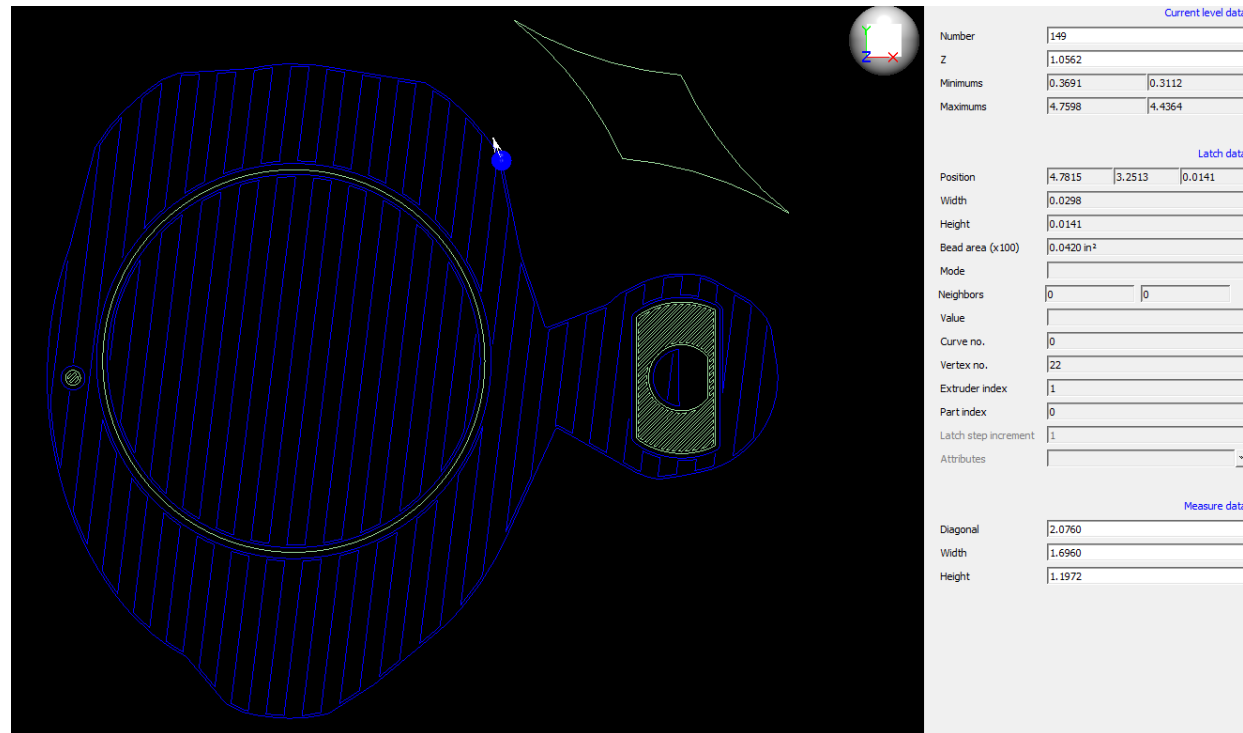
[16] (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support

The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to print a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower, satisfying element [16c].

For example, the screenshots below of Exhibit E depict this process. Shown below is layer 149, where the green lines (surrounded by the blue lines) indicate the tool paths for (c) printing a first layer of the three-

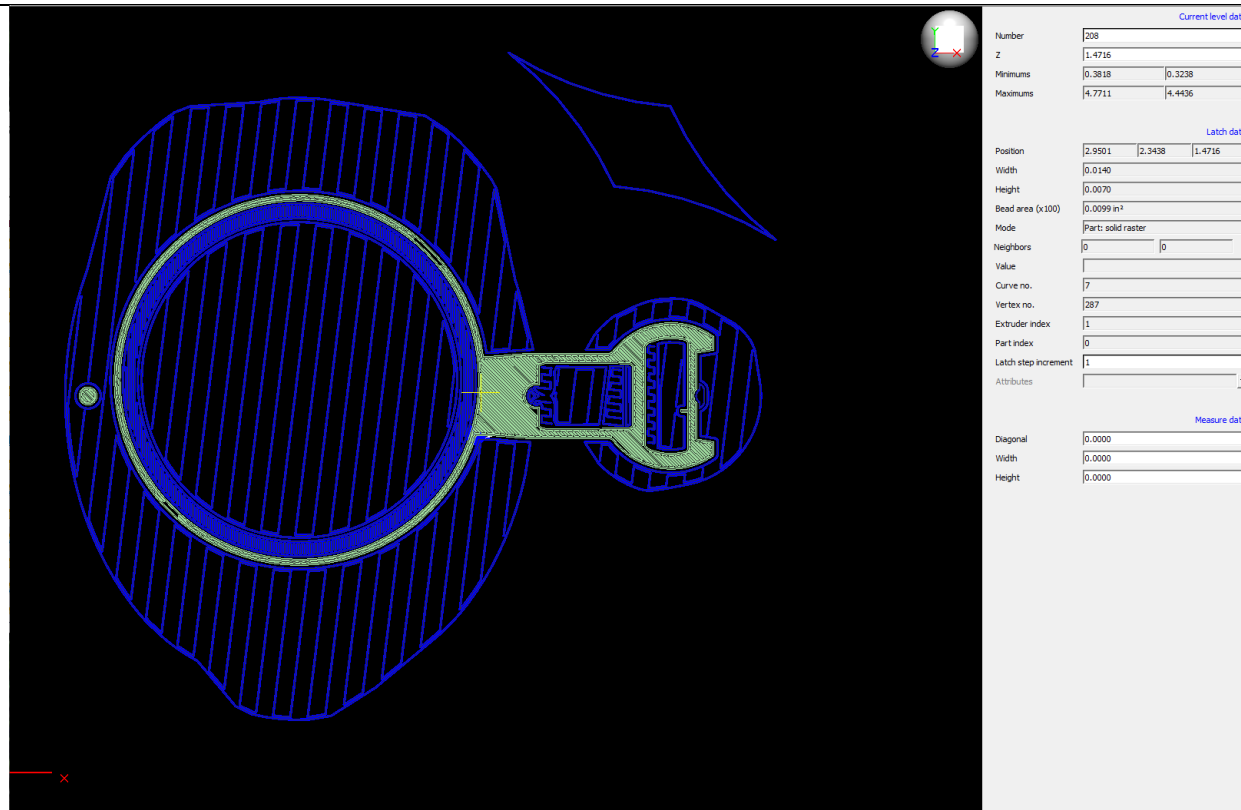
structure from the part material after printing the first layer of the purge tower;

dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower. As described above for claim 9, the purge tower would be packed first in Control Center™ so that each layer would begin with printing the layer of the purge tower.

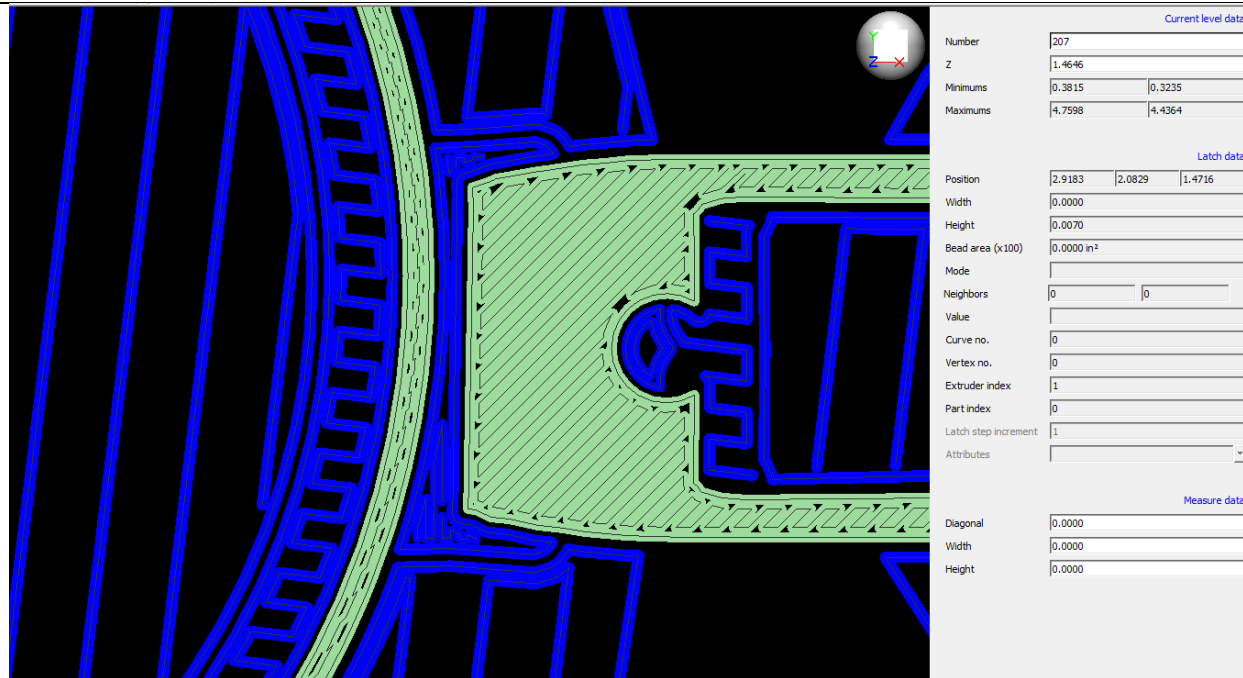


Ex. E (July 5, 2011, packed CMB file) at 12.

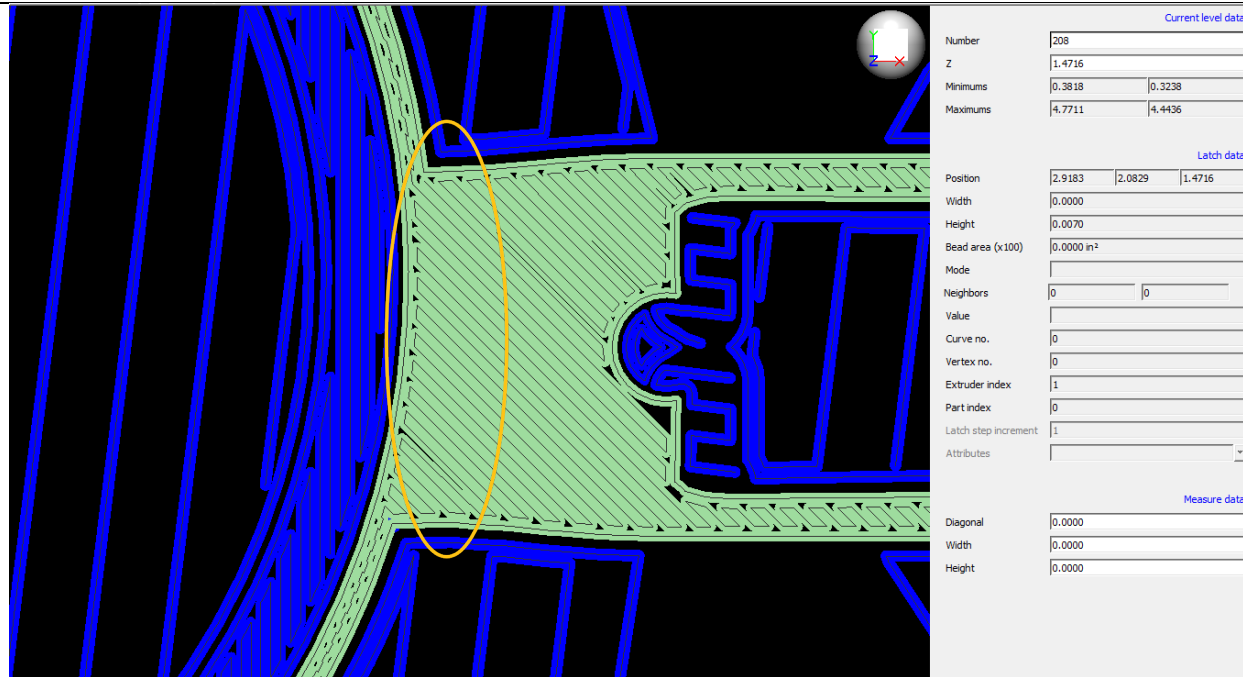
As another example, layer 208 also depicts this element, as shown below:



Ex. E (July 5, 2011, packed CMB file) at 35. The image above shows that the layer of the three-dimensional part near the center of the image in layer 208 is printed on at least a portion of the support structure in layer 207 where there was previously a gap between two portions of the part material (as seen for the element above). Below is a close-up comparison between layers 207 and 208, which shows the printing of a layer of the part on the previous layer of the support structure:



Ex. E (July 5, 2011, packed CMB file) at 36.

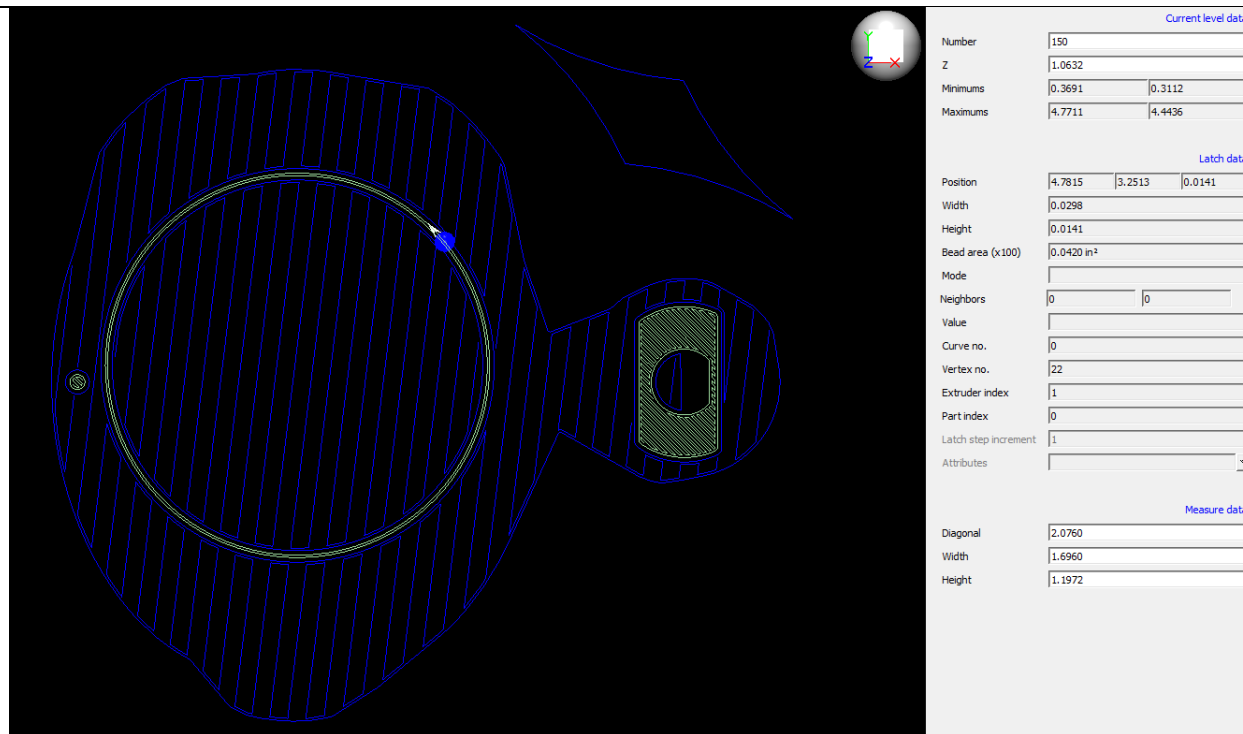


Ex. E (July 5, 2011, packed CMB file) at 37 (annotated to show part of the first layer of the three-dimensional part on at least a portion of the first layer of the support structure).

[16] (d) printing a second layer of the purge tower from the support material; and

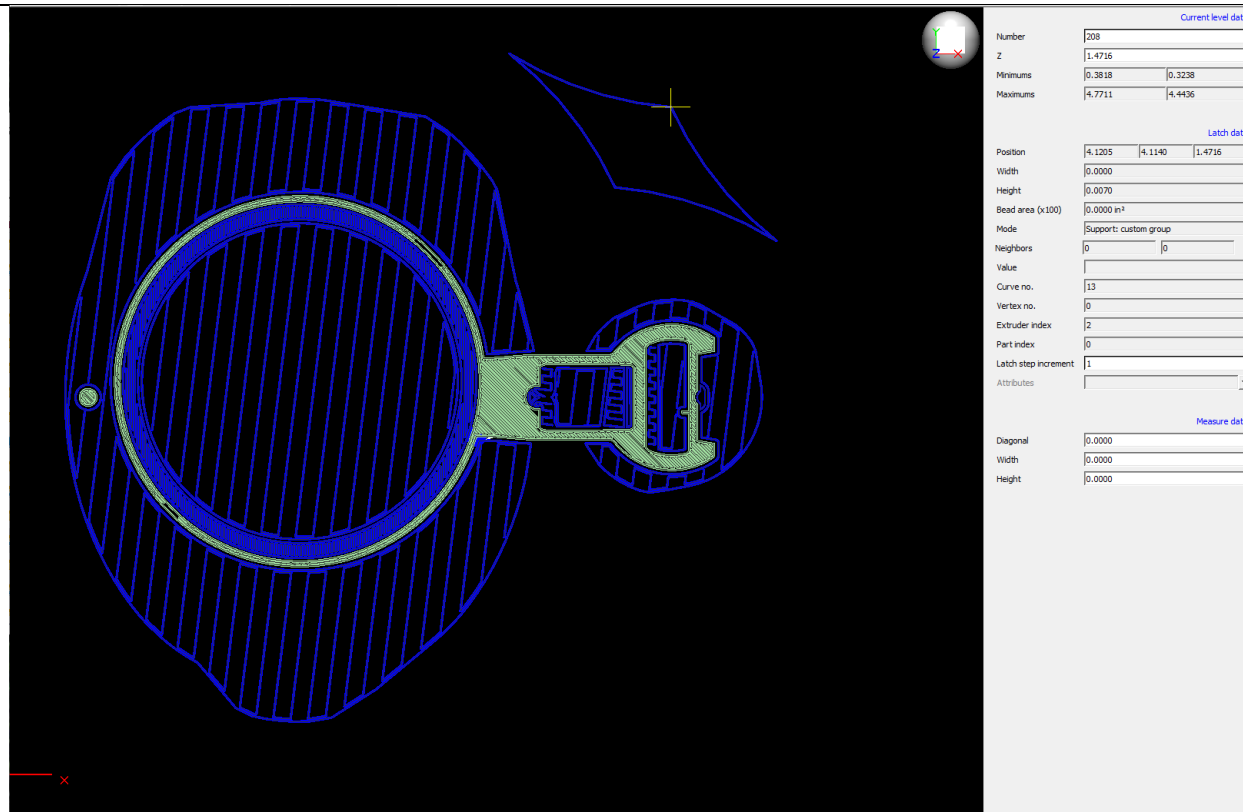
The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to print a second layer of the purge tower from the support material, satisfying element [16d].

For example, the screenshots below of Exhibit E depict this process. Shown below is layer 150, where the blue lines (in a diamond shape) indicate the tool paths for (d) printing a second layer of the purge tower from the support material.



Ex. E (July 5, 2011, packed CMB file) at 13.

As another example, layer 208 also depicts this element, as shown below:



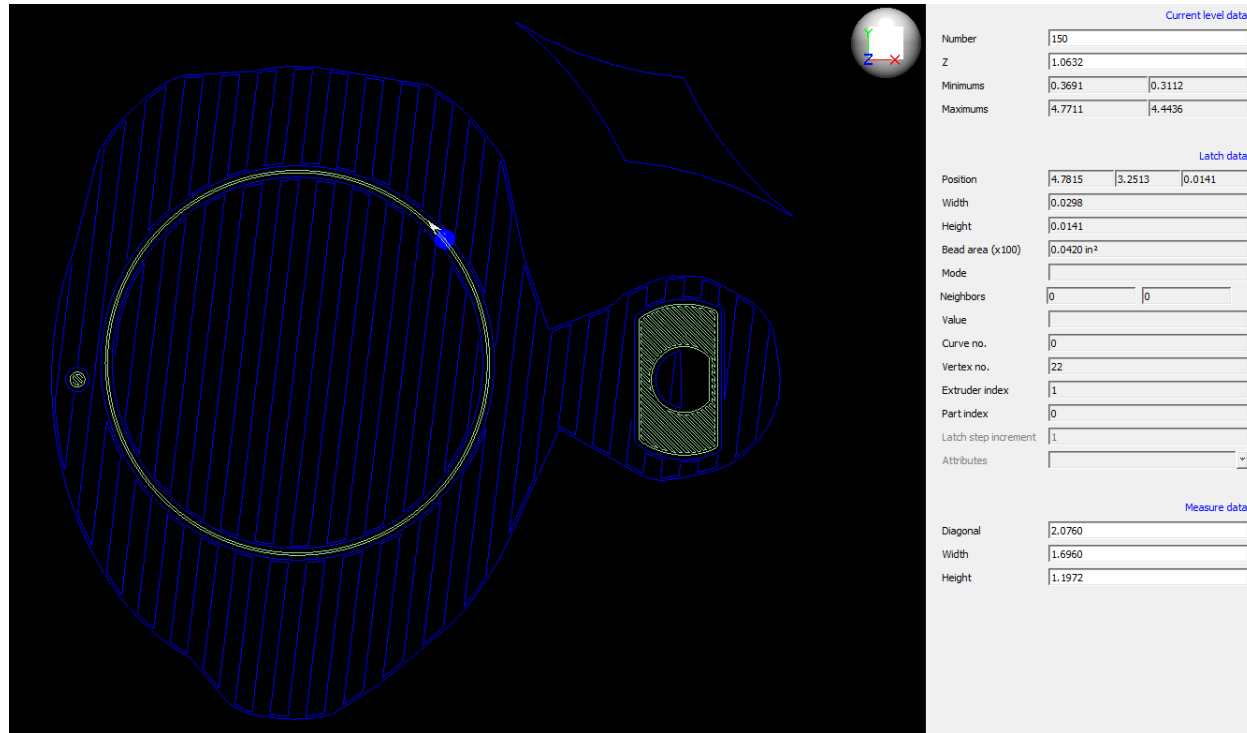
Ex. E (July 5, 2011, packed CMB file) at 38. Shown above in layer 208, the blue lines (in a diamond shape) indicate the tool paths for (d) printing a second layer of the purge tower from the support material.

[16] (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional

The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to print a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower, satisfying element [16e].

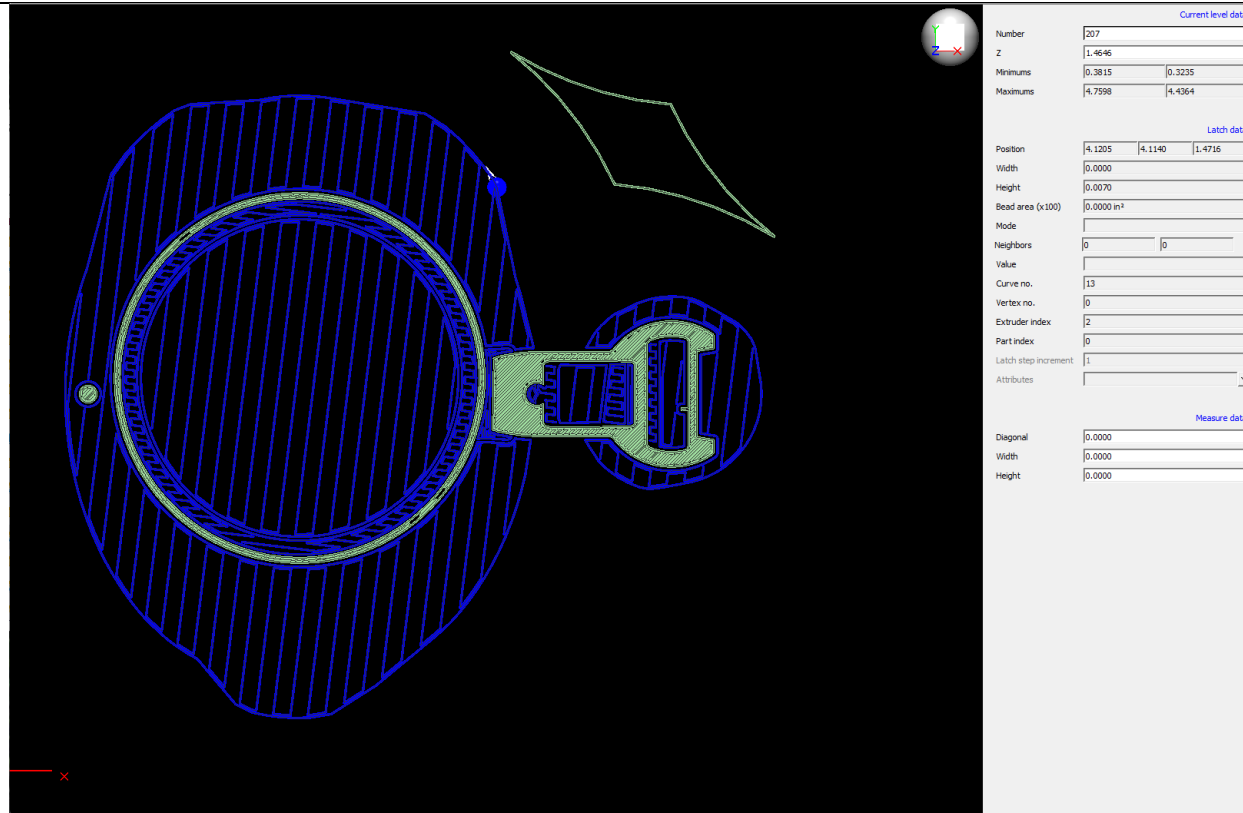
part from the support material after printing the second layer of the purge tower.

For example, the screenshots below of Exhibit E depict this process. Shown below is layer 150, where the blue lines (surrounding the green lines) indicate the tool paths for (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower. As described above for claim 9, the purge tower would be packed first in Control Center™ so that each layer would begin with printing the layer of the purge tower.

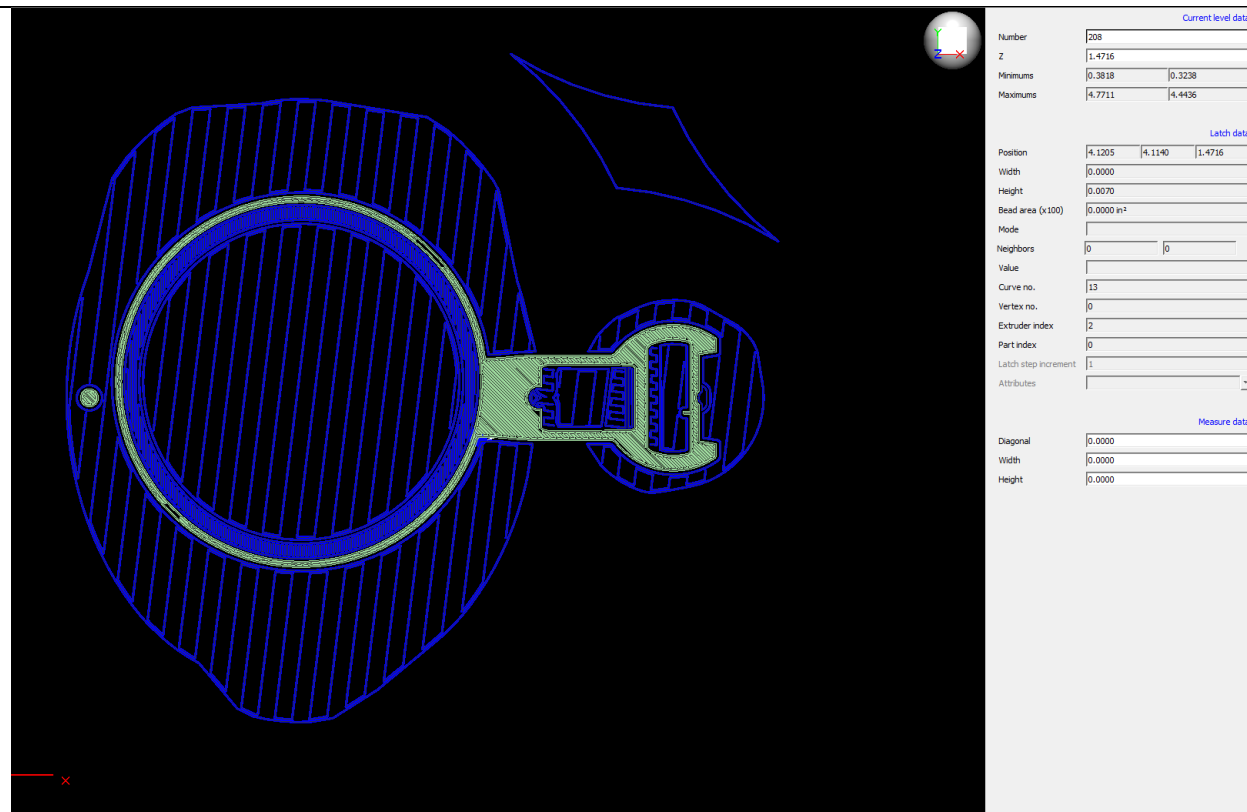


Ex. E (July 5, 2011, packed CMB file) at 13.

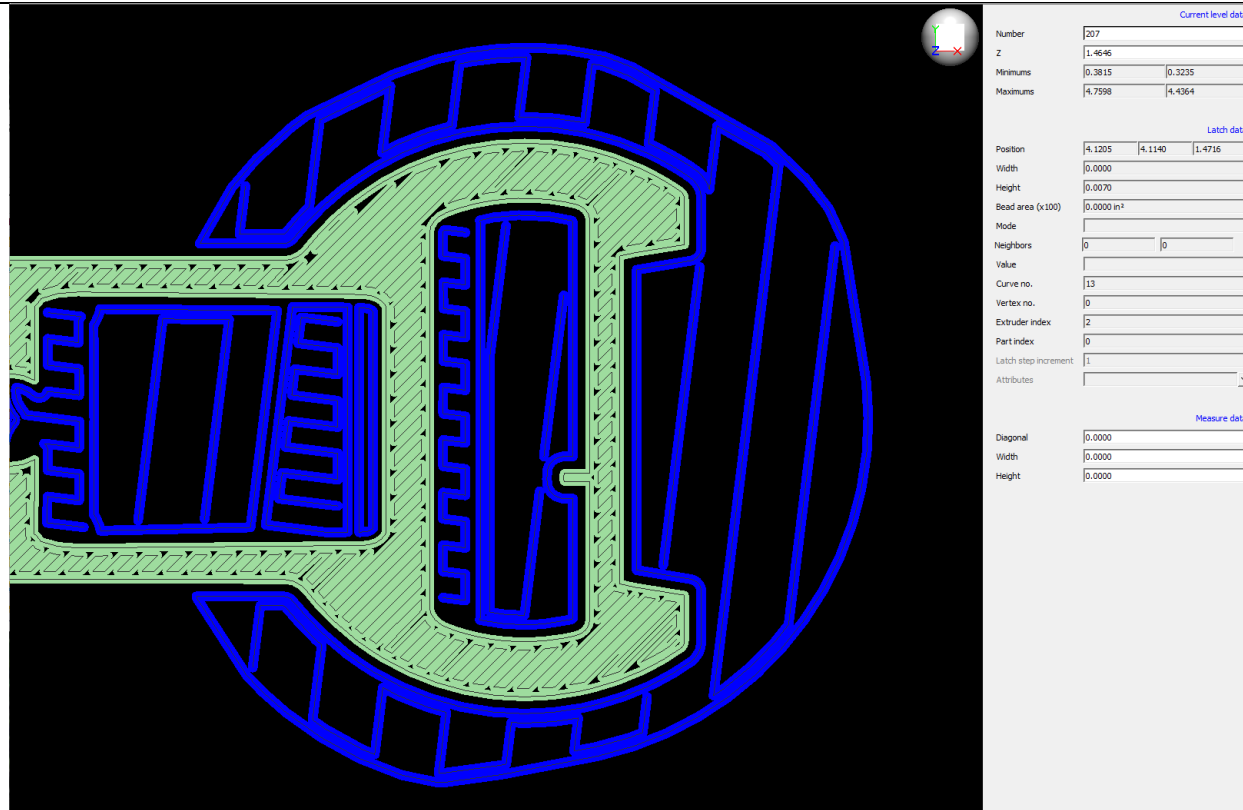
As another example, layer 208 also depicts this element, as shown below:



Ex. E (July 5, 2011, packed CMB file) at 39.



Ex. E (July 5, 2011, packed CMB file) at 40. The images above show that the layer of the support structure on the right-hand side of the image in layer 208 extends over and is printed on at least a portion of the three-dimensional part in layer 207. Close-ups of this portion of layers 207 and 208 are shown below, depicting the printing of a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower.



Ex. E (July 5, 2011, packed CMB file) at 41.



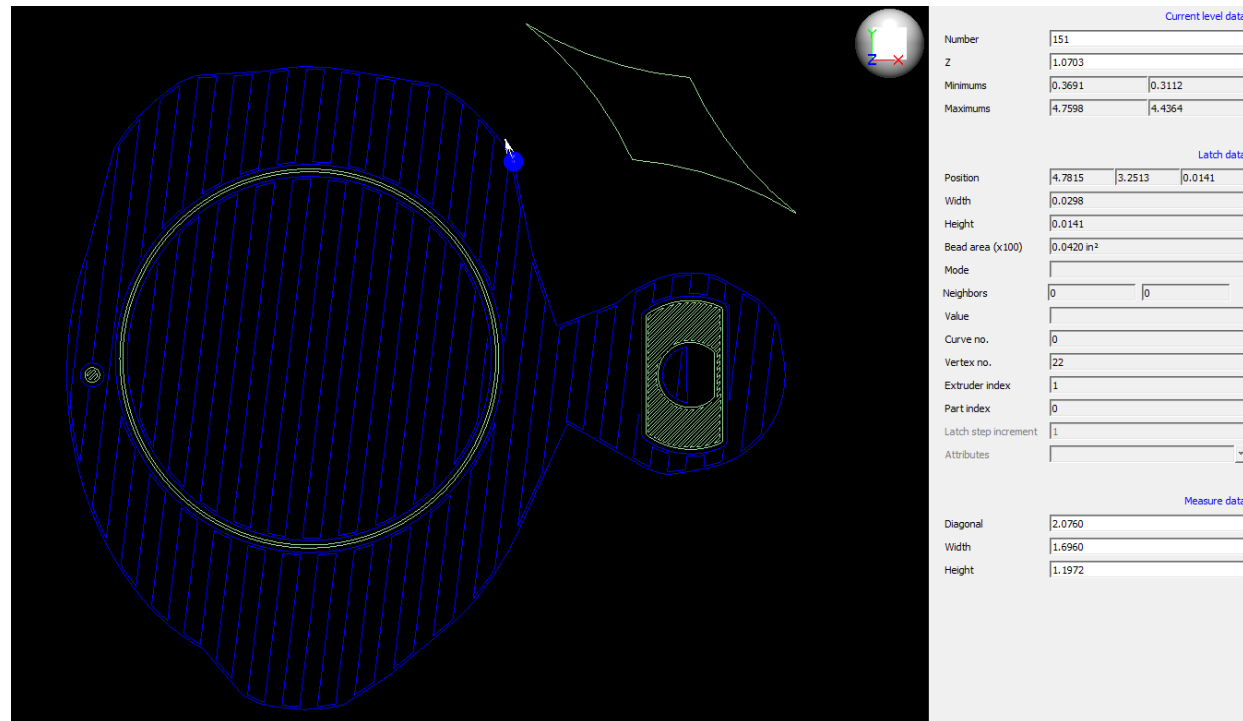
Ex. E (July 5, 2011, packed CMB file) at 42 (annotated to show part of the second layer of the support structure on at least a portion of the first layer of the three-dimensional part).

17. The method of claim 16, and further comprising repeating steps (b)-(e) for at least a portion of the three-

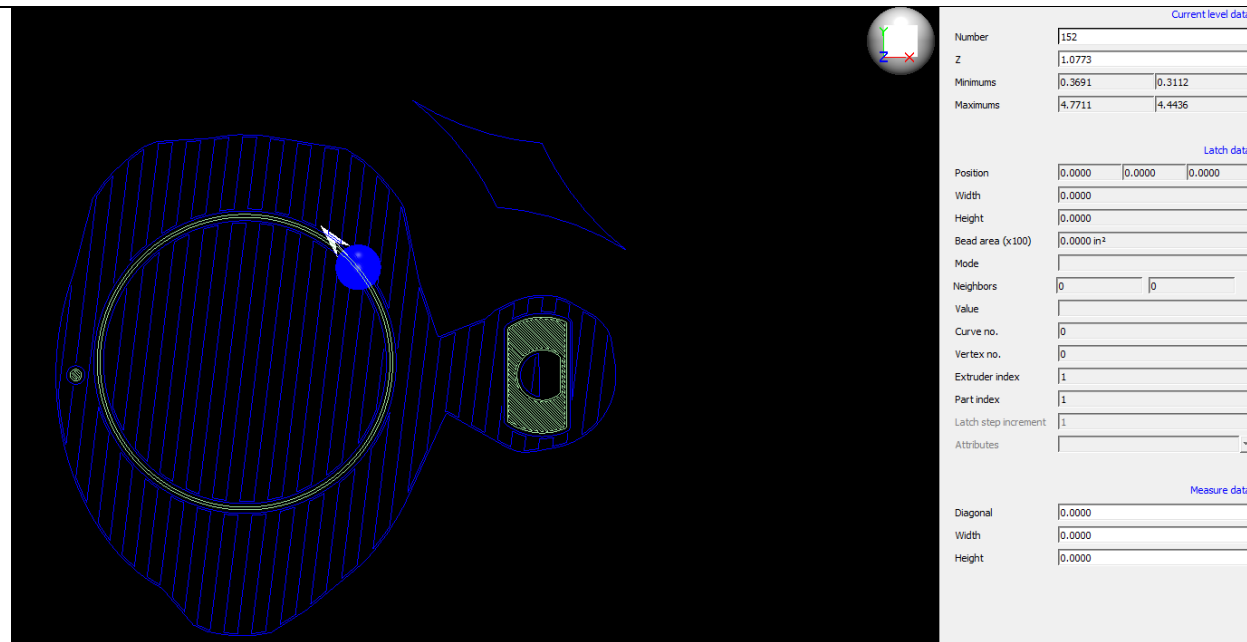
The developmental Solo printer, as conceived of and reduced to practice before at least September 21, 2012, was used to repeat the steps (b)-(e) described above for claim 16 for at least a portion of the three-dimensional part and support structure, satisfying claim 17.

dimensional part and support structure.

