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Analysis from the Functional Viewpoint of a Single-Cylinder Horizontal Steam Engine with a Crosshead Trunk Guide through Engineering Graphics

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Abstract: This paper explores a historical innovation created by Henry Muncaster: a stationary steam engine featuring a single-cylinder horizontal design with a crosshead trunk guide. Through the application of engineering graphics techniques, we have elucidated the functioning of this invention by developing a 3D CAD model based on the original drawings published in *Model Engineer* magazine in 1957. However, the geometric modeling process faced challenges due to missing and erroneous dimensions for several components. Consequently, dimensional, geometric, and movement constraints were applied to ensure the coherence and functionality of the 3D CAD model, alongside conducting an interference analysis. Ultimately, the proper alignment of the cylinder and crosshead was ascertained, which is crucial for maintaining uniform forces and motions within the steam engine. This alignment is pivotal for achieving balanced operation, minimizing vibrations, and enhancing the overall efficiency of the invention.

Keywords: Henry Muncaster; steam engine; engineering graphics; computer-aided design; virtual reconstruction; technical historical heritage

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1. Introduction

Steam engines were pivotal in the technological advancements of the 18th and 19th centuries, primarily due to the widespread utilization of steam as an energy source. The conversion of thermal energy from steam into mechanical energy enabled these engines to perform work, which was crucial in powering locomotives such as trains, ships, and motor vehicles [1].

The technological evolution of these machines involved numerous modifications in both geometry and operational principles, driven by various inventors. Recent studies have examined these evolutions from multiple perspectives, including mechanical engineering [2], thermodynamics [3], and fluid engineering [4,5].

Among these inventors was Henry Muncaster, a distinguished English engineer and builder born in the mid-18th century and deceased in 1935. Muncaster applied his expertise in steam engines to industrial sectors like mining, coal, and steel [6]. From the early 20th century, he contributed numerous articles to the magazine Model Engineer and published a monograph in 1912 [7] on stationary steam-powered inventions. These stationary inventions were notably effective due to their ability to provide consistent work without dependence on time. One such invention is the single-cylinder horizontal steam engine with a crosshead trunk guide.

This particular steam engine features a single cylinder, resulting in a more abrupt steam expansion, which renders its operation less balanced compared to two-cylinder engines. This imbalance is mitigated by the crosshead mechanism. The invention in focus converts the piston's reciprocating motion into the crankshaft's rotary motion. Ideally, assuming no simulation validations are performed, the connecting rod follows a consistent path within the cylinder, displacing an equal volume of steam at the bottom dead center as at the top dead center, thereby maintaining symmetrical work output with the same intake pressure, using the cylinder's median plane as a reference.

This research adheres to the study of technical historical heritage through engineering graphics and computer-aided design (CAD) techniques [8]. The study has two primary objectives: First, to elucidate a plausible operation of the invention by creating a reliable 3D CAD model. There is no existing descriptive information clearly explaining its operation, only original drawings published in Model Engineer [9] and reproduced by Julius de Waal [10]. The 3D CAD model development follows the Seville Principles on virtual archaeology [11] and the London Charter on computer-assisted visualization of cultural heritage [12], emphasizing research, documentation, dissemination, authenticity, historical accuracy, and scientific transparency. The second objective is to produce a realistic virtual recreation to demonstrate its operation, which will be deposited in a repository alongside the 3D CAD model to facilitate knowledge transfer and reproducibility of the research.

Future work will involve validating the 3D CAD model through computer-aided engineering (CAE) analysis, which will be detailed in subsequent publications. This will ascertain whether the invention was correctly designed and functioned properly.

The potential impact of this research extends to various applications of the 3D CAD model, including the following:

- Conducting static linear analysis to validate the model and assess its structural integrity under operational stresses [13].
- Developing virtual and augmented reality applications to enhance user interaction and understanding of the invention's components and functionality, including specific nomenclature and related information [14].
- Utilizing additive manufacturing techniques to create physical models for hands-on interaction.
- Creating WebGL models for integration into thematic websites.

The paper is structured as follows: Section 2 details the materials and methods used in this research; Section 3 presents the main results and discussion; and Section 4 summarizes the key conclusions.

2. Materials and Methods

The foundational data for this investigation were the original drawings of the invention, initially published in 1957 [9] and subsequently reproduced by Julius de Waal [10] utilizing the decimal metric system. These drawings encompass the dihedral projections and dimensions of each constituent element of the invention, facilitating accurate geometric modeling through an understanding of descriptive geometry. The geometric modeling process was meticulously executed to ensure the comprehensive definition of the invention's movement in its final assembly.

Additionally, the Autodesk Inventor Professional 2024 software [15] was employed to accomplish the geometric modeling and digital restoration of the steam engine. This enabled the derivation of graphic documentation (including assembly plans and perspectives) from the 3D CAD model, as well as a virtual simulation demonstrating a plausible operation, given the absence of information on the invention beyond its drawings.

During the CAD modeling process, it was identified that some components lacked dimensional specifications, necessitating calculations to enable proper assembly. Furthermore, errors and inconsistencies within certain components were discovered, requiring resizing to facilitate coherent assembly, as geometric incompatibilities were present. Consequently, dimensional, geometric, and movement constraints (degrees of freedom) were implemented to impart coherence and functionality to the 3D CAD model, grounded in mechanical engineering principles regarding the operation of the various components.

For example, one of the components in which issues have been identified both in its design and assembly is the crankshaft, which is composed of three segments joined by two counterweights. Some of these parts did not meet the exact length specifications required for the correct execution of the assembly process, being necessary a redesign to ensure the optimal functioning of the engine.

