Introduction

The purpose of this Design Validation Testing (DVT) report is to document the lessons learned, issues encountered, and corrective measures taken during the creation and testing of our epoxy-molded pepper grinder assembly. Over the course of this project, we evaluated various manufacturing steps including 3D printing, silicone mold creation to epoxy casting, CNC machining, screw assembly, and water-jet cutting. By detailing these steps, we hope to capture a clear picture of where our design and processes succeeded and where they can be improved for future production runs.

Objectives

Our main objective was to verify that each component of the pepper grinder, as originally designed, could be manufactured consistently and function as intended. This included testing the epoxy molding process to ensure a high-quality aesthetic finish and proper internal cavity alignment, verifying that the CNC-machined base of the grinder could withstand multiple machining operations without part slippage, and confirming that the screw and clip assembly could be integrated without damaging the threads. Additionally, we aimed to validate that the water-jet cut magnetic rings and clips met dimensional requirements and that the male and female grinders mated correctly. These objectives guided our validation strategy and shaped the corrective actions taken when issues arose.

DVT Procedure

Throughout this DVT, we took a systematic approach to manufacturing and testing. First, we created a 3D-printed master for the grinder body, which was then used to fabricate a silicone mold. Epoxy was carefully mixed and degassed before pouring into the mold to create the body. After curing, each molded body was inspected for aesthetic and structural integrity.

For the bottom portion of the grinder, we performed several CNC operations including facing and drilling. We paid particular attention to how the part was secured in the six jaw chuck and how the reference zero was set, as the design features of this bottom piece significantly influence the overall dimensions and assembly fit.

We also evaluated two methods for securing the main grinder screw. Initially, the plan involved a nylon press-fit component, but this was replaced with E-clips that fit into grooves machined directly into the screw. Finally, we water-jet cut the magnetic rings and retaining clips, focusing on clamp security to avoid warping or misalignment. Parallel to these efforts, the male grinder was split into two separate components to simplify CNC machining, while the female grinder was produced via wire EDM to achieve the intricate geometry needed for proper grinding action.

Observations and Findings

Epoxy-Molded Body:

One of the most prominent issues was the presence of bubbles in the epoxy body, despite degassing. We suspect that the layer lines on the 3D-printed mold master contributed to small pockets where air could become trapped. These surfaces, once transferred into the silicone mold, made it more challenging to eliminate bubbles entirely. Moreover, the epoxy did not fully cure in certain areas, resulting in a tacky surface. We believe this issue arose from either an inferior epoxy brand or insufficiently thorough mixing. The silicone core that creates the internal cavity of the pepper grinder also proved too flexible, causing the cavity to shift off-center. Incorporating a metal rod to reinforce the silicone core is an ongoing solution to maintain the desired alignment.

CNC-Machined Base:

When milling the base of the grinder, an initial concave curvature along the outer surface left minimal contact area for the vise. During subsequent operations such as resurfacing and drilling, the part slipped from the vise, causing damage to both the part and the tooling. This highlighted the importance of providing adequate flat surfaces or more robust clamping features in the design. Additionally, we discovered that the machining process was zeroed from the wrong reference point, meaning too little material was removed from the top, and the resulting geometry did not match our intended tolerances. Moving forward, we plan to always zero from the surface that requires the greatest dimensional precision—in this case, the surface where the holes are to be drilled.

Screw and Retention Mechanism:

Originally, we planned to press-fit a nylon component onto the base of the grinder to constrain the screw's lateral movement while allowing free rotation. The necessary groove for this nylon piece, however, proved cumbersome and expensive to machine. We then switched to an E-clip design, machining grooves into the screw and clipping the E-clip in place to secure the assembly. This approach simplified the design of the bottom grinder piece but introduced a risk of damaging the screw threads when cutting the grooves. To address this, we used a die to rethread the screw post-machining, ensuring that any damaged threads were restored to maintain the proper grinding adjustment function.

Water-Jet Cut Magnetic Rings and Clips:

In the early trials, warping was observed on the water-jet cut parts. We traced this issue back to incomplete clamping on the water-jet bed. By verifying that all three clamps on the water-jet cutter were firmly secured before each operation, we minimized warping and produced flat, dimensionally accurate components. The design of the magnetic rings and clips themselves remained sound and required no modifications, indicating that the issue was strictly related to the manufacturing process.

Male and Female Grinder Components:

The male grinder was redesigned to be machined in two separate pieces - a top and a bottom - to simplify manufacturing steps and reduce the complexity of toolpaths. This approach maintained the grinder's functional requirements while reducing the likelihood of machining errors. Meanwhile, the female grinder was produced via EDM, which provided the required precision for this small, detailed part. Both the split male grinder and the EDM-fabricated female grinder met our dimensional and functional specifications without significant design revisions.

Recommendations and Next Steps

Moving forward, we will refine the manufacturing process to address the issues uncovered during this DVT. For the epoxy molding, a higher-quality epoxy resin and more rigorous mixing techniques will be adopted. We may explore pressure casting and additional mold master preparation, such as sanding or priming the 3D-printed surface, to further minimize bubble formation. Reinforcing the silicone core with a metal rod is also essential to maintain the desired cavity alignment in each cast part.

In terms of CNC machining, redesigning the base of the grinder to include a larger flat surface or an alternative clamping feature should be a priority. We will also implement standard operating procedures to ensure the machine zero is consistently referenced from the most critical surface. For the screw retention mechanism, the transition to E-clips will remain the preferred method, but we will continue refining the machining process around the groove to mitigate any thread damage and reduce the need for post-machining rethreading.

Finally, maintaining proper workholding practices on the water-jet cutter will be an ongoing goal to avoid the warping of thin metal parts like the magnetic rings and clips. As for the male and female grinders, the split male grinder design appears reliable and will continue to be employed. The female grinder's performance via EDM was effective, and we see no immediate need to change that process.

Conclusion

Overall, the design validation testing for this pepper grinder assembly has underscored the critical importance of robust process control, proper fixturing, and material handling at every stage of production. While we encountered challenges such as bubble-filled epoxy molds, shifting silicone cores, part slippage in CNC machining, and damage to threads during screw grooving, each of these issues revealed valuable insights for process improvements. By integrating the recommended changes - improving mold masters, using better epoxy, redesigning the bottom part for better clamping, reinforcing the silicone core, and refining the screw retention method - we will move closer to a stable, repeatable manufacturing process. These iterative refinements not only bolster product quality and functionality but also pave the way for a more efficient and cost-effective path to high-volume production.