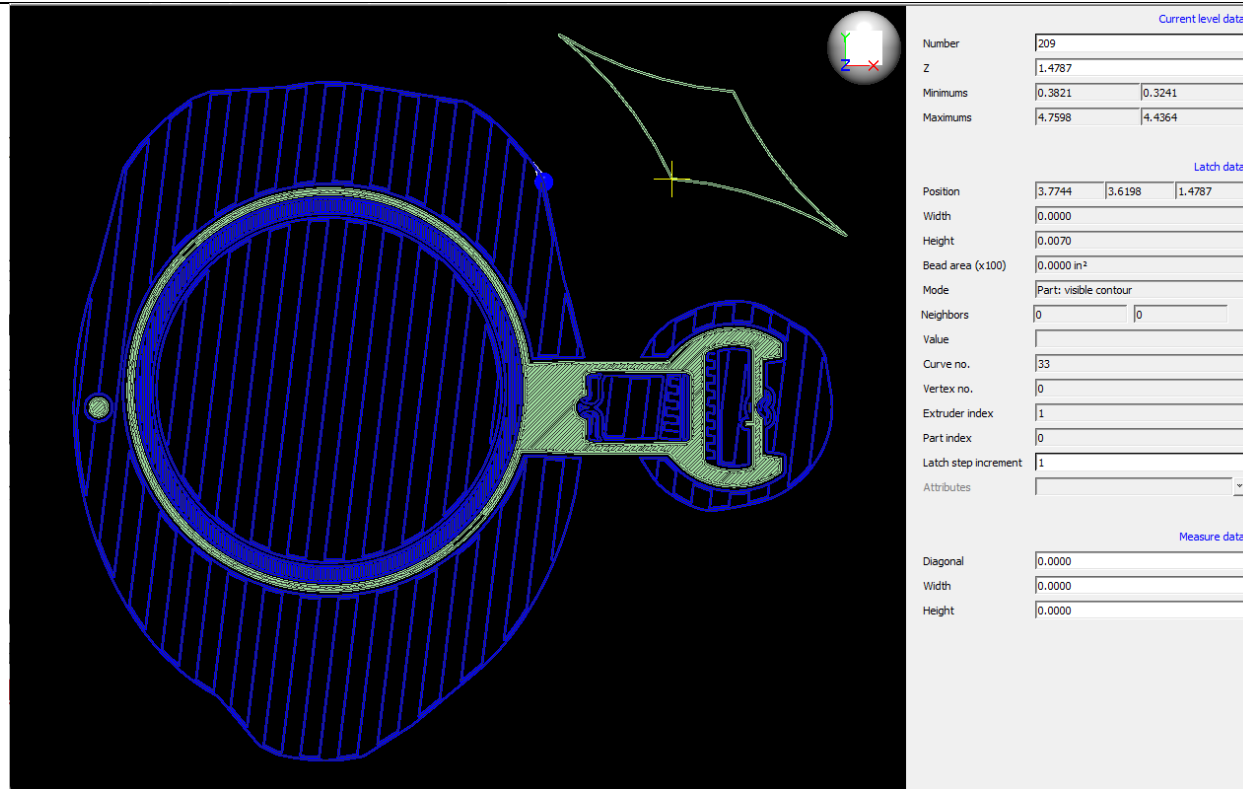
For example, the screenshots below of Exhibit E depict this process. Shown below are layers 151 and 152, the blue and green lines indicate the tool paths for repeating steps (b)-(e) described above to build successive layers of the three-dimensional part, support structure, and purge tower.



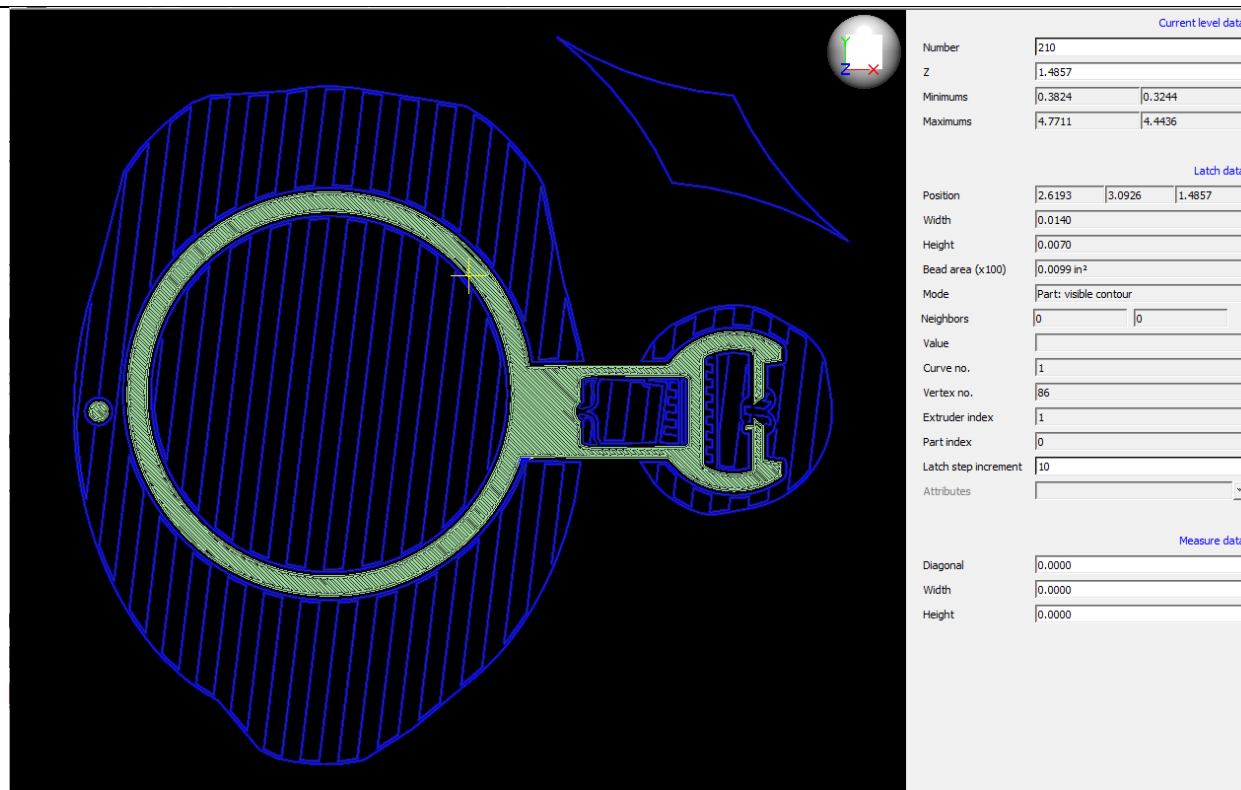
Ex. E (July 5, 2011, packed CMB file) at 14.



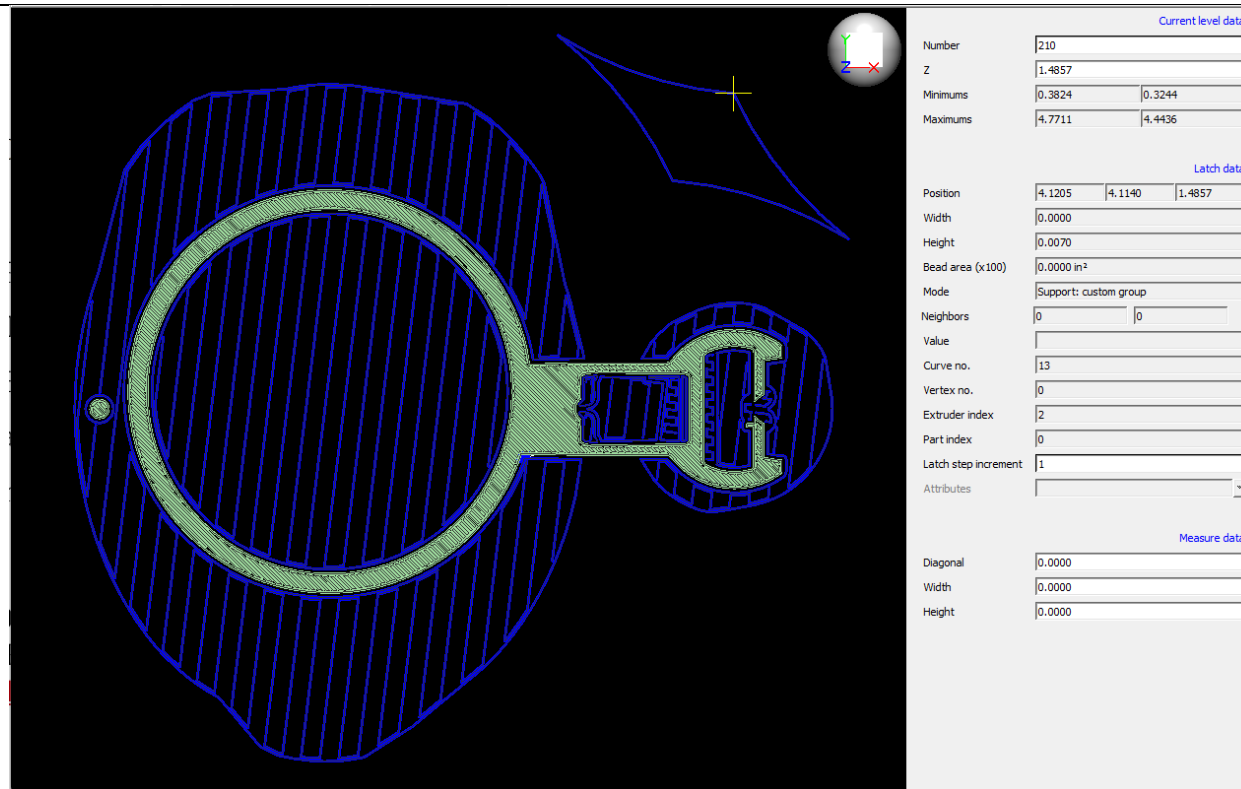
Ex. E (July 5, 2011, packed CMB file) at 15. As another example, layer 209 and 210 also depicts this element. As shown below in layers 209 and 210, the blue and green lines indicate the tool paths for repeating steps (b)-(e) described above to build successive layers of the three-dimensional part, support structure, and purge tower. For instance, as shown in layer 209, the green lines in a diamond shape indicate the tool paths for (b) printing a layer of a purge tower from a part material.



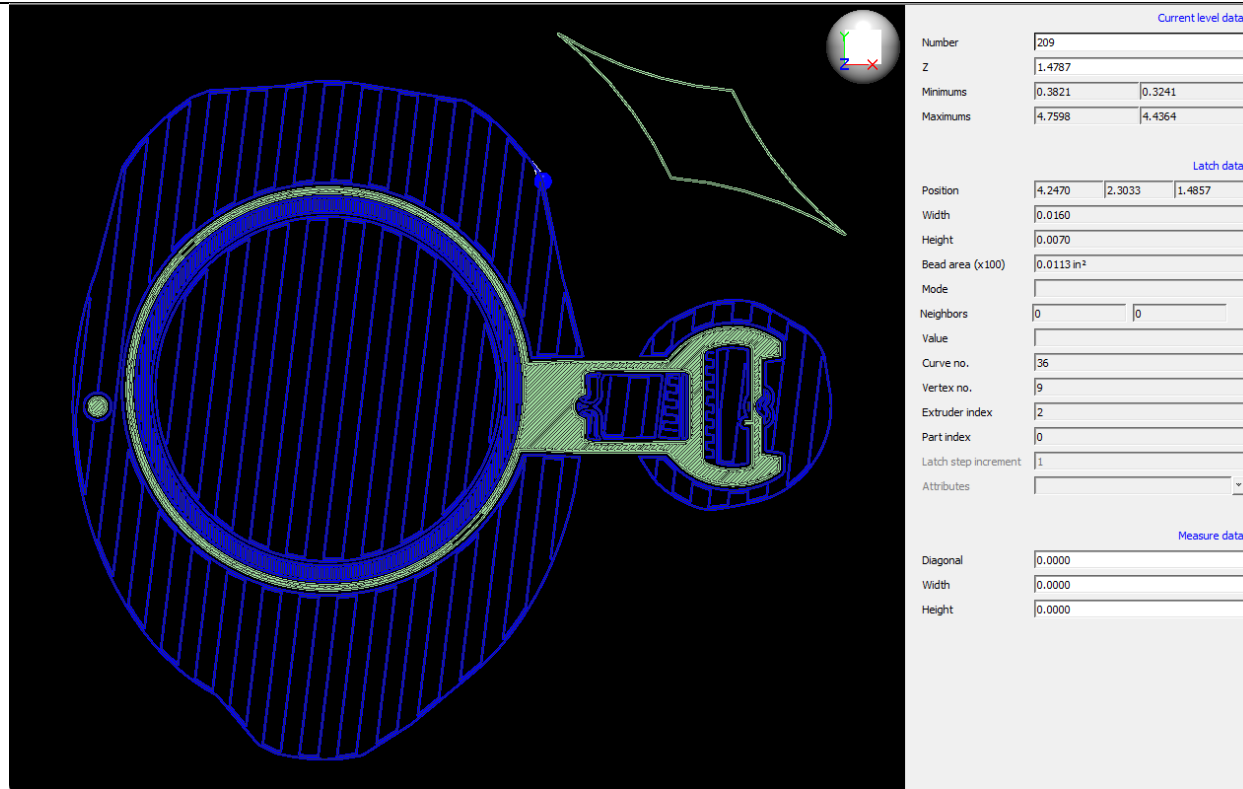
Ex. E (July 5, 2011, packed CMB file) at 43. As shown in layer 210, the green lines surrounded by the blue lines indicate the tool paths for (c) printing another layer of the three-dimensional part on at least a portion of the layer of the support structure from the part material after printing the layer of the purge tower. This is shown by the thickening of the green ring near the center of the image below.



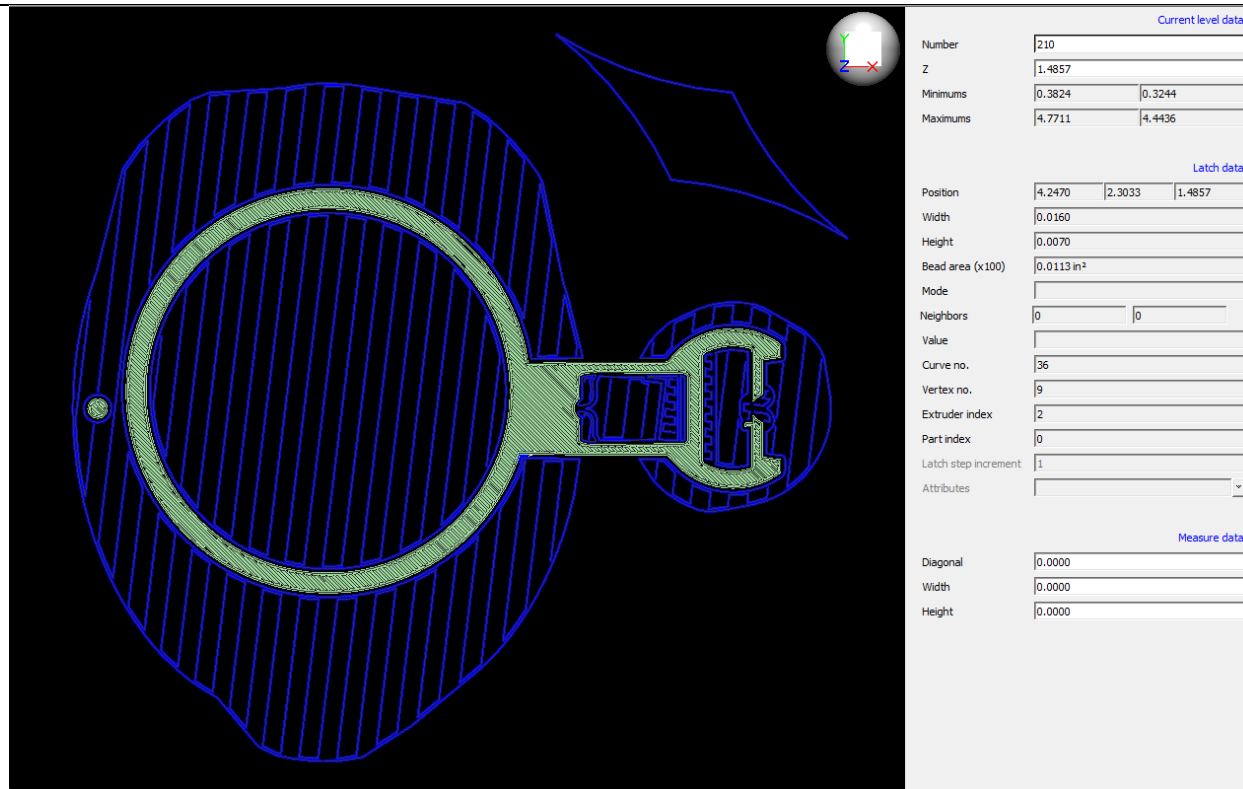
Ex. E (July 5, 2011, packed CMB file) at 44. As also shown in layer 210, the blue lines in a diamond shape indicate the tool paths for (d) printing another layer of the purge tower from the support material.



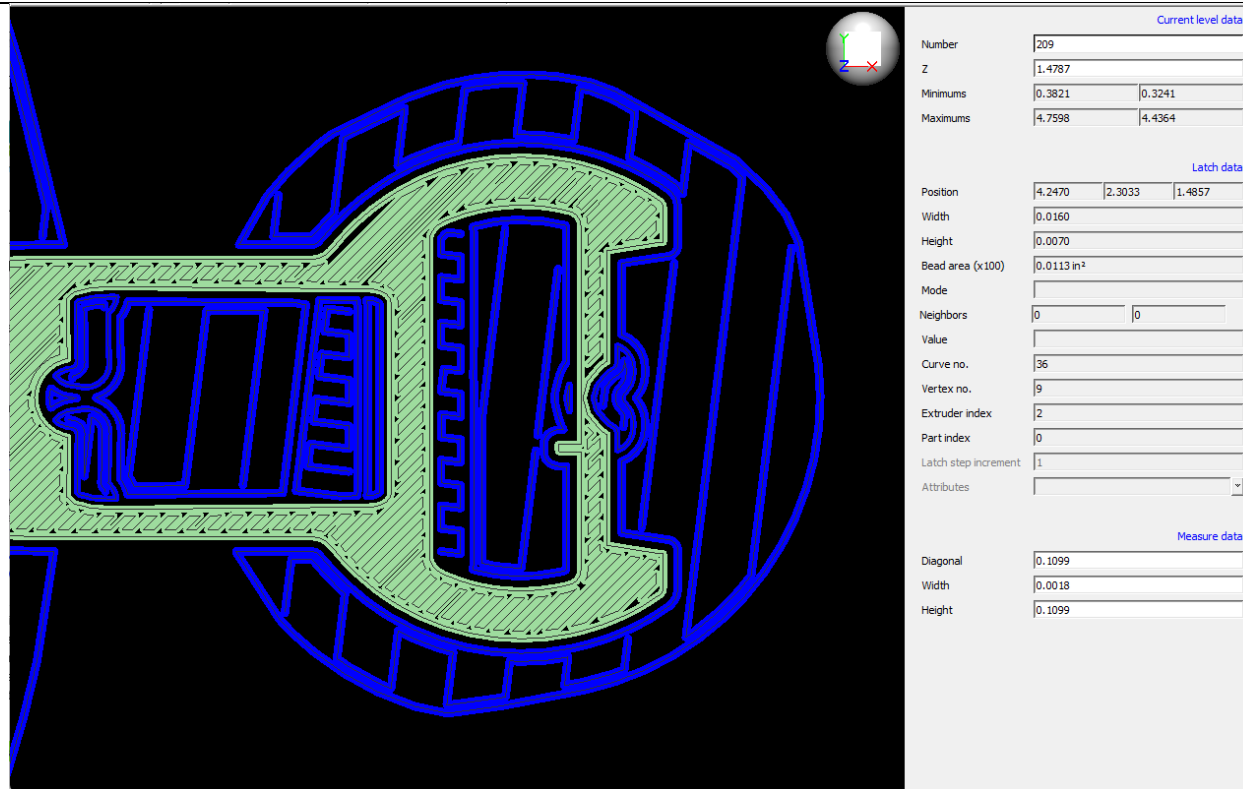
Ex. E (July 5, 2011, packed CMB file) at 45. As also shown in layer 210, the blue lines further indicate tool paths for (e) printing another layer of the support structure on at least a portion of the layer of the three-dimensional part from the support material after printing the layer of the purge tower. The images below show that the layer of the support structure on the right-hand side of the image in layer 210 extends over and is printed on at least a portion of the three-dimensional part in layer 209.



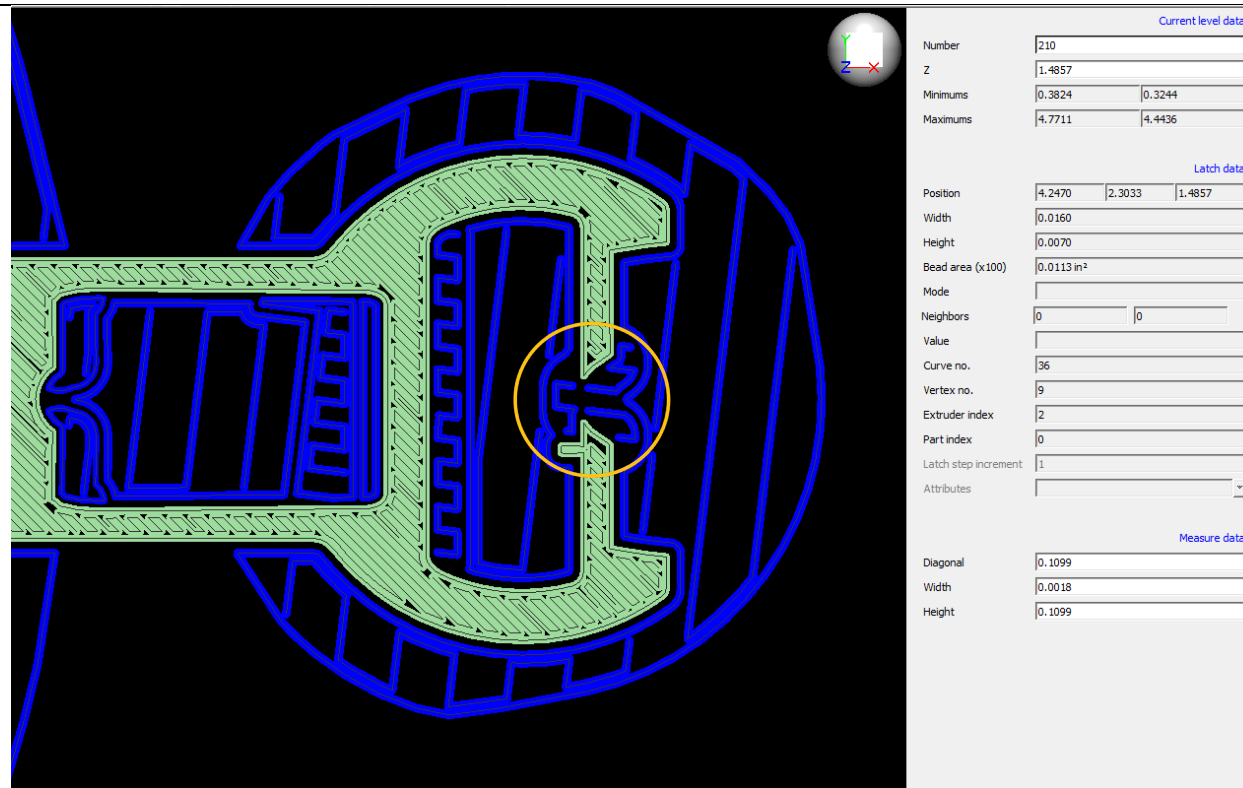
Ex. E (July 5, 2011, packed CMB file) at 46.



Ex. E (July 5, 2011, packed CMB file) at 47. Close-ups of this portion of layers 209 and 210 are shown below, depicting the printing of a layer of the support structure on at least a portion of the layer of the three-dimensional part from the support material after printing the layer of the purge tower.



Ex. E (July 5, 2011, packed CMB file) at 48.



Ex. E (July 5, 2011, packed CMB file) at 49 (annotated to show part of the layer of the support structure on at least a portion of the layer of the three-dimensional part).

EXHIBIT B



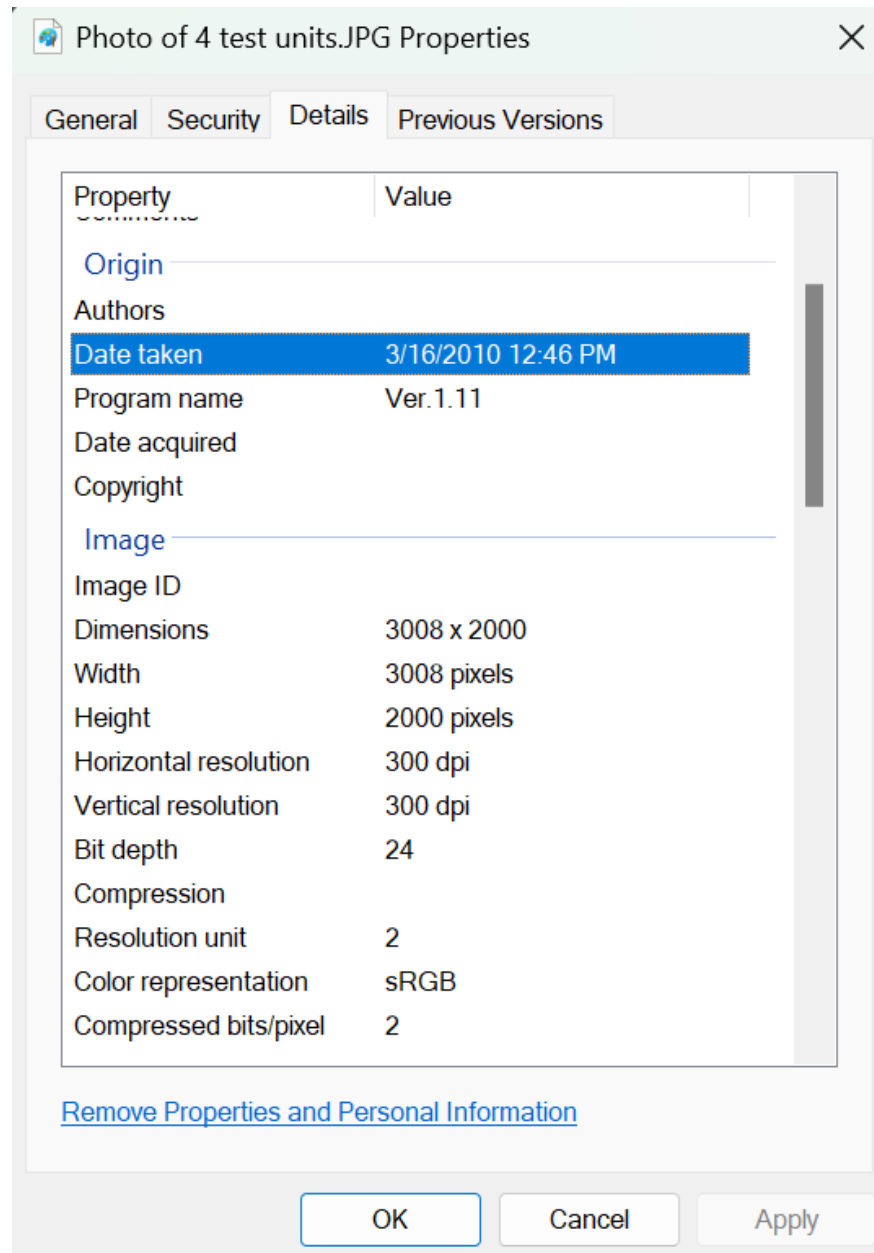
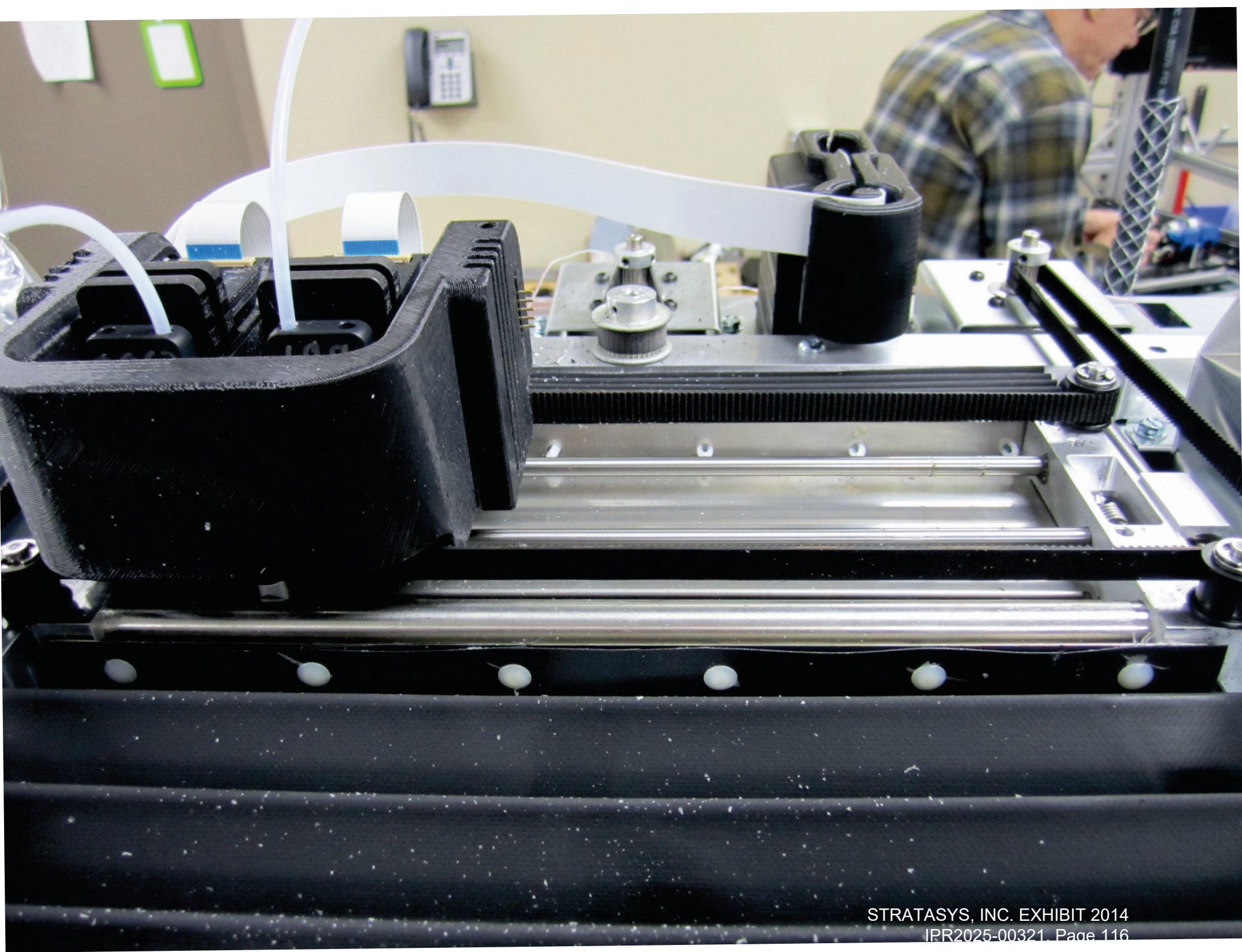


EXHIBIT C



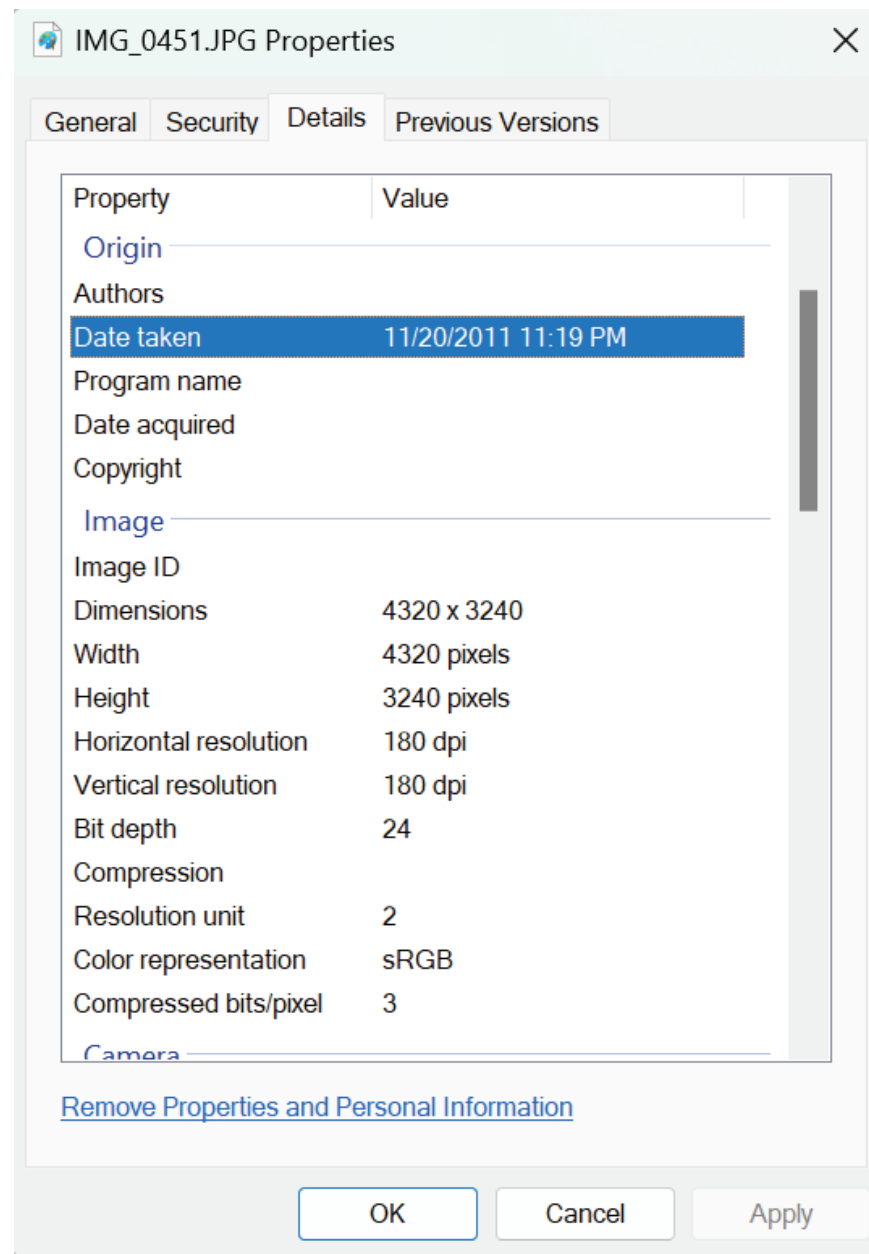


EXHIBIT D



US009421713B2

(12) **United States Patent**
Swanson et al.

(10) **Patent No.:** **US 9,421,713 B2**

(45) **Date of Patent:** **Aug. 23, 2016**

(54) **ADDITIVE MANUFACTURING METHOD
FOR PRINTING THREE-DIMENSIONAL
PARTS WITH PURGE TOWERS**

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(*) Notice: Subject to any disclaimer, the term of this
patent is extended or adjusted under 35
U.S.C. 154(b) by 530 days.

(21) Appl. No.: **13/790,924**

(22) Filed: **Mar. 8, 2013**

(65) **Prior Publication Data**

US 2014/0252684 A1 Sep. 11, 2014

(51) **Int. Cl.**
B29C 67/00 (2006.01)

(52) **U.S. Cl.**
CPC **B29C 67/0055** (2013.01); **B29C 67/0096**
(2013.01)

(58) **Field of Classification Search**
CPC B29C 67/0055; B29C 67/0096
USPC 264/308, 401
See application file for complete search history.

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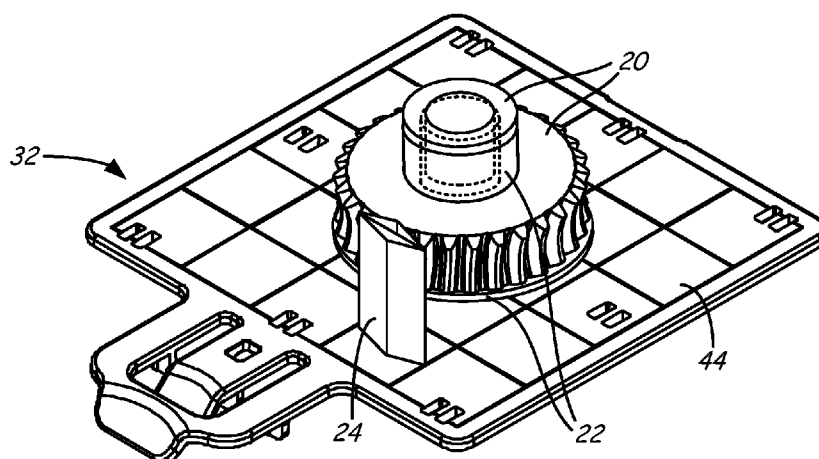
Primary Examiner — Robert J Grun

(74) *Attorney, Agent, or Firm* — Westman, Champlin &
Koehler, P.A.

(57) **ABSTRACT**

A method for printing a three-dimensional part with an
additive manufacturing system, the method including print-
ing layers of the three-dimensional part and of a support
structure for the three-dimensional part from multiple print
heads or deposition lines, and switching the print heads or
deposition line between stand-by modes and operating
modes in-between the printing of the layers of the three-
dimensional part and the support structure. The method also
includes performing a purge operation for each print head or
deposition line switched to the operating mode, where the
purge operation includes printing a layer of at least one
purge tower from the print head or deposition line switched
to the operating mode.

