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DESIGNING A MOLD TOOL FOR A RUBBER COMPONENT

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Abstract. The rubber components are an integral part of many machines and devices which are used in the automotive industry, hydraulics, pneumatics, construction machinery, HVAC, medical, etc. Rubber components function to solve the problems. Generally, those problems are vibrations, sharp edge that could cause damage to another components, rubber components that serve to isolation, protection, seal. The perfect material to address structural and functional issues in physical systems across a wide range of industries is rubber, thanks to its elasticity, high resilience, and tensile strength. The several manufacturing processes such as compression molding, rubber injection molding, transfer molding, rotational molding, etc., can be used for rubber component manufacturing. The aim of this paper is to present the design process and manufacturing of rubber components, presenting a necessary steps from idea to real prototype. The design process focuses on customer needs, minimizing manufacturing costs and reducing the carbon footprint. The design methodology for the manufacturing of rubber components will be presented in this paper. The design process includes customer needs, identification of the market needs, process planning, developing engineering specifications, developing the product using 3D CAD models, developing mold tools, making technical drawings, defining all information necessary for production, etc. The overall design process for developing and manufacturing rubber components will be presented through illustrative photos and prototype of mold tool and rubber component will be presented.

Keywords: Mold tool, CNC milling machine, CNC turning machine, rubber component.

Introduction

Rubber is usually a thermoset elastomer with high elongation and deformation under external loading, consistent high temperature characteristics, good vibration and energy absorber, low sensitivity to ultraviolet radiation, etc [1]. Rubber components are designed to solve specific problems, such as unwanted vibration or sharp edges that could damage other components. In any situations rubber parts serve to isolate, seal, and protect. Due to its elasticity, high resilience, and tensile strength, rubber is an ideal material for resolving structural and functional challenges in physical systems across various industries. The rubber components are an integral part of many machines and devices which are used in the automotive industry, hydraulics, pneumatics, construction machinery, HVAC, medical, etc.

This paper outlines the design methodology and creation of a mold tool for rubber components, leveraging CNC technology, including both milling and turning operations. The mold tool for injection compression molding will be used. The initial phase involves defining operational parameters based on factors such as the expected production volume, component complexity, and desired manufacturing timeline. After a thorough review of technical schematics, with careful consideration of cost-effectiveness and product quality, the mold tool is engineered to produce a functional prototype. The mold tool is constructed using 1.1730-grade steel for the turned sections and 1.2312-grade steel for the milled parts. The manufacturing process utilizes a CLX 450 lathe and a DMU 50 milling machine. Before production begins, the mold undergoes a preparatory phase, where manufacturing components are prepared. This includes generating the necessary G-code in SolidCAM software, which is then sent to the respective machines for execution. Once the mold tool fabrication is complete, rubber is injected into the mold tool to produce the final product.

Review of Modern Information Sources on the Subject of the Paper

The design process methodology focuses on customer needs, minimizing manufacturing costs and reducing the carbon footprint. The design process of a rubber component and its mold tool is a complex process which consists of a several phases such as [2]: identification of market needs, project planning, product definition or definition of the product engineering specifications, conceptual design and developing the product using CAD models, calculations, selection of materials, making technical drawings for the prototype production and defining all necessary information for manufacturing. Developing of a rubber component begins by using CAD software package SolidWorks in according of customer needs and market research. Furthermore, 3d model of rubber component will be used to be create a mold tool with CNC technology, including both milling and turning operations. In this paper, injection compression molding process will be used for producing rubber components. Injection compression molding is a manufacturing process which includes conventional injection molding and compression molding [3]. Compression molding of rubber [4, 5] is a process where in a heated mold cavity preheat rubber will be placed. Injection compression molding is a fully automated process, and material is heat to a flowing state and injected under pressure through one or several runners or sprues into the mold [6, 7].

