Mechanical Watch Model

SolidWorks mechanical watch model and motion analysis

Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of Bachelor of Science in Engineering at the University of New Brunswick

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Abstract

This report outlines the full process of designing, modeling, and analyzing the mechanical watch mechanism. The purpose of this project was to design and model the full mechanism of the mechanical watch, become familiar with modeling techniques in SolidWorks, and develop a strong understanding of motion analysis.

The project began with research and brainstorming, followed by detailed design using SolidWorks modeling. After making some assumptions due to unavailability of precise dimensions and time constraints, the assembly was set up, and the proper mates were used to create the motion.

Once the assembly was finalized, the motion study was set up to simulate the motion of the mechanism. By trial and error, proper configuration for the features responsible for the movement were determined. Based on the created motion study, the graphs for the angular displacement of the second's hand and angular velocity were generated. It was necessary to check the accuracy of the mechanism and to determine what could be improved in the future.

Overall, the project met its objectives by successfully recreating the motion of the mechanical watch with moderate accuracy. It also provided valuable experience in CAD modeling, motion analysis, and how to apply critical and creative thinking to solve the design challenges.

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1. INTRODUCTION

This project outlines the mechanism inside the mechanical hand watch (see Figure 1). The mechanism does not require any battery and is powered by the elastic force generated by a tight-wound mainspring, which winds itself by the force of gravity while the person is walking or shakes the watch.

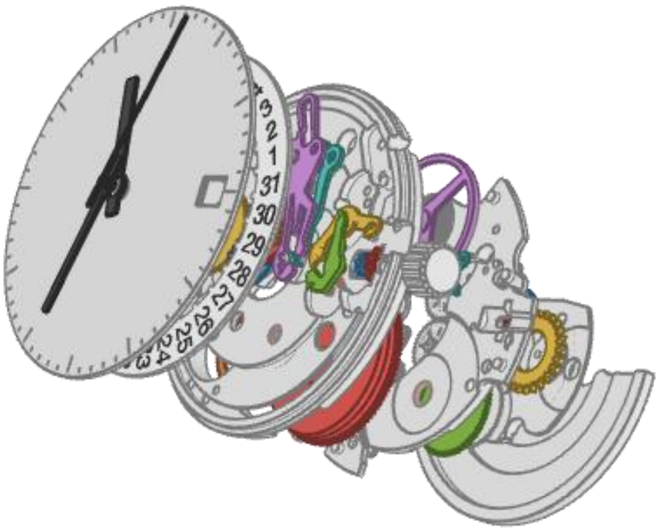

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Figure 1 – The inside of the mechanical watch. The figure outlines the entire mechanism and presents it layer by layer. [1]

1.1. Description of Chosen Mechanism

The main part of a mechanical watch mechanism is the mainspring, a tightly wound coil of steel inside the barrel (see Figure 2, the first gear on the left) that stores potential energy obtained during the movement of the mechanism or the watch itself. As the mainspring unwinds, the energy is being transferred through the terrain of gears.

The escape wheel and the fork, also called escapement, are the key components in the watch mechanism. It releases the energy in small, regular increments to ensure the accuracy of the mechanism. This regulates the movement of the gears and ensures that the hands of the watch move consistently.

The gear train also includes the balance wheel (see Figure 2, last gear on the right) which is oscillating with about 5 Hz. It works with the escapement to divide the stored energy into small time intervals, usually measured in seconds. Typically, the preciseness of the balance wheel and escapement determines how smooth the hands of the watch move.

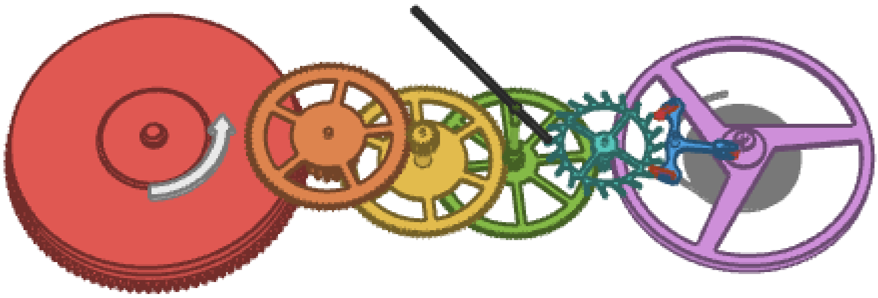

Figure 2 – The main mechanism of the mechanical watch. It includes the barrel (with mainspring), escapement and balance wheel. [1]

1.2. Application in Mechanical Engineering

Mechanical watches are a perfect example of precise engineering and planning in mechanical systems. The principles behind its operation, such as energy storage, energy transfer, and precise control of the mechanism, are extremely useful in mechanical engineering. The study of this mechanism introduces gear design, energy efficiency, and system control, which can be applied in every field of mechanical engineering. The practice of creating such a tiny mechanism supports the development of smaller and more efficient mechanisms with very tight tolerances.

2. DESIGN METHODOLOGY

2.1. Design intent

Before even thinking about modeling, the research for some mechanical mechanism was conducted. The main goal was to recreate some existing mechanisms, which would deepen the understanding of the mechanical system and support further studies in mechanical engineering.

The mechanical watch movement was selected after careful consideration. First, because to its complexity, which involves the study of the gears, springs, motion control and the intense interest about how it functions. Additionally, due of the task's complexity which creates the challenge to overcome and learn.

The main purpose of this project is to design and model the mechanical watch's functional mechanism, familiarize with SolidWorks modeling techniques, and enhance the understanding of motion analysis.

The objectives include understanding how gears work, how the energy is stored in the spring, and ways to control the mechanism. And the ability to overcome design difficulties such as lack of dimensions and complexity of assembly.

2.2. Modeling plan and assumptions

The first step in the modeling process was to research, a lot of research on mechanical watches. When it comes to the mechanical watch, it is close to impossible to find technical drawings of the parts, dimensions, or clear pictures of the mechanism. Usually mechanical watches are unique, and while the main mechanism stays almost the same from model to model, its dimensions and small details vary a lot to achieve the best performance

Following research, the model created by Bartosz Ciechanowski (see Figure 3) was chosen for further recreation and modeling. It was mainly chosen because the author clearly explains the mechanism behind each component and at the very least shows all the components.

Figure 3 – The model of the mechanical watch by Bartosz Ciechanowski. [1]

Next, the detailed list of parts was written down, which included about sixty distinct parts. Then using internet and AI models, some estimations for dimensions were made, which was not precise as it turned out later. The creation of parts started with gears, whose size was estimated, and the assumption was made that teeth size and form would be irrelevant. The springs inside the barrel (see Figure 4) and inside the balance wheel were ignored to simplify the modeling process, as well as small parts of the mechanism such as screws and jewels.

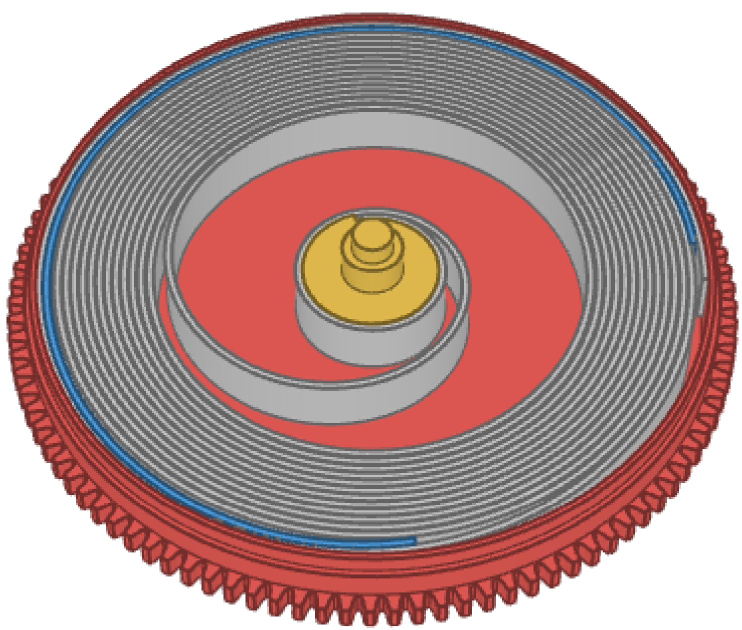

Figure 4 – The barrel with a spring inside. Presents the visual representation of the spring inside the barrel which stores potential energy. [1]

After approximation and recreation of the main gear terrain, the first assembly was set to check if the gear ratios were approximately right. Additional adjustments to the gear sizes were made to ensure proper ratios between gears when they are moving together.

One of the last and most complex parts was the mainplate, it does not look that complex, but due to the lack of dimension, it was extremely hard to compact all the gears on it. To recreate the plate, in-context modeling was used. First, the approximate location of each gear was mapped, after which the cuts on the main plate were made (see Figure 5).

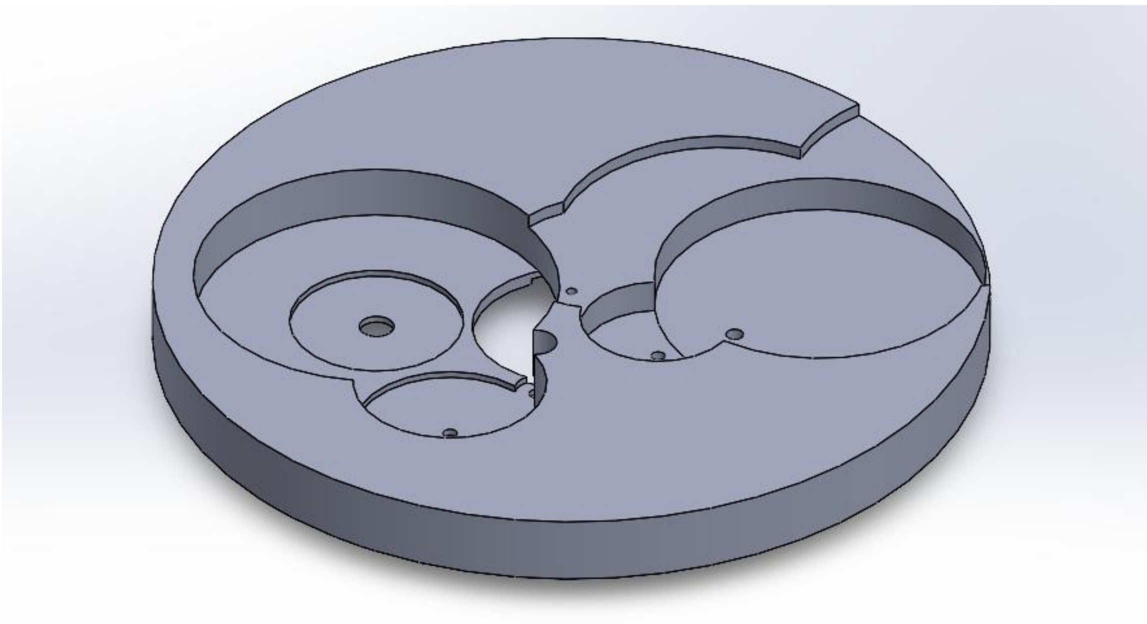

Figure 5 – The SolidWorks isometric model of the mainplante. Visual representation of the mainplante used in the project.

Creation of the mainplate followed by setting up the final assembly. The location of every gear's axis was mapped on the mainplate, and then the gears were mated to each other using the gear mate based on the gear ratios. For the ratios, the diameter of the gears was used. After setting up all the gears, one of the requirements for the project was incorporating the unique design, thus the custom clock face, and the hands were modeled in addition to the determining dimensions and applying color/materials for each part.

Lastly, the final assembly was set, the motion defined, and the exploded view was created to present the inside of the watch (see Figure 6).

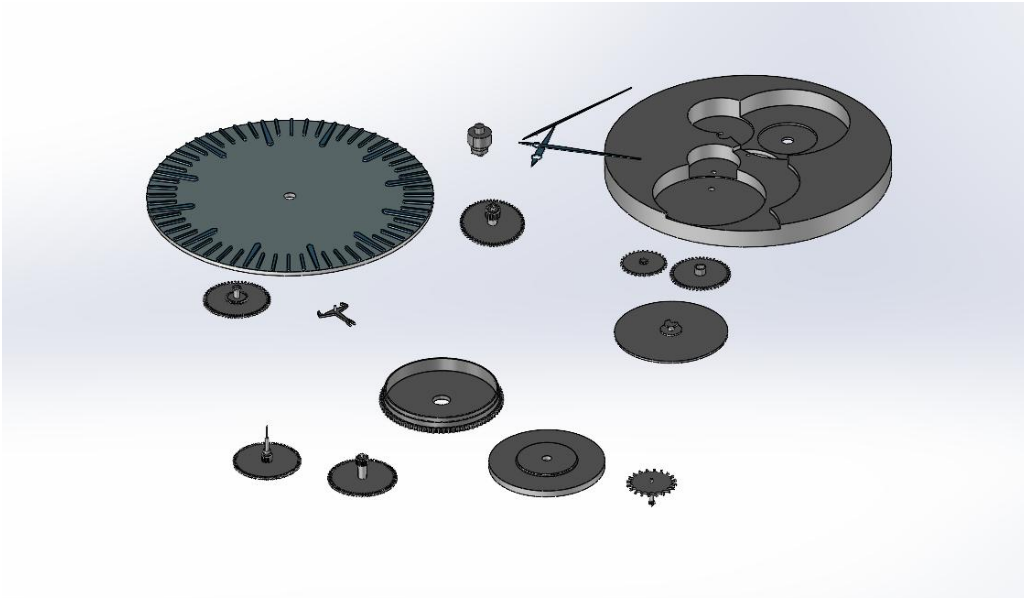

Figure 6 – Exploded view for the final assembly of the mechanical watch.