20 Claims, 7 Drawing Sheets



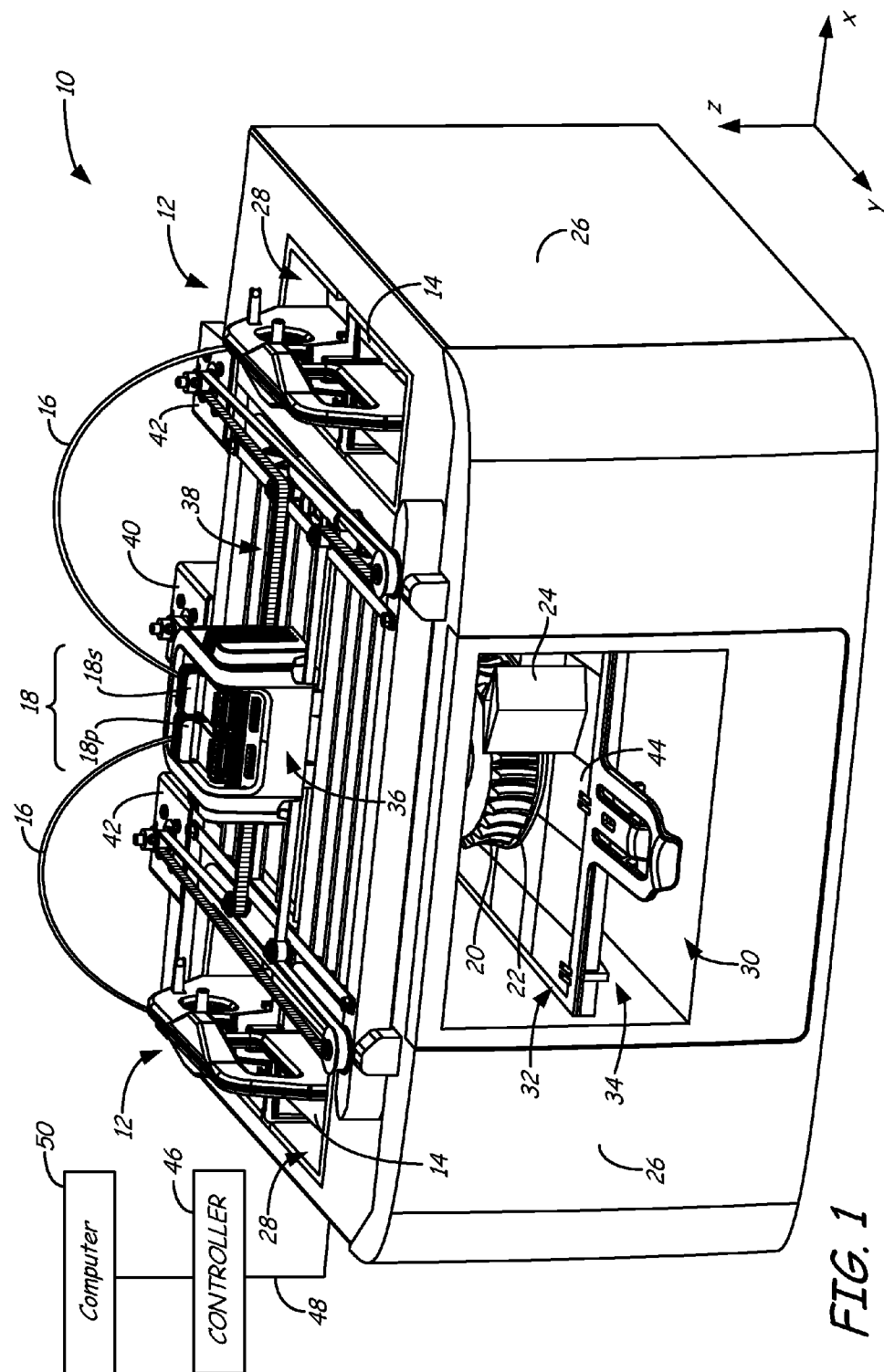
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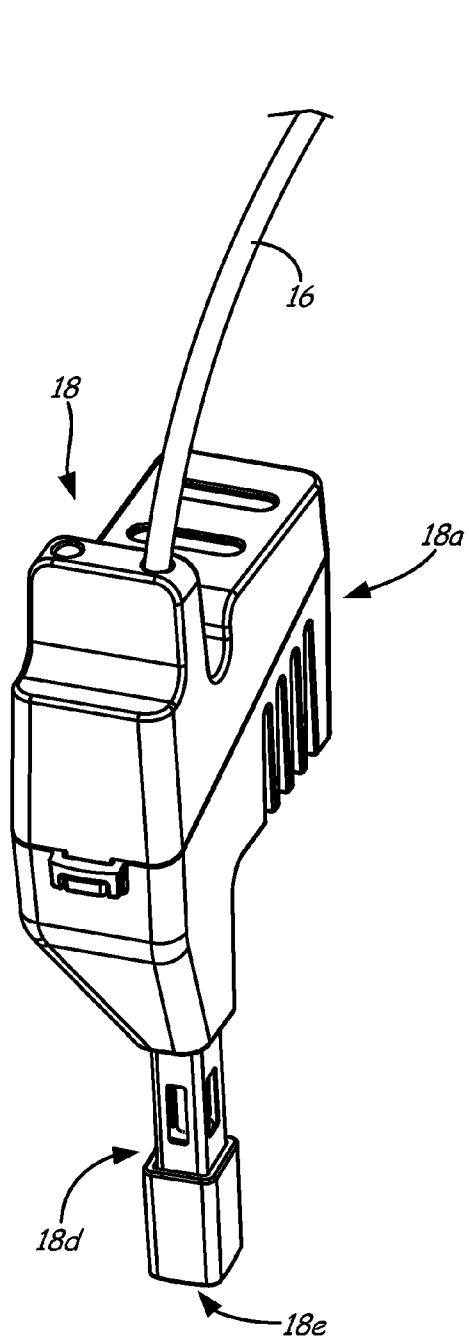


FIG. 2A

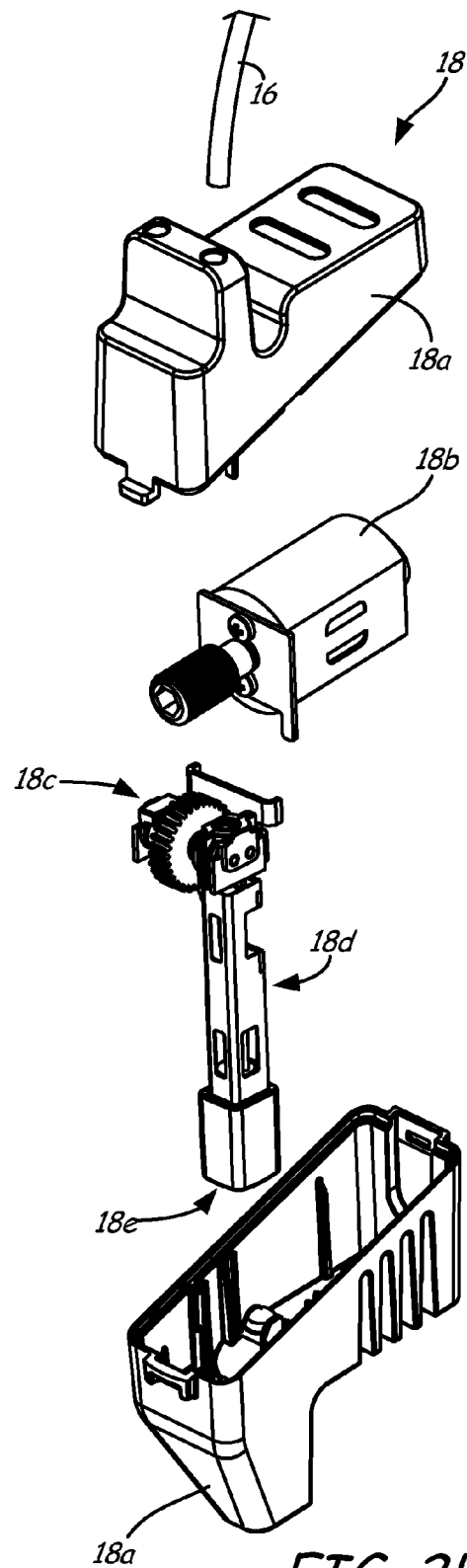


FIG. 2B

FIG. 3A

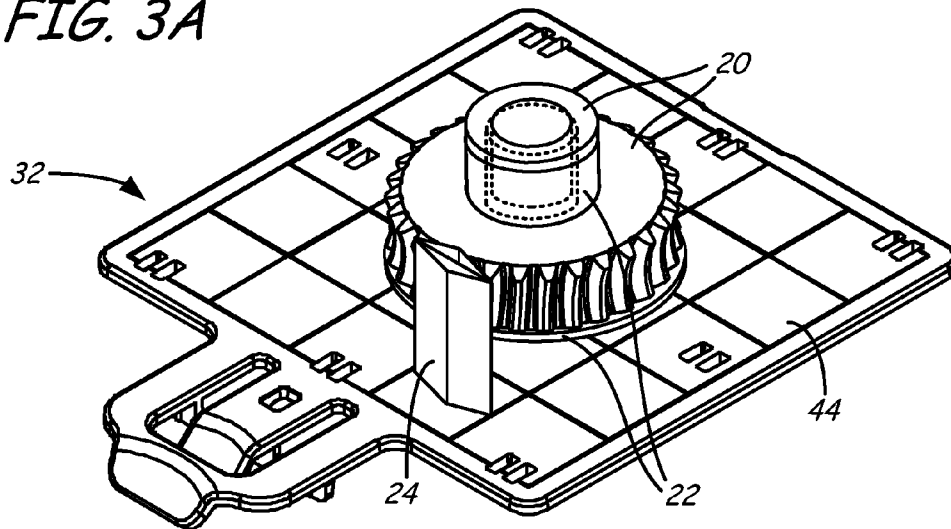
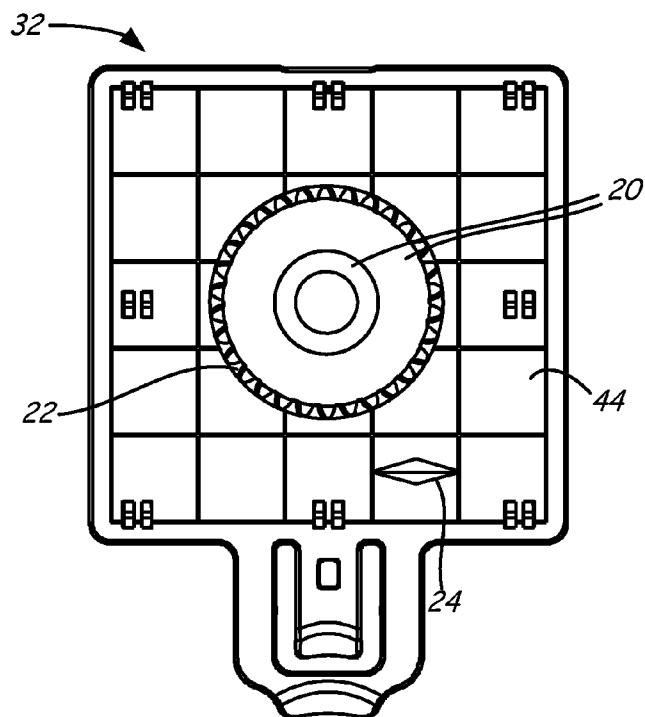
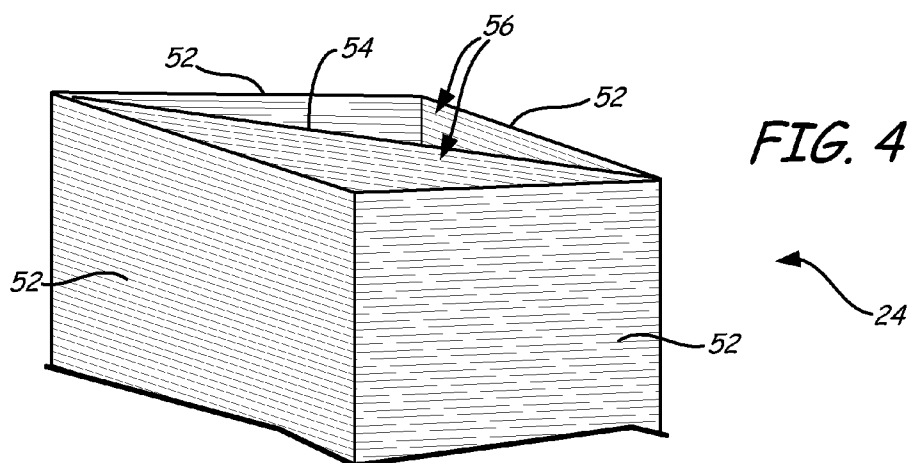
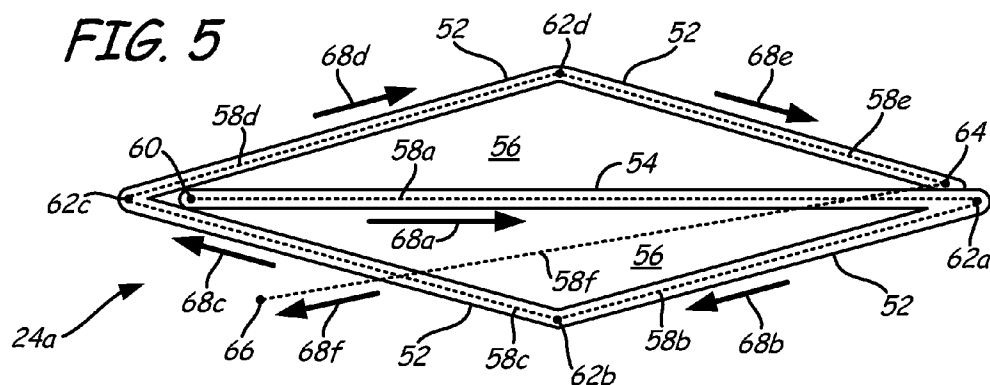
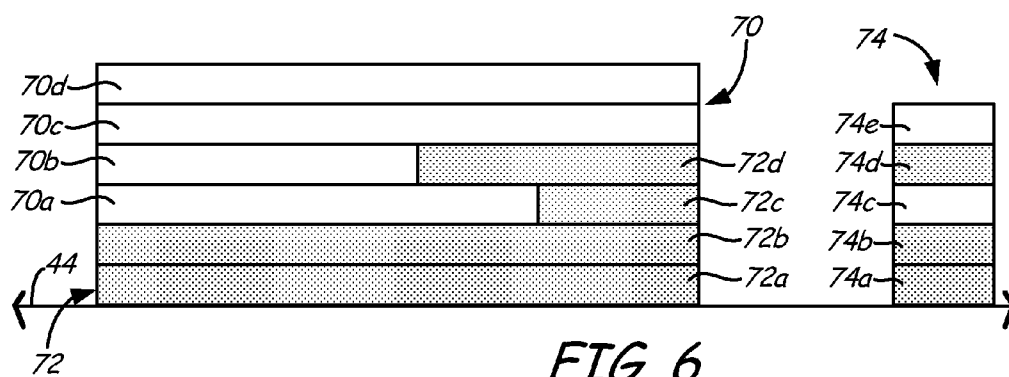


FIG. 3B



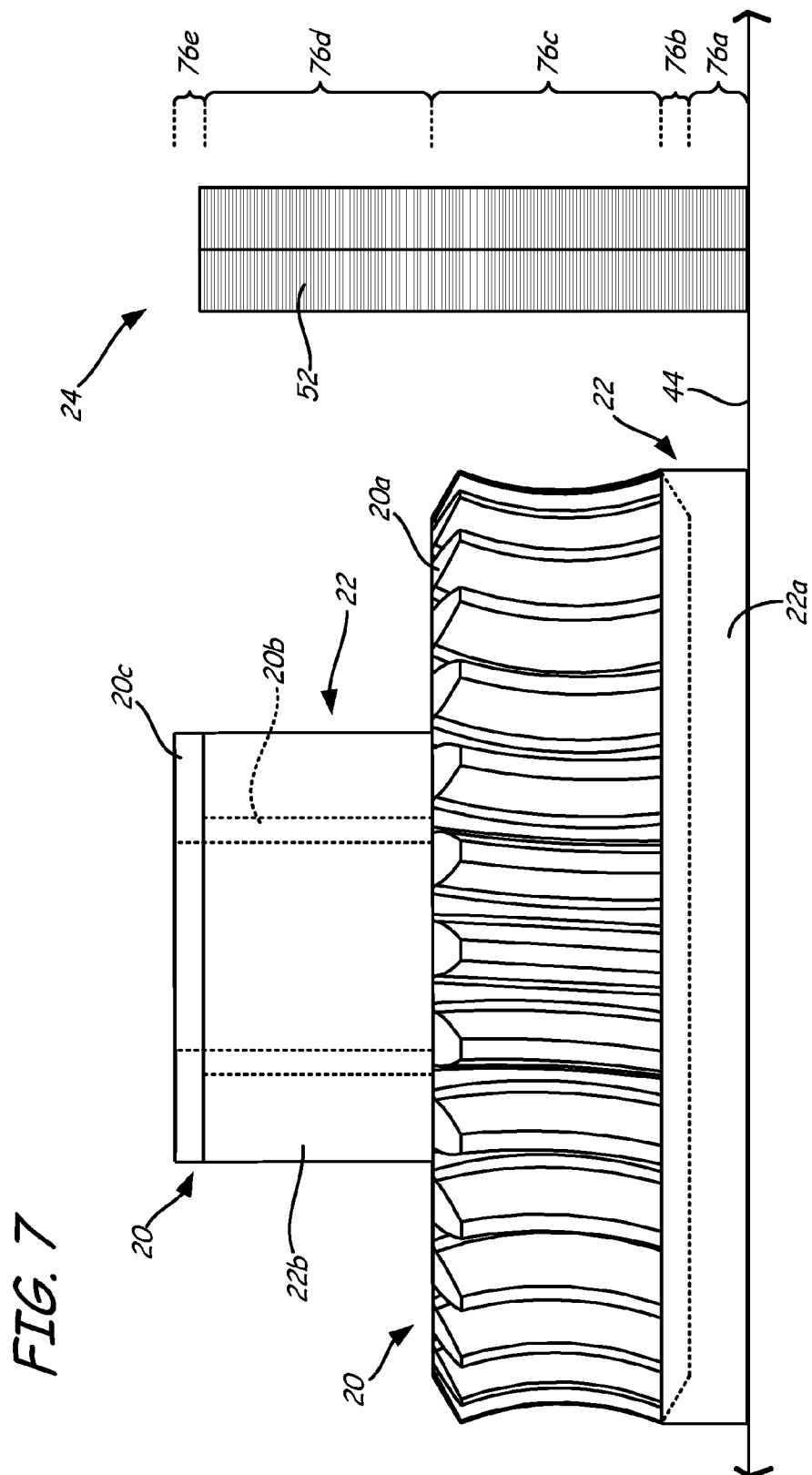


FIG. 8

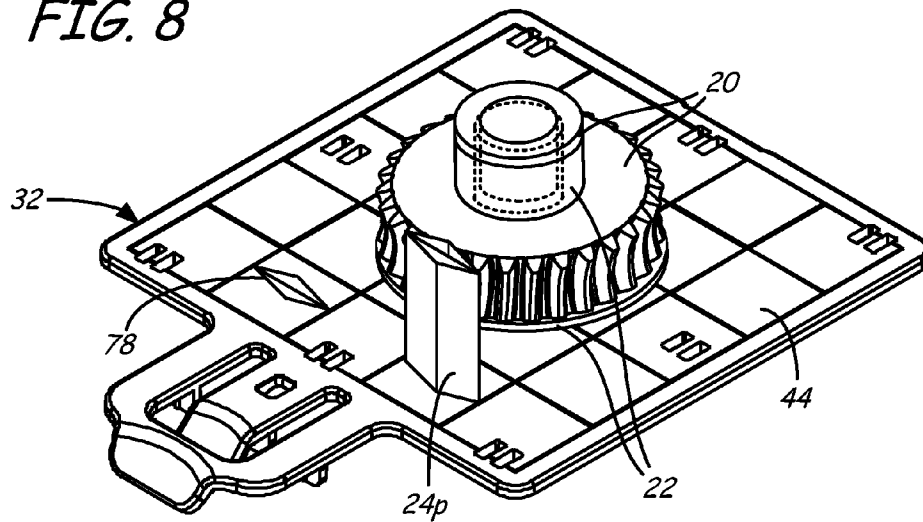
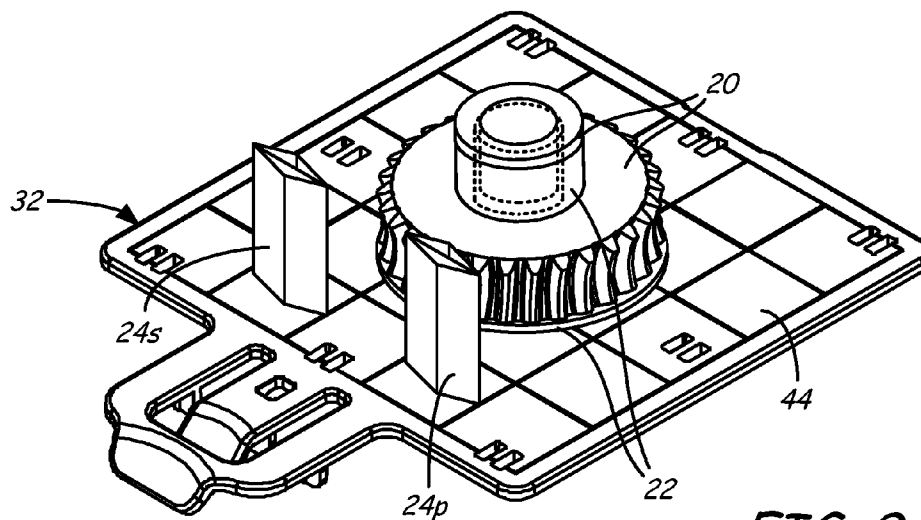
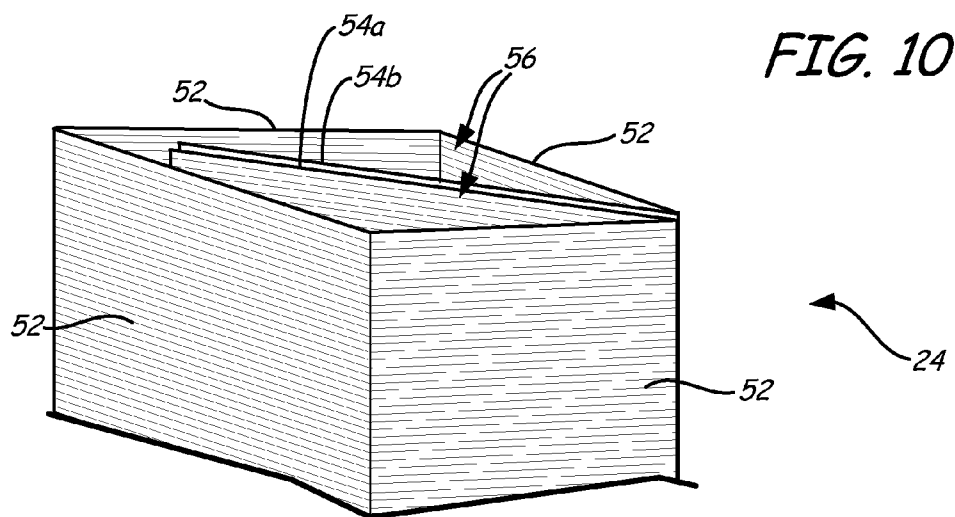
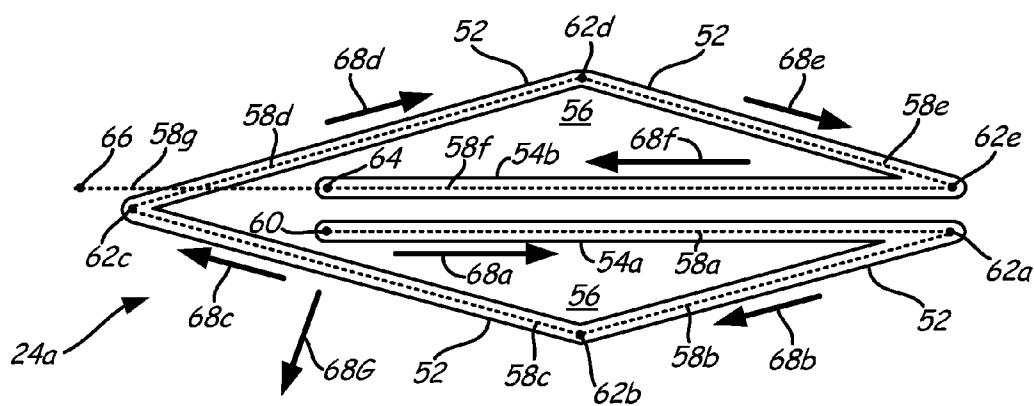


FIG. 9



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ADDITIVE MANUFACTURING METHOD FOR PRINTING THREE-DIMENSIONAL PARTS WITH PURGE TOWERS

BACKGROUND

The present disclosure relates to additive manufacturing systems for printing or otherwise building three-dimensional (3D) parts with layer-based, additive manufacturing techniques. In particular, the present disclosure relates to purge operation techniques for use in extrusion-based additive manufacturing systems.

Additive manufacturing systems are used to print or otherwise build 3D parts from digital representations of the 3D parts (e.g., AMF and STL format files) using one or more additive manufacturing techniques. Examples of commercially available additive manufacturing techniques include extrusion-based techniques, jetting, selective laser sintering, powder/binder jetting, electron-beam melting, and stereolithographic processes. For each of these techniques, the digital representation of the 3D part is initially sliced into multiple horizontal layers. For each sliced layer, a tool path is then generated, which provides instructions for the particular additive manufacturing system to print the given layer.

For example, in an extrusion-based additive manufacturing system, a 3D part may be printed from a digital representation of the 3D part in a layer-by-layer manner by extruding a flowable part material. The part material is extruded through an extrusion tip or nozzle carried by a print head of the system, and is deposited as a sequence of roads on a substrate in an x-y plane. The extruded part material fuses to previously deposited part material, and solidifies upon a drop in temperature. The position of the print head relative to the substrate is then incremented along a z-axis (perpendicular to the x-y plane), and the process is then repeated to form a 3D part resembling the digital representation.

In fabricating 3D parts by depositing layers of a part material, supporting layers or structures are typically built underneath overhanging portions or in cavities of 3D parts under construction, which are not supported by the part material itself. A support structure may be built utilizing the same deposition techniques by which the part material is deposited. The host computer generates additional geometry acting as a support structure for the overhanging or free-space segments of the 3D part being formed. Support material is then deposited from a second nozzle pursuant to the generated geometry during the printing process. The support material adheres to the part material during fabrication, and is removable from the completed 3D part when the printing process is complete.

SUMMARY

An aspect of the present disclosure is directed to a method for printing a 3D part with an additive manufacturing system. The method includes printing layers of the 3D part and of a support structure for the 3D part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique, and switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the 3D part and the support structure. The method also includes performing a purge operation for each print head or deposition line switched to the operating mode, where the purge

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operation includes printing a layer of at least one purge tower from the print head or deposition line switched to the operating mode.

Another aspect of the present disclosure is directed to a method for printing a 3D part with an additive manufacturing system, which includes bringing a first print head or deposition line from a stand-by mode to an operating mode, printing a first layer of a purge tower from a support material using the first print head or deposition line in the operating mode, and printing a layer of a support structure from the support material using the first print head in the operating mode after printing the first layer of the purge tower. The method also includes bringing a second print head or deposition line from a stand-by mode to an operating mode, printing a second layer of the purge tower from a part material using the second print head or deposition line in the operating mode, and printing a layer of the 3D part from the part material using the second print head in the operating mode after printing the second layer of the purge tower.

Another aspect of the present disclosure is directed to a method for printing a 3D part with an additive manufacturing system, which includes printing a first layer of a support structure for the 3D part, printing a first layer of a purge tower from a part material, and printing a first layer of the 3D part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower. The method also includes printing a second layer of the purge tower from the support material, and printing a second layer of the support structure on at least a portion of the first layer of the 3D part from the support structure after printing the second layer of the purge tower.

DEFINITIONS

Unless otherwise specified, the following terms as used herein have the meanings provided below:

The terms “preferred” and “preferably” refer to embodiments of the invention that may afford certain benefits, under certain circumstances. However, other embodiments may also be preferred, under the same or other circumstances. Furthermore, the recitation of one or more preferred embodiments does not imply that other embodiments are not useful, and is not intended to exclude other embodiments from the scope of the present disclosure.

Directional orientations such as “above”, “below”, “top”, “bottom”, and the like are made with reference to a layer-printing direction of a 3D part. In the embodiments shown below, the layer-printing direction is the upward direction along the vertical z-axis. In these embodiments, the terms “above”, “below”, “top”, “bottom”, and the like are based on the vertical z-axis. However, in embodiments in which the layers of 3D parts are printed along a different axis, such as along a horizontal x-axis or y-axis, the terms “above”, “below”, “top”, “bottom”, and the like are relative to the given axis.

The term “providing”, such as for “providing a print head”, when recited in the claims, is not intended to require any particular delivery or receipt of the provided item. Rather, the term “providing” is merely used to recite items that will be referred to in subsequent elements of the claim(s), for purposes of clarity and ease of readability.

The terms “about” and “substantially” are used herein with respect to measurable values and ranges due to

expected variations known to those skilled in the art (e.g., limitations and variabilities in measurements).

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a top, front perspective view of an additive manufacturing system in use with consumable assemblies for printing 3D parts, support structures, and a purge tower of the present disclosure.

FIG. 2A is a perspective view of a print head and guide tube for use with the additive manufacturing system.

FIG. 2B is an exploded perspective view of the print head.

FIG. 3A is a perspective view of a printed 3D part, support structure, and purge tower on a build substrate.

FIG. 3B is a top view of the printed 3D part, support structure, and purge tower on the build substrate.

FIG. 4 is a perspective view of a top portion of the purge tower.

FIG. 5 is a top view of a layer of the purge tower, illustrating a process for printing the layer.

FIG. 6 is a side view of simplified layers of a printed 3D part, support structure, and purge tower on a build substrate.

FIG. 7 is a side view of the printed 3D part, support structure, and purge tower on the build substrate.

FIG. 8 is a perspective view of a printed 3D part, support structure, purge tower, and a separate purge layer on a build substrate, which illustrates a first alternative purge tower embodiment.

FIG. 9 is a perspective view of a printed 3D part, support structure, and multiple purge towers on a build substrate, which illustrates a second alternative purge tower embodiment.

FIG. 10 is a perspective view of a top portion of a first alternative purge tower.

FIG. 11 is a top view of a layer of the first alternative purge tower, illustrating a process for printing the layer.

DETAILED DESCRIPTION

The present disclosure is directed to a method for printing 3D parts and support structures using an additive manufacturing system with the use of a purge tower (or multiple purge towers). As briefly mentioned above, in fabricating 3D parts by depositing layers of a part material, one or more support structures may be built underneath overhanging portions or in cavities of 3D parts under construction, which are not supported by the part material itself. The support structures are preferably printed from a support material that is removable from the associated 3D part after the printing operation is completed.

To accomplish this, the additive manufacturing system may utilize multiple print heads or deposition lines, where a first print head or deposition line may be used to print the 3D part, and a second material print head or deposition line may be used to print the support structure. For ease of discussion, the following disclosure is made with reference to separate print heads for printing 3D parts and support structures, referred to as a "part print head" and a "support print head". Examples of such part and support print heads include those disclosed in Swanson et al., U.S. Publication Nos. 2010/0283172 and 2012/0164256. However, the method of the present disclosure is equally applicable for use with a single deposition head having multiple deposition lines for printing 3D parts and support structures. Examples of such deposition heads include those disclosed in Leavitt, U.S. Pat. No. 7,625,200, and LaBossiere et al., U.S. Pat. No. 7,604,470.

When printing with multiple print heads (or multiple deposition lines), each print head or deposition line is preferably switchable between an "operating mode" and a "stand-by mode". The operating mode is preferably a mode in which a liquefier assembly of the print head is heated to its set point operating temperature(s) to generate a desired thermal gradient for melting the part or support material. In comparison, the stand-by mode is preferably a mode in which the liquefier assembly of the print head is cooled down from its operating mode to prevent its part or support material from thermally degrading, oozing or dripping out.

Additionally, in some embodiments, when switching between the operating mode and the stand-by mode, one or more of the print heads are may be lifted, pivoted, or otherwise moved relative to the build plane and/or each other, such as also disclosed in Leavitt, U.S. Pat. No. 7,625,200, LaBossiere et al., U.S. Pat. No. 7,604,470, and Swanson et al., U.S. Publication Nos. 2010/0283172 and 2012/0164256. For example, when switching from the operating mode to the stand-by mode, a print head may be lifted, pivoted, or otherwise moved away from the build plane by a small distance to prevent interference with the printed layers. Then, when subsequently switched back to its operating mode, the print head moved back to its original distance relative to the build plane for printing a subsequent layer.

Typically, when the part print head is in its operating mode to print a layer of the 3D part, the support print head is its stand-by mode, and vice versa. For example, after a 3D part layer is completed, the additive manufacturing system may then switch the print heads such that the support print head is brought to its operating mode to print a layer of the support structure, and the part print head is brought to its stand-by mode. Then, after the support structure layer is completed, the additive manufacturing system may switch the print heads back such that the part print head is brought to its operating mode to print a layer of the support structure, and the part print head is brought to its stand-by mode.

When each print head is brought to its operating mode, it preferably undergoes a purge operation prior to printing the next layer. As discussed in Turley et al., U.S. Pat. No. 7,744,364, a purge operation conventionally involves moving the given print head to a purge station, where it extrudes a strand of the part or support material into a purge bucket, optionally followed by a tip wipe operation.

This purge operation provides several desired functions. First, it frees any part or support material filament that may be adhered to the walls of the liquefier assembly, and verifies that the print head can extrude the part or support material. It also removes any entrained gases and degraded materials in the print head, and brings the print head to a known operating state for printing the subsequent layer, such as bringing a meniscus in the liquefier assembly to a substantially known position and raising the internal temperature of the liquefier assembly to a substantially steady-state condition. It also removes variable ooze that may hang from a nozzle of the liquefier assembly while the print head is idle or in its stand-by mode, and can account for variability of any voids in a tip pipe region of the nozzle. Additionally, for very low-volume-per-layer 3D parts, it may provide a minimum flow volume per layer to reduce the residence time-at-temperature for the part material.

However, the use of a purge station typically requires a sufficient amount of the part or support material to be extruded from the print head to have enough weight to fall away from the given print head and into a purge bucket. Furthermore, the purge station itself can take up a sizeable

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footprint in the additive manufacturing system, which may reduce the usable build volume for printing 3D parts. Moreover, the purge buckets periodically need to be emptied of the accumulate purged strands. This can inhibit the additive manufacturing system from functioning in a fully automated manner, such as in a printer farm.

As such, the method of the present disclosure is directed to a process in which the part and support print heads print a purge tower (or multiple purge towers) during the purge operations. As discussed below, the purge tower allows each print head to achieve the above-discussed desired functions of a purge operation without requiring the use of a separate purge station. This can increase the useable build volume in the additive manufacturing system, as well as reducing the amount of part and support materials consumed during the purge operations and allowing the additive manufacturing system to operate in a fully automated manner.

FIG. 1 shows system 10 in use with two consumable assemblies 12, which illustrates a suitable additive manufacturing system for performing the method of the present disclosure to print 3D parts and support structures along with one or more purge towers. Each consumable assembly 12 is an easily loadable, removable, and replaceable container device that retains a supply of a consumable filament for printing with system 10. Typically, one of the consumable assemblies 12 contains a part material filament ("part material consumable assembly"), and the other consumable assembly 12 contains a support material filament ("support material consumable assembly"). However, both consumable assemblies 12 may be identical in structure.

In the shown embodiment, each consumable assembly 12 includes container portion 14, guide tube 16, print heads 18, where print heads 18 are individually referred to as part print head 18_p (for the part material) and support print head 18_s (for the support material). Container portion 14 may retain a spool or coil of a consumable filament, such as discussed in Mannella et al., U.S. patent application Ser. Nos. 13/334,910 and 13/334,921. Guide tube 16 interconnects container portion 14 and print head 18, where a drive mechanism of print head 18 (or of system 10) draws successive segments of the consumable filament from container portion 14, through guide tube 16, to a liquefier assembly of the print head 18.

In this embodiment, guide tube 16 and print head 18 are subcomponents of consumable assembly 12, and may be interchanged to and from system 10 with each consumable assembly 12. In alternative embodiments, guide tube 16 and/or print head 18 may be components of system 10, rather than subcomponents of consumable assemblies 12.

Suitable part and support materials for consumable assemblies 12 include those disclosed and listed in Crump et al., U.S. Pat. No. 5,503,785; Lombardi et al., U.S. Pat. Nos. 6,070,107 and 6,228,923; Priedeman et al., U.S. Pat. No. 6,790,403; Comb et al., U.S. Pat. No. 7,122,246; Batchelder, U.S. Patent Application Publication No. 2009/0263582; Hopkins et al., U.S. Patent Application Publication No. 2010/0096072; Batchelder et al., U.S. Patent Application Publication No. 2011/0076496; and Batchelder et al., U.S. Patent Application Publication No. 2011/0076495.

System 10 is an additive manufacturing system for printing 3D parts or models and corresponding support structures (e.g., 3D part 20 and support structure 22) from the part and support material filaments, respectively, of consumable assemblies 12, using a layer-based, additive manufacturing technique. Additionally, as described further below, system 10 may also print purge tower 24 from the part and support materials during purge operations.

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Suitable additive manufacturing systems for system 10 include extrusion-based systems developed by Stratasys, Inc., Eden Prairie, Minn. under the trademarks "FDM" and "FUSED DEPOSITION MODELING". As shown, system 10 includes system casing 26, two bays 28, chamber 30, platen 32, platen gantry 34, head carriage 36, head gantry 38, z-axis motor 40, and a pair of x-y motors 42.

System casing 26 is a structural component of system 10 and may include multiple structural sub-components such as support frames, housing walls, and the like. In the shown embodiment, system casing 26 defines the dimensions of bays 28, and of chamber 30. Bays 28 are container bays configured to respectively receive container portions 14 of consumable assemblies 12. Typically, each of bays 28 may be intended to receive either a part material consumable assembly 12 or a support material consumable assembly 12.