Objectives and Problems of Research

The aim of this paper is to present the design process and manufacturing of mold tool and rubber components, presenting in detail the essential steps involved in transforming an idea into real prototype. The design process focuses on customer needs, minimizing manufacturing costs and reducing the carbon footprint. The overall design process for developing and manufacturing rubber components will be presented through illustrative photos and prototype of mold tool and rubber component will be presented.

Main Material Presentation

Mold Tool Design for the Rubber Component

The design of the specified product for manufacturing is complex, and consequently, the fabrication of its mold tool is also complex. By using SolidWorks software, the mold tool cavities of the product are designed. The mold tool is divided into the following components: the upper plate, lower plate, central plate, cores, cavities, and core guides (see Fig. 1).

The cavities are divided along the parting line, meaning they are split into two parts. This division is necessary due to the product's circular shape (resembling a tree), which would otherwise make its removal impossible. The cavities are embedded in the upper and lower plates. This particular design choice for the mold is largely driven by economic considerations [8-10]. The cores and cavities are manufactured on a lathe, while all other mold components are made using a milling machine. The upper plate contains an opening through which rubber is injected, and the rubber flows through the guides to fill the channels around the product.

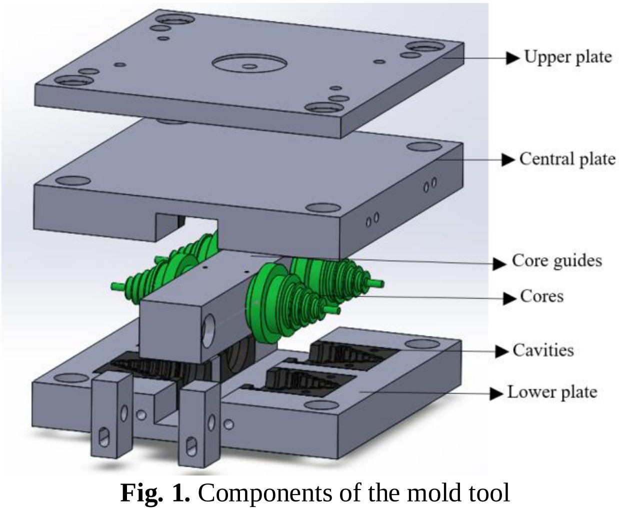

Fig. 1. Components of the mold tool

To machine the part on a CNC machine, a code must first be generated and sent to the machine. This code is created using the SolidCAM program.

Turning Processes Using SolidCAM

Turning is a fundamental machining process where a workpiece is rotated while a cutting tool removes material to shape it. SolidCAM enhances this process by allowing detailed G-code generation, which translates design parameters into actionable machine instructions. This section explores the specific details of the turning operations carried out using the CLX 450 CNC lathe.

Machine Configuration

The CLX 450 CNC lathe (see Fig. 2), used extensively for turning operations, supports four-axis machining and advanced automation features. It ensures consistent precision and high productivity, particularly for producing cylindrical parts such as pins and cavities in molds. Its robust design and user-friendly interface make it an ideal choice for both prototype and mass production applications.

Workflow in SolidCAM

The turning process begins with defining the stock material and the coordinate system in SolidCAM. The following steps illustrate the workflow:

• Stock Setup: The raw material is defined with additional offsets to accommodate clamping and machining operations. SolidCAM's intuitive interface allows operators to visualize stock setups and plan machining strategies effectively.

• Toolpath Generation: SolidCAM's simulation environment facilitates the creation of roughing and finishing toolpaths, ensuring minimal material waste. Techniques like spiral turning optimize material removal, while contour finishing refines the geometry to meet precise specifications (see Fig. 3).

• Tool Selection: Profiling tools are selected to achieve smooth surfaces and accurate contours. Specialized tools, such as threading and grooving inserts, are used for intricate features, including internal threads and sharp edges.

• Advanced Features: The turning operations often involve precise threading and groove cutting, which require specialized G-code commands. SolidCAM enables fine-tuning of tool parameters to achieve desired outcomes in complex geometries.