2.3. Challenges encountered and solutions

The most obvious and hardest challenge was the lack of dimensions. Even after intense research, technical drawing could not be found, which led to the need for approximation for each dimension. First, the size of the barrel was chosen based on the average size found on manufacturers' pages, and then based on it, the approximations for the rest of the system were made.

After deciding on the diameter of the gears, the teeth had to be modeled, which was accompanied by another challenge. To model the teeth properly, the equations inside SolidWorks had to be used, which would make the complex model even harder. Following some consideration and research, it was decided to ignore the teeth simply and model them just for "look," as they would not play any role in the motion analysis. They are not meshing properly (see Figure 7), but in the framework of this project it is acceptable.

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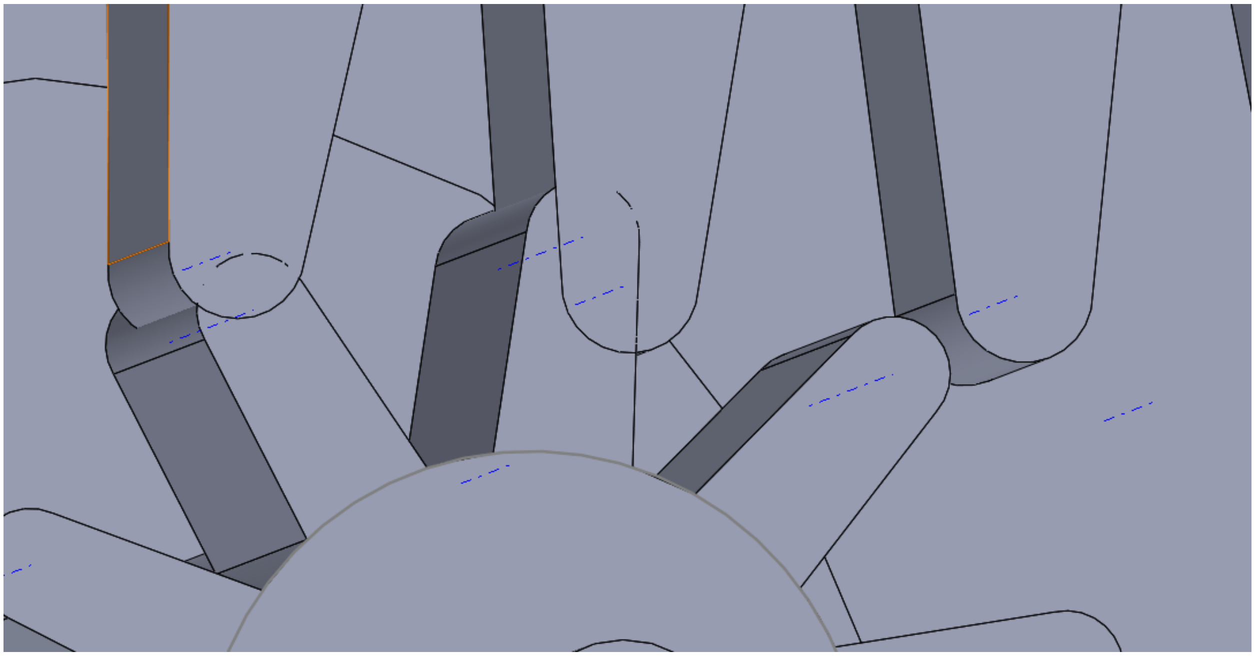
Figure 7- The visual presentation of incorrect meshing of the gear teeth on the project.

Following the recreation of the main gears, it was decided to give up on recreating the entire mechanism with every single part. The time was limited, which resulted in the need to simplify the model to finish every requirement for the project. Only the main parts needed for proper motion analysis were recreated (see Figure 8).

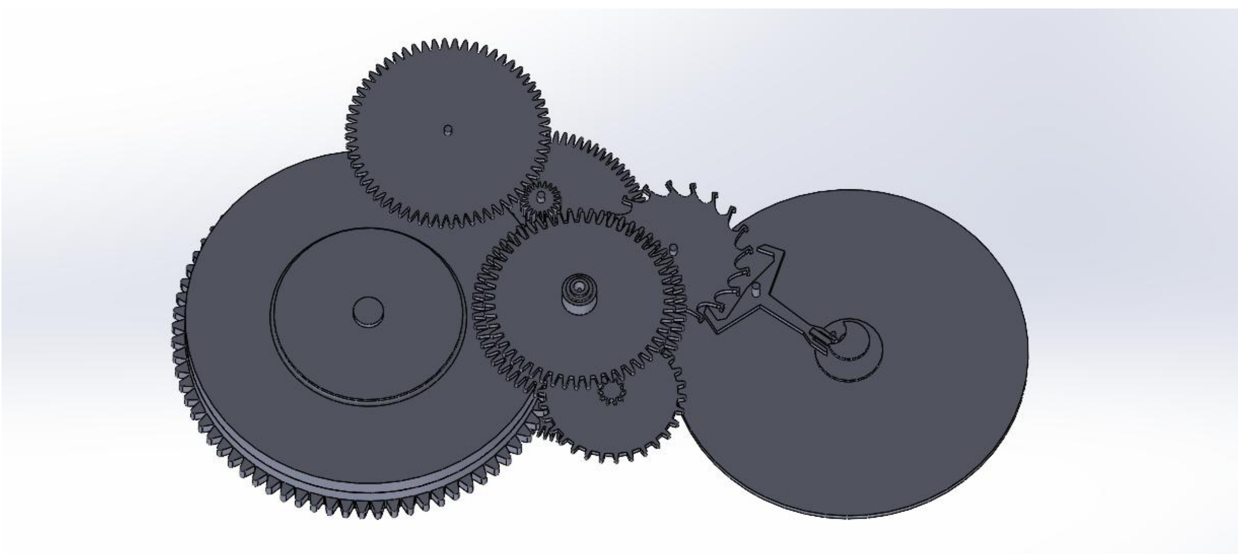

Figure 8 – The isometric view of the final mechanism used for the motion analysis.

Setting up assembly incorporated another challenge with it. Typically, an assembly should be fully defined, and when it comes to gears, it is hard to achieve it without fully restricting the motion. Therefore, to meet the project requirements, the assembly was fully defined, but the rotation of the gears was restricted (see Figure 9, final assembly).

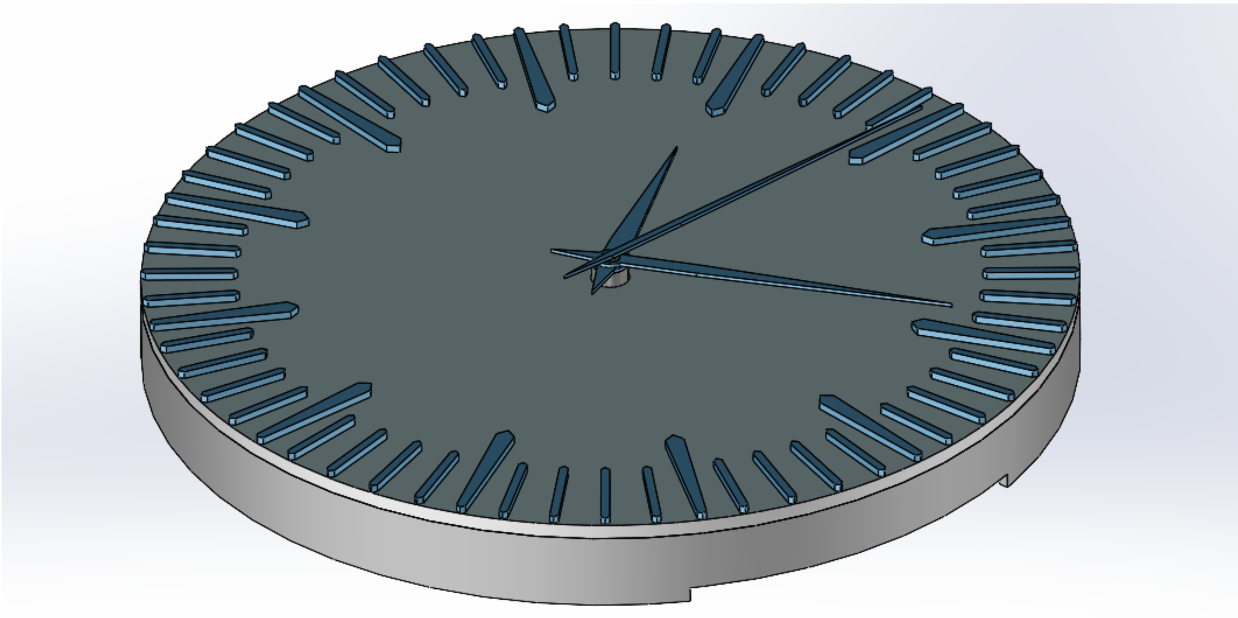

Figure 9 – The isometric view of the final assembly for the mechanical watch project.

3. Design Analysis

3.1. Motion analysis – creating motion

Following assembly, the motion study was conducted to demonstrate the clock motion. Spring mate with a stiffness of 0.0005 $^{N \cdot mm}/_{deg}$ was placed inside the barrel, it was defined to have enough stored energy to rotate the barrel for 200°. Then, the oscillating motor mate was placed on the balance wheel with the rate of 5 Hz, and the contact mate between the balance wheel and the fork was placed to make the balance wheel push the fork, which was restricting the motion of the escape wheel.

During the placements of the mate, some challenges were encouraged. First, it was necessary to choose the proper orientation for the balance wheel and fork so that they touch each other with every oscillation. Because of the contact mate, if it was not orientated perfectly from the beginning, it just did not work. The other problem was to match the size of the fork so that it properly restricted the motion of the escape wheel. After some time, these problems were resolved by trial and error, and the desirable results were achieved (see Figure 10).

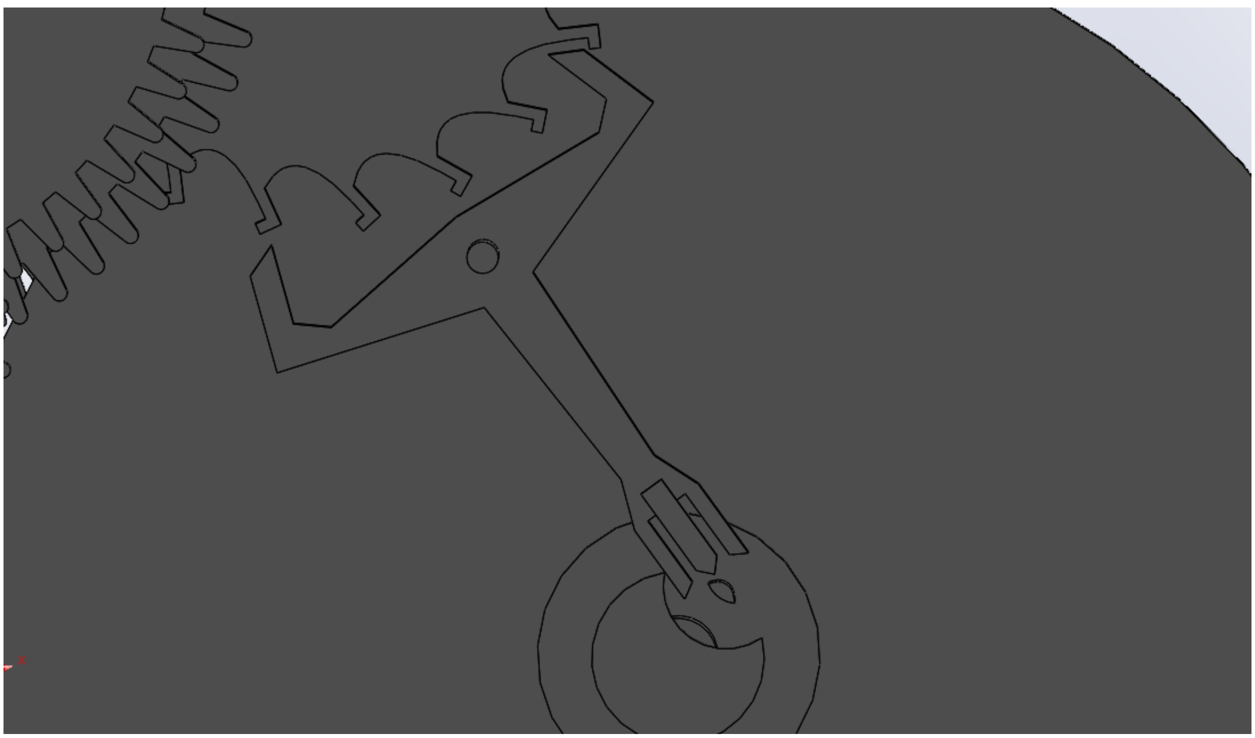

Figure 10 – The visual representation of the orientation for the fork, and the balance wheel before the start of motion analysis.