In an alternative embodiment, bays 28 may be omitted to reduce the overall footprint of system 10. In this embodiment, container portions 14 may stand adjacent to system casing 26, while providing sufficient ranges of movement for guide tubes 16 and print heads 18. Bays 28, however, provide convenient locations for loading consumable assemblies 12.

Chamber 30 is an enclosed environment that contains platen 32 for printing 3D part 20 and support structure 22. Chamber 30 may be heated (e.g., with circulating heated air) to reduce the rate at which the part and support materials solidify after being extruded and deposited (e.g., to reduce distortions and curling). In alternative embodiments, chamber 30 may be omitted and/or replaced with different types of build environments. For example, 3D part 20 and support structure 22 may be built in a build environment that is open to ambient conditions or may be enclosed with alternative structures (e.g., flexible curtains).

Platen 32 is a platform on which 3D part 20, support structure 22, and purge tower 24 are printed in a layer-by-layer manner, and is supported by platen gantry 34. In some embodiments, platen 32 may engage and support a build substrate 44, which may be a tray substrate as disclosed in Dunn et al., U.S. Pat. No. 7,127,309, fabricated from plastic, corrugated cardboard, or other suitable material, and may also include a flexible polymeric film or liner, painter's tape, polyimide tape (e.g., under the trademark KAPTON from E.I. du Pont de Nemours and Company, Wilmington, Del.), or other disposable fabrication for adhering deposited material onto the platen 32 or onto the build substrate 44. Platen gantry 34 is a gantry assembly configured to move platen 32 along (or substantially along) the vertical z-axis and is powered by z-axis motor 40.

Head carriage 36 is a unit configured to receive one or more removable print heads, such as print heads 18, and is supported by head gantry 38. Examples of suitable devices for head carriage 36, and techniques for retaining print heads 18 in head carriage 36, include those disclosed in Swanson et al., U.S. Publication Nos. 2010/0283172 and 2012/0164256.

As mentioned above, in some embodiments, guide tube 16 and/or print head 18 may be components of system 10, rather than subcomponents of consumable assemblies 12. In these embodiments, additional examples of suitable devices for print heads 18, and the connections between print heads 18 and head gantry 38 include those disclosed in Crump et al., U.S. Pat. No. 5,503,785; Swanson et al., U.S. Pat. No. 6,004,124; LaBossiere, et al., U.S. Pat. Nos. 7,384,255 and 7,604,470; Batchelder et al., U.S. Pat. No. 7,896,209; and Comb et al., U.S. Pat. No. 8,153,182.

In the shown embodiment, head gantry **38** is a belt-driven gantry assembly configured to move head carriage **36** (and the retained print heads **18**) in (or substantially in) a horizontal x-y plane above chamber **30**, and is powered by x-y motors **42**. Examples of suitable gantry assemblies for head gantry **38** include those disclosed in Comb et al., U.S. patent Ser. No. 13/242,561.

In an alternative embodiment, platen **32** may be configured to move in the horizontal x-y plane within chamber **30**, and head carriage **36** (and print heads **18**) may be configured to move along the z-axis. Other similar arrangements may also be used such that one or both of platen **32** and print heads **18** are moveable relative to each other. Platen **32** and head carriage **36** (and print heads **18**) may also be oriented along different axes. For example, platen **32** may be oriented vertically and print heads **18** may print 3D part **20** and support structure **22** along the x-axis or the y-axis.

System **10** may also include a pair of sensor assemblies (not shown) configured to read encoded markings from successive segments of the consumable filaments moving through guide tubes **16**, such as disclosed in Batchelder et al., U.S. Patent Application Publication Nos. 2011/0117268, 2011/0121476, and 2011/0233804.

System **10** also includes controller **46**, which is one or more control circuits configured to monitor and operate the components of system **10**. For example, one or more of the control functions performed by controller **46** can be implemented in hardware, software, firmware, and the like, or a combination thereof. Controller **46** may communicate over communication line **48** with print heads **18**, chamber **30** (e.g., with a heating unit for chamber **30**), head carriage **36**, motors **40** and **42**, sensor assemblies **44**, and various sensors, calibration devices, display devices, and/or user input devices. In some embodiments, controller **46** may also communicate with one or more of bays **28**, platen **32**, platen gantry **34**, head gantry **38**, and any other suitable component of system **10**.

While illustrated as a single signal line, communication line **48** may include one or more electrical, optical, and/or wireless signal lines, allowing controller **46** to communicate with various components of system **10**. Furthermore, while illustrated outside of system **10**, controller **46** and communication line **48** may be internal components to system **10**. System **10** and/or controller **46** may also communicate with one or more computer-based systems, such as computer **50**, which may include computer-based hardware, such as data storage devices, processors, memory modules and the like for generating, storing, and transmitting tool path and related printing instructions to system **10**, and may be external and/or internal to system **10**. In some embodiments, controller **46** itself may perform one or more of the operations typically performed by computer **50** or other components of system **10**, such as generating and storing tool path and related printing instructions, perform compiler functions, and the like.

During operation, controller **46** may direct z-axis motor **40** and platen gantry **34** to move platen **32** to a predetermined height within chamber **30**. Controller **46** may then direct motors **42** and head gantry **38** to move head carriage **36** (and the retained print heads **18**) around in the horizontal x-y plane above chamber **30**. Controller **46** may also direct print heads **18** to selectively draw successive segments of the consumable filaments from container portions **14** and through guide tubes **16**, respectively.

FIGS. 2A and 2B illustrate an example print head **18**, which includes housing **18a**, motor assembly **18b**, drive mechanism **18c**, and liquefier assembly **18d**, where liquefier

assembly **18d** includes nozzle **18e**. At each print head **18**, motor assembly **18b** and drive mechanism **18c** feed successive segments of the consumable filament to liquefier assembly **18d**, which thermally melts the received successive segments such that the consumable filament becomes a molten material. The molten material is then extruded from nozzle **18e** and deposited onto platen **32** for printing 3D part **20**, support structure **22**, and purge tower **24** in a layer-by-layer manner.

As discussed in Swanson et al., U.S. patent application Ser. No. 13/587,002, nozzle **18e** may have an axial channel any suitable length-to-diameter ratio. For example, in some embodiments, nozzle **18e** may have an axial channel with a length-to-diameter ratio to generate high flow resistance, such as a ratio of about 2:1 to about 5:1. In other embodiments, nozzle **18e** may have an axial channel with a length-to-diameter ratio to generate lower flow resistance, such as a ratio less than about 1:1. Accordingly, suitable length-to-diameter ratios for the axial channel of nozzle **18e** may range from about 1:2 to about 5:1, where in some low-flow resistance embodiments, ratios ranging from about 1:2 to about 1:1 may be preferred for use with the method of the present disclosure.

After the print operation is complete, the resulting 3D part **32** and support structure **22** may be removed from chamber **30**, and support structure **22** may be removed from 3D part **20**. Purge tower **24** itself may be then recycled or otherwise discarded as desired. 3D part **20** may then undergo one or more additional post-processing steps.

As shown in FIG. 1, and further shown in FIGS. 3A and 3B, purge tower **24** may be printed at any suitable free location on build substrate **44** (i.e., at any location in the x-y build plane not occupied by 3D part **20** or support structure **22**). As discussed further below, each layer of purge tower **24** is printed by either the part material or by the support material depending on when print heads **18** switch between their operating modes and their stand-by modes and perform the purge operations.

As further shown in FIG. 4, purge tower **24** is printed in a layer-by-layer manner to define perimeter wall **52** and interior wall **54**, where perimeter wall **52** has a diamond-shaped cross-sectional geometry in the x-y build plane that defines interior volume **56**. Interior wall **54** resides inside interior volume **56**, and, in the shown embodiment, bisects or substantially bisects interior volume **56**. This is a particularly suitable geometry for printing purge tower **24** at fast print rates and with low amounts of materials since, for each layer, perimeter wall **52** and interior start wall **54** may be printed from a single tool path. This accordingly reduces delays and material consumption during the purge operations. However, in other embodiments, one or more of the layers of purge tower **24** may be printed with two or more tool paths.

In alternative embodiments, purge tower **24** may have any suitable perimeter wall geometry that preferably defines an interior volume that is substantially enclosed in the x-y build plane for retaining an interior wall **52**. Examples of suitable perimeter wall geometries include square walls, rectangular walls, circular walls, elliptical walls, and the like, where single-tool path, simple geometries are preferred for fast print rate purposes.

As shown in FIG. 5, each layer of purge tower **24** (referred to as layer **24a**) is preferably printed along the same tool path **58**, which has a start vertex **60**, corner vertices **62a-62d**, and stop vertex **64**, and tool path segments **58a-58d** extending therebetween. As mentioned above, controller **46** may direct one of print heads **18** to perform a purge operation by

printing a layer **24a** of purge tower **24** after the given print head **18** switches from its stand-by mode to its operating mode, and prior to printing a subsequent layer of 3D part **20** or support structure **22**.

When performing the purge operation, controller **46** may direct head gantry **36** to move the print head **18** over to start vertex **60**. Controller **46** may then direct a drive mechanism of the print head **18** to feed the part or support material filament to the print head **18** to extrude the part or support material. Controller **46** may also direct head gantry **36** to move the print head **18** along tool path segments **58a-58e** in the direction of arrows **68a-68e**. Upon reaching stop vertex **64**, controller **46** may direct the print head **18** to stop extruding the part or support material to complete layer **24a**.

This tool path pattern is beneficial for containing any excess stringing at the extrusion start up to a region within interior volume **56**. In other words, perimeter wall **52** prevents any stringing that may occur from exiting purge tower **24**, which could otherwise potentially interfere with the printing of 3D part **20** or support structure **22** due to the close proximity of purge tower **24** and 3D part **20** (compared to the offset locations of conventional purge stations).

The length of tool path segment **58a** between start vertex **60** and the first corner vertex **62a** may vary depending on the stringing conditions of the print head **18**, which may be based on multiple factors, such as the thermal properties of the print head **18**, the composition of the part or support material, the extrusion rate and movement rate of print head **18**, the temperature within chamber **30**, the amount of degraded materials and gases accumulated in the print head **18** during its stand-by mode, and the like. The lengths of tool path segments **58b-58e** may accordingly be based on the length of tool path segment **58a**.

Furthermore, while illustrated as extending entirely across interior volume **56**, tool path segment **58a** may alternatively be shorter, such that start vertex may be positioned at any suitable location relative to the first corner vertex **62a** to contain the excess stringing to a region within interior volume **56**. Overall, the entire length of tool path **58** is preferably sufficient such that the print head **18** attains a known operating state for printing the subsequent layer of 3D part **20** or support structure **22**, and more preferably such that print head **18** achieves all of the above-discussed desired functions of a purge operation (without requiring the use of a separate purge station).

Optionally, as shown, stop vertex **64** may alternatively function as another corner vertex, and tool path **58** may be directed across the top of layer **24a**, such as illustrated by tool path segment **58f** to a subsequent stop vertex **66** located outside of purge tower **24**. However, when following tool path segment **58f**, controller **46** preferably directs the print head **18** not to extrude any material. Instead, the movement of the print head along tool path segment **58f** (or any other similar tool path segment) allows nozzle **18e** of the print head **18** to wipe along perimeter wall **52** at tool path segment **58c**. As such, purge tower **24** may also function as a tip wipe device, which further precludes the need for a separate purge station.

As mentioned above, each layer **24a** of purge tower **24** is preferably printed along the same tool path **58**. However, in situations in which purge tower **24** will be printed high enough that its height is substantially greater than its cross-sectional area, it can be beneficial to print the lower layers **24a** of purge tower **24** with larger cross-sectional areas, with walls that slope or taper to small cross-sectional areas at the higher layers. This preferably prevents to the portion of

purge tower **24** from wobbling during the printing operation, which can otherwise impair the printing of subsequent layers.

Computer **50** (or controller **46**) may generate tool path instructions for printing purge tower **24** at any suitable time before and/or during the printing operation. In a first embodiment, purge tower **24** may be generated when slicing and generating supports for 3D part **20**. For example, upon receipt of a digital model for 3D part **20**, computer **50** may run a pre-processing program to slice 3D part **20** into the separate layers, generate support structure **22**, and generate tool paths for 3D part **20** and support structure **22**. Examples of suitable pre-processing programs includes those developed by Stratasys, Inc., Eden Prairie, Minn. under the trademarks "INSIGHT" and "CATALYST", which may be modified to generate the tool paths (e.g., tool path **58**) for each layer of purge tower **24**.

In a second embodiment, the tool paths for purge tower **24** may be post-processed into the previously-generated tool path instructions with a separate post-processing program (after running the pre-processing program). This post-processing program may be operated manually by a user, or may be invoked in an automated manner by the pre-processing program and/or controller **46**.

In a third embodiment, the tool paths for purge tower **24** may be compiled by computer **50** during the printing operation. In this embodiment, when system **10** is printing a given layer, computer **50** may look ahead at the generated tool path instructions and identify when the next material switch will occur. At this point, computer **50** may compile and insert a tool path (e.g., tool path **58**) for purge tower **24** in the timing sequence to occur after the next print head **18** switch. Preferably, computer **50** may also compute the amount of part or support material required to print the given layer of purge tower **24** to ensure that consumable assemblies **12** still have enough supplies of the part or support materials to complete the printing operation.

The particular material used for each layer **24a** depends on which print head **18** will be switched from its stand-by mode to its operating mode for the given layer of 3D part **20** and support structure **22**. This timing typically depends on when the tool paths for the layers of 3D part **20** and support structure **22** require material switching. For instance, FIG. 6 illustrates a simplified layer arrangement for a 3D part **70** and support structure **72** that may be printed with system **10**, where 3D part **70** is printed from part print head **18p** with part layers **70a-770d**, and support structure **72** is printed from support print head **18s** with support layers **72a-72d** (shown with speckle fill). In this example, print heads **18** may also print purge tower **74** from the part and support materials during the purge operations.

As shown, the first two printed layers **72a** and **72b** are for support structure **72**. As such, prior to printing support layer **72a** on build substrate **44**, support print head **18s** may be brought to its operating mode and undergo a purge operation by printing layer **74a** of purge tower **74** from the support material, preferably following the same tool path **58** discussed above for purge tower **24** (shown in FIG. 5). Support print head **18s** may then print support layer **72a** from the support material following designated tool paths. When support layer **72a** is completed, platen gantry **34** may lower platen **32** and build substrate **44** downward along the z-axis by a single layer increment.

Then, because support layer **72b** is also printed entirely from the support material, support print head **18s** may print support layer **72b** following designated tool paths, and then print layer **74b** of purge tower **74** from the support material.

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Alternatively, if desired, the tool path configuration may be arranged such that support print head 18s prints layer 74b prior to printing support layer 72b. Support layer 72b is necessary for maintaining purge tower 74 at the same height as the printed layers of 3D part 70 and support structure 72.

When layers 72b and 74b are completed, platen gantry 34 may then lower platen 32 and build substrate 44 downward along the z-axis by a single layer increment. As can be seen, layers 70a and 72c are coplanar with each other. As such, because support print head 18s is the current print head 18 in its operating mode (part print head 18p is currently in its stand-by mode), support layer 72c may be printed prior to part layer 70a. Accordingly, support print head 18s may print support layer 72c from the support material following designated tool paths.

Then, print heads 18 may be switched such that support print head 18s is brought to its stand-by mode and part print head 18p is brought to its operating mode. Part print head 18p may then undergo a purge operation by printing layer 74c of purge tower 74 from the part material, preferably following the same tool path 58 discussed above for purge tower 24. Part print head 18p may then print part layer 70a from the part material following designated tool paths. When part layer 70a is completed, platen gantry 34 may lower platen 32 and build substrate 44 downward along the z-axis by a single layer increment.

The next layers 70b and 72d are also coplanar with each other. As such, because part print head 18p is the current print head 18 in its operating mode (support print head 18s is currently in its stand-by mode), part layer 70b may be printed prior to support layer 72d. Accordingly, part print head 18p may print part layer 70b from the part material following designated tool paths.

Then, print heads 18 may be switched back such that part print head 18p is brought to its stand-by mode and support print head 18s is brought to its operating mode. Support print head 18s may then undergo a purge operation by printing layer 74d of purge tower 74 from the support material. Support print head 18s may then print support layer 72d from the support material following designated tool paths. When support layer 72d is completed, platen gantry 34 may lower platen 32 and build substrate 44 downward along the z-axis by a single layer increment.

Then, because support layer 70c is printed entirely from the part material, and because support print head 18s is the current print head 18 in its operating mode, print heads 18 may be switched such that support print head 18s is brought to its stand-by mode and part print head 18p is brought to its operating mode. Part print head 18p may then undergo a purge operation by printing layer 74e of purge tower 74 from the part material. Part print head 18p may then print part layer 70c from the part material following designated tool paths. When part layer 70a is completed, platen gantry 34 may lower platen 32 and build substrate 44 downward along the z-axis by a single layer increment.

Then, because part layer 70d is also printed entirely from the part material, and because part print head 18p is the current print head 18 in its operating mode, print head 18p may print part layer 70d following designated tool paths. At this point, because there are no further layers of support structure 72, there will be no further switching between operating and stand-by modes for print heads 18. In particular, purge tower 70 can be stopped at the highest layer at which there is a material change (i.e., a switch from part to support material, or vice versa). Accordingly, additional layers for purge tower 24 are no longer necessary, and may be omitted. On the other hand, if additional support layers

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for support structure 72 are to be subsequently printed, additional layers of purge tower may be printed from the part material with each layer of 3D part 70 until the next print head switching and purge operation is required.

FIG. 7 illustrates a suitable example for printing 3D part 20, support structure 22, and purge tower 24 in the same manner, where 3D part 20 has a base portion 20a, a shaft portion 20b, and an overhanging top portion 20c. Similarly, support structure 22 has an anchor portion 22a that supports and anchors base portion 20a to build substrate 44, and an upper portion 22b that supports overhanging top portion 20c and encapsulates shaft portion 20b.

As further shown, the layers of 3D part 20 and support structure 22 may be grouped into stack regions 76a-76e. At stack region 76a, the layers only include the support material for anchor portion 22a. Above that, at stack region 76b, each layer includes the part material for base portion 20a and the support material for anchor portion 22a. Then, at stack region 76c, the layers only include the part material for base portion 20a. Above that, at stack region 76d, each layer includes the part material for shaft portion 20b and the support material for upper portion 22b. Finally, at stack region 76e, the layers only include the part material for overhanging top portion 20c.

As discussed above for purge tower 74 (shown in FIG. 6), the layers of purge tower 24 may also stagger and interlace between the part and support materials in patterns that are based on the layer patterns of stack regions 76a-76e. For example, prior to printing the layers for anchor portion 22a of support structure 22, support print head 18s may switch to its operating mode and perform a purge operation by printing a first layer of purge tower 24 onto build substrate 44 from the support material. Support print head 18s may then print the first layer of anchor portion 22a onto build substrate 44 from the support material.

The printing of purge tower 24 and anchor portion 22a may then be repeated for each layer in stack region 76a, where platen gantry 32 may incrementally lower platen 30 and platen substrate 44 downward by a single layer increment between each printed layer. As such, the layers of purge tower 24 at stack region 76a may be printed entirely from the support material, and purge tower 24 preferably has the same height as the printed layers of anchor portion 22a.

After the last layer in stack region 76a is completed, and platen gantry 32 lowers platen 30 and platen substrate 44 downward by a single layer increment, the situation changes because the next layer increment (i.e., the first layer in stack region 76b) includes a layer of base portion 20a (i.e., part material) and a layer of anchor portion 22a (i.e., support material). As such, because support print head 18s is the current print head 18 in its operating mode, support print head 18s may print the layer of anchor portion 22a from the support material. Print heads 18 may then be switched such that support print head 18s is brought to its stand-by mode and part print head 18p is brought to its operating mode. Part print head 18p may then undergo a purge operation by printing the next layer of purge tower 24 from the part material, and then print the layer for base portion 20a.

After the current layer is completed, platen gantry 32 may lower platen 30 and platen substrate 44 downward by a single layer increment, and part print head 18p may print the next layer of base portion 20a from the part material. Print heads 18 may then be switched such that part print head 18p is brought to its stand-by mode and support print head 18s is brought to its operating mode. Support print head 18s may

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then undergo a purge operation by printing the next layer of purge tower 24 from the support material, and then print the layer for anchor portion 22a.

This back-and-forth switching may then be repeated for each layer in stack region 76b following the same pattern as discussed above for part layers 70a and 70b, support layers 72c and 72d (shown in FIG. 6), and purge tower layers 74c and 74d. As such, for stack region 76b, the layers of purge tower 24 have an interlaced pattern that switches back and forth between the part material and the support material on a layer-by-layer basis.

After the last layer in stack region 76b is completed, and platen gantry 32 lowers platen 30 and platen substrate 44 downward by a single layer increment, the situation changes again because the next layer (i.e., the first layer in stack region 76c) includes only the part material for base portion 20a. As such, if support print head 18s is currently the print head 18 in its operating mode, print heads 18 may be switched such that support print head 18s is brought to its stand-by mode and part print head 18p is brought to its operating mode. Part print head 18p undergo a purge operation by printing the next layer of purge tower 24 from the part material.

Alternatively, if part print head 18p is currently the print head 18 in its operating mode, it may remain in its operating mode, and print the next layer of purge tower 24 from the part material to maintain the height of purge tower 24. Part print head 18p may then print each successive layer of base portion 20a and purge tower 24 in stack region 76c from the part material, where platen gantry 32 may incrementally lower platen 30 and platen substrate 44 downward by a single layer increment between each printed layer. As such, the layers of purge tower 24 at stack region 76c may be printed entirely from the part material, and purge tower 24 preferably has the same height as the printed layers of base portion 20a.

After the last layer in stack region 76c is completed, and platen gantry 32 lowers platen 30 and platen substrate 44 downward by a single layer increment, the situation changes again because the next layer (i.e., the first layer in stack region 76d) includes a layer of shaft portion 20b (i.e., part material) and a layer of upper portion 22b (i.e., support material). As such, because part print head 18p is the current print head 18 in its operating mode at this point, part print head 18p may print the first layer of shaft portion 22b from the part material.

Print heads 18 may then be switched such that part print head 18p is brought to its stand-by mode and support print head 18s is brought to its operating mode. Support print head 18s may then undergo a purge operation by printing the next layer of purge tower 24 from the support material, and then print the first layer for upper portion 22b. The same back-and-forth switching as discussed above for stack region 76b may then be repeated for each layer in stack region 76d. As such, for stack region 76d, the layers of purge tower 24 have an interlaced pattern that switches back and forth between the part material and the support material on a layer-by-layer basis.

After the last layer in stack region 76b is completed, and platen gantry 32 lowers platen 30 and platen substrate 44 downward by a single layer increment, the situation changes again because the next layer (i.e., the first layer in stack region 76e) includes only the part material for overhanging top 20c. As such, if support print head 18s is currently the print head 18 in its operating mode, print heads 18 may be switched such that support print head 18s is brought to its stand-by mode and part print head 18p is brought to its

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operating mode. Part print head 18p undergo a purge operation by printing the next layer of purge tower 24 from the part material.

Alternatively, if part print head 18p is currently the print head 18 in its operating mode, it may remain in its operating mode, and print the next layer of purge tower 24 from the part material to maintain the height of purge tower 24. Part print head 18p may then print each successive layer of overhanging top in stack region 76e from the part material, where platen gantry 32 may incrementally lower platen 30 and platen substrate 44 downward by a single layer increment between each printed layer.

At this point, because there are no subsequent layers of support structure 22, no additional layers of purge tower 24 are required, as shown. As mentioned above, purge tower 24 can be stopped at the highest layer at which there is a material change (i.e., a switch from part to support material, or vice versa). As such, at stack region 76e, purge tower only requires a single part material layer if part print head 18p was required to be switched to its operating mode for a purge operation. Otherwise, subsequent layers of purge tower 24 may be omitted to reduce material consumption and printing time.

As discussed above, 3D part 20 is preferably printed on one or more layers of support structure 22 (i.e., anchor portion 22a) to anchor 3D part 20 to build substrate 44. This can assist in reducing curl in 3D part 20 during the printing operation. However, alternative printing instructions may produce a situation where the first layer to be printed on build substrate 44 includes tool paths for the 3D part (i.e., part material) and tool paths for the support structure (i.e., support material). In this case, two purge operations will be required for printing the first layer.

However, because purge tower 24 needs to grow at the same layer rate as the 3D part/support structure, both purge operations cannot be stacked at purge tower 24. Instead, as shown in FIG. 8, one of the purge operations will require a second tool path location (as a single layer 78) laterally adjacent to the first layer of purge tower 24. The remaining purge operations may then be printed on top of the first layer of purge tower 24.

Alternatively, as shown in FIG. 9, two or more grown purge towers (referred to purge towers 24p and 24s) may be used. In this embodiment, purge tower 24p may be printed entirely from the part material, and purge tower 24s may be printed entirely from the support material. As such, for each layer of 3D part 20 and/or support structure 22, a layer of part material is printed for purge tower 24p and a layer of support material is printed for purge tower 24s. As can be appreciated, this embodiment is less preferred to that shown above with the integrated part/support material purge tower 24, but may function as a usable alternative for performing purge operations.

FIGS. 10 and 11 illustrate an alternative embodiment for purge tower 24, which includes a pair of interior walls 54a and 54b in lieu of a single interior wall 54. As shown in FIG. 11, each layer of this embodiment purge tower 24 may be printed with tool path 58, starting at start vertex 60, and printing a road of part or support material that follows tool path segments 58a-58f and around corner vertices 62a-62e, until stop vertex 64 is reached. As such, in this embodiment, both the start vertex 60 and the stop vertex 64 are located within interior volume 56.

This is beneficial for containing any excess stringing that may occur after the extrusion is stopped to the region within interior volume 56, along with any excess stringing that may occur at the start point, as discussed above. In this embodi-

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ment, stop vertex **64** may also optionally function as another corner vertex, and tool path **58** may be directed across the top of layer **24a**, as illustrated by tool path segment **58g** to a subsequent stop vertex **66** located outside of purge tower **24** to wipe nozzle **18e** of the print head **18** to wipe along perimeter wall **52** at tool path segment **58d** (or any other suitable location along perimeter wall **52**). As such, in this embodiment, purge tower **24** may also function as a tip wipe device, which further precludes the need for a separate purge station.

In some embodiments, system **10** may be operated in a continuous-build manner utilizing scaffolds, such as disclosed in Crump et al., U.S. patent application Ser. No. 13/587,009; Swanson et al., U.S. patent application Ser. No. 13/587,012; and Mannella, U.S. patent application Ser. No. 13/587,015. In these embodiments, separate purge towers **24** may be used with each subsequent 3D part, and may be formed on starter wedges along with each subsequent 3D part.

Accordingly, the method of the present disclosure for performing purge operations by printing one or more purge towers (e.g., purge towers **24** and **74**) is beneficial for achieving the above-discussed desired functions of a purge operation without requiring the use of separate purge stations. Additionally, because the purge towers (e.g., purge towers **24** and **74**) are generated as 3D parts/support structures, they may be implemented entirely by software/firmware changes to controller **46** and/or computer **50** rather than with hardware changes. As such, the above-discussed method may be readily retrofitted into existing additive manufacturing systems for immediate use. This is particularly useful for establishing printing farms of additive manufacturing systems, which may require full automation of the systems to print numerous 3D parts over extended durations (e.g., over days, weeks, or months).

Although the present disclosure has been described with reference to preferred embodiments, workers skilled in the art will recognize that changes may be made in form and detail without departing from the spirit and scope of the disclosure.

The invention claimed is:

1. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:
 - printing layers of the three-dimensional part and of a support structure for the three-dimensional part from multiple print heads or deposition lines using a layer-based, additive manufacturing technique;
 - switching the print heads or deposition line between stand-by modes and operating modes in-between the printing of the layers of the three-dimensional part and the support structure;
 - performing a purge operation for each print head or deposition line switched to the operating mode, the purge operation comprising printing at least one purge tower in a layer-by-layer manner, wherein the layers of the at least one purge tower are printed from the print head or deposition line switched to the operating mode.
2. The method of claim 1, wherein the multiple print heads or deposition lines comprise a first deposition line and a second deposition line, and wherein switching the deposition lines between the stand-by modes and the operating modes comprises:
 - switching the first deposition line from the stand-by mode to the operating mode; and
 - switching the second deposition line from the operating mode to the stand-by mode.

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3. The method of claim 1, wherein the multiple print heads or deposition lines comprise a first print head and a second print head, and wherein switching the print heads between the stand-by modes and the operating modes comprises:
 - switching the first print head from the stand-by mode to the operating mode; and
 - switching the second print head from the operating mode to the stand-by mode.

4. The method of claim 1, wherein printing the layer of the at least one purge tower comprises:
 - printing along a first tool path segment between a start vertex and a first corner vertex;
 - printing along one or more additional tool path segments from the first corner vertex to a stop vertex, which at least partially encases the first tool path segment in a build plane.

5. The method of claim 1, wherein the at least one purge tower has a cross-sectional area that reduces in height along an axis that is perpendicular to a build plane.

6. The method of claim 1, wherein the at least one purge tower is stopped at a highest layer at which there is a material change for the printed layers of the three-dimensional part and support structure.

7. The method of claim 1, and further comprising:
 - generating tool path instructions for printing the layers of the three-dimensional part and of the support structure; and
 - generating tool path instructions for printing the layer of the at least one purge tower.

8. The method of claim 7, wherein the generating of the tool path instructions for printing the layer of the at least one purge tower is performed after printing a portion of the layers of the three-dimensional part, after printing a portion of the layers of the support structure, or both.

9. The method of claim 7, wherein the generating of the tool path instructions for printing the layer of the at least one purge tower is performed prior to printing the layers of the three-dimensional part and of the support structure.

10. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising:

- bringing a first print head or deposition line from a stand-by mode to an operating mode;
- printing a first layer of a purge tower printed in a layer-by-layer manner from a support material using the first print head or deposition line in the operating mode;
- printing a layer of a support structure from the support material using the first print head in the operating mode after printing the first layer of the purge tower;
- bringing a second print head or deposition line from a stand-by mode to an operating mode;
- printing a second layer of the purge tower from a part material using the second print head or deposition line in the operating mode; and
- printing a layer of the three-dimensional part from the part material using the second print head in the operating mode after printing the second layer of the purge tower.

11. The method of claim 10, wherein bringing the first print head or deposition line from the stand-by mode to the operating mode comprises heating a liquefier assembly of the first print head or deposition line.

12. The method of claim 10, and further comprising:
 - bringing the first print head or deposition line from the operating mode to the stand-by mode while bringing the second print head or deposition line from the stand-by mode to the operating mode;

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bringing the first print head or deposition line back from the stand-by mode to the operating mode;
 printing a third layer of a purge tower from the support material using the first print head or deposition line brought back to the operating mode;
 printing a layer of the support structure from the support material using the first print head brought back to the operating mode after printing the third layer of the purge tower.

13. The method of claim **10**, and further comprising printing additional layers of the purge tower such that the purge tower maintains the same height perpendicular to a build plane the printed layers of the three-dimensional part and support structure.

14. The method of claim **10**, wherein printing the first layer and the second layer of the one purge tower each comprises:

printing along a first tool path segment between a start vertex and a first corner vertex;

printing along one or more additional tool path segments from the first corner vertex to a stop vertex, which at least partially encases the first tool path segment in a build plane.

15. The method of claim **14**, wherein the one or more additional tool path segments define a diamond-shaped pattern in the build plane.

16. A method for printing a three-dimensional part with an additive manufacturing system, the method comprising: (a)

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printing a first layer of a support structure from a support material for the three-dimensional part; (b) printing a first layer of a purge tower from a part material; (c) printing a first layer of the three-dimensional part on at least a portion of the first layer of the support structure from the part material after printing the first layer of the purge tower; (d) printing a second layer of the purge tower from the support material; and (e) printing a second layer of the support structure on at least a portion of the first layer of the three-dimensional part from the support material after printing the second layer of the purge tower.

17. The method of claim **16**, and further comprising repeating steps (b)-(e) for at least a portion of the three-dimensional part and support structure.

18. The method of claim **17**, wherein at least a portion of the layers of the purge tower are interlaced between the part material and the support material on a layer-by-layer basis.

19. The method of claim **16**, wherein the purge tower comprises a perimeter wall and an interior wall printed from a single tool path, wherein for each printed layer of the purge tower, the interior wall is printed prior to the printing of the perimeter wall.

20. The method of claim **19**, wherein the perimeter wall defines a diamond-shape cross-sectional geometry in a build plane.

* * * * *

EXHIBIT E

76 Information on

General

Machine typeFortus 400mc Large

Extruder index1

MaterialABS-M30

Colornot specified

Tip sizeT12

Volume4.274194

Slice height0.0070

Number of slices607

System modenone

Part build stylenone

Shrink factor (X Y Z)1.0000001.0000001.000000

☐ Has variable width

☐ CMB locked

User name

Embedded version

System Serial#

Internals

CommentPacked file written by Control Center!!!