• G-code Export: After simulation, the finalized toolpaths are converted into G-code, which is then transferred to the CLX 450 lathe for execution. Real-time feedback from the machine ensures that operations proceed smoothly.

Fig. 2. CLX 450 CNC lathe

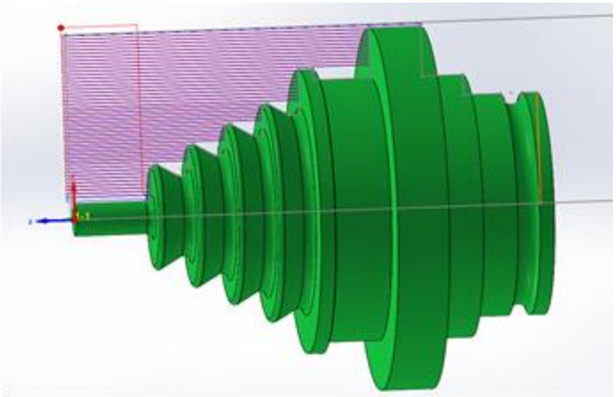

Fig. 3. Turning path for rough finishing

Milling Processes Using SolidCAM

Milling, a subtractive manufacturing process, involves cutting material from a stationary workpiece using a rotating tool. SolidCAM streamlines this process with features like adaptive roughing, high-speed machining, and multi-axis operations. This section delves deeper into the technical intricacies of milling operations.

Machine Configuration

The DMU 50 milling machine (see Fig. 4), with its five-axis capability, is optimal for creating complex mold geometries. Its versatility allows for simultaneous multi-directional toolpaths, reducing the need for part reorientation and improving surface finish. The machine's high-speed spindle and integrated cooling systems enhance tool life and maintain dimensional accuracy during prolonged operations.

Workflow in SolidCAM

- Selection of Coordinate System (see Fig. 5)
  - ➢ The CNC machine on which the piece will be manufactured is selected,
  - ➢ The work coordinate system is chosen,
  - ➢ It is specified that the plate is unprocessed,
  - ➢ The target for how the plate should look is selected.

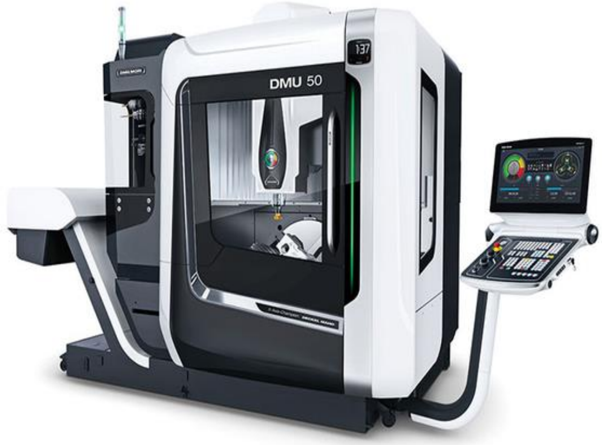

Fig. 4. DMU 50 milling machine

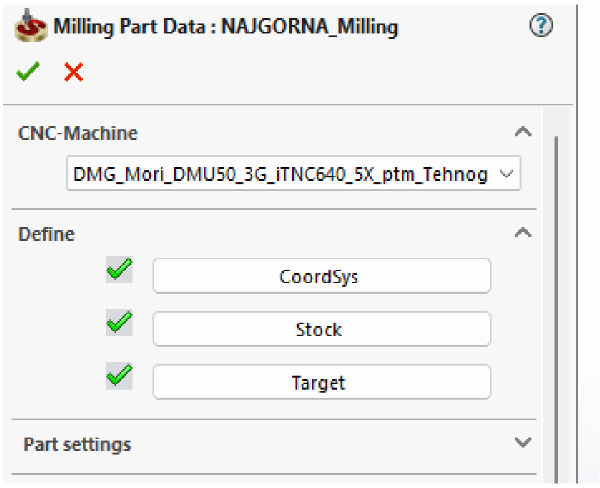

Fig. 5. Selection of coordinate system

- Plate Alignment

After selecting the coordinate origin, the initial operation is always aligning the plate. Both the top and bottom surfaces, as well as the sides, are aligned. A specific tool, the Face Mill, is used for this operation (see Fig. 6). Its design and dimensions are optimized for executing the task efficiently. For side alignment, similar steps are followed with different parameters and tools.