Then, some challenges were encountered while choosing the stiffness of the spring and the speed of the oscillating motor. The first one was resolved just by trial and error until the point when the stiffness was low enough to not overpower the oscillating motor so that the fork could stop the escape wheel from rotating too fast and dissipating all the energy from the spring at once. As for the speed of the oscillating motor, after some research and adjustments, it was chosen to be

5 Hz. With this value, the second's hand was moving perfectly, almost matching the real second's timing.

3.2. Motion analysis – plots and the interpretation of the results

The motion analysis was set to calculate the motion for 25 seconds. After successfully calculating the motion, the plots for the angular displacement and the angular velocity of the second's hand were generated.

The creation of the angular displacement plot was necessary to analyze the accuracy of the watch. Tracking the displacement of the second's hand and matching it with theoretical values shows the accuracy of the seconds. From the plot overall displacement from 0 to 25 seconds came up to 132.2° (see Figure 11). To figure out the theoretical value, the simple calculation was done:

$$\theta = \frac{360°}{60\ sec} \cdot 25\,\text{sec} = 150°$$

Therefore, $150° - 132.2° = 17.8°$, and $17.8° \cdot \frac{60\ \text{sec}}{360°} = 3.0\ \text{sec}$, this means that in 25 real seconds, the created mechanism moves approximately 22 seconds, which is not completely accurate. This inaccuracy of 3 seconds could be due to inaccurate gear ratios and the speed of the oscillating motor.

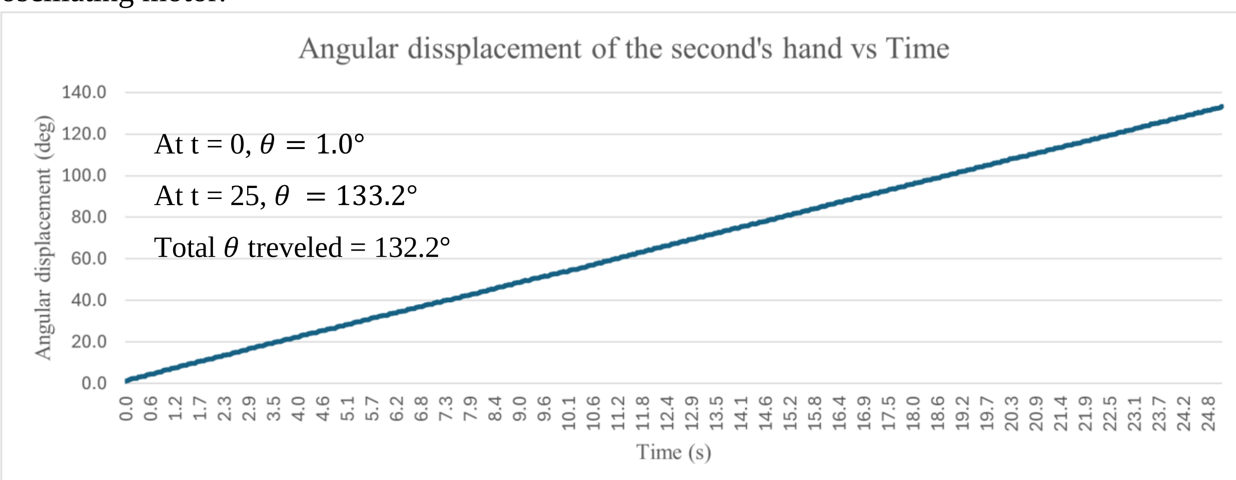

Figure 11 – The angular displacement graph for the second's hand based on the motion analysis, includes simple calculation for the total angle traveled.

During the generation of this plot, the error was encountered. If the standard "angular displacement" option to generate the graph was used, it showed a displacement of 0 degrees, which is clearly wrong. After some research and random clicking, the solution was to use the option of "Eurel's angles", which are usually used to describe the rotation in 3D. The graph generated using this option (see Figure 11) gave the desirable results.

The second plot, which was analyzed – angular velocity of the second's hand. It was necessary to see how smooth the motion is. In perfect conditions, the speed should always be constant, which is almost impossible to achieve.

Based on the graph (see Figure 12) velocity of the created mechanism is not even close to constant, but it follows the pattern (see Figure 13), meaning that the mechanism moved not randomly.

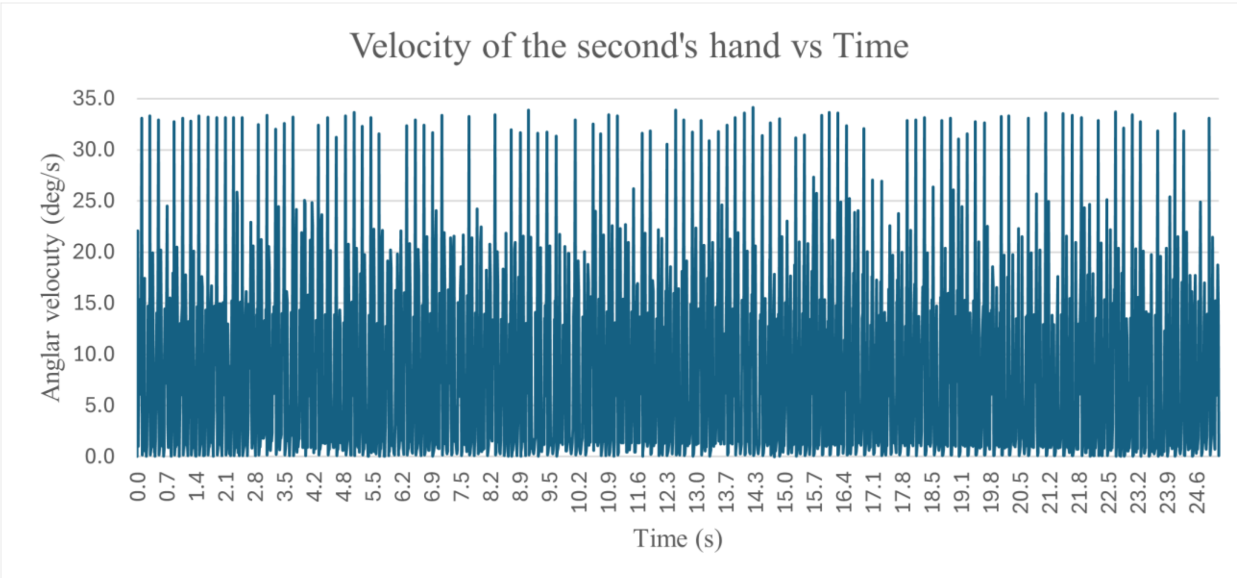

Figure 12 - The angular velocity graph for the second's hand based on the motion analysis.

This pattern proves the actual movement of the hand. It is somehow smooth because of the pattern, which is a good result considering the previous assumptions such as gear ratios, the dementing speed of the motor, etc.

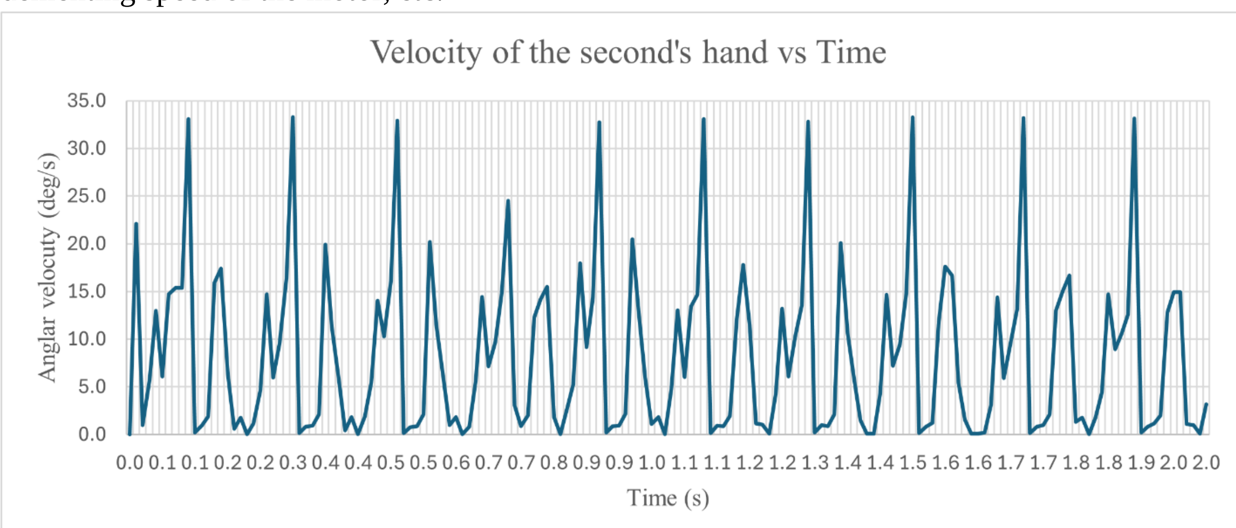

Figure 13 - The angular velocity graph for the second's hand based on the motion analysis, visually presents the pattern.

To summarize, the motion analysis was successfully completed, and the desired motion was achieved. The accuracy of the motion was moderate with an inaccuracy of about 3 seconds.

This inaccuracy was lower than expected considering all assumptions made during the modeling process and the setting up of the motion analysis.

As for future studies, the gear ratios could be calculated more accurately as well as the teeth size to achieve smooth motion and constant velocity. The oscillating motor's speed can be adjusted more accurately to achieve the perfect timing second to second.

When it comes to graphs, the energy dissipation in the barrel's spring can be analyzed to see how long the watch can work on one charge. Also, stress analysis can be conducted to see the weak points of the design.

3.3. Manufacturing requirements – tolerances, fits, and mates

Manufacturing requirements for the mechanical watches are extreme due to their tiny size, which requires high precision and low tolerances. For example, the mainplate itself has a diameter of only 24mm, and all the gears must be placed inside this plate without restricting the motion.

For this project, all dimensions in the design are in millimeters, and tolerances are consistent throughout (see Appendix: Technical drawings for each component). Tolerances were set to extremely low limits to meet the requirements of the small scale of the components.

Linear dimensions have a general tolerance of ±0.001 mm, while angular dimensions are set to be ±0.001 degrees. Circular features such as gears, pivots, and pinion shafts are also set to be within a ±0.001 mm tolerance to ensure proper meshing and rotational balance.

For all mating components, particularly shafts and holes, interference fits were chosen. Shafts must be manufactured with an upper limit of +0.001 mm and a lower limit of 0.000 mm, while corresponding holes are produced with an upper limit of 0.000 mm and a lower limit of –0.001 mm. This results in a fit that eliminates play between the parts, which is critical considering such a precise and tiny mechanism.

In addition to usual tolerances, geometric tolerances should be applied. Flatness tolerance is applied to the mainplate to ensure proper seating of components. Cylindricity tolerance is used for pivot shafts and axles to secure smooth rotation. Circular runout and total runout tolerances are also applied to rotating components to maintain balance and reduce movement during rotation.

Overall, the precision required for manufacturing demands advanced CNC machining, wire EDM, lapping, and polishing techniques [2]. Components must often be assembled under magnification due to their small size, and post-machining inspection using coordinate measuring machines or optical comparators is essential to verify dimensional requirements.

4. CONCLUSION

This project brought together everything that has been learned throughout the course and gave an opportunity to apply this knowledge to replicate an existing mechanical watch mechanism. The task to design the mechanical watch based on a real-life mechanism provided a challenging experience, one that was closely transferable to a real engineering environment. From the early stages of research and planning to the final stages of testing and evaluation, the project followed a consistent engineering design process.

By completing the entire project in SolidWorks software, the project highlighted the ability to visualize and analyze complex designs. The software made it possible to model a detailed and precise version of a mechanical watch, create the movement, and conduct a motion study. These tools are essential in engineering because they allow verification and testing of the designs before manufacturing begins, which saves a lot of money and effort.