The constraints applied during assembly included types for both assembly (coincidence, leveling, and tangency) and movement (rotation). Assembly constraints were the most frequently used, while movement constraints, particularly those defining circular motions between different axes, were less common and more complex. During the CAD modeling process, most edges were rounded to prevent sharp edges that could cause significant manufacturing issues for the steam engine.

3. Results and Discussion

Figures 1 and 2 present the front and rear axonometric views, respectively, of the 3D CAD model of the invention. These views were produced following a sophisticated digital restitution process (it is composed of 44 elements), signaling the most significant ones.

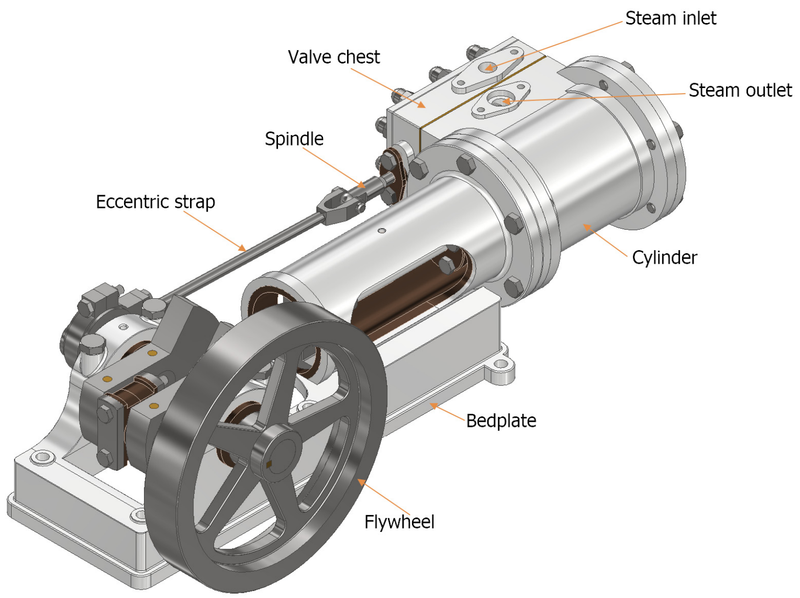

Figure 1. Front view of the 3D CAD model.

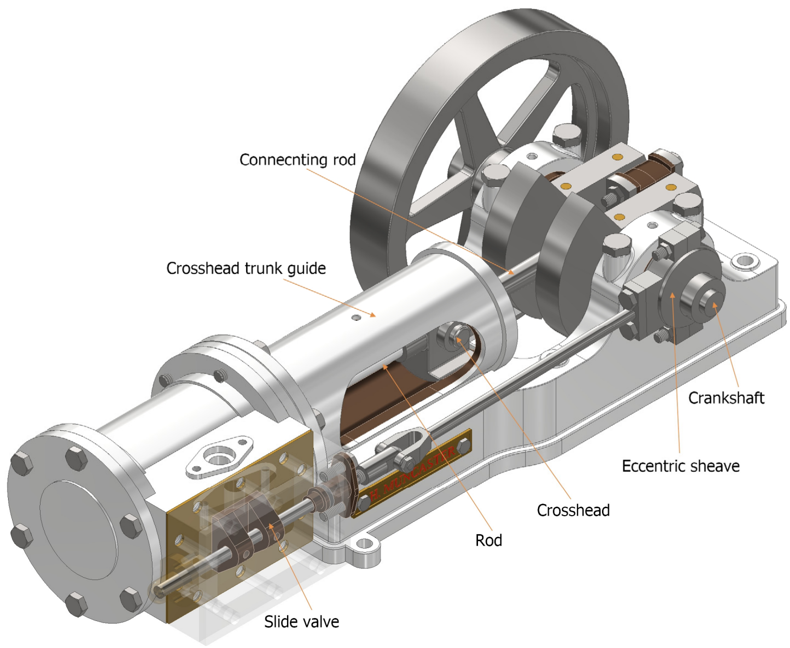

Figure 2. Rear view of the 3D CAD model.

Figure 3 shows a flowchart of the operation of the steam engine whose functioning is described below.

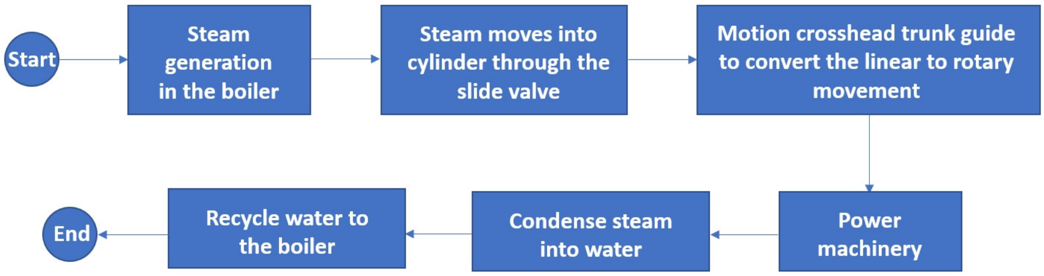

Figure 3. Flowchart of the operation.

The operational principle of a steam engine is the conversion of thermal energy into mechanical energy. Specifically, the thermal energy generated by the combustion of fossil fuels is transferred to water within a boiler, producing high-pressure steam (inlet steam to the engine). This mechanical energy enables the engine to perform work.

The operation of a typical steam engine involves several distinct stages and components. Initially, the pump directs water to the boiler, where it is heated to its boiling point, thereby increasing the pressure. Subsequently, the steam enters the steam inlet pipe. The cylinder, which is thermally insulated to preserve the steam temperature, features two apertures: one for steam intake and the other for exhaust. These apertures facilitate the movement of the piston. The pressure exerted by the steam is then transmitted to the connecting rod (which links the piston to the crankshaft), converting the piston's reciprocating motion into rotary motion via the flywheel. Ultimately, the