- Centering Holes with a Spot Drill

Spot drilling is used to establish the center of the holes to ensure precise drilling. A spot drill tool is employed for this operation.

- Drilling Holes with a Drill pit

After determining the center of the holes, the next step is complete drilling of the holes. A drill bit is used for this process. Holes are created using spot drills for centering and twist drills for full-depth penetration (see Fig. 7). SolidCAM's drilling module enables precise control of depth, speed, and entry angle, ensuring accuracy and minimizing tool wear.

- Machining a Countersunk Area Around the Central Hole (Rough and Fine Finishing)

Additional operations include machining holes for screw heads on the underside and creating rubber channels (rough and fine finishing). For rough machining, extra material is left, which is later removed during the fine finishing to achieve a smooth surface.

- Machining of holes for screw heads on the underside
- Production of rubber grooves (Rough and Fine Finishing)

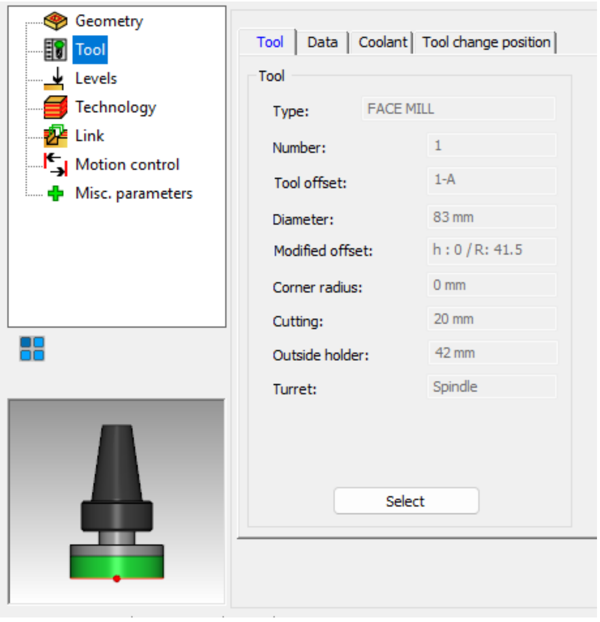

Fig. 6. Face mill tool

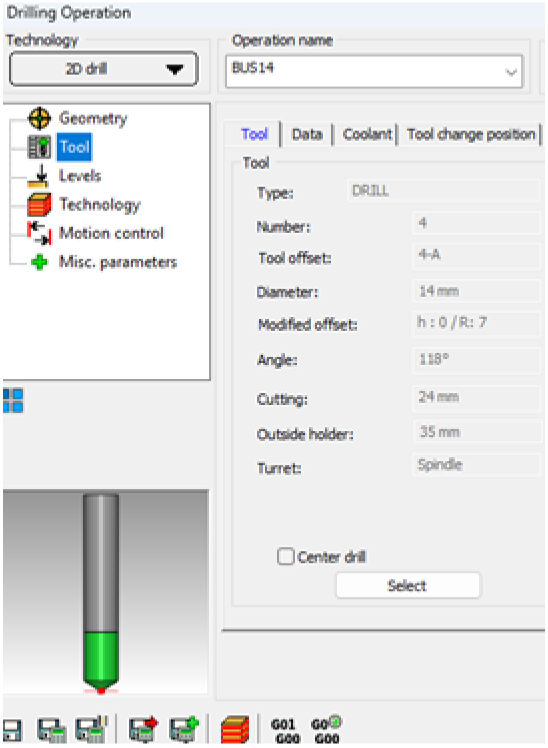

Fig. 7. Drill tool

In Figure 8, the fine processing of the rubber channels can be seen with a blue outline.