As the project progressed, it was obvious that designs often don't work perfectly the first time. Many elements did not work properly, and frequent adjustments were made due to time constraints, missing dimensions, and the complexity of the model. Assumptions on dimensions and the look of the parts had to be made, as well as critical thinking was required to create the proper motion study.

One of the most significant challenges was the complexity of the watch's mechanism itself. Mechanical watches involve many tiny, interconnected parts that must move together. In addition, a lack of any dimensions made it difficult to achieve the precise movement. These challenges were resolved by researching, making assumptions, and working consistently on the project. As a result, the final motion study captured the motion of the mechanical watch's mechanism, presenting a close approximation of the real watch movement.

Through this project, a lot of valuable experience was gained in using SolidWorks features, mates, and techniques. These included advanced mates to control the motion of the gears, exploded views to showcase the assembly, motion studies to simulate the motion, and plotting the graphs to analyze the motion. It also involved the creation of engineering drawings suitable for manufacturing, including tolerances.

In conclusion, this project has significantly strengthened the modeling skills and improved the ability to think critically and solve design challenges. It also deepened the understanding of how modeling tools work and how they are used in a professional engineering environment. While the design could be enhanced further with proper calculations, more precise modeling, and better motion analysis, this project achieved its main goals. It successfully demonstrated a complete and visually accurate model of a mechanical watch while also providing hands-on experience in engineering design, modeling, and analysis.

5. REFERENCES

[1] B. Ciechanowski, “Mechanical Watch – Bartosz Ciechanowski.” Accessed: Jan. 27, 2025. [Online]. Available: https://ciechanow.ski/mechanical-watch/

[2] “What Defines A Handmade Mechanical Watch In The Modern World? - Reprise - Quill & Pad.” Accessed: Apr. 06, 2025. [Online]. Available: https://quillandpad.com/2021/10/16/what-defines-a-handmade-mechanical-watch-in-the-modern-world-reprise/

6. APPENDIX: TECHNICAL DRAWINGS FOR EACH COMPONENT

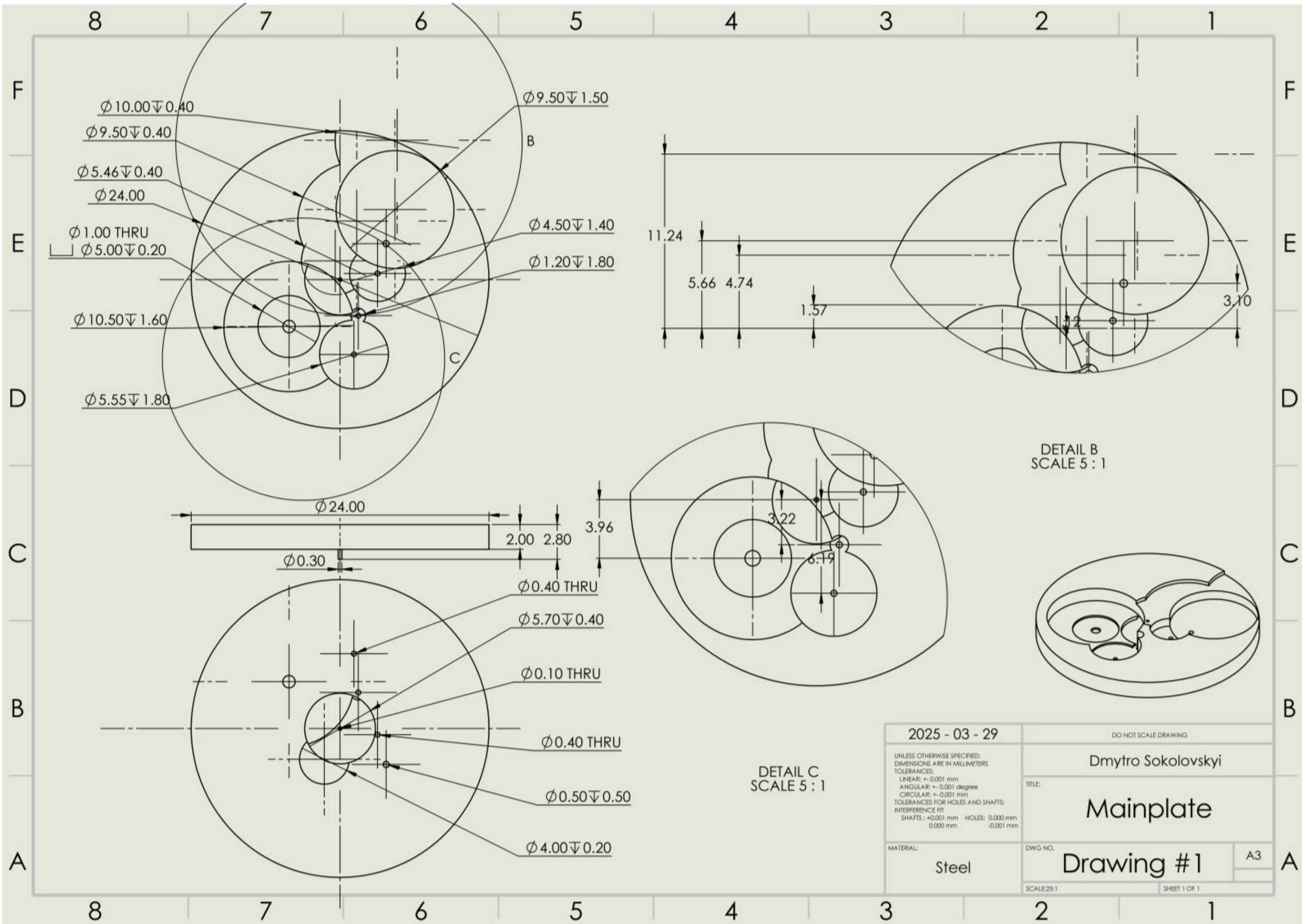

Figure 14 – The technical drawing of the Mainplate.

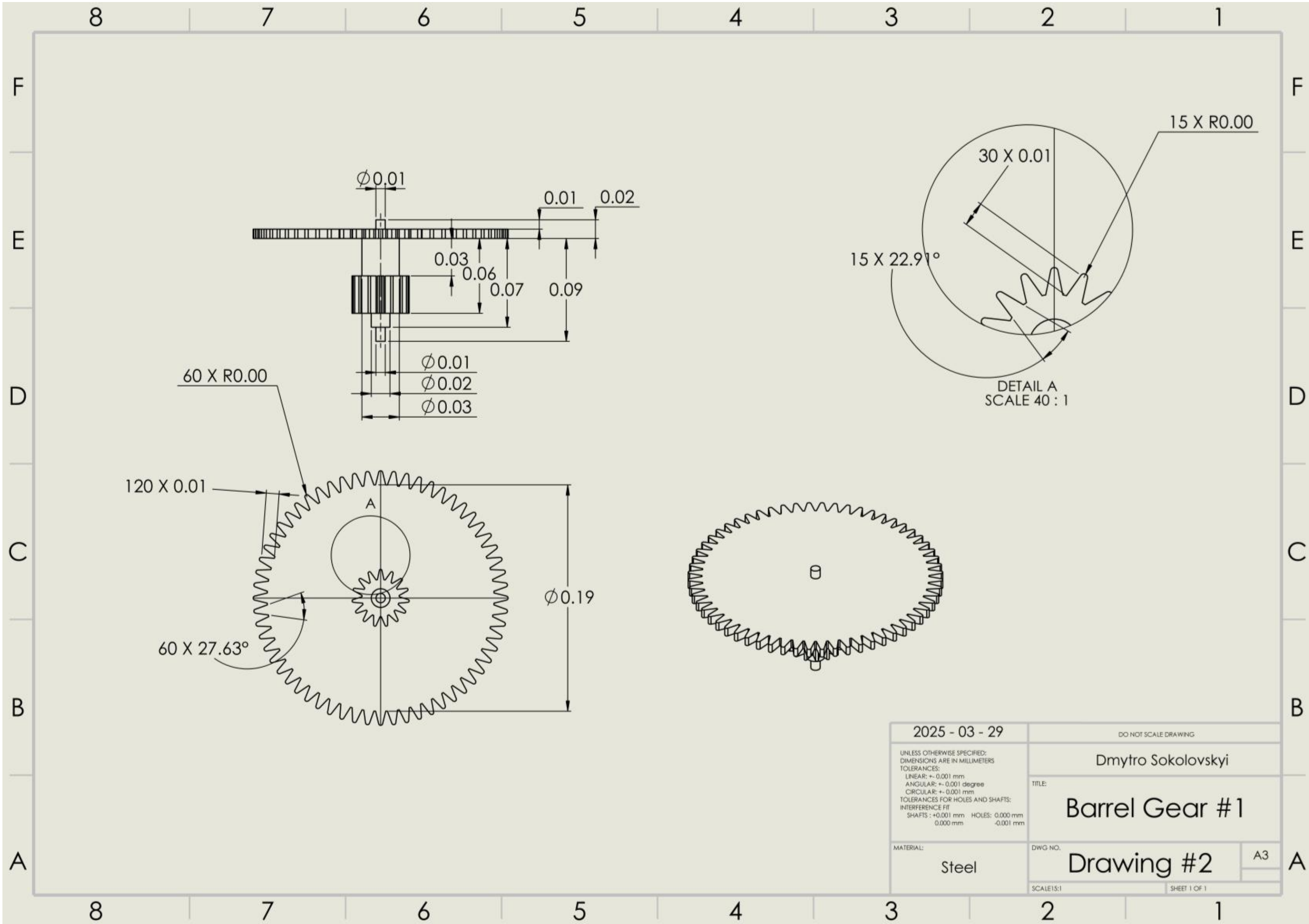

Figure 15 - The technical drawing of the barrel gear #1.

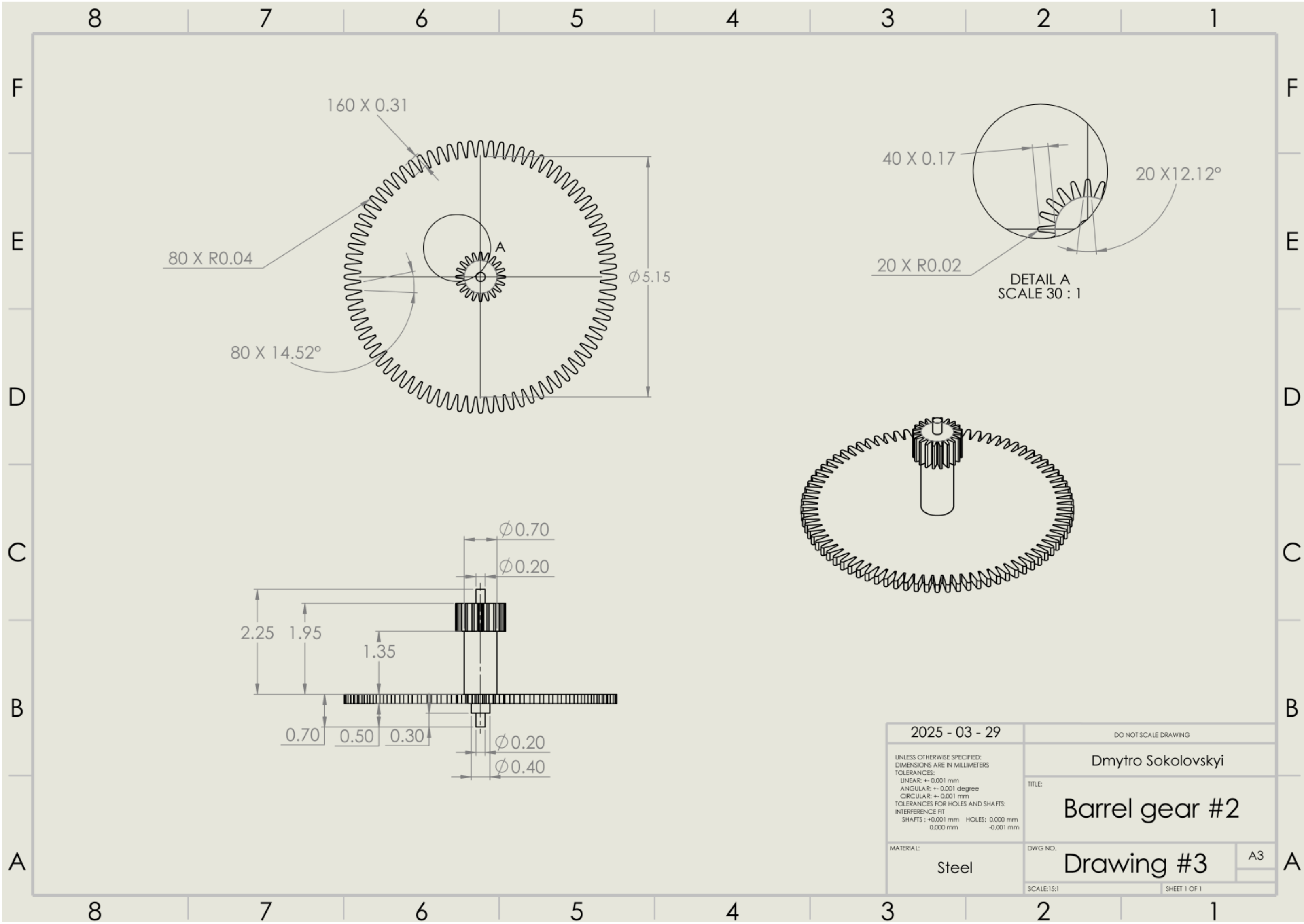

Figure 16 – The technical drawing of the barrel gear #2.