Pack listpurge_part+support-11

Versions8.1 (4255)8.9

GUID

Limits

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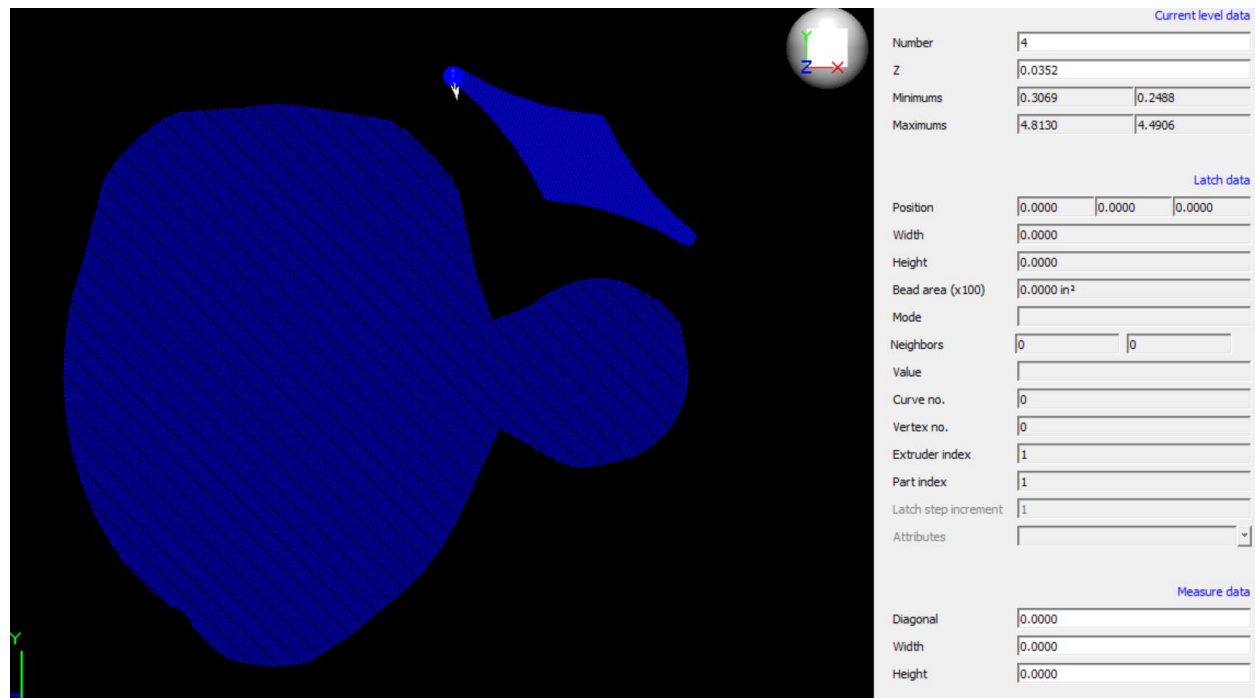
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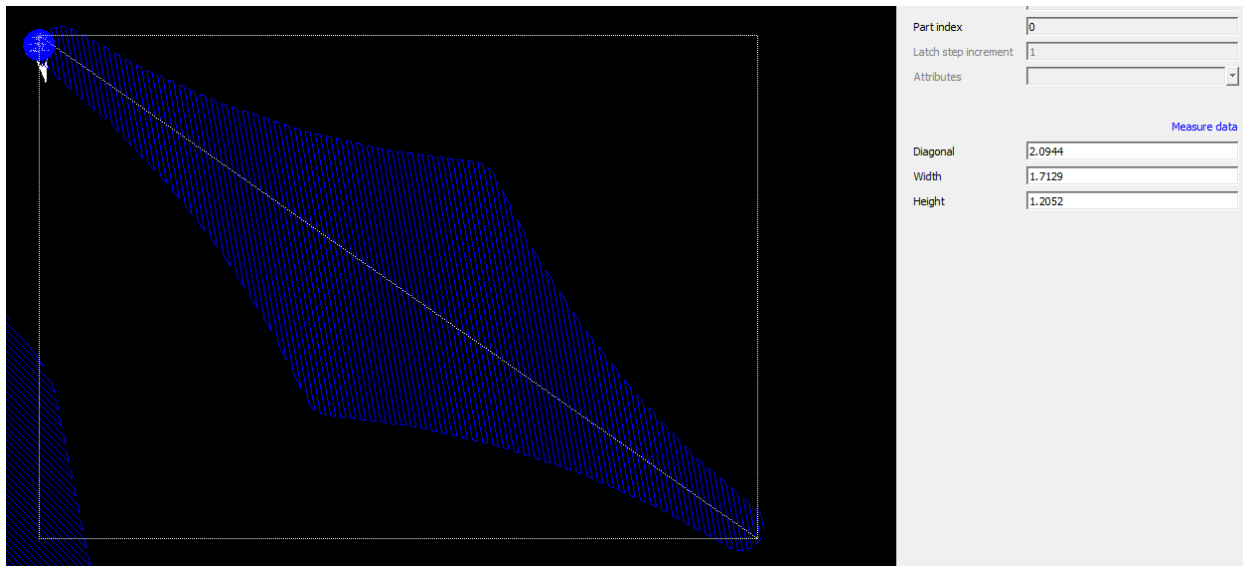
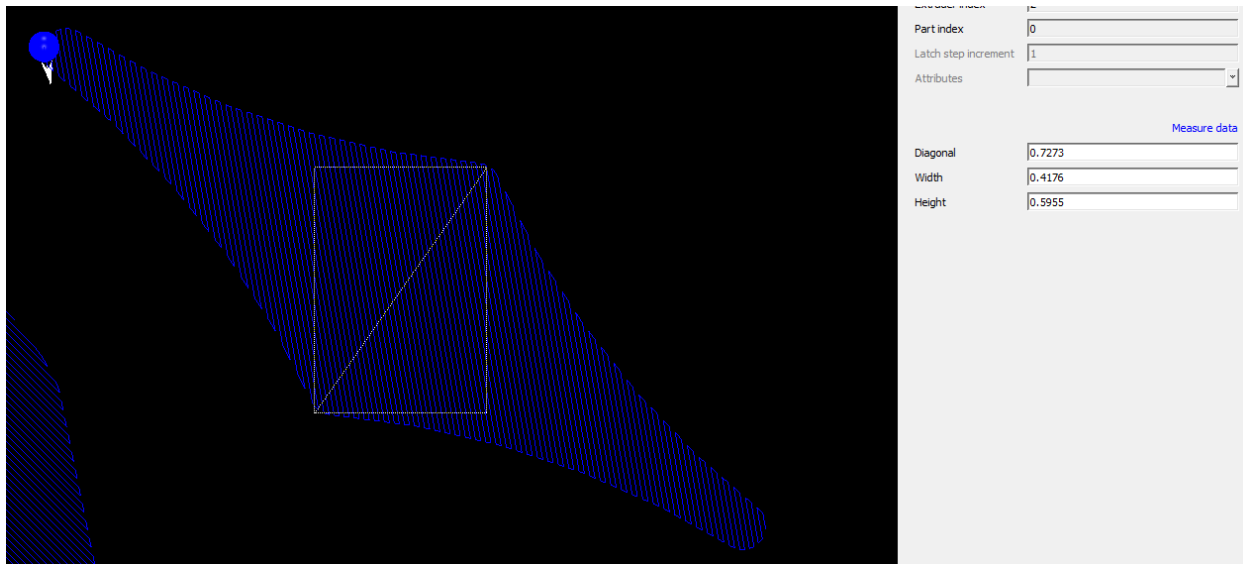
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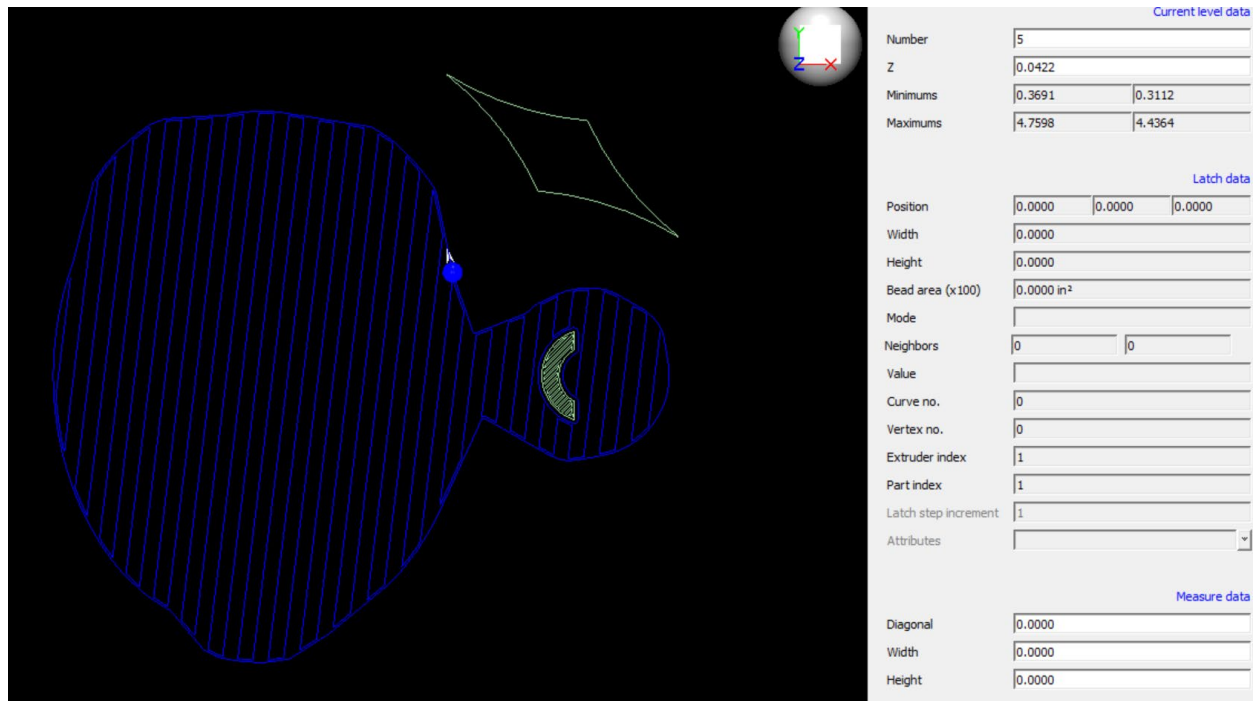
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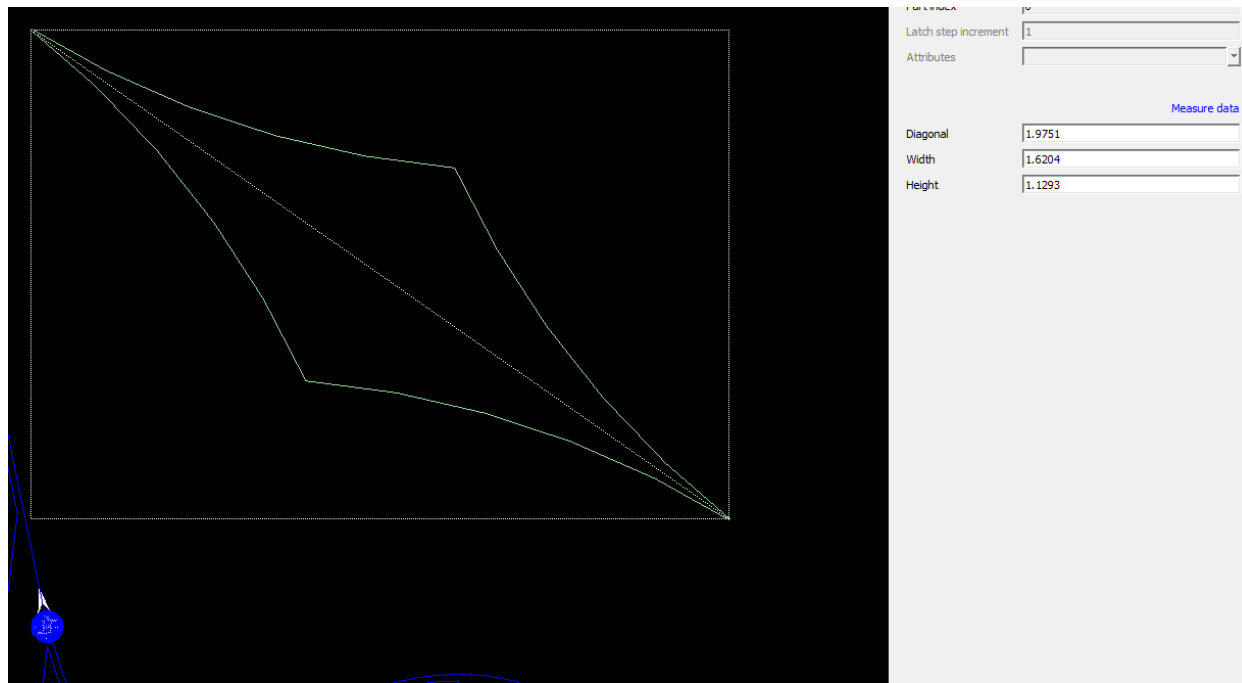
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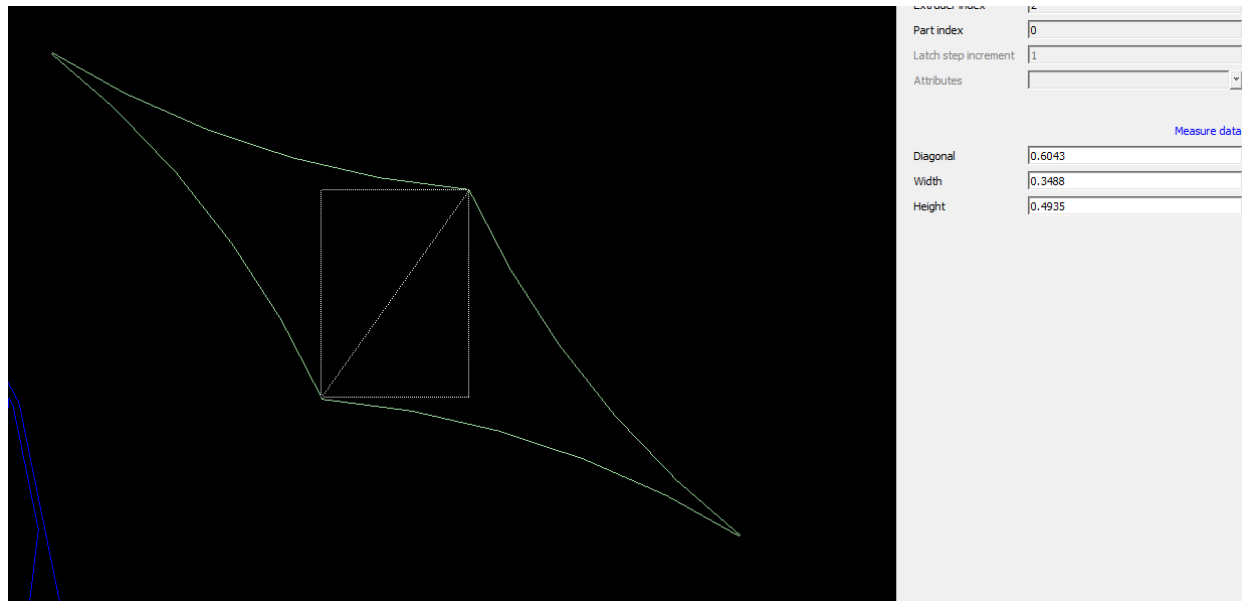
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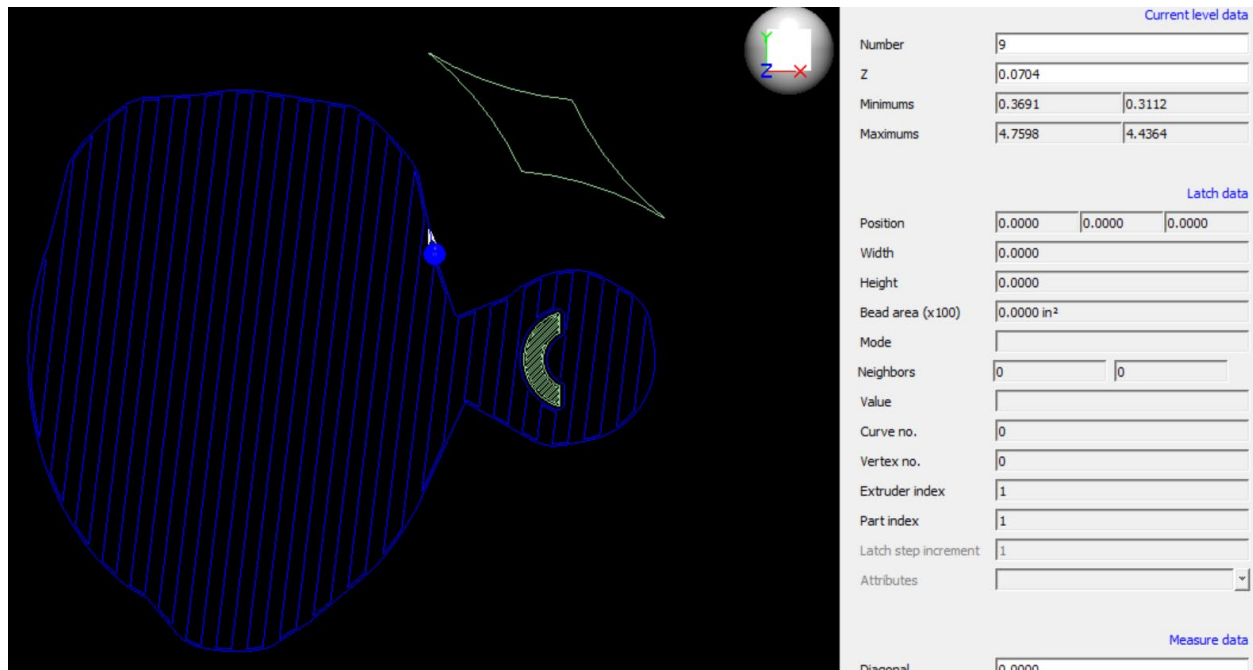


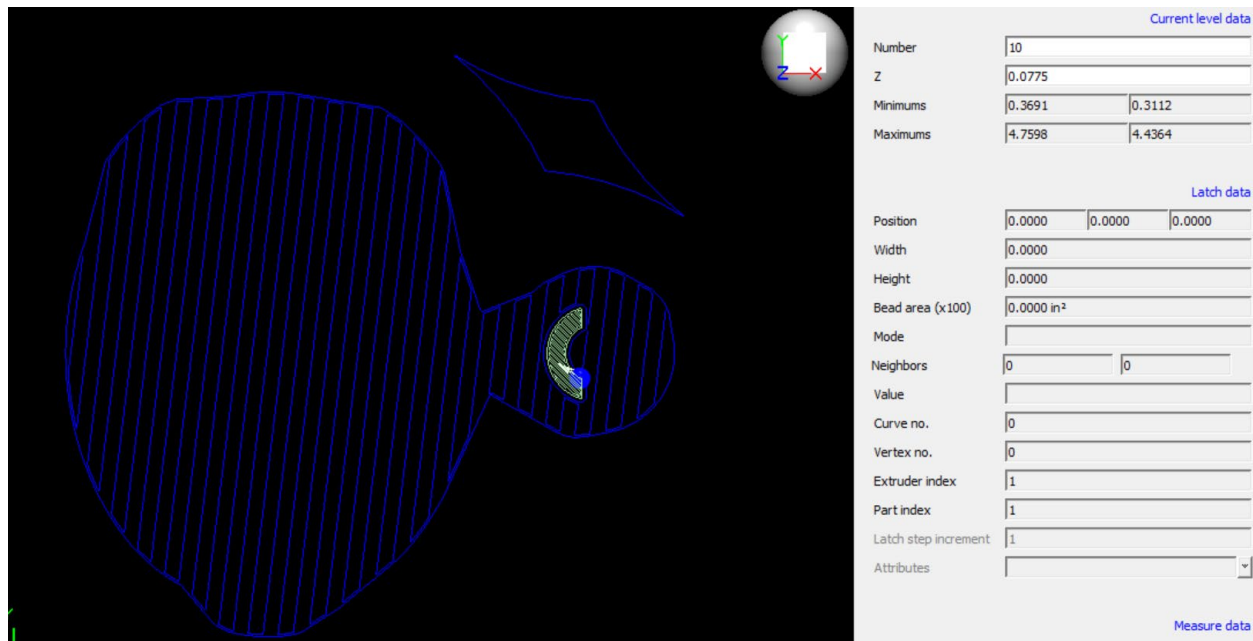


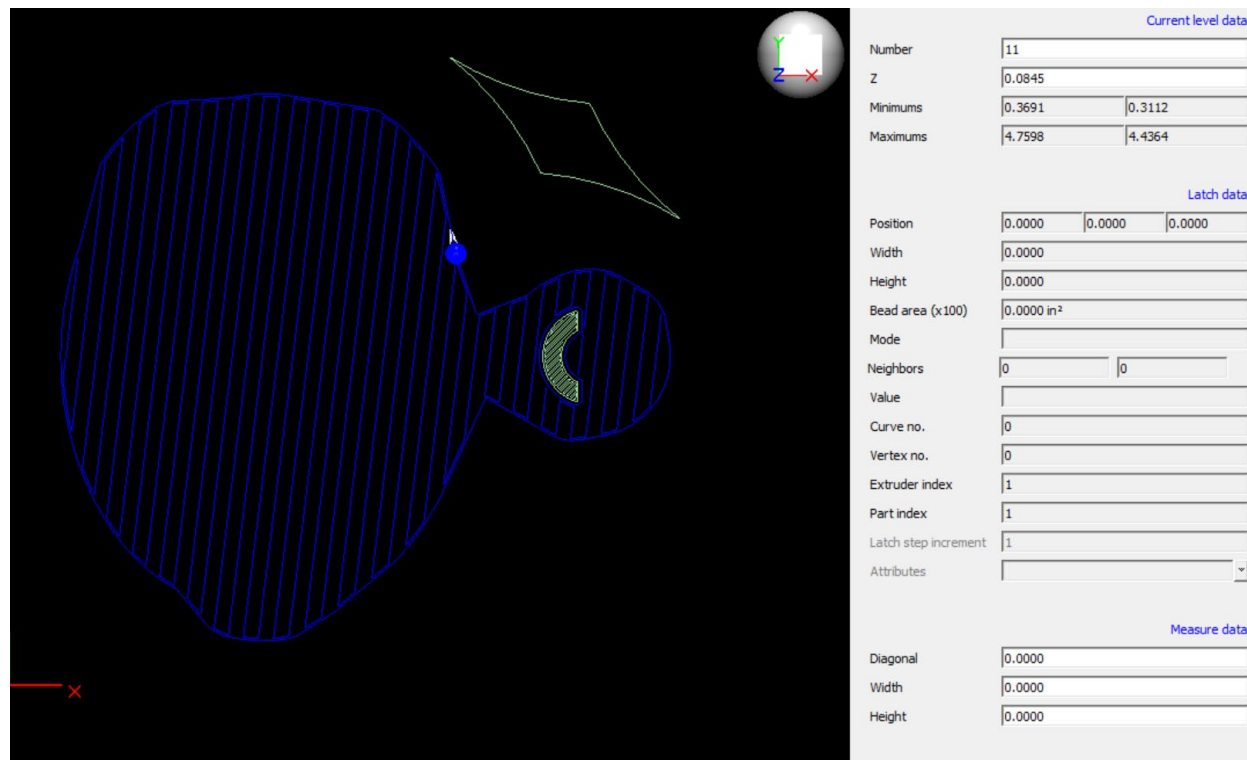


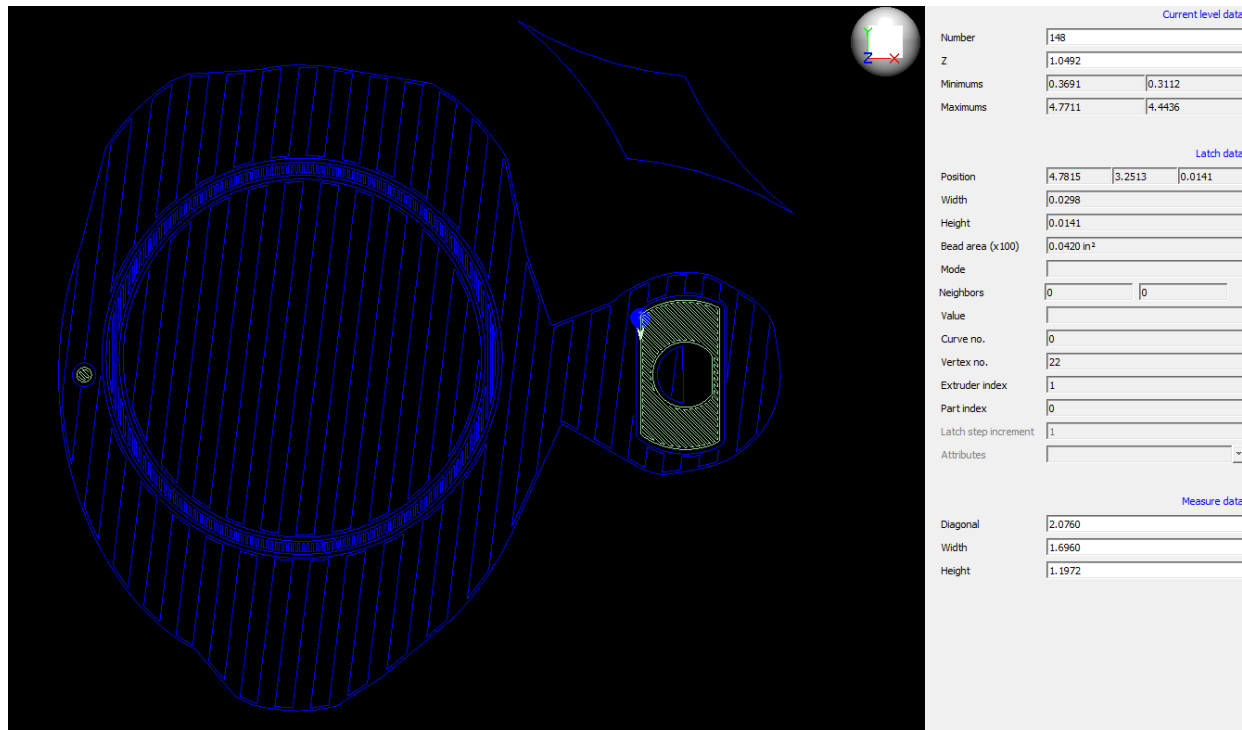


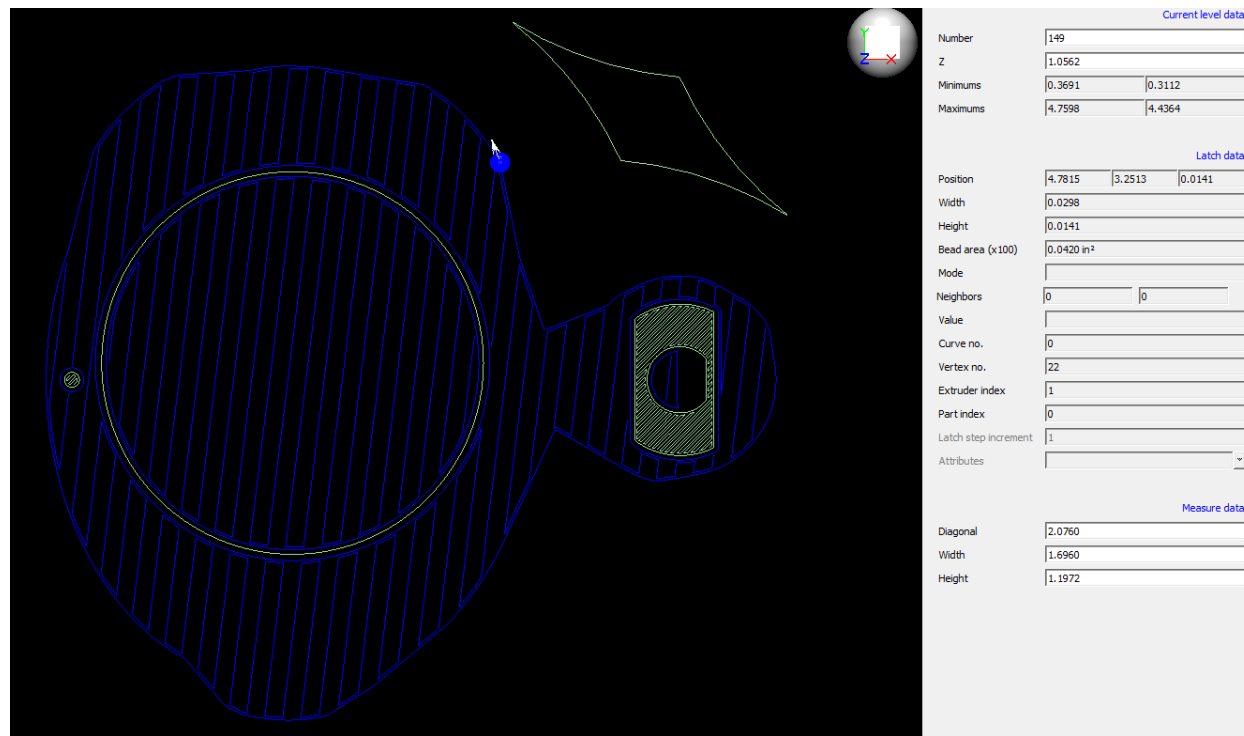


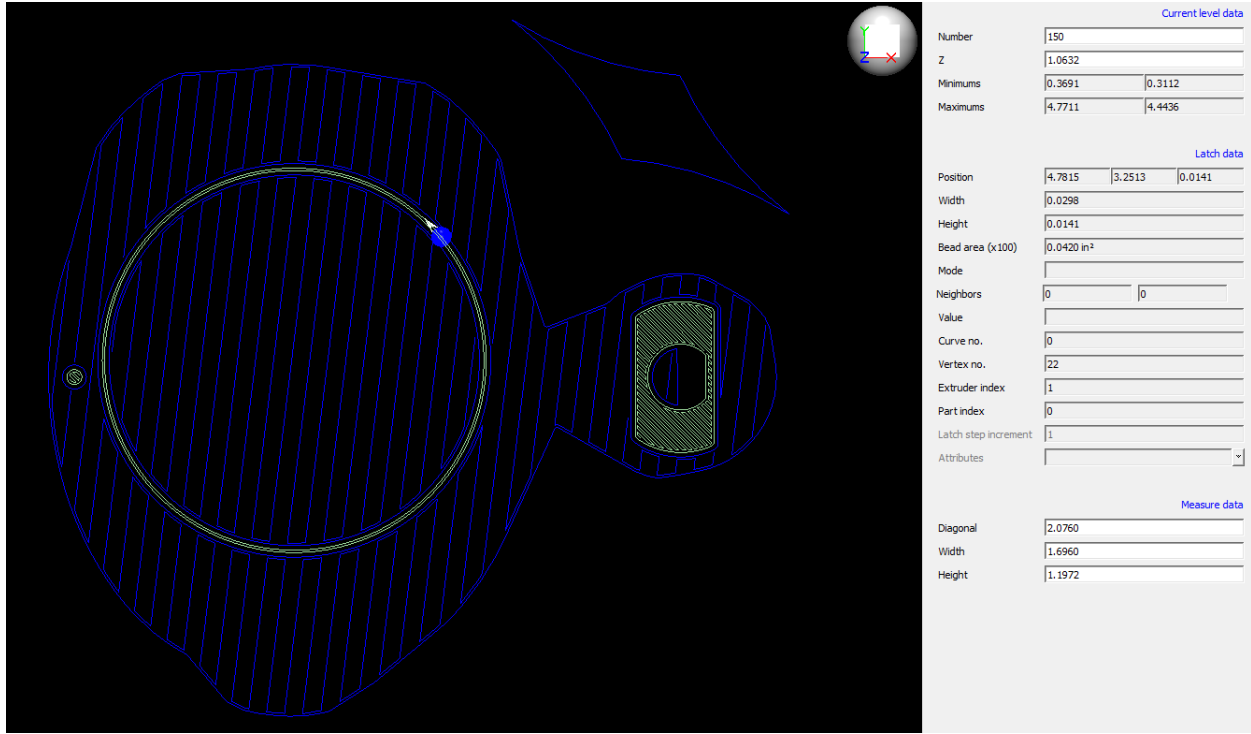


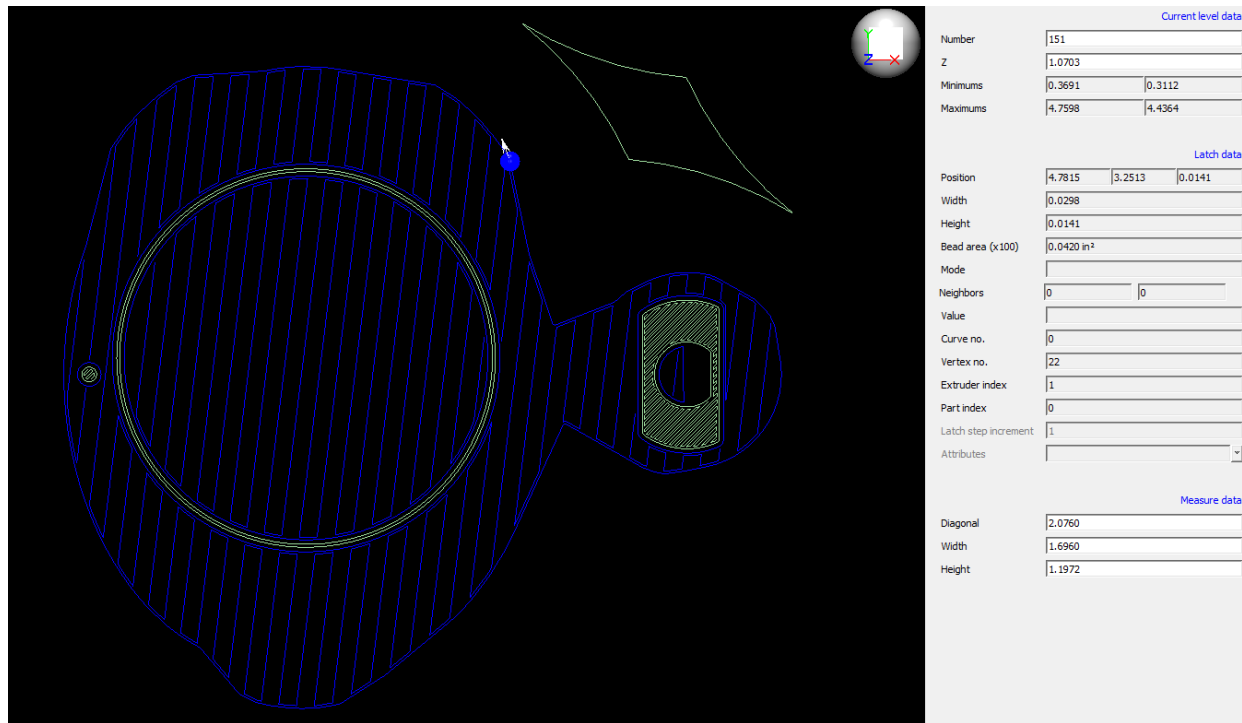


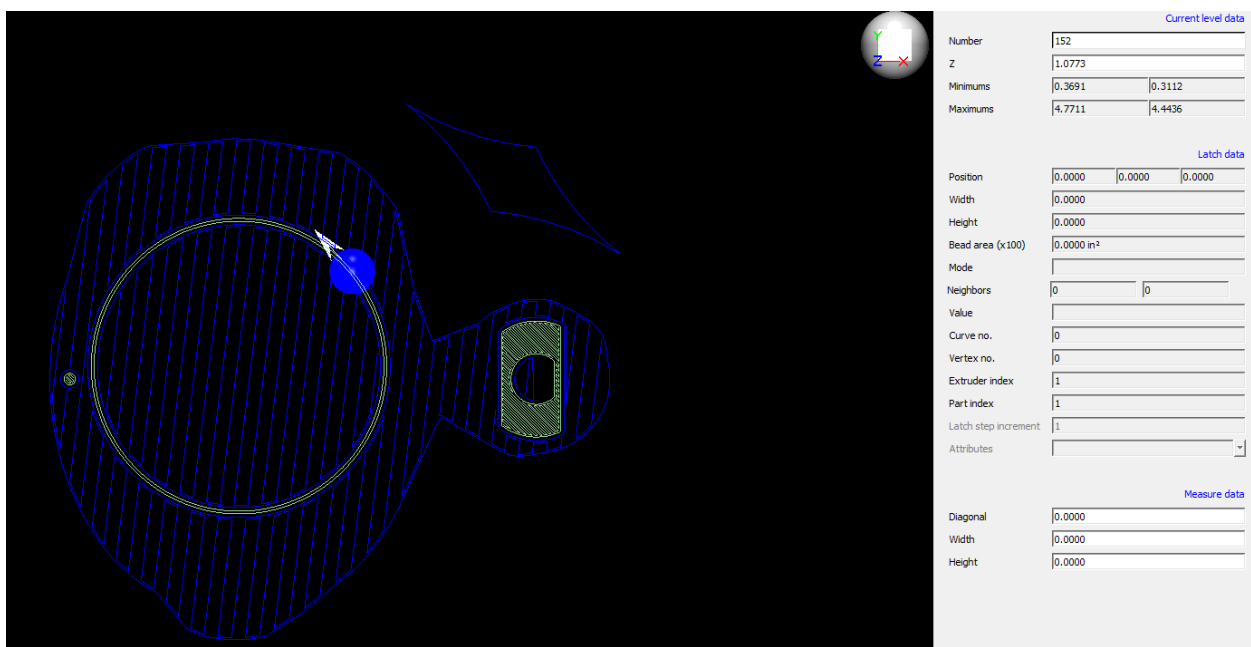


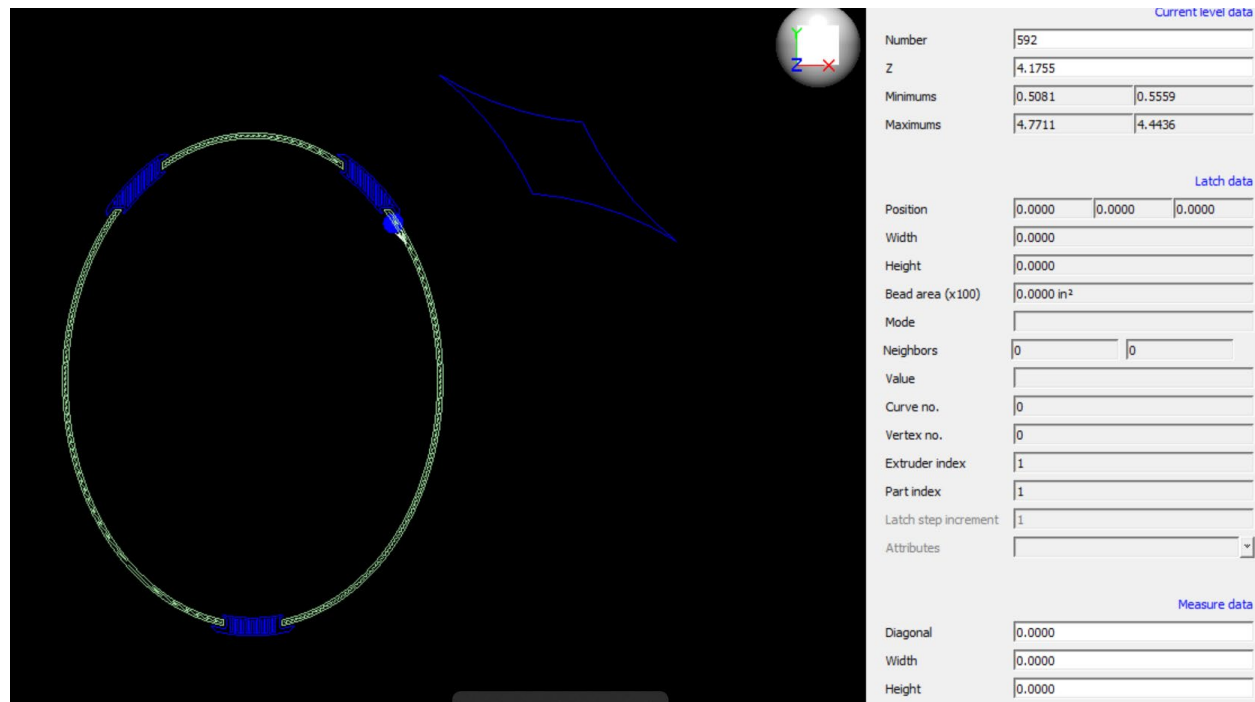


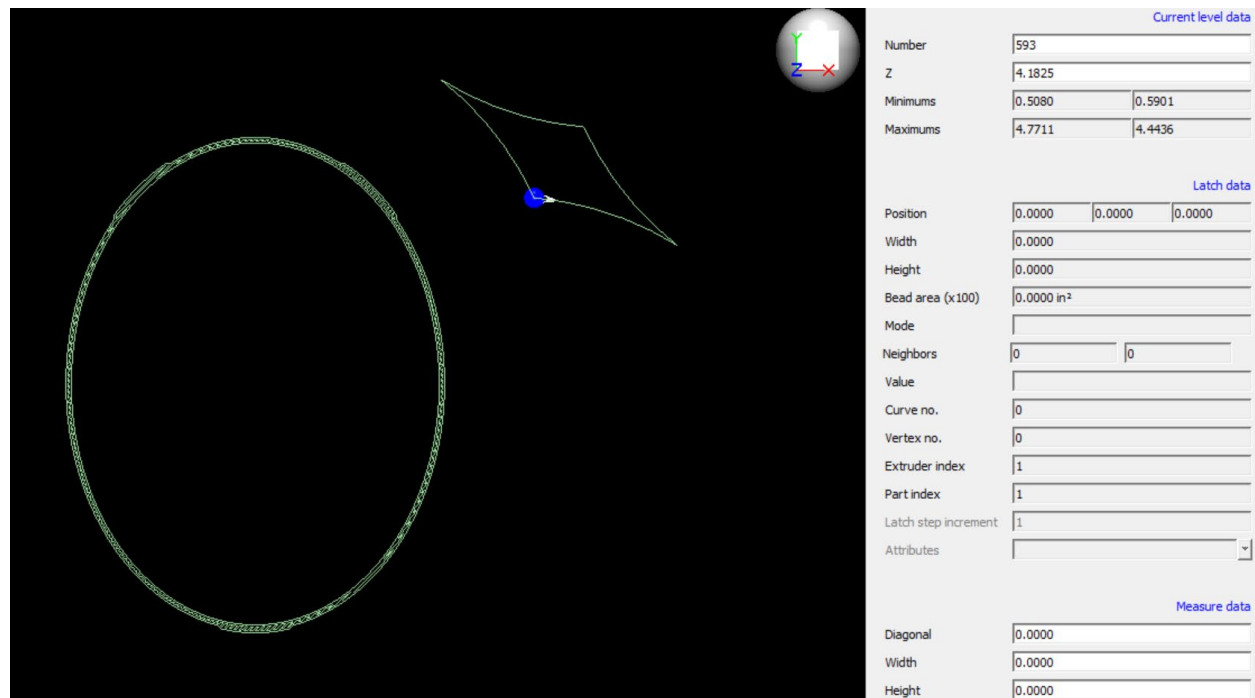


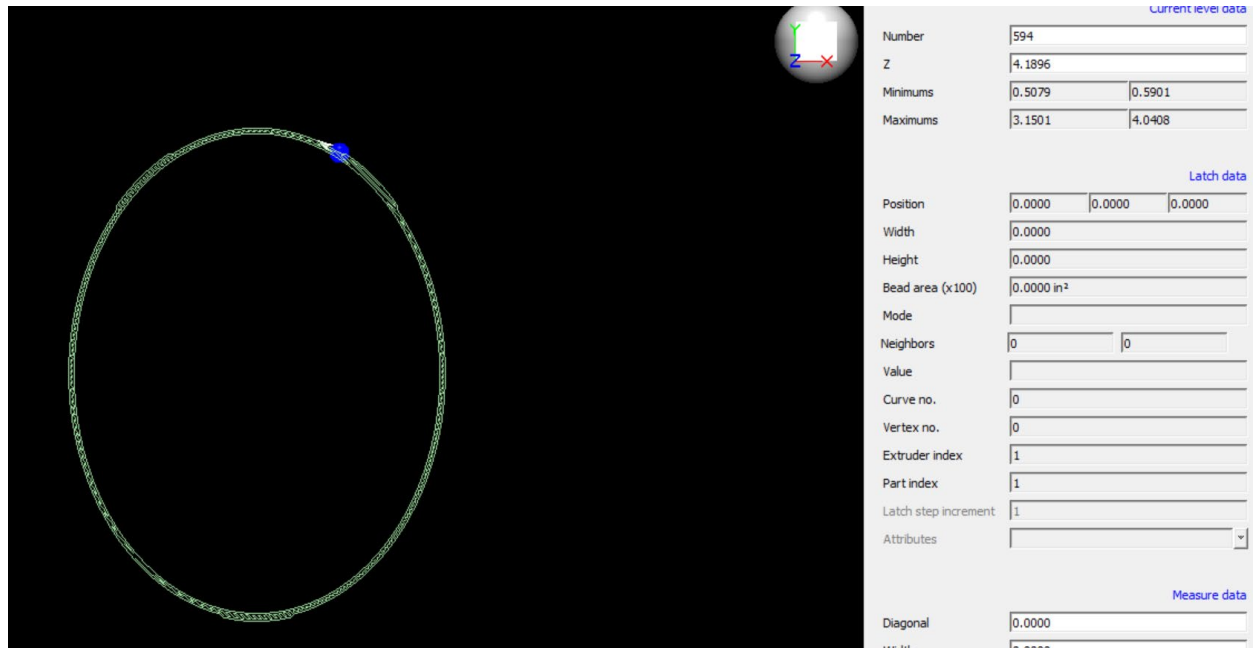


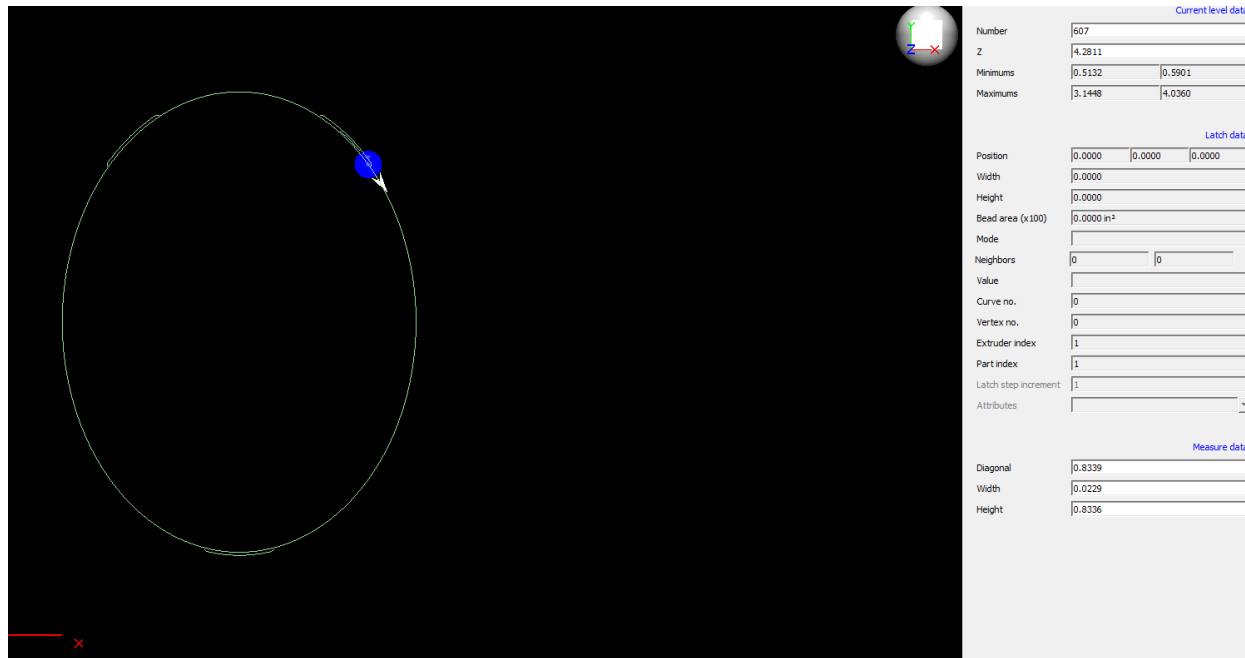




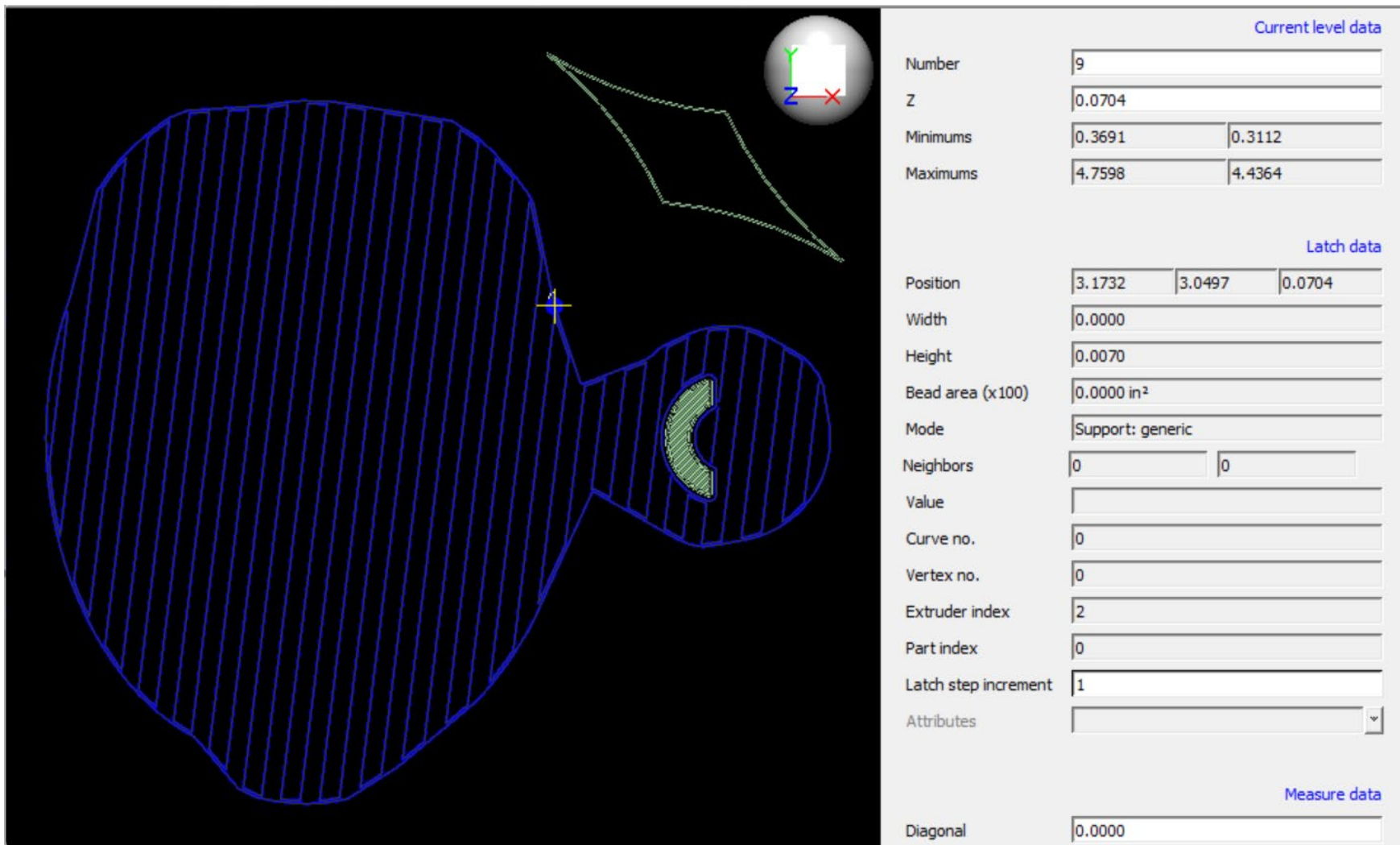


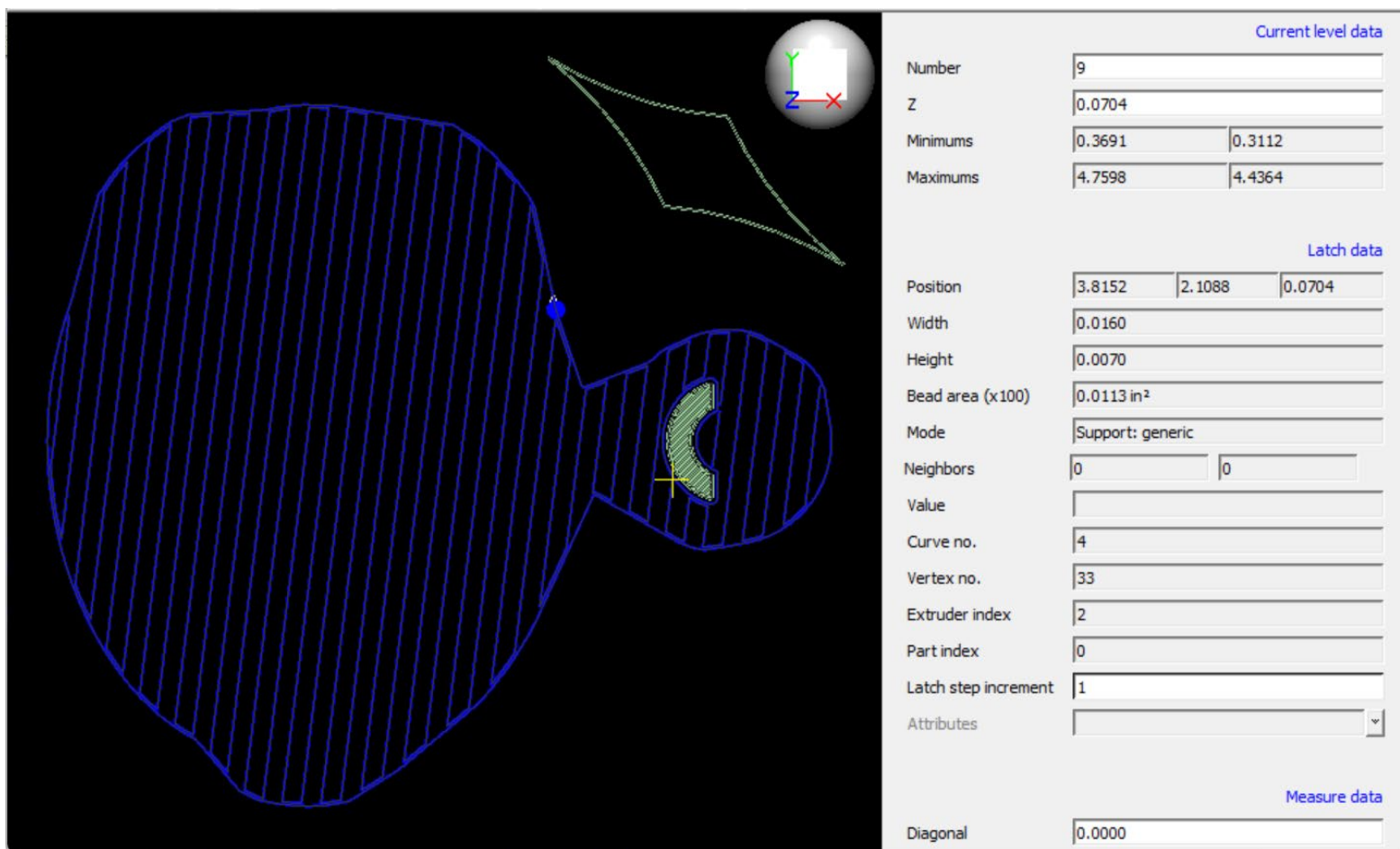


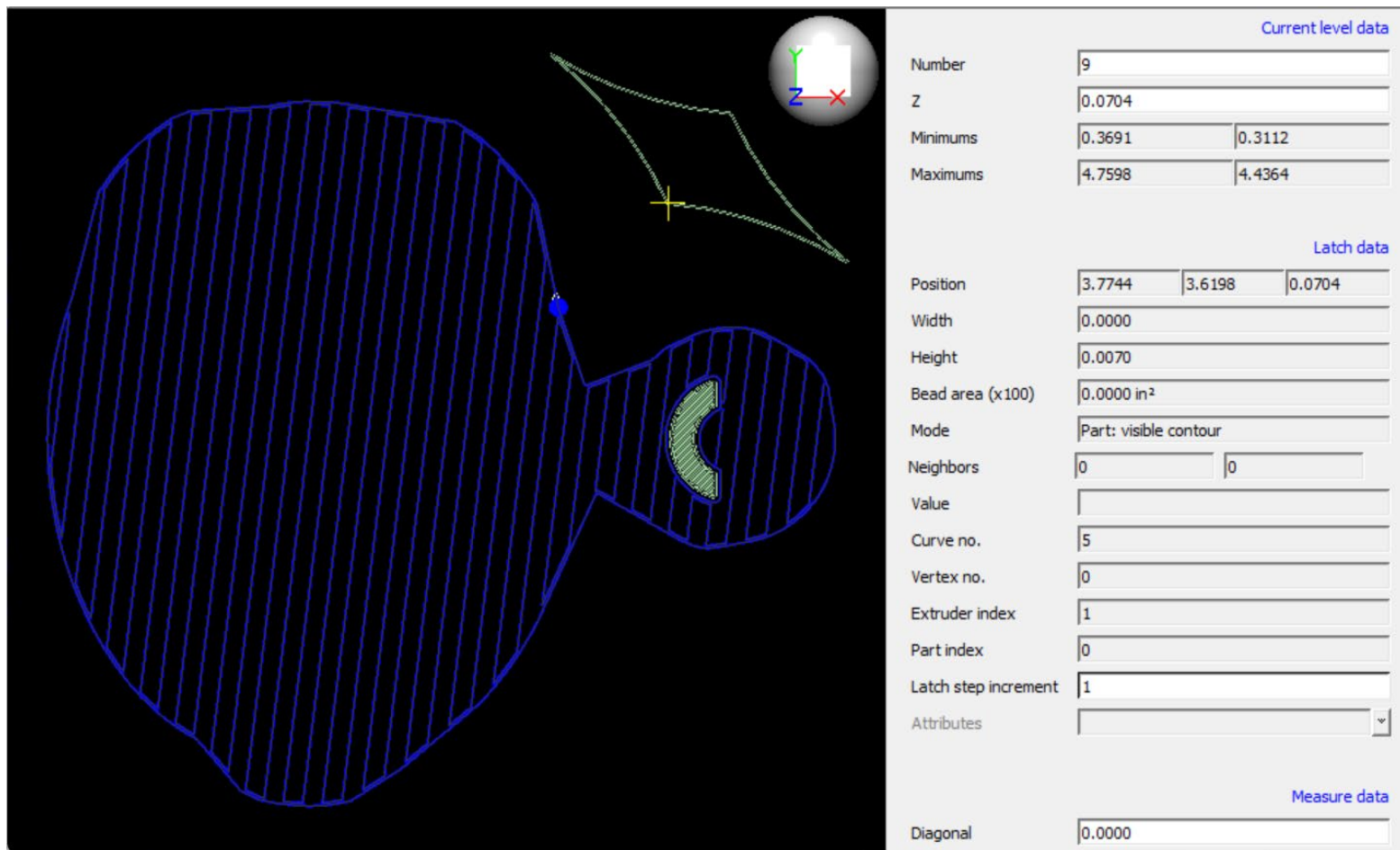


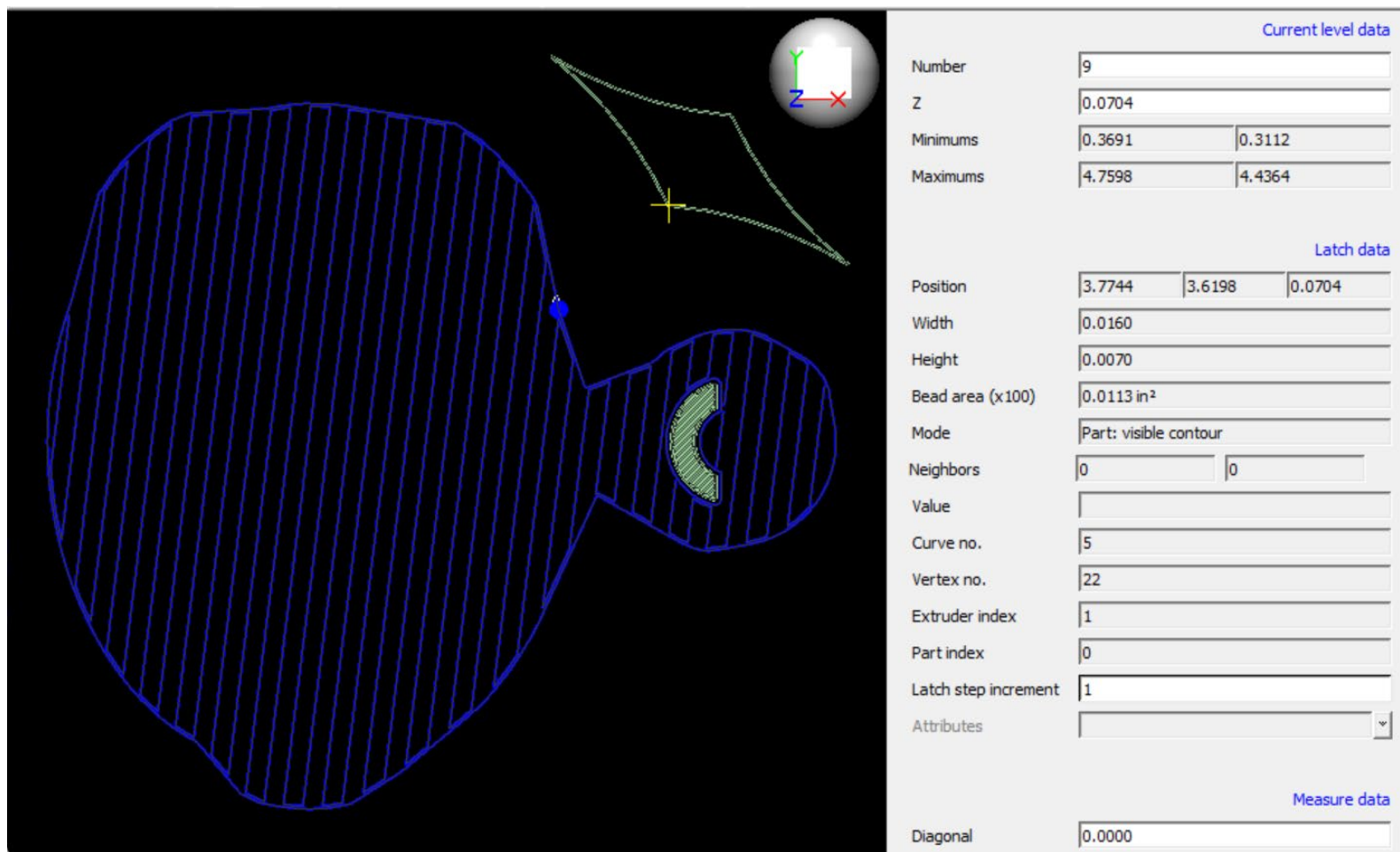


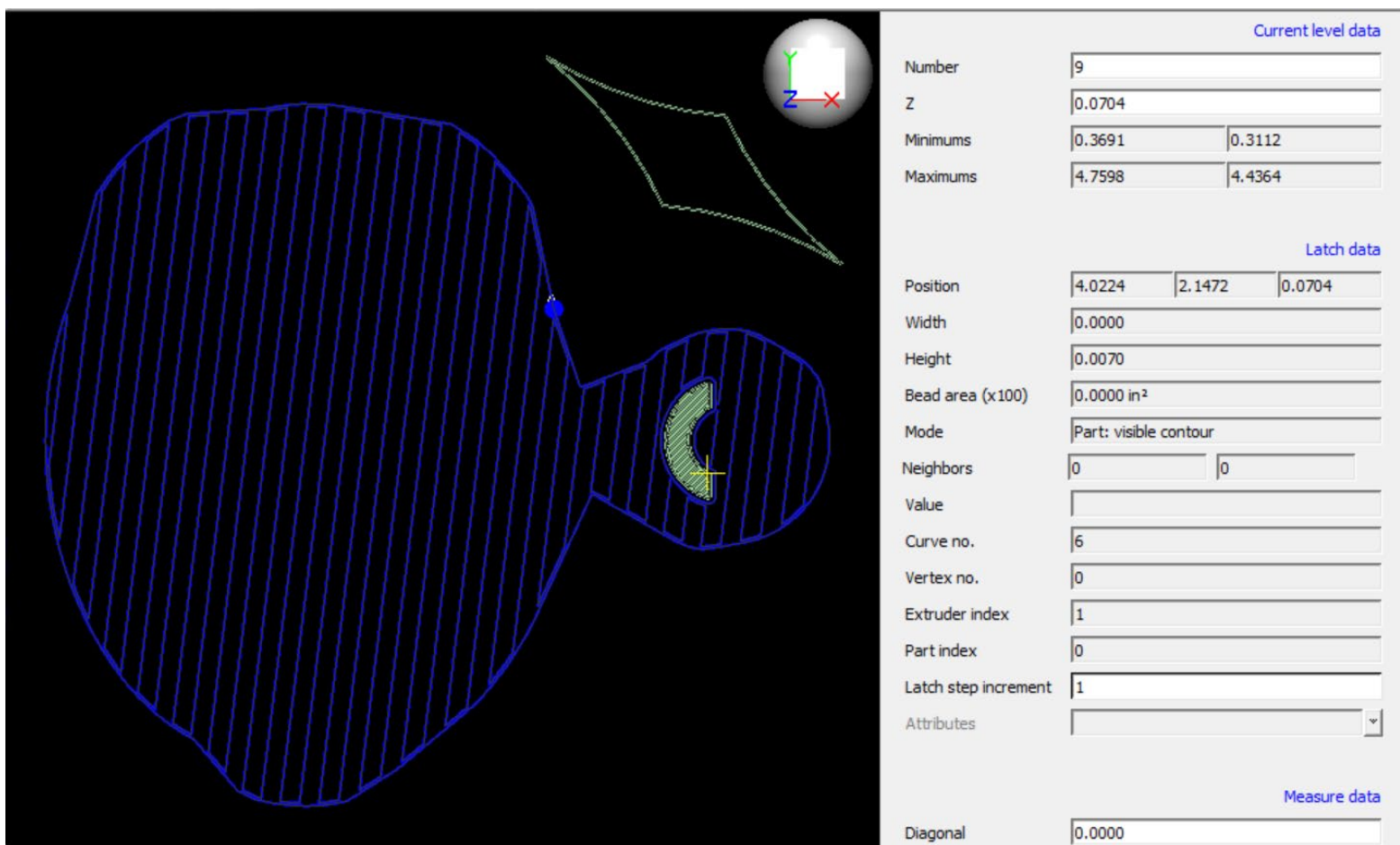
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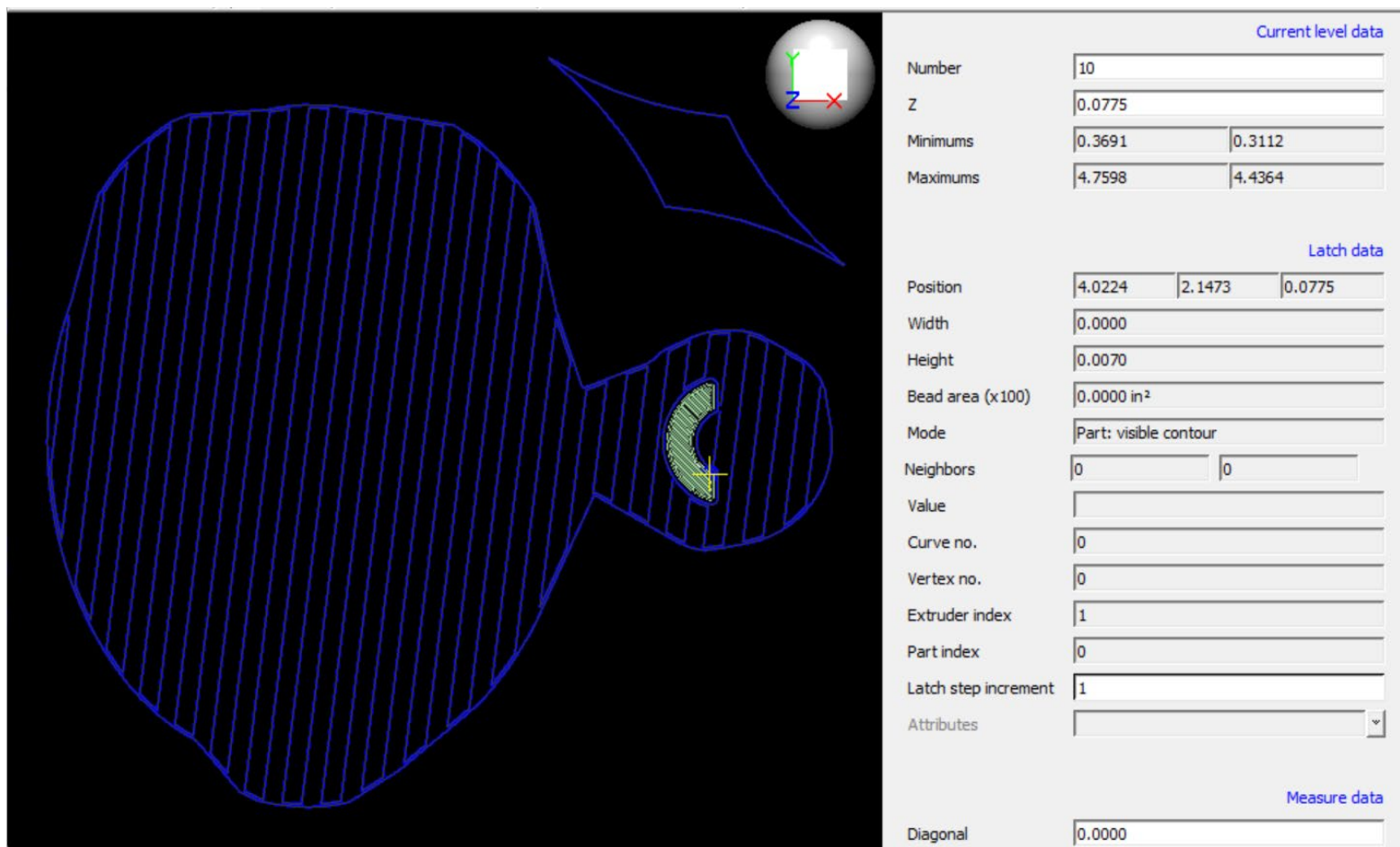


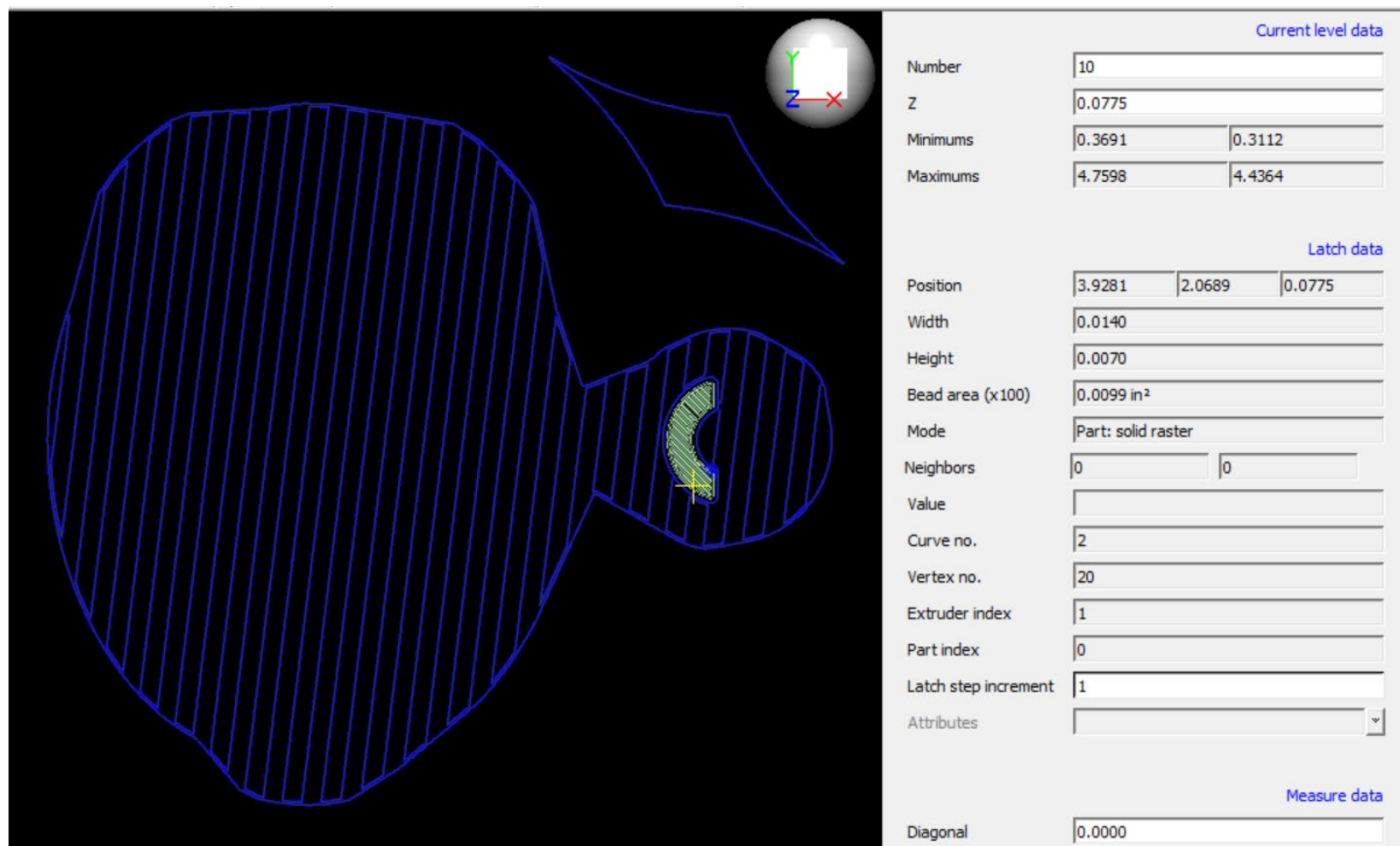


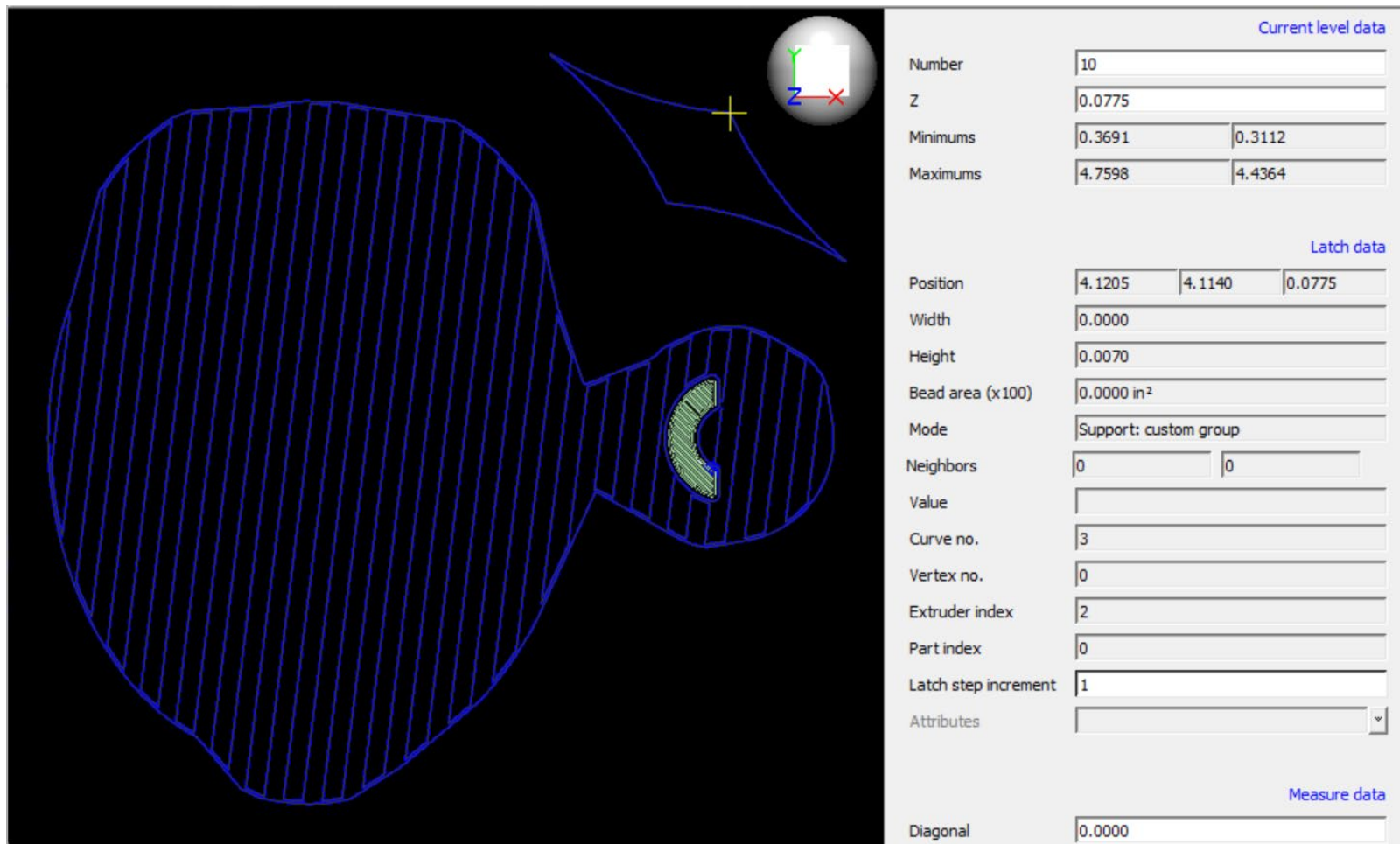


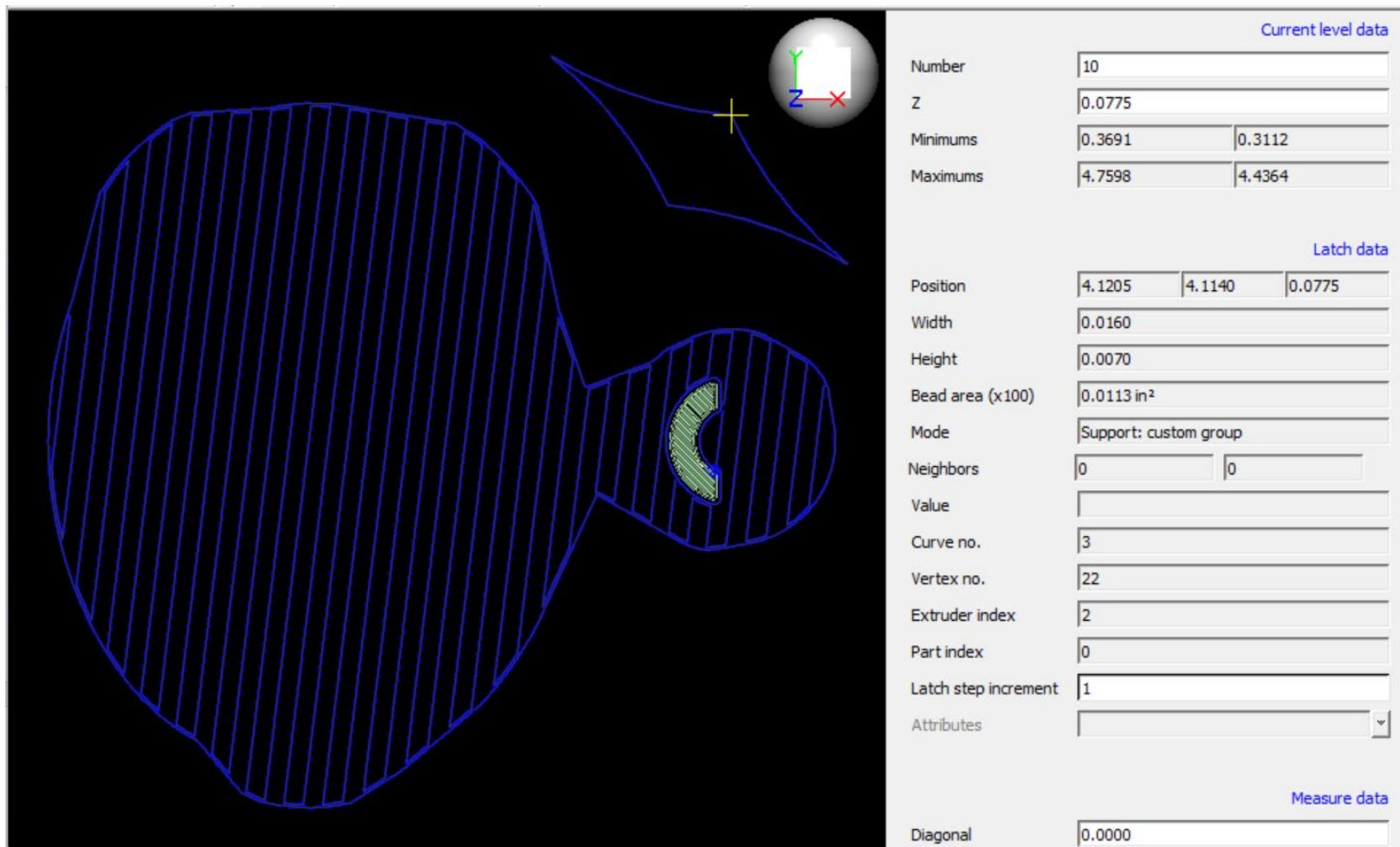


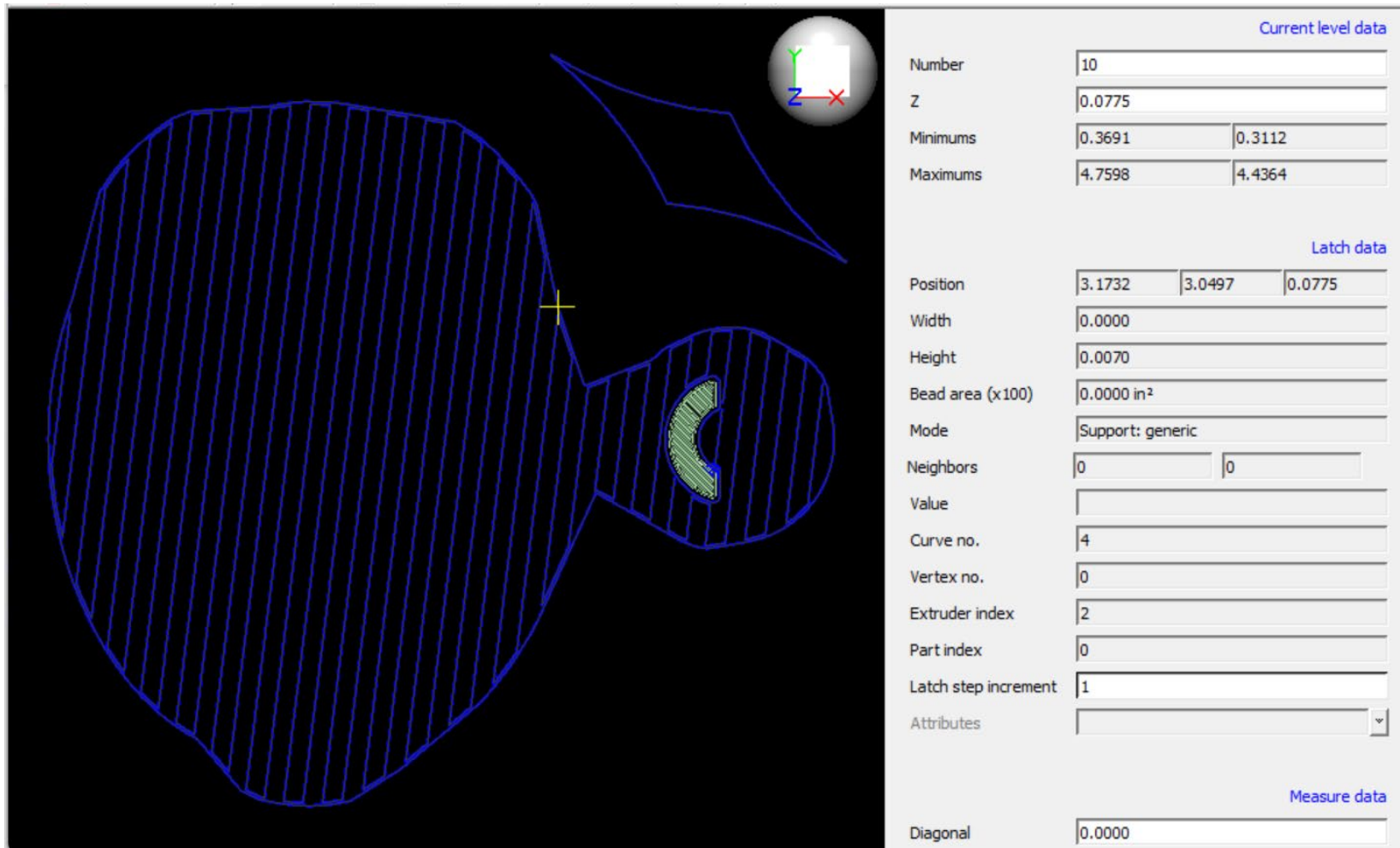


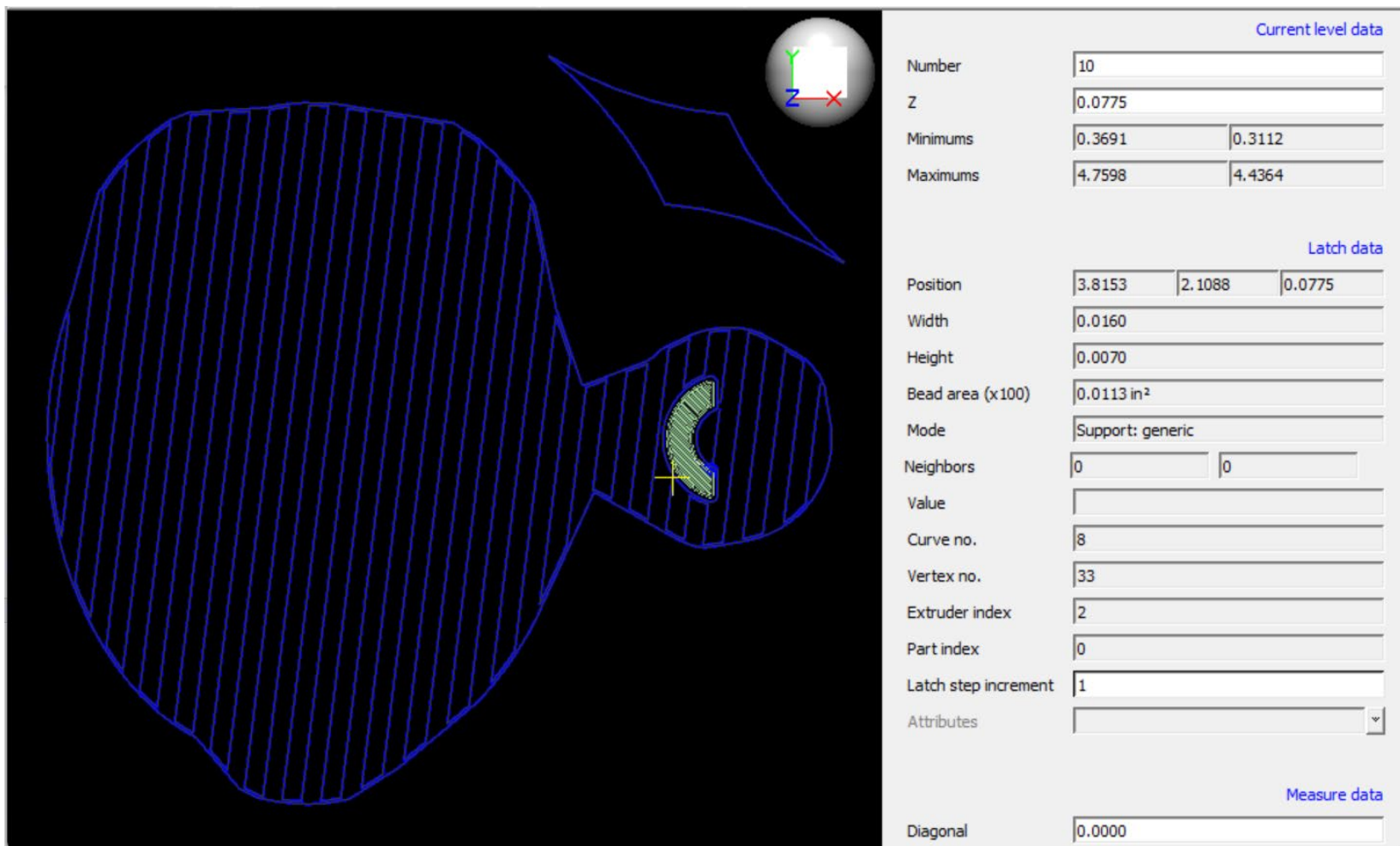


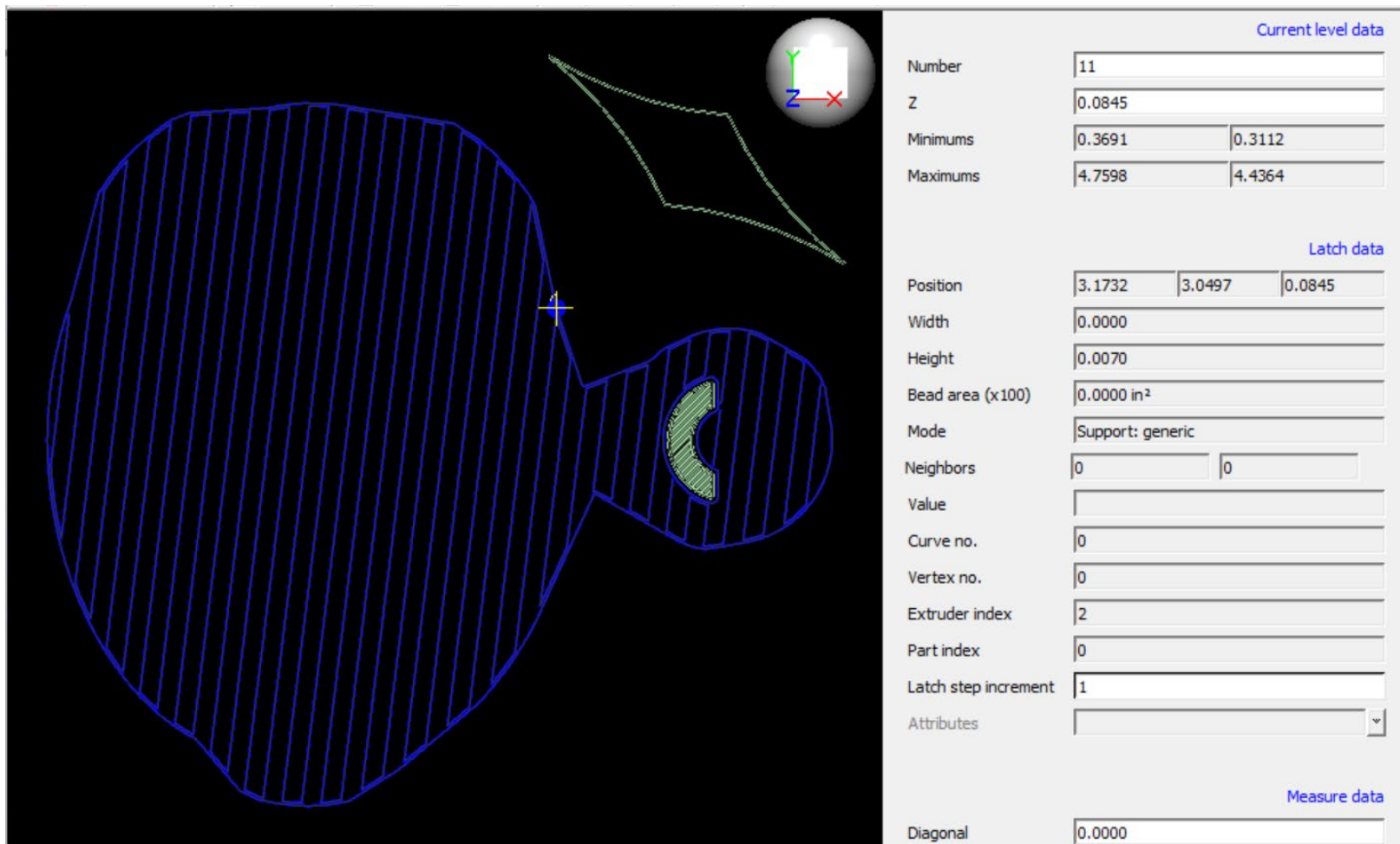


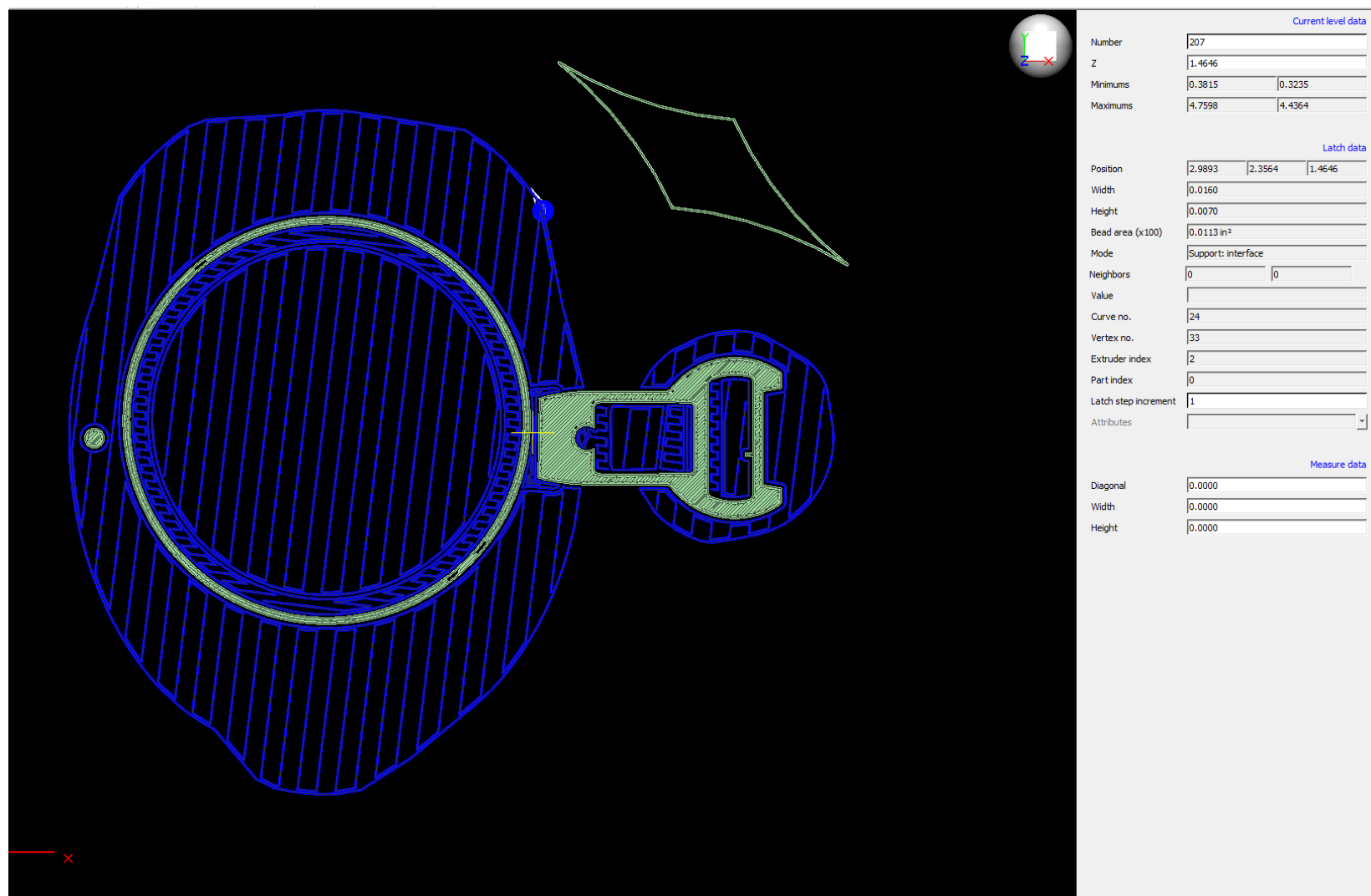


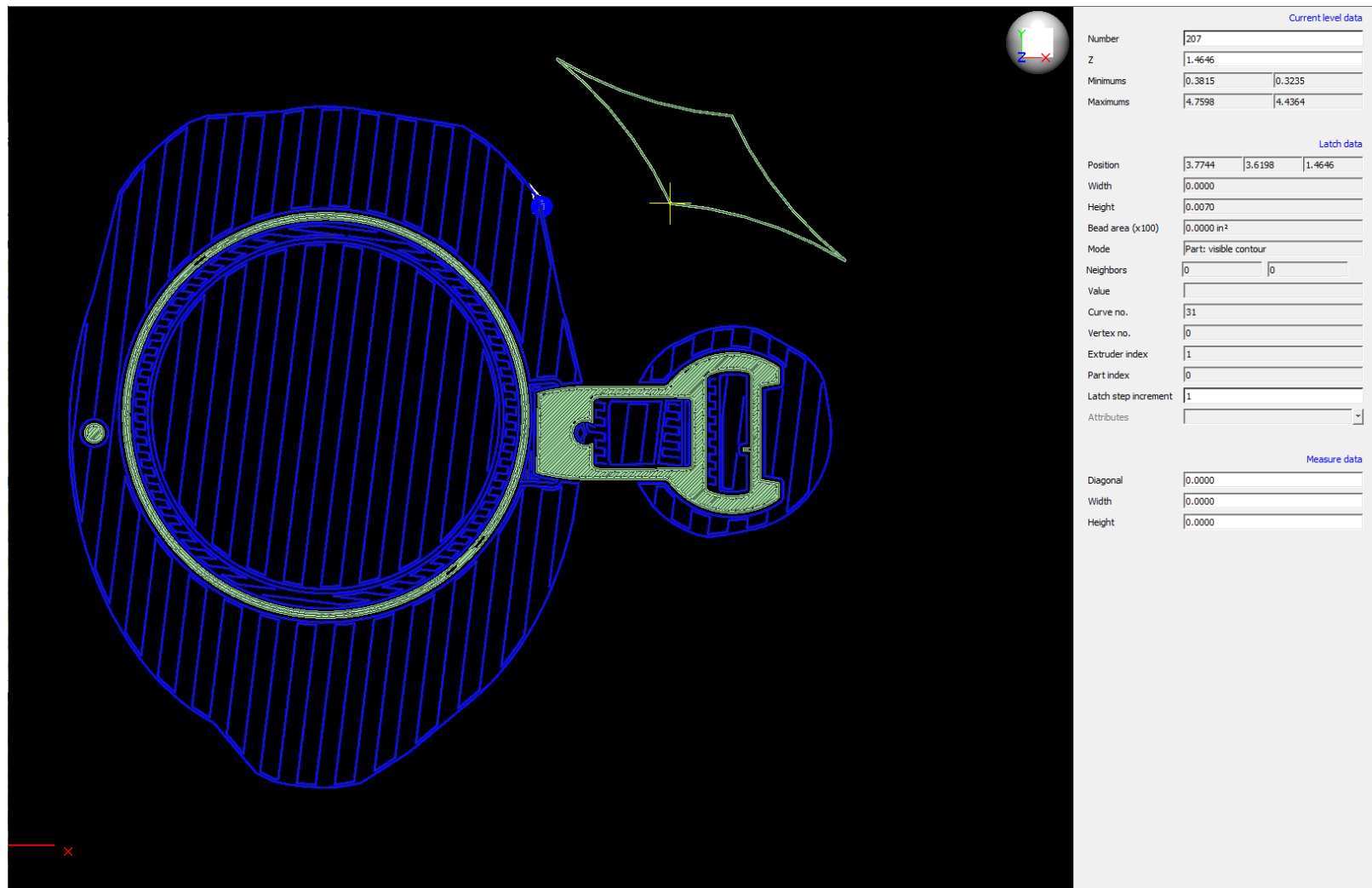


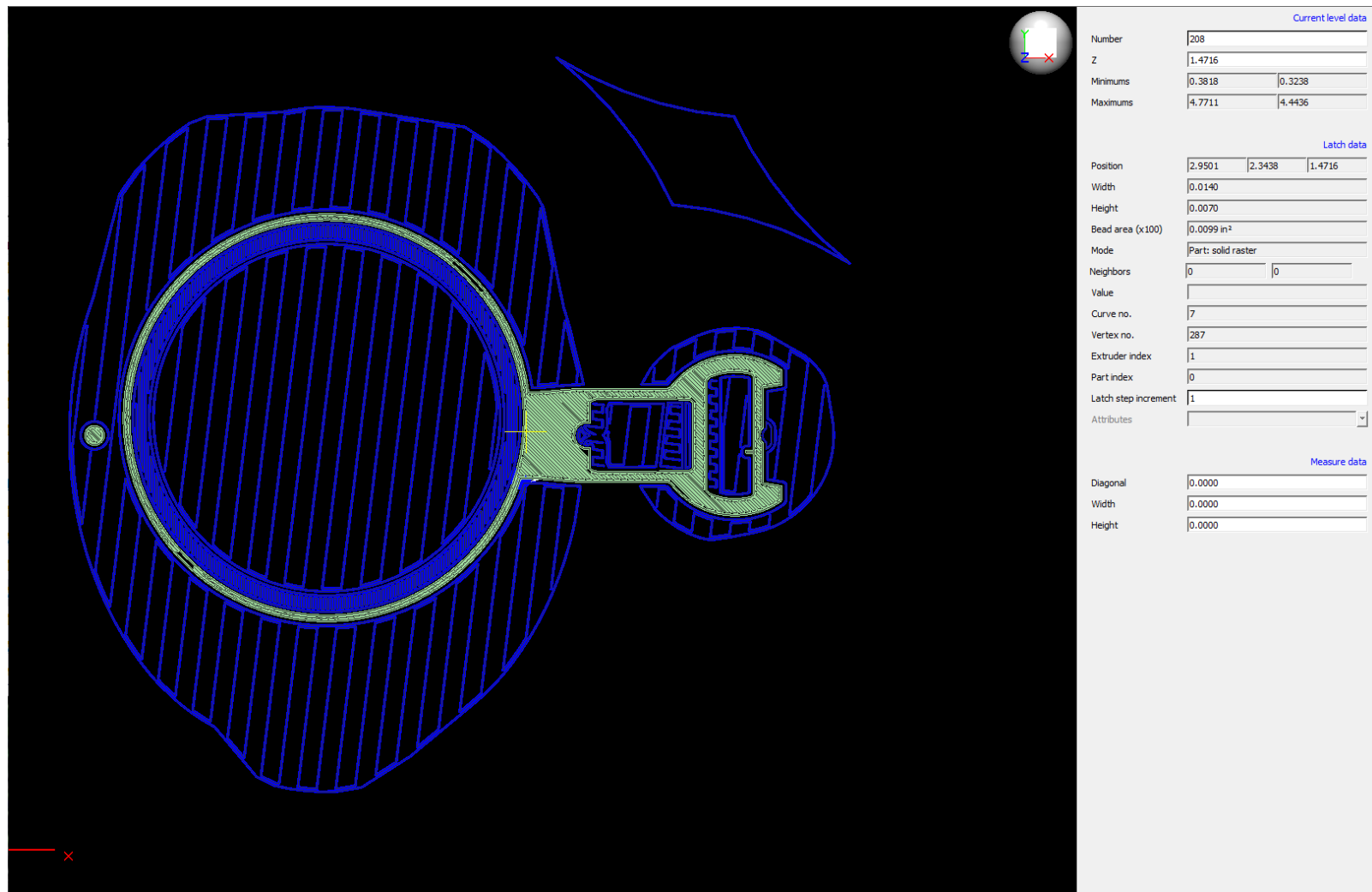


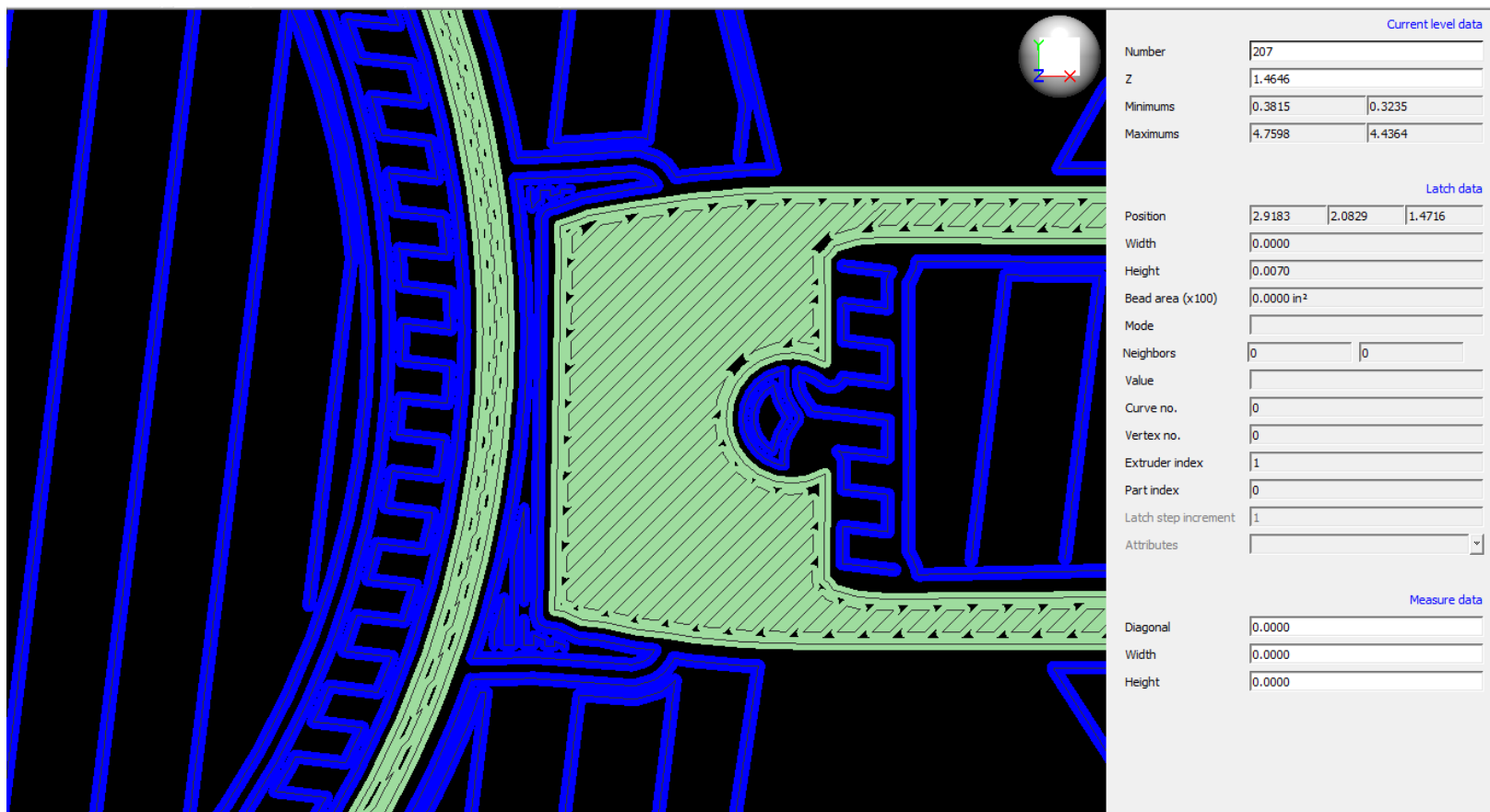


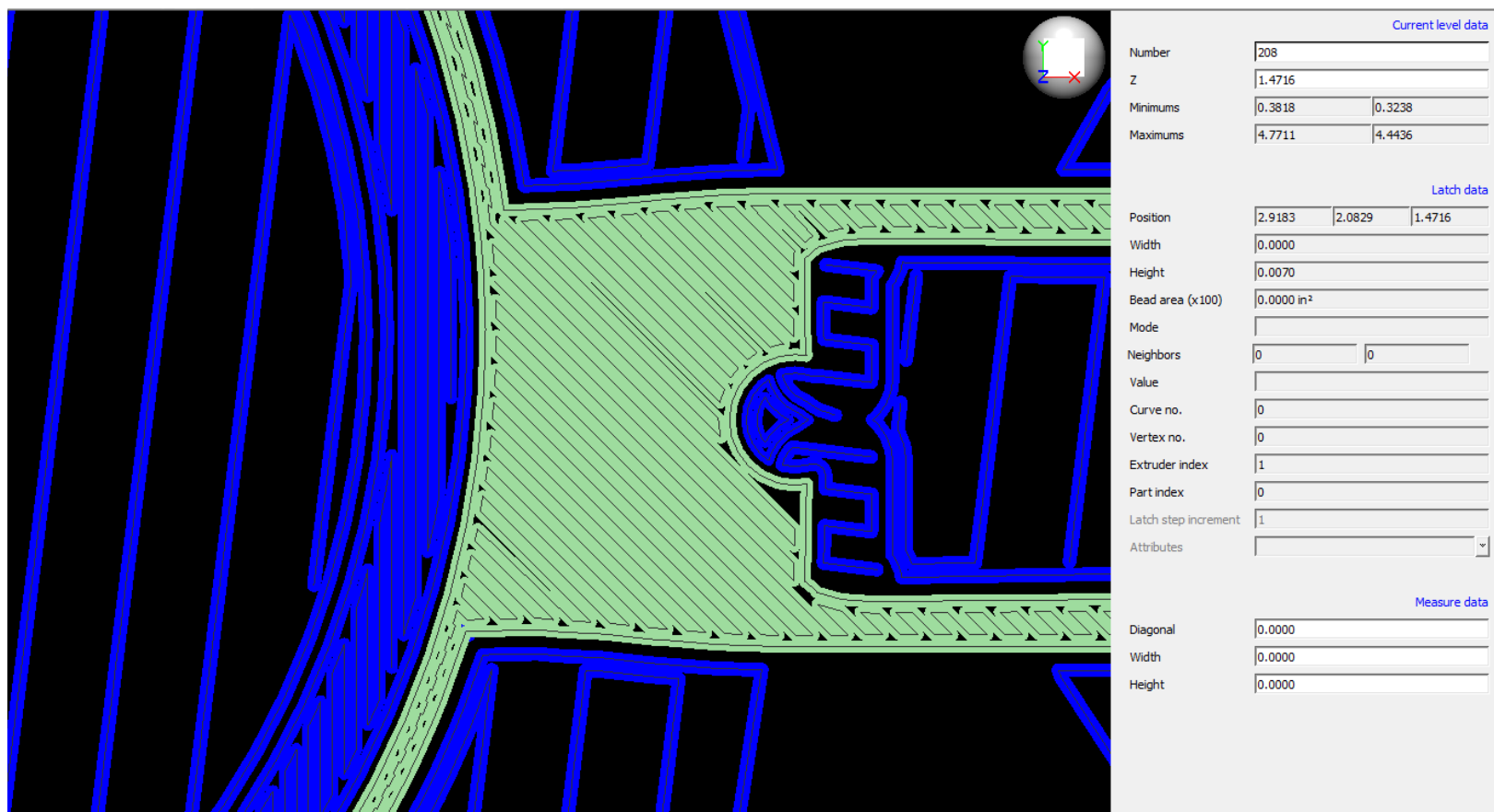


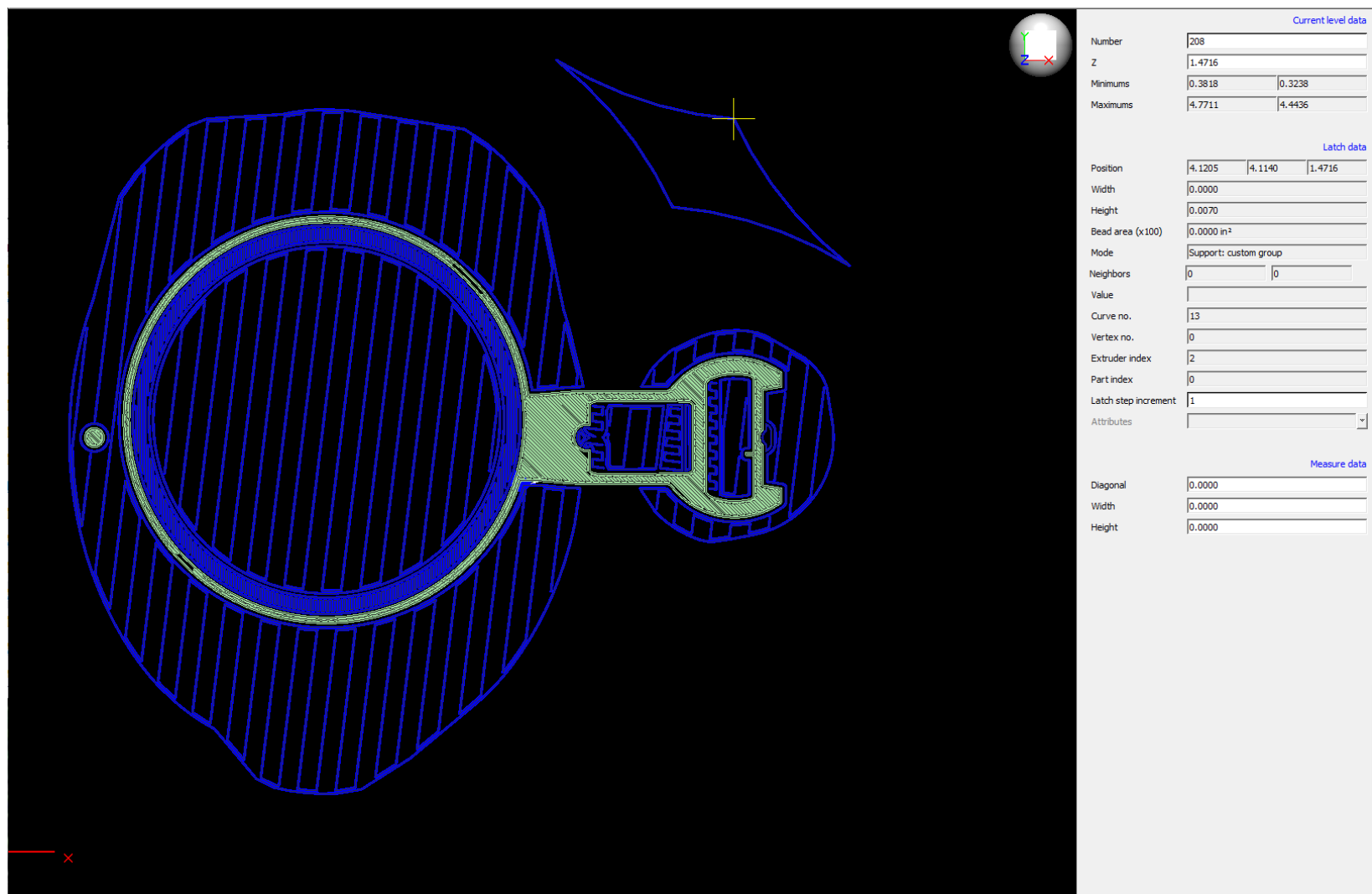


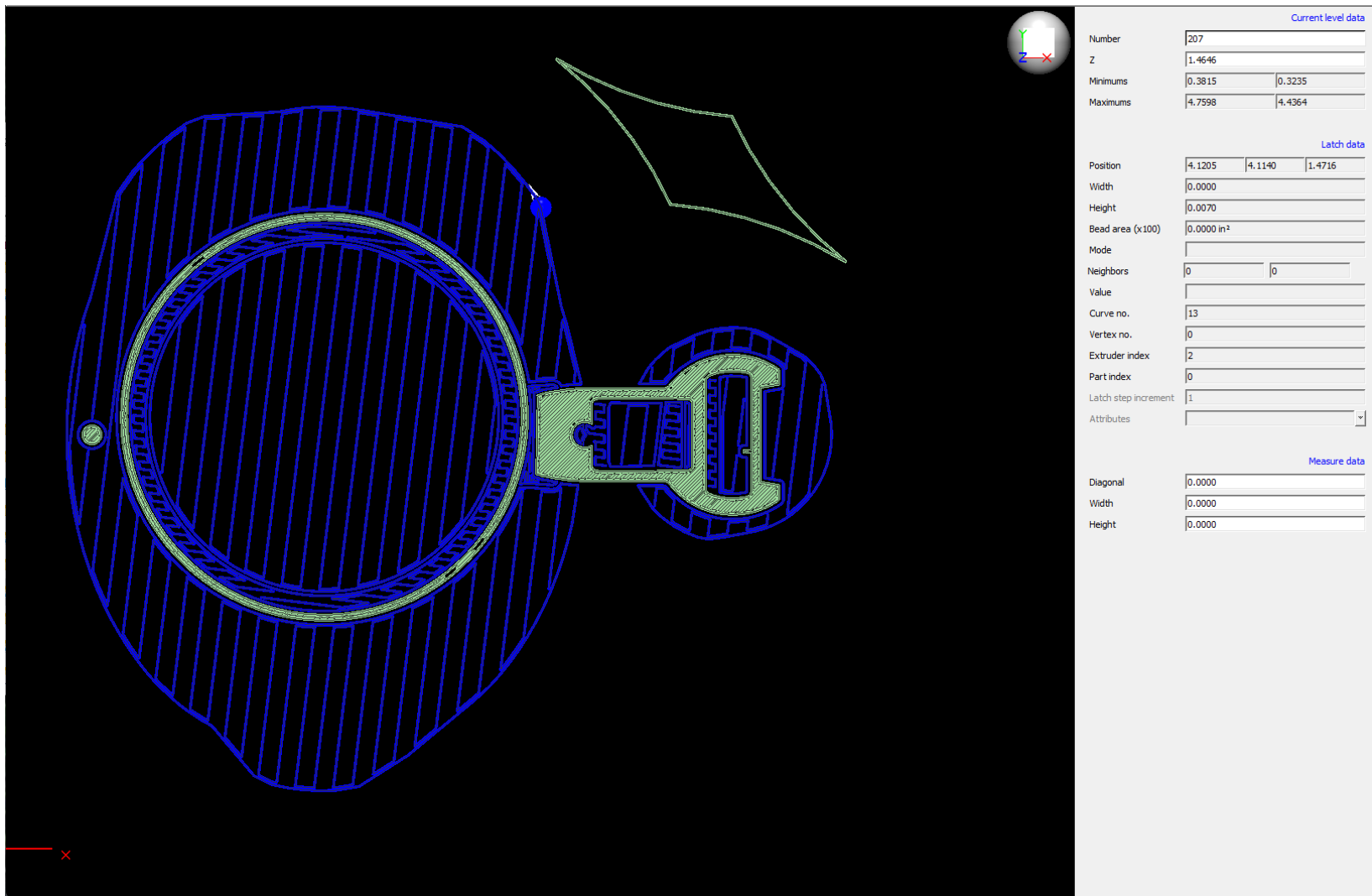


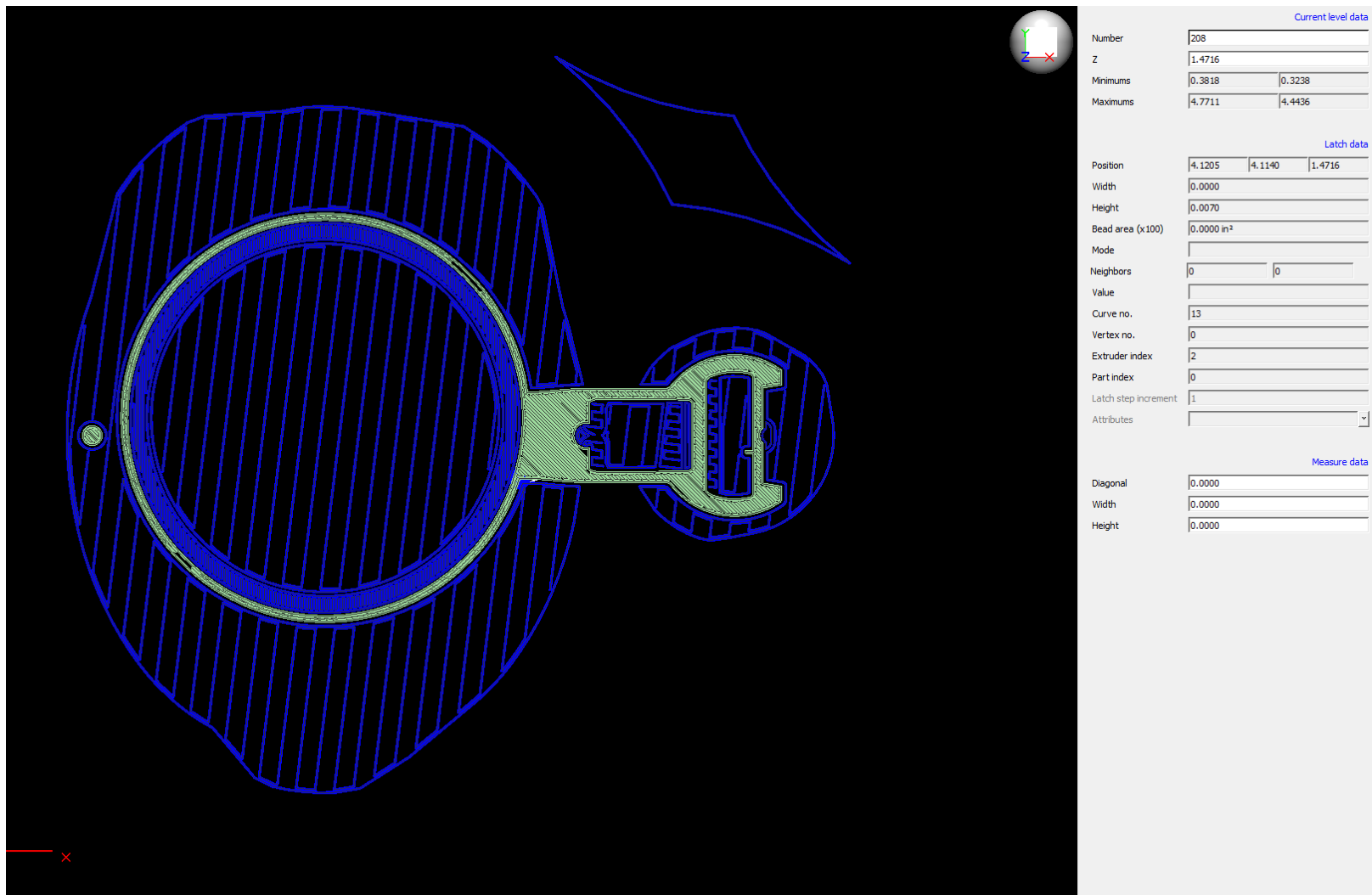






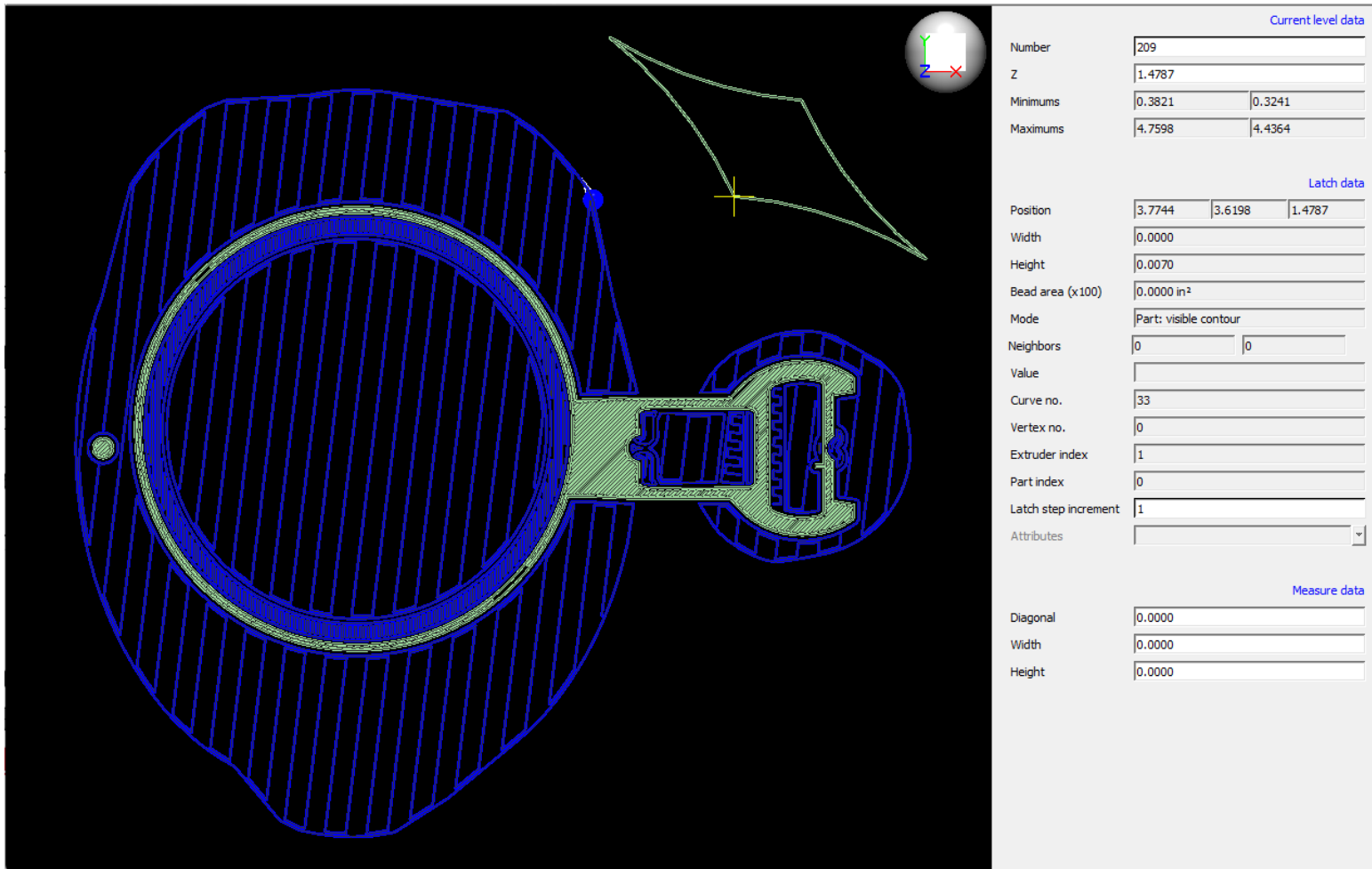


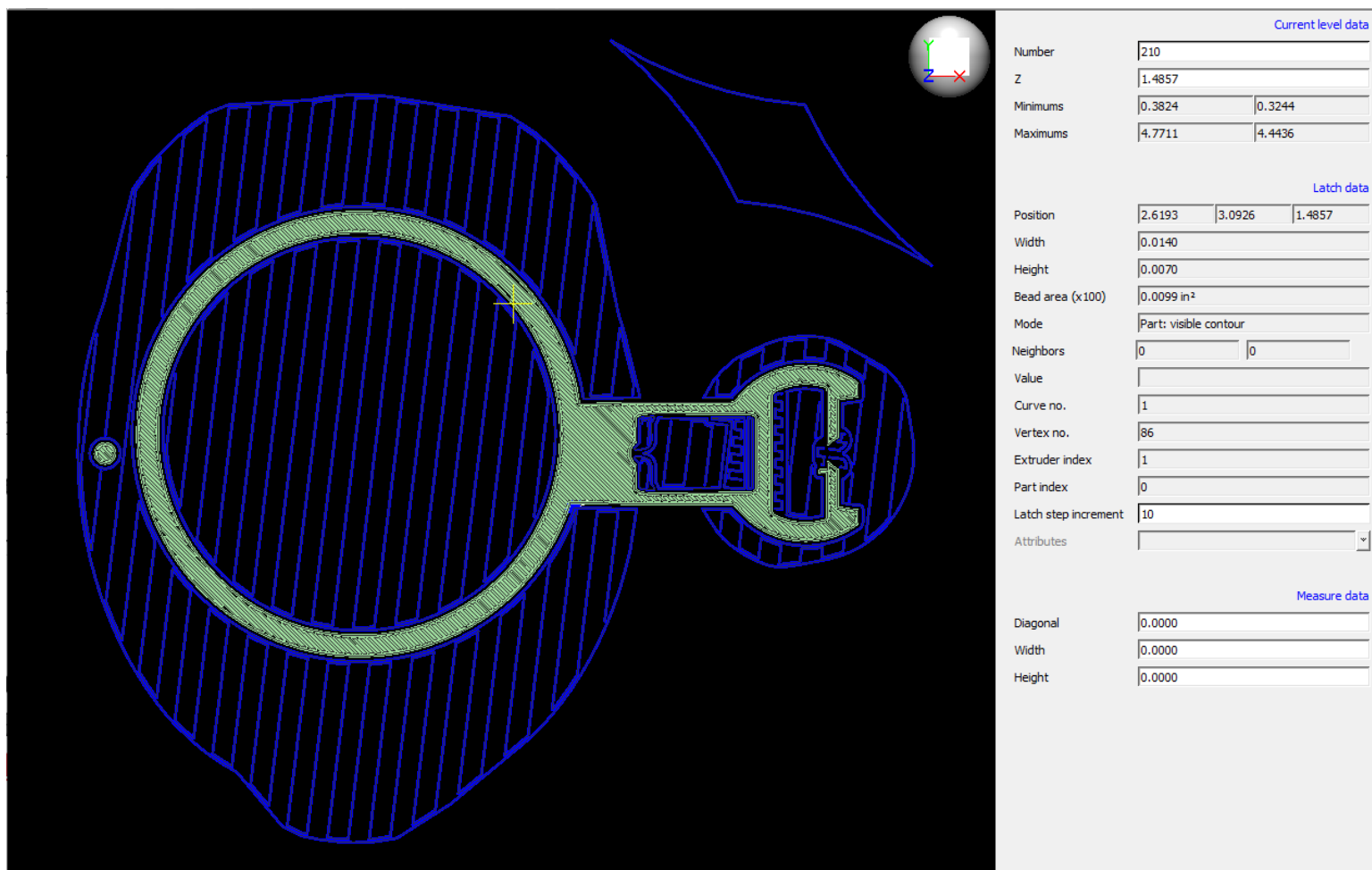


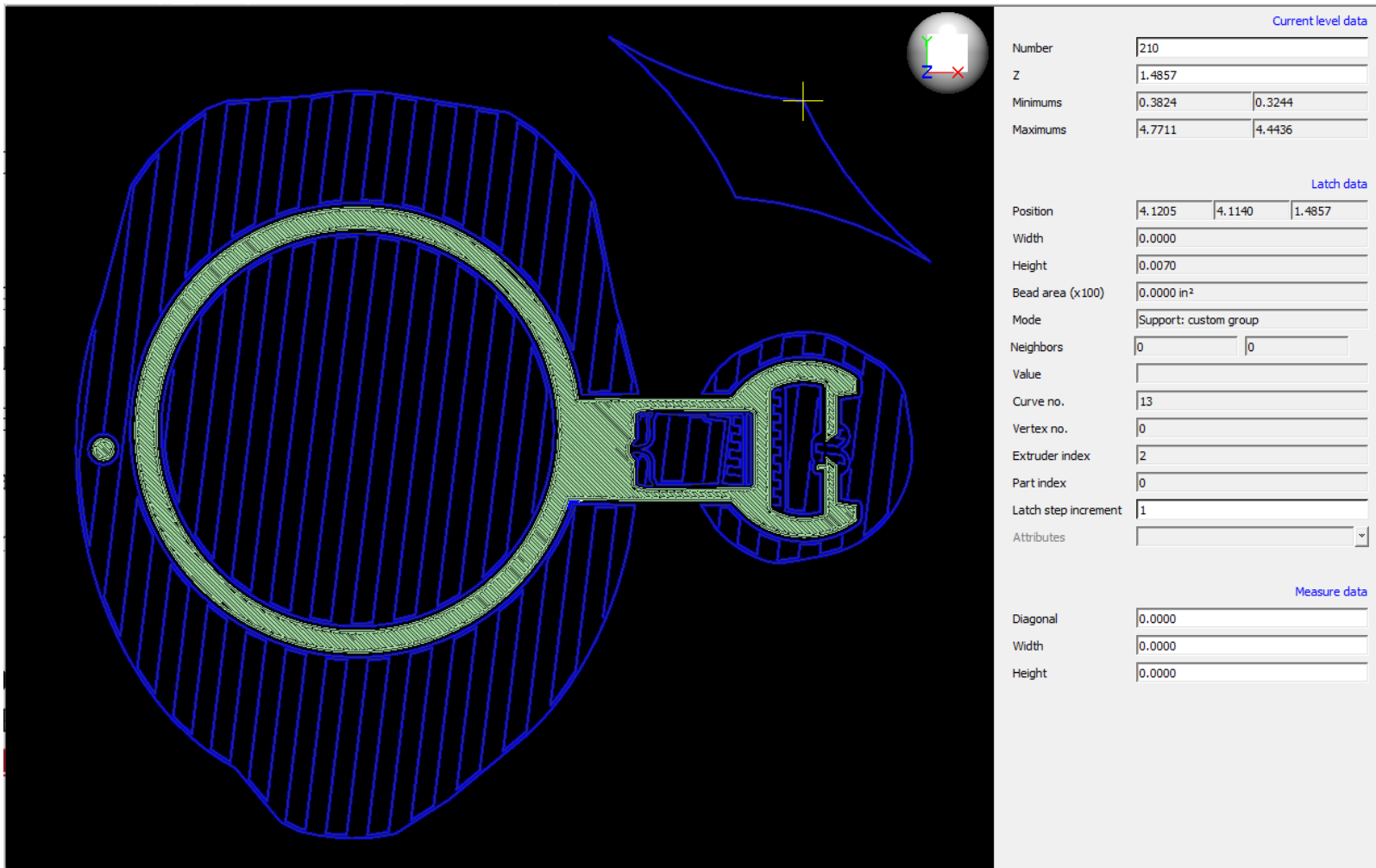


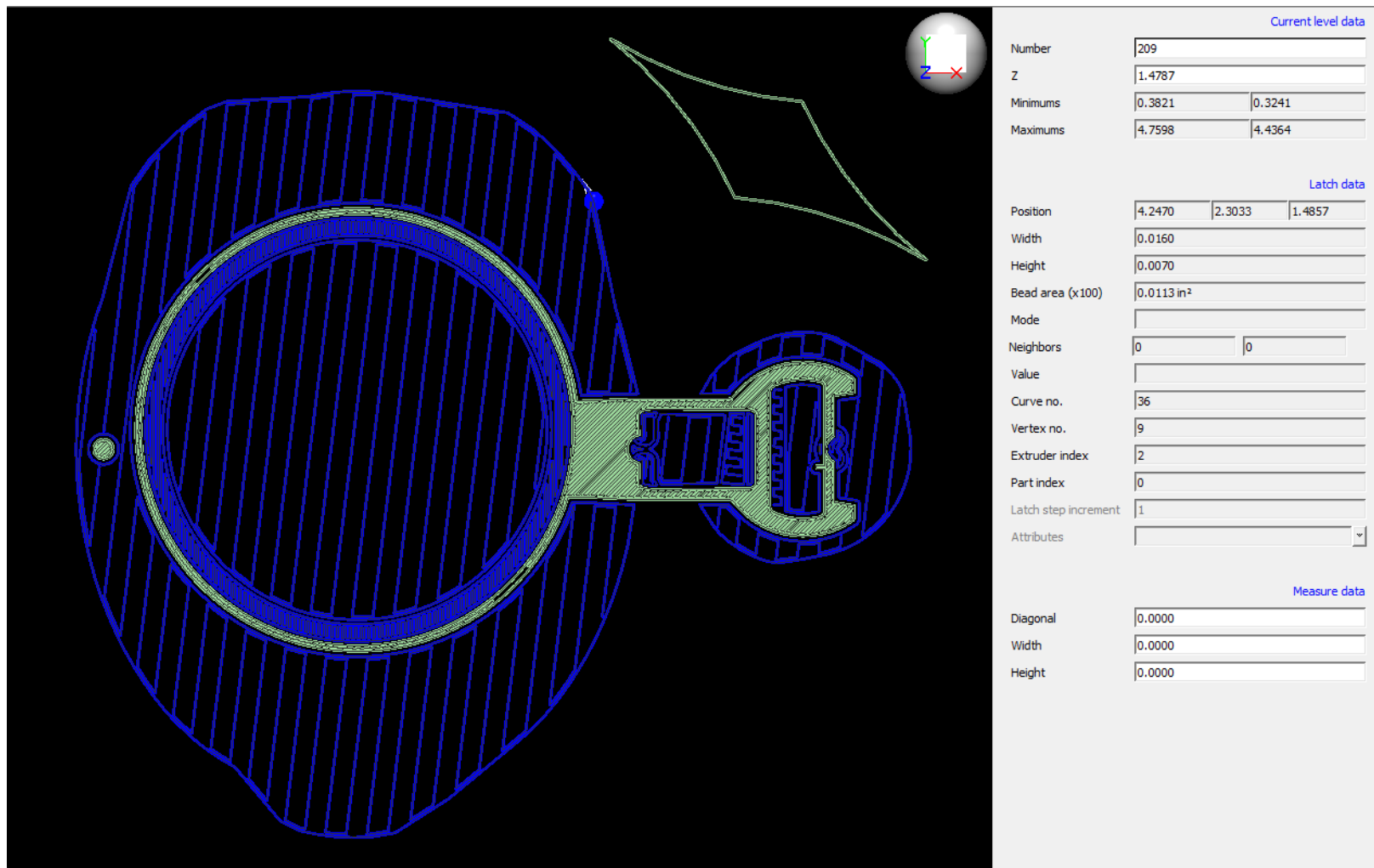


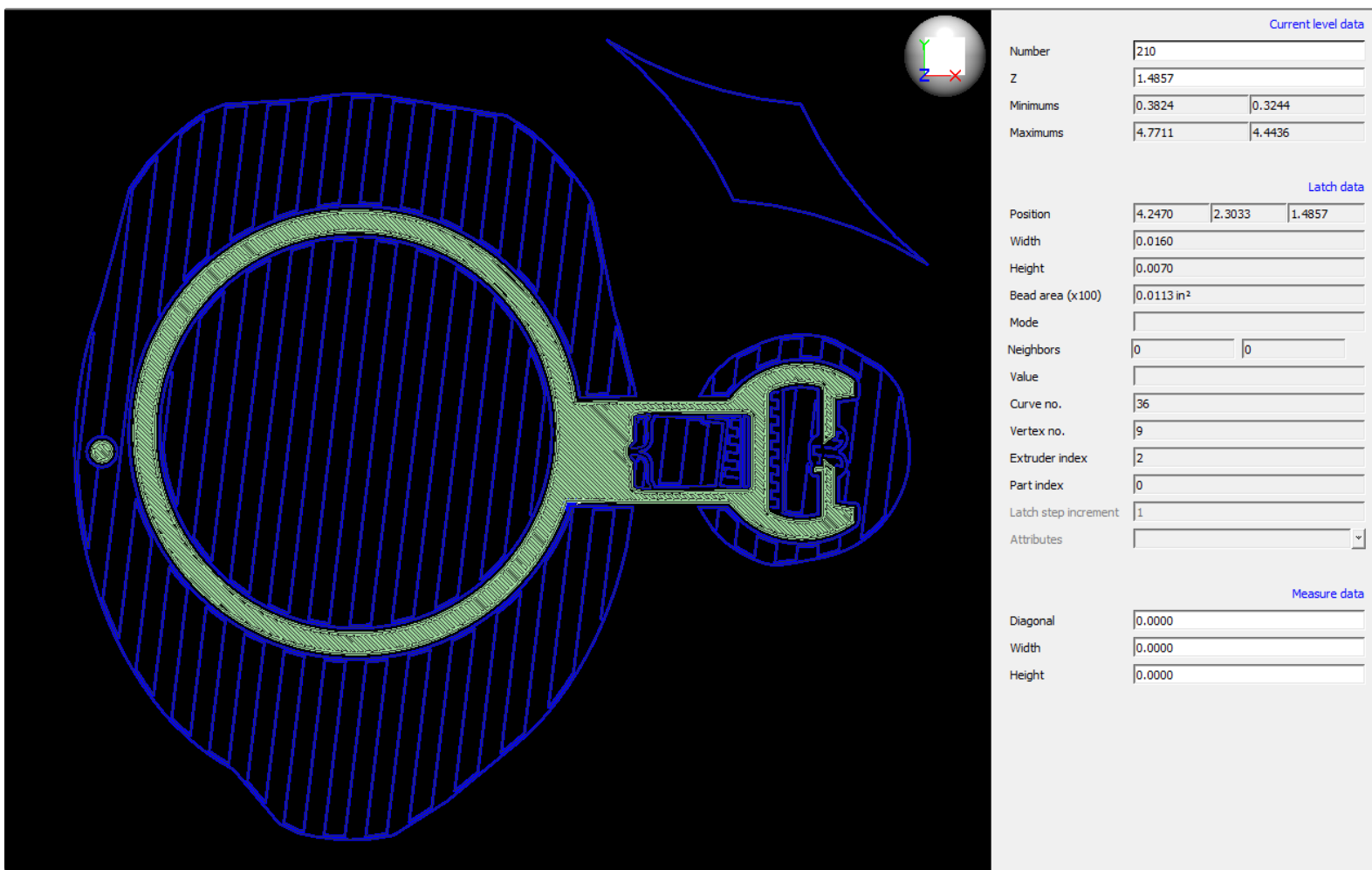


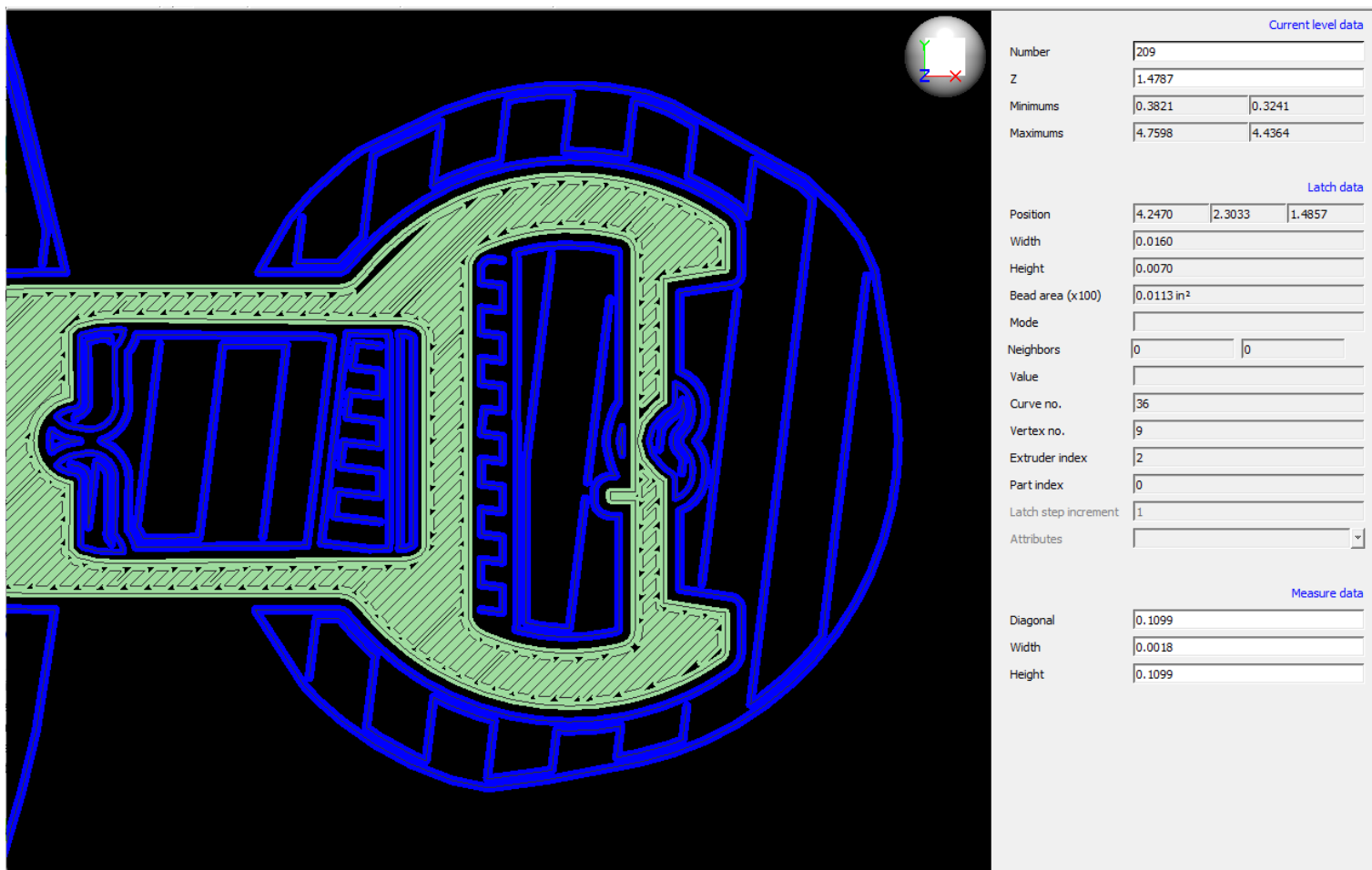


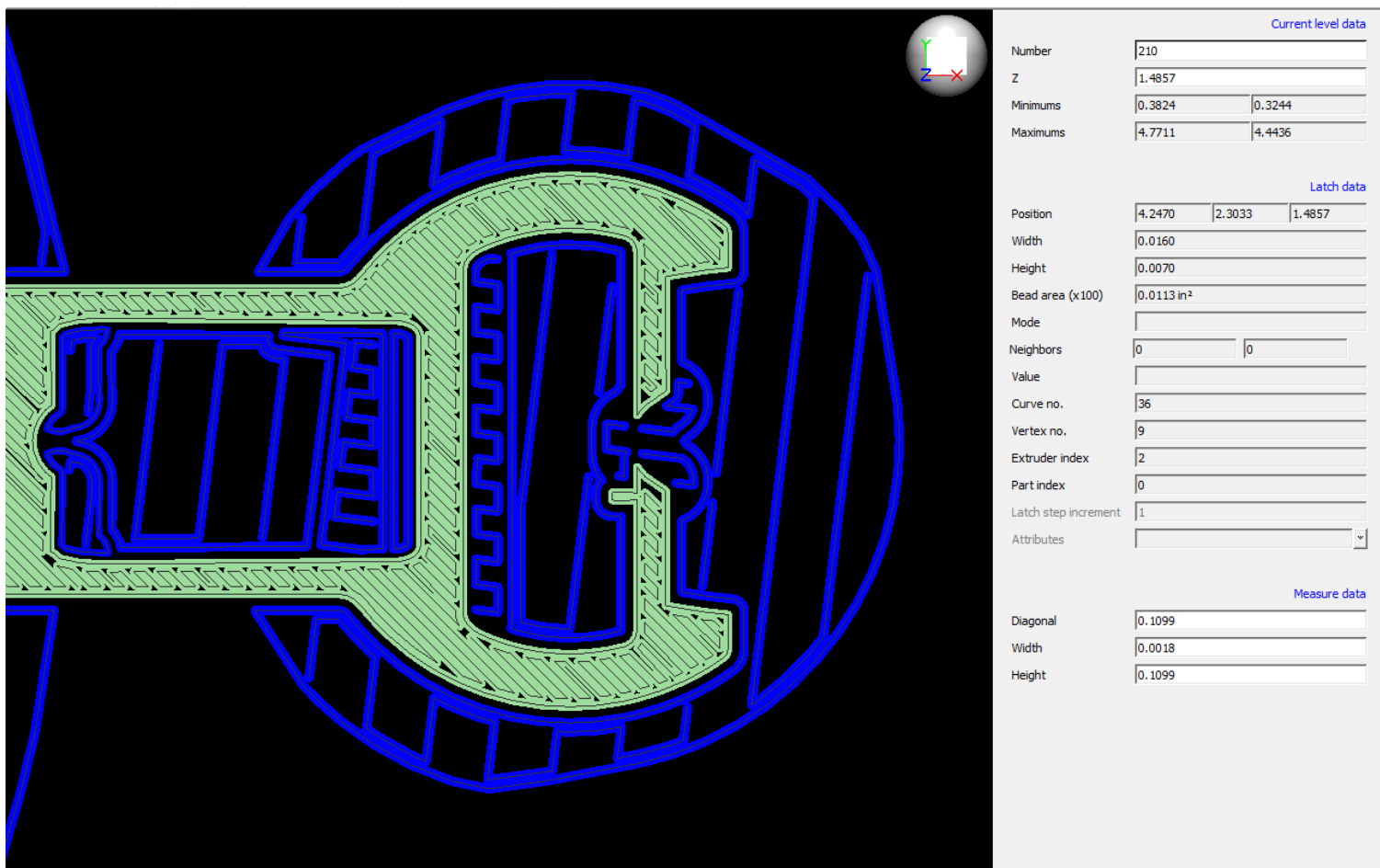






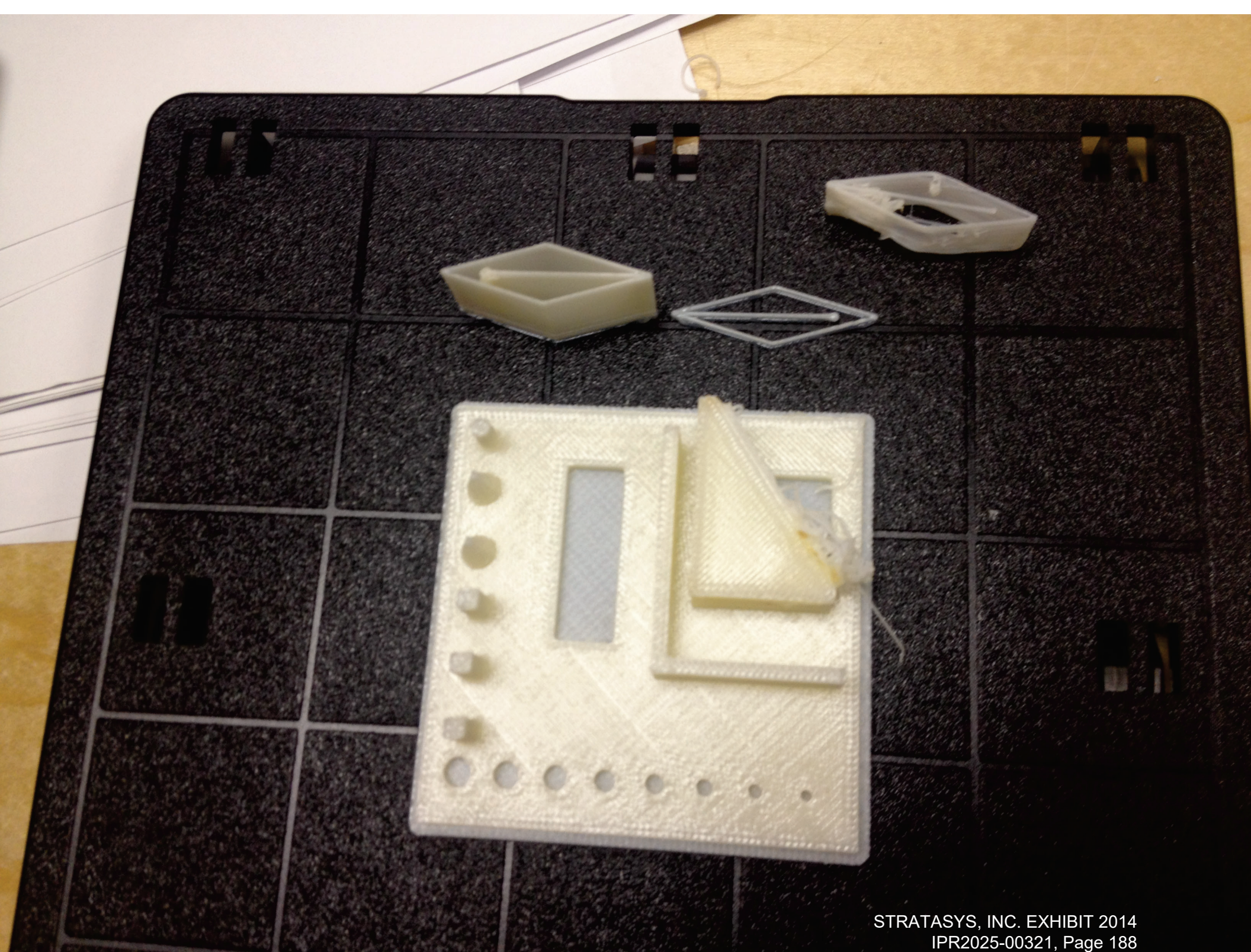






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Color	not specified			GUID	
Tip size	T12			Limits	
Volume	6.469729			Part width	0.0110 0.0600
Slice height	0.0070			Part area	0.0001 in ² 0.0004 in ²
Number of slices	607			Part aspect ratio	1.5767 8.5714
System mode	none			Support width	0.0121 0.0191
Part build style	none			Support area	0.0001 in ² 0.0001 in ²
Shrink factor (X Y Z)	1.000000	1.000000	1.000000	Support aspect ratio	1.7244 2.7303
Has variable width					
CMB locked					
User name					
Embedded version					
System Serial#					

EXHIBIT F



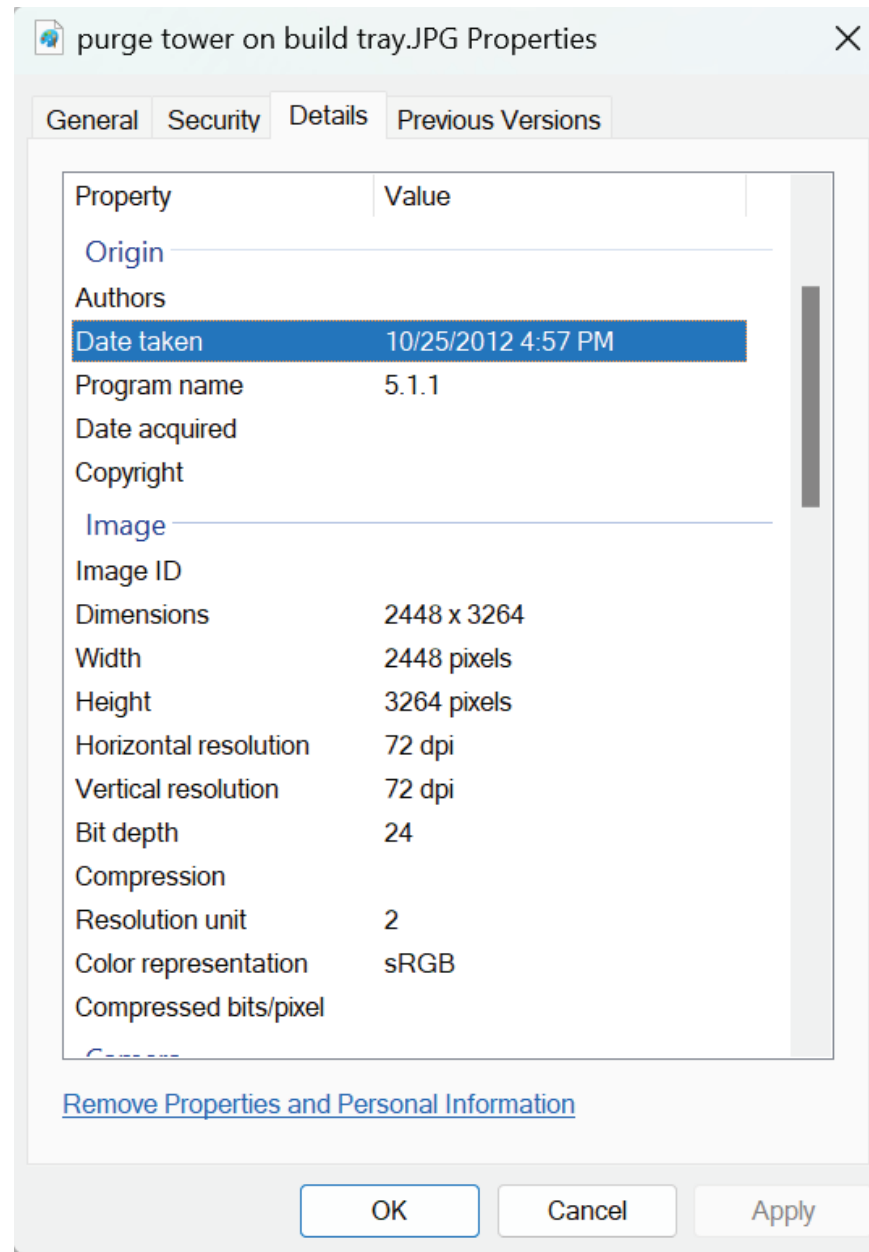


EXHIBIT G