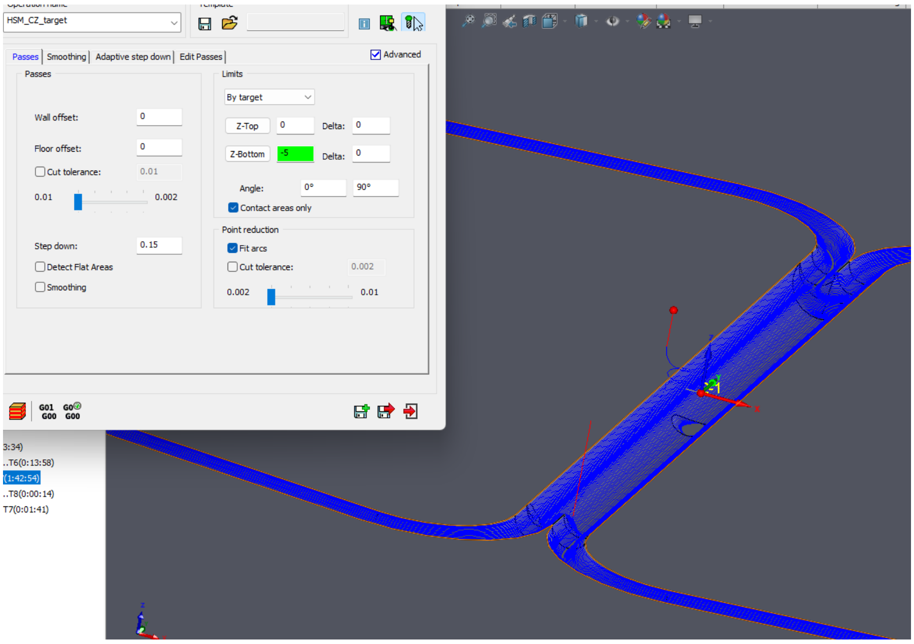

Fig. 8. Rubber channels – Fine finishing

Case Study: Mold Tool Manufacturing

In the production of a rubber mold, both turning and milling operations play critical roles. The mold is divided into components such as upper and lower plates, guiding pins, and cavities.

• Material Selection: Steel grades 1.1730 and 1.2312 were chosen for their durability and machinability. 1.1730 steel was used for its wear resistance in turned parts, while 1.2312 steel's ability to undergo thermal treatments made it suitable for milled components.

- Turning Operations: Pins and cylindrical cavities were produced using the CLX 450 lathe. Accurate toolpath generation in SolidCAM ensured tight tolerances and smooth finishes, vital for achieving seamless assembly. Operations included rough turning for material removal and fine profiling for precise dimensions.
- Milling Operations: Plates and complex geometries were machined using the DMU 50. SolidCAM's multi-axis capabilities allowed for intricate designs such as rubber flow channels and alignment features. Strategies like trochoidal milling ensured efficient material removal in hard-to-reach areas while preserving tool life.

Integration and Assembly: The machined parts were assembled to create a complete mold, which underwent final testing to ensure proper functionality. Alignment features, such as dowel holes and guide slots, were critical for the mold's operational precision during the injection process.

Advantages of Using SolidCAM

- Efficiency: SolidCAM reduces machining time by optimizing toolpaths and minimizing material waste. Its algorithms for high-speed machining increase productivity without compromising accuracy.
- Accuracy: The software ensures high precision, meeting tight tolerances required in mold manufacturing. Real-time feedback from simulations minimizes deviations from design specifications.
- Flexibility: Multi-axis operations enable the production of complex geometries, accommodating a wide range of industries and applications.
- Cost-Effectiveness: By streamlining processes, SolidCAM lowers production costs without compromising quality. Reduced setup times and material waste further enhance economic efficiency.