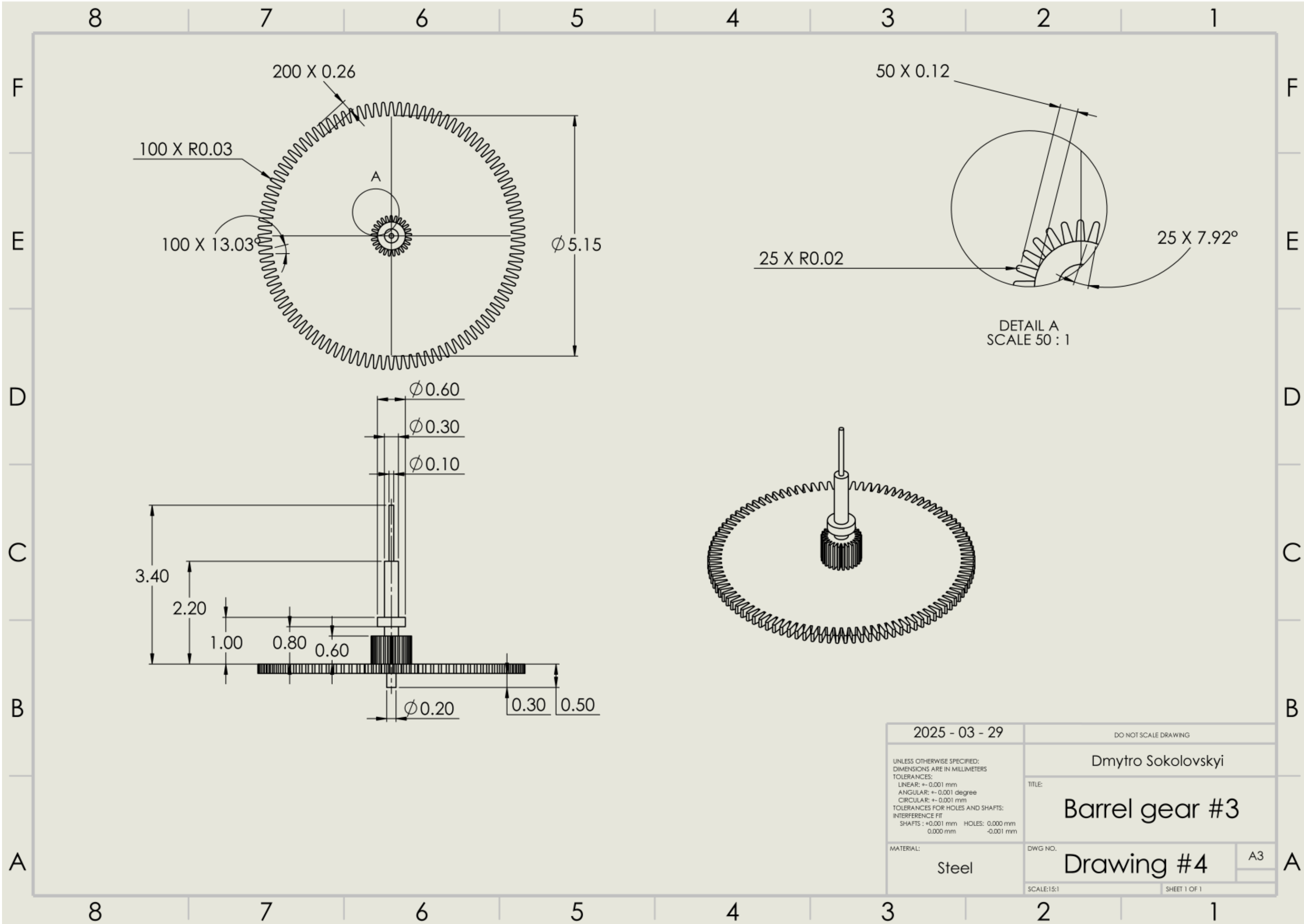

Figure 17 - The technical drawing of the barrel gear #3.

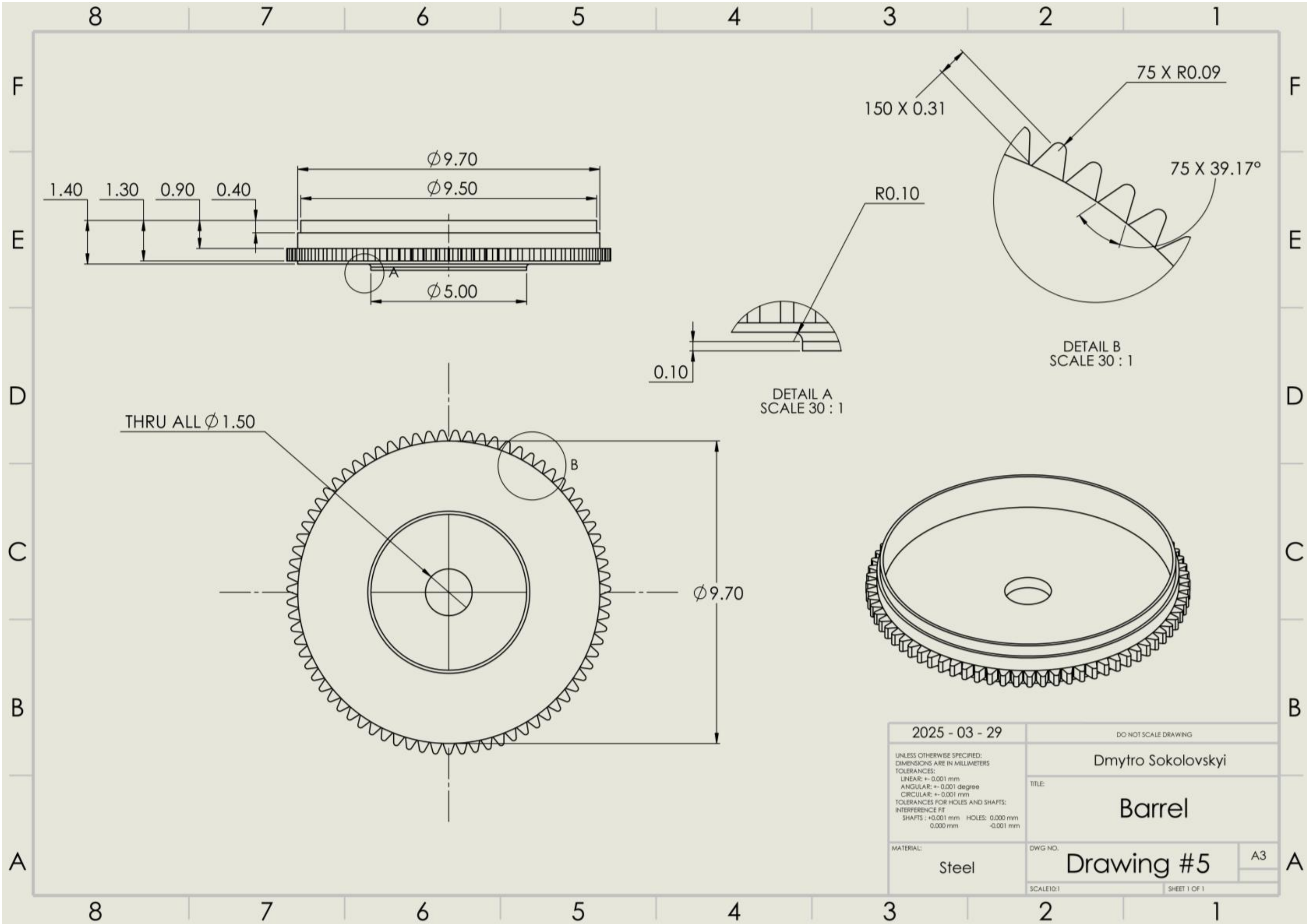

Figure 18 - The technical drawing of the barrel.

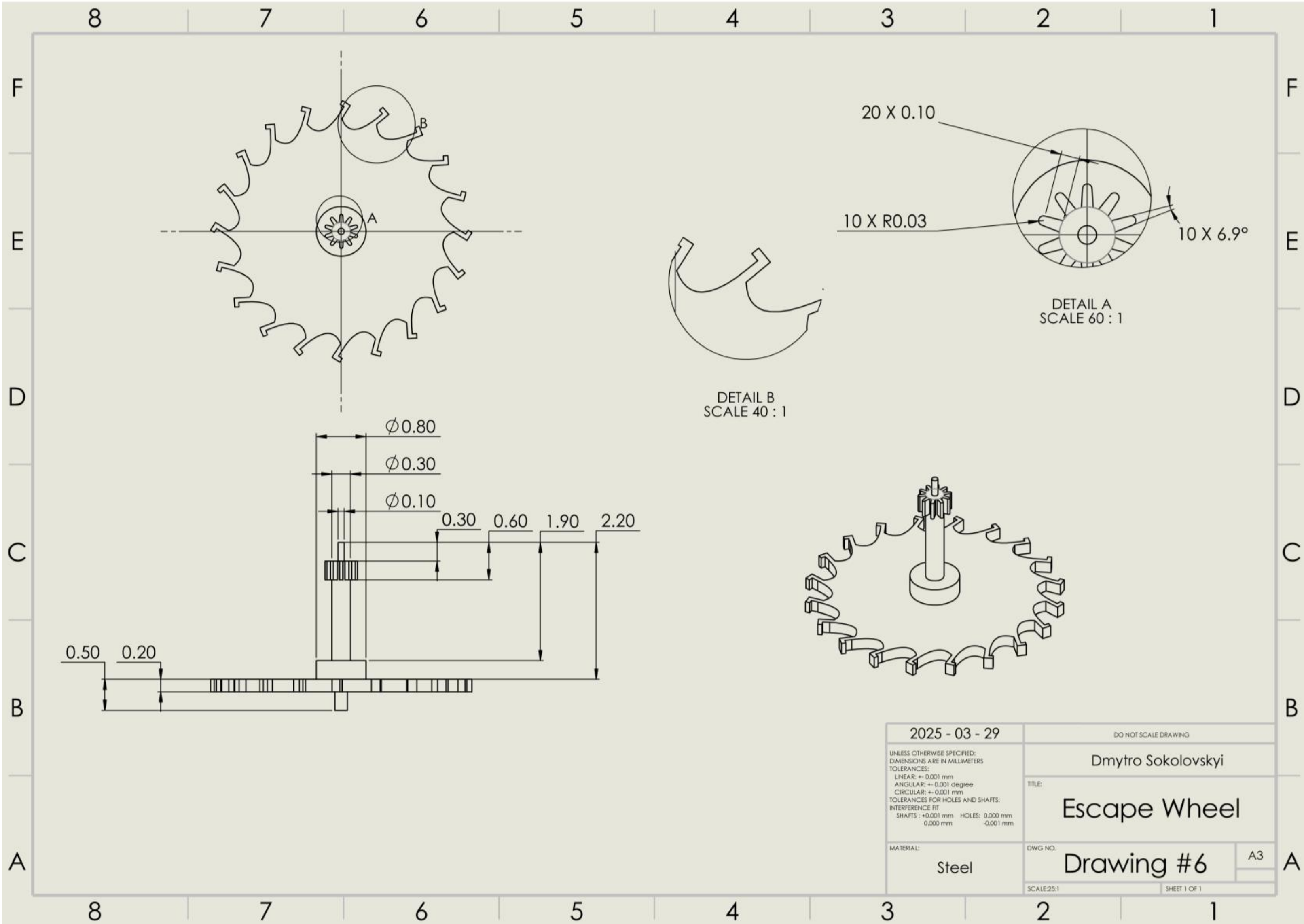

Figure 19 - The technical drawing of the escape wheel.

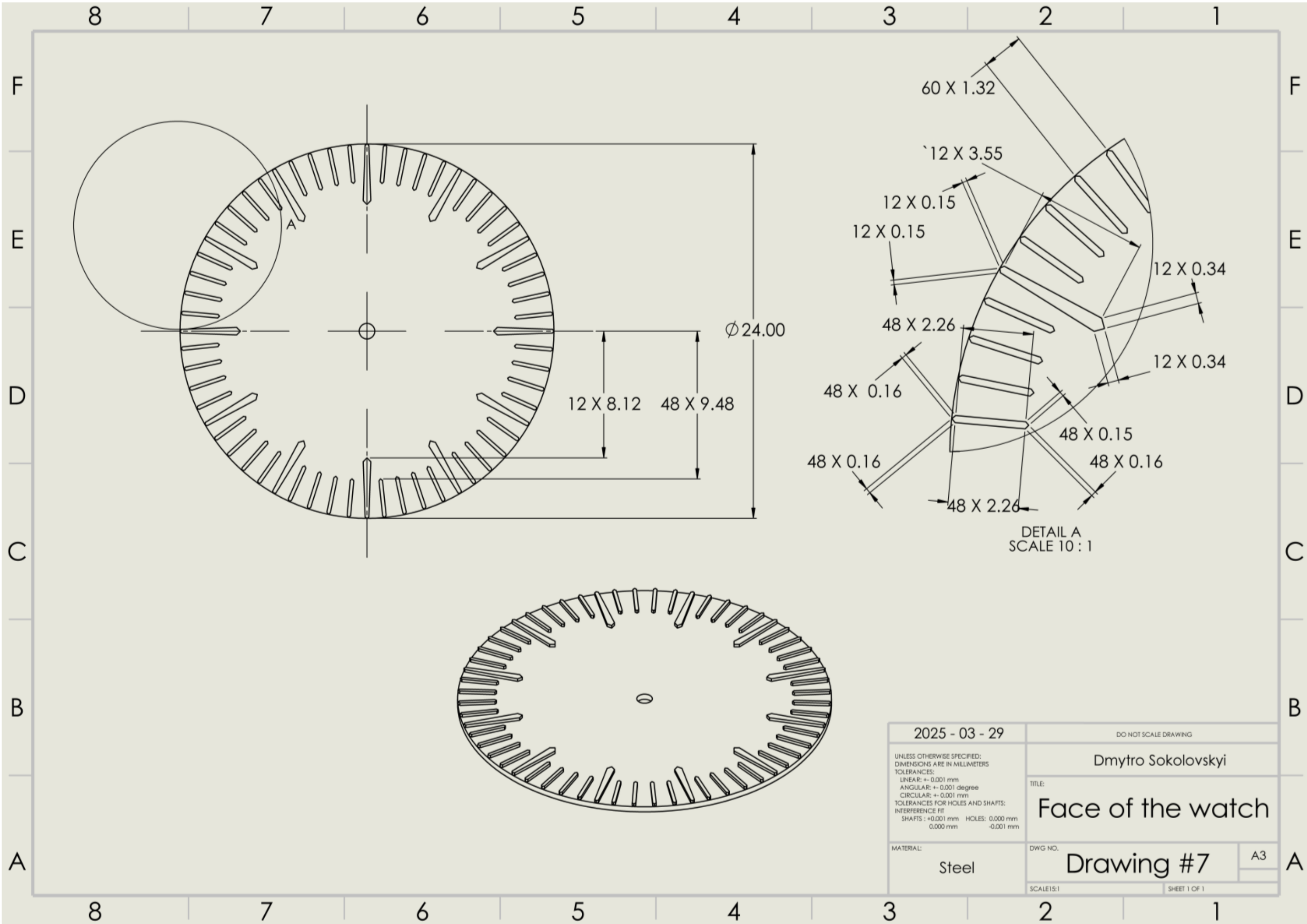

Figure 20 - The technical drawing for the face of the watch.

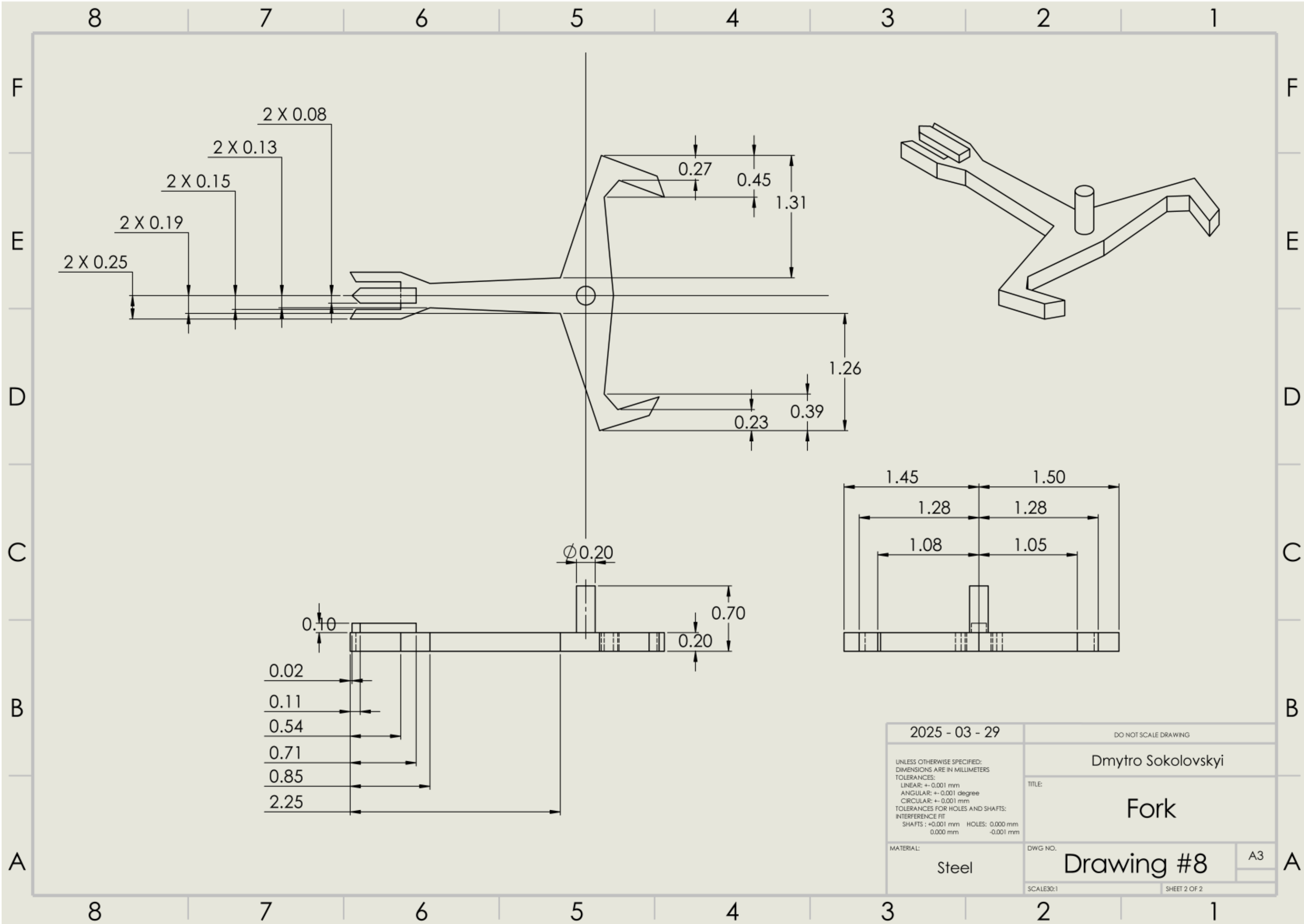

Figure 21 - The technical drawing of the fork.

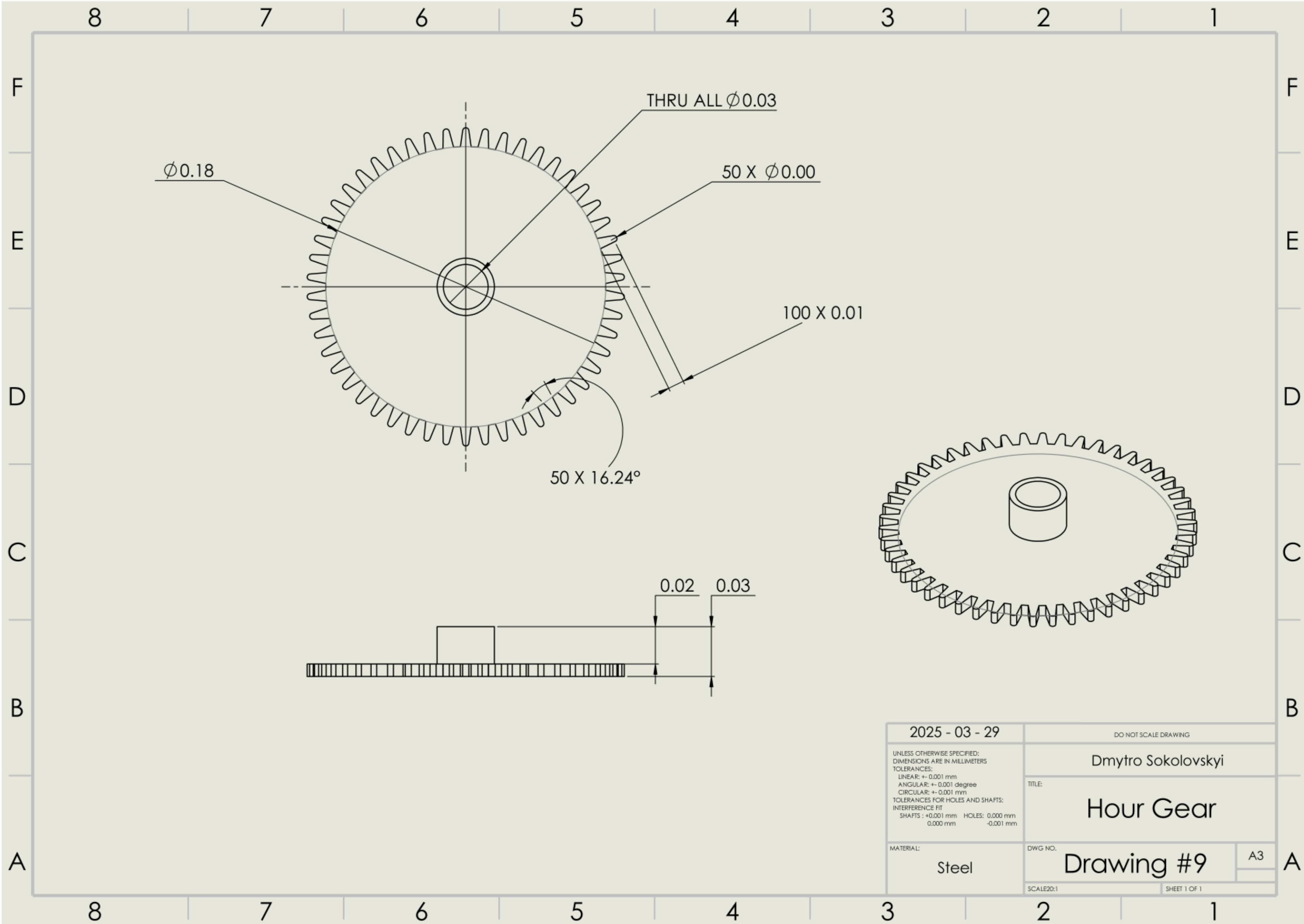

Figure 22 - The technical drawing of the hour gear.

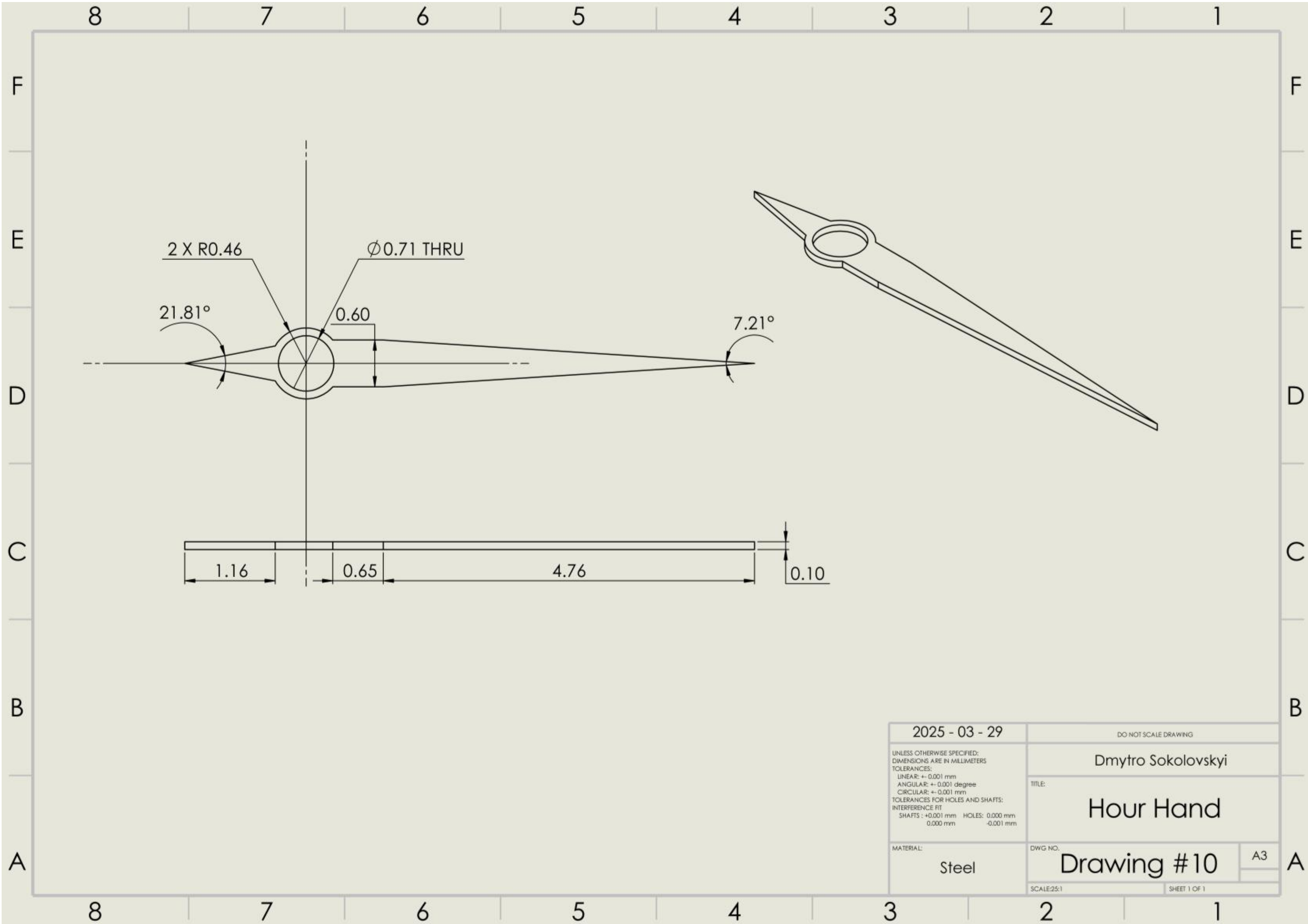

Figure 23 - The technical drawing of the hour hand.

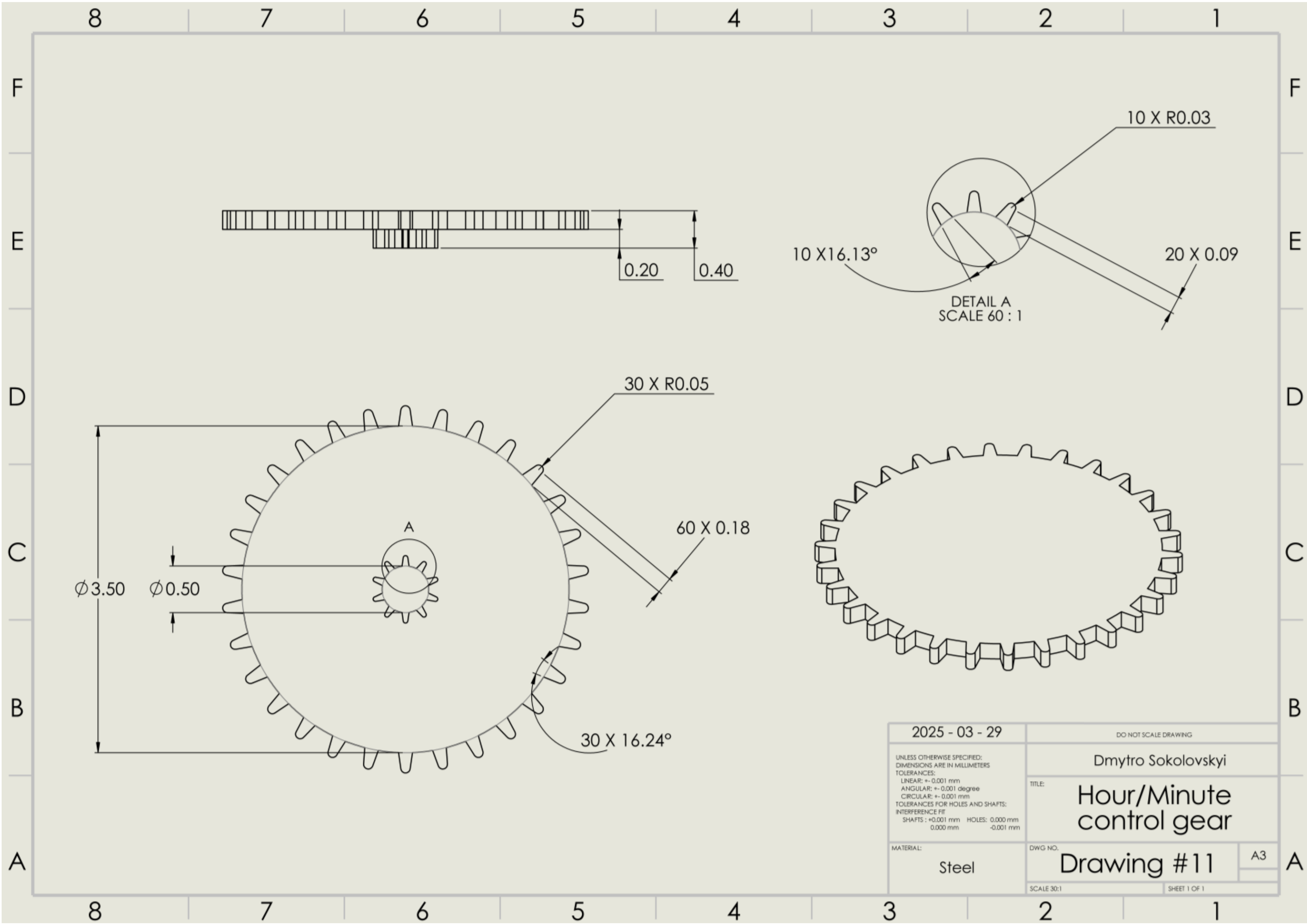

Figure 24 - The technical drawing of the hour/minute control gear.

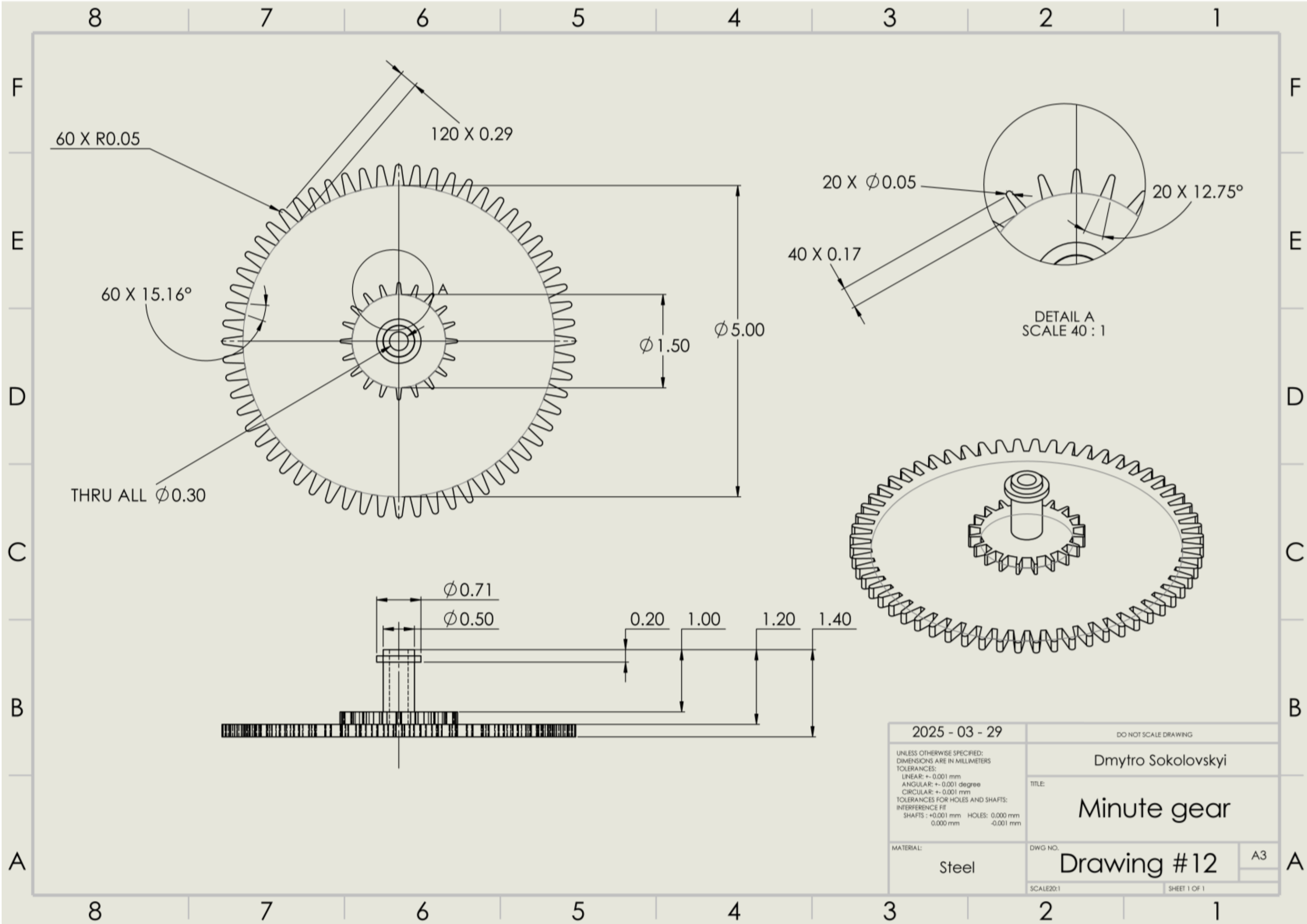

Figure 25 - The technical drawing of the minute gear.

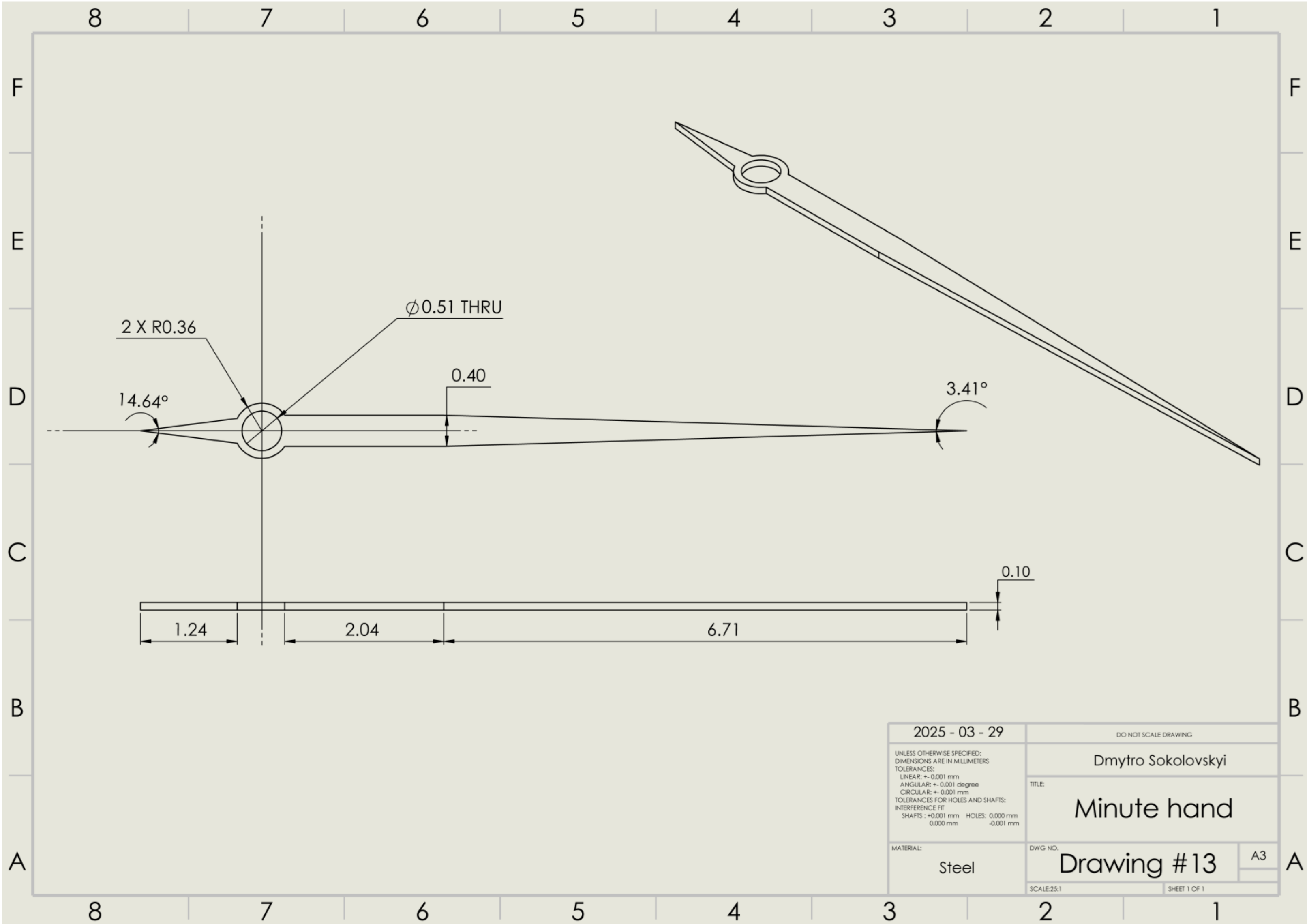

Figure 26 - The technical drawing of the minute hand.