Challenges and Solutions

- Tool Wear: High-speed operations can lead to rapid tool degradation. Implementing real-time monitoring and adaptive strategies in SolidCAM mitigates this issue. Tools with coatings like titanium nitride enhance wear resistance.
- Complex Geometries: Designing intricate parts demands advanced knowledge of toolpath strategies. SolidCAM's intuitive interface and simulation tools reduce this complexity, while training modules help operators gain proficiency.
- Material Properties: Variability in material hardness affects machinability. Preprocessing simulations help predict and adjust for these challenges. Additionally, adaptive feeds and speeds are utilized to handle materials with varying properties effectively.

Final Prototype of Mold Tool and Rubber Component

The prototyping of a mold tool, the first step is preparing the material used for the production. A raw piece of steel is used. Before securing the piece in the machine, the sides, top, and bottom surfaces are first processed. Once processed, the piece is clamped into the machine, and the center of the piece is determined using a touch probe. After determining the center, the mold cavity is created based on the previously generated G-code. The images below show the prototype of the actual mold (see Fig. 9).

Figure 10 illustrates the rubber component produced using injected compression manufacturing process, with the mold tool shown in fig. 9.

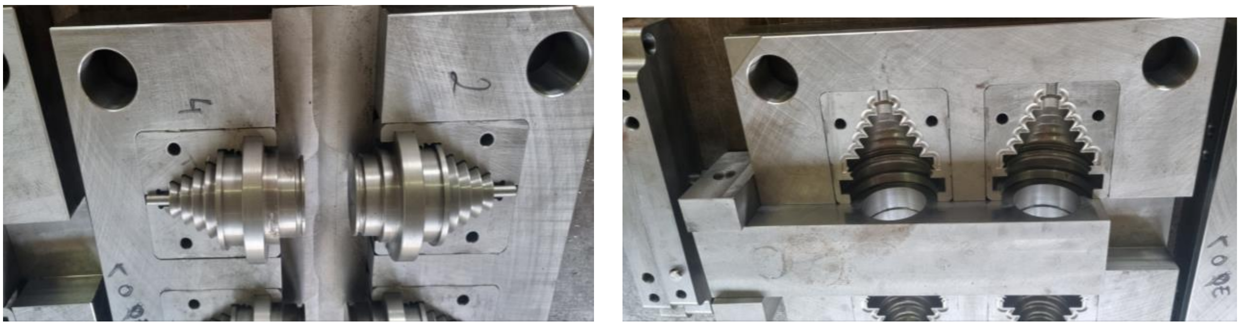

Fig. 9. Final prototype of mold tool

Fig. 10. Final prototype of rubber component

Conclusions

This work showed a design methodology process for the manufacturing of mold tool and rubber components, with a focus on preparing mold components through milling and turning. The entire preparation process was carried out using SolidCAM software, which generated the necessary G-code for corresponding machine production. The final mold tool prototype was produced using the CLX 450 lathe and DMU 50 milling machine. The design and manufacturing process for rubber components is illustrated through photos of the prototype mold tool and rubber component. From an economic standpoint, it is more cost-effective to manufacture the circular parts (cores and cavities) separately on a lathe and embed them into the plates, rather than machining the entire plate in one go, which would be significantly more complex and economically unfeasible.

Acknowledgements

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References

[1] M. Bont, C. Barry, and S. Johnston, "A review of liquid silicone rubber injection molding: Process variables and process modeling," Polym Eng Sci. vol. 61, issue 2, pp. 331–347, 2021. https://doi.org/10.1002/pen.25618

[2] D. G. Ulman, "The Mechanical Design Process, Fourth edition", McGraw-Hill Series in Mechanical Engineering, Boston, 2010

[3] G. Ramorino, S. Agnelli, and M. Guindani, "Analysis of Reactive Injection Compression Molding by Numerical Simulations and Experiments," Advances in Polymer Technology, vol. 2020, pp. 1-8, 2020. https://doi.org/10.1155/2020/1421287