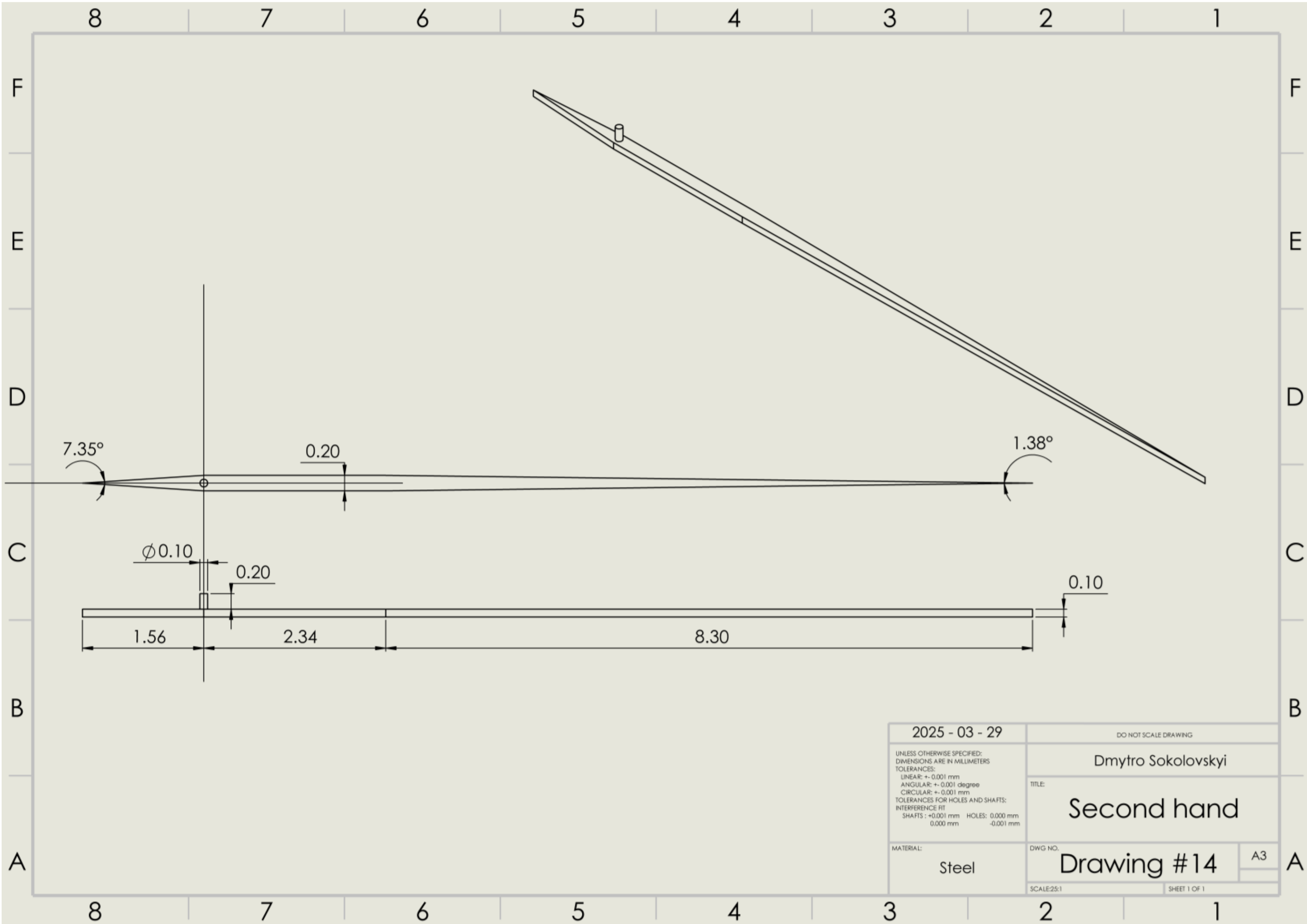

Figure 27 - The technical drawing of the second hand.

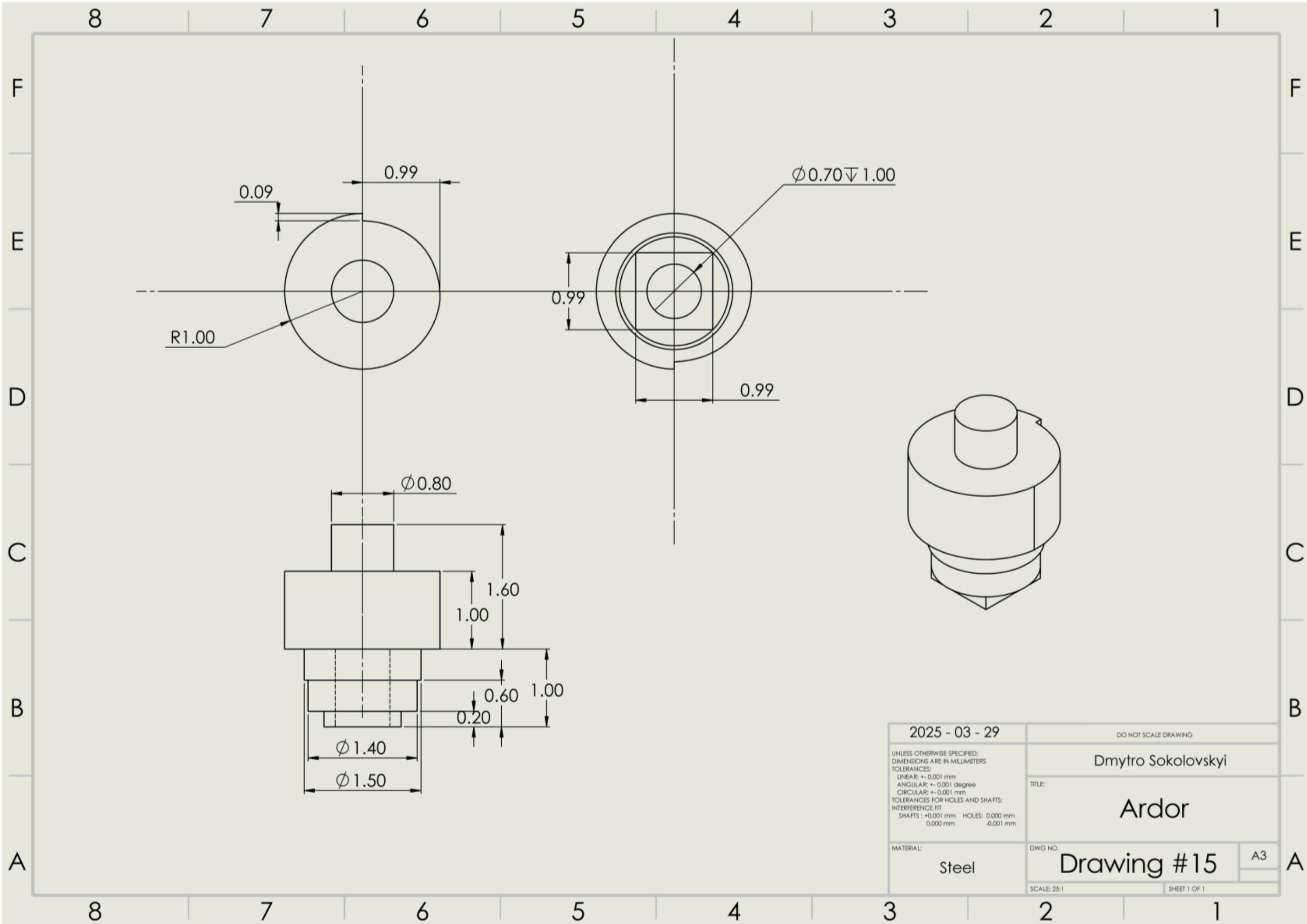

Figure 28 - The technical drawing of the ardor.

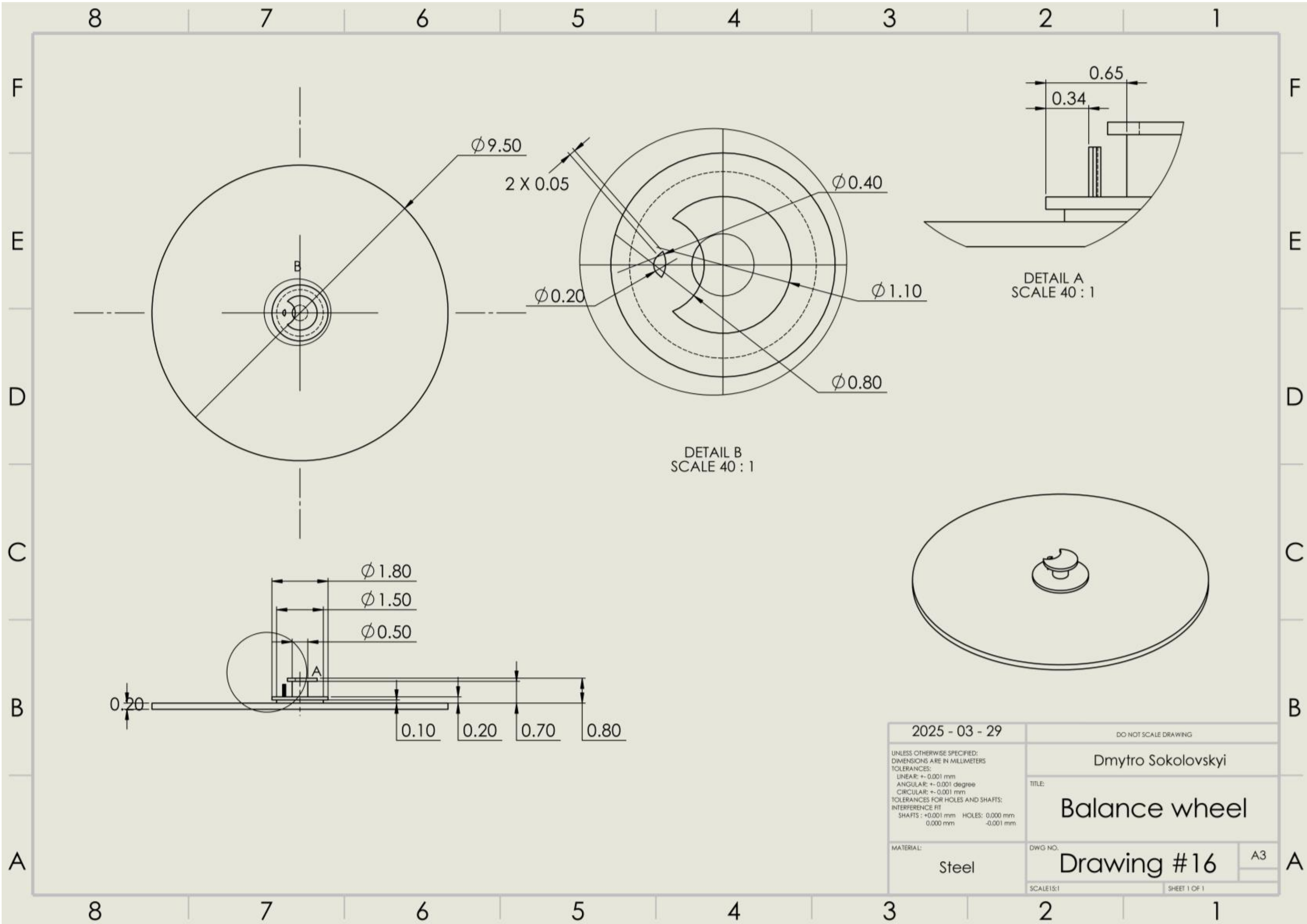

Figure 29 - The technical drawing of the balance wheel.