[4] K. Maghsoudi, G. Momen, R. Jafari, and M. Farzaneh, "Direct replication of micro-nanostructures in the fabrication of superhydrophobic silicone rubber surfaces by compression molding," Applied Surface Science, vol. 458, pp. 619–628, 2018. https://doi.org/10.1016/j.apsusc.2018.07.099

[5] K. Maghsoudi, G. Momen, and R. Jafari, "Micro-nanostructured silicone rubber surfaces using compression molding," in Proceedings of the 8ermec 2018: 10th International Conference on Processing and Manufacturing of Advanced Materials, vol. 941, pp. 1802–1807, Paris, FRANCE, July 2018. https://doi.org/10.4028/www.scientific.net/MSF.941.1802

[6] K. Kyas, M. Stanek, D. Manas et al., "Novel trends in rheology V," Book Series: AIP Conference Proceedings, vol. 1526, pp. 142–147, 2013. https://doi.org/10.1063/1.4802609

[7] M.-S. Wu, T. Centea, and S. R. Nutt "Compression molding of reused in-process waste – effects of material and process factors," Advanced Manufacturing: Polymer & Composites Science, vol. 4, no. 1, pp. 1-12, 2018. https://doi.org/10.1080/20550340.2017.1411873

[8] A. Łukaszewicz, K. Panas, and R. Szczebiot, "Design process of technological line to vegetables packaging using CAx tools", Proceedings of 17th International Scientific Conference on Engineering for Rural Development, Latvia, 2018, pp. 871-876. https://doi.org/10.22616/ERDev2018.17.N494

[9] A. Łukaszewicz, G. Skorulski, and R. Szczebiot, "The main aspects of training in the field of computer-aided techniques (CAx) in mechanical engineering", Proceedings of 17th International Scientific Conference on Engineering for Rural Development, Latvia, 2018, pp. 865-870. https://doi.org/10.22616/ERDev2018.17.N493

[10] I. Mircheski, A. Łukaszewicz, and R. Szczebiot, "Injection process design for manufacturing of bicycle plastic bottle holder using CAx tools", Procedia Manufacturing, Elsevier, Vol. 32, pp. 68-73, 2019. https://doi.org/10.1016/j.promfg.2019.02.184

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ПРОЄКТУВАННЯ ПРЕС-ФОРМИ ДЛЯ ГУМОВОГО ВИРОБУ

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Анотація. Гумові компоненти є невід'ємною частиною багатьох машин і пристроїв, які використовуються в автомобільній промисловості, гідравліці, пневматиці, будівельній техніці, системах HVAC, медицині тощо. Гумові компоненти вирішують різноманітні проблеми, зокрема, вплив вібрації, захист від гострих країв, які можуть пошкодити інші деталі, а також забезпечують ізоляцію, захист і герметизацію.

Гума є ідеальним матеріалом для вирішення конструкційних і функціональних завдань у фізичних системах у різних галузях промисловості завдяки своїй еластичності, високій пружності та міцності на розтягування. Для виготовлення гумових компонентів можуть використовуватися різні виробничі процеси, такі як компресійне формування, лиття гуми під тиском, трансферне формування, ротаційне формування тощо.

Метою цієї роботи є представлення процесу проєктування та виробництва гумових компонентів, демонстрація необхідних етапів від ідеї до створення реального прототипу. Процес проєктування зосереджується на потребах клієнтів, мінімізації виробничих витрат і зниженні вуглецевого сліду.

У роботі буде представлено методологію проєктування для виготовлення гумових компонентів. Процес проєктування включає аналіз потреб клієнтів, визначення ринкових вимог, планування процесу, розробку інженерних специфікацій, створення продукту за допомогою 3D CAD-моделей, розробку прес-форм, створення технічних креслень, визначення всієї необхідної інформації для виробництва тощо. Загальний процес проєктування та виготовлення гумових компонентів буде представлений за допомогою ілюстративних фотографій, а також буде продемонстровано прототип прес-форми та гумового компонента.

Ключові слова: прес-форма, фрезерний верстат з ЧПК, токарний верстат з ЧПК, гумовий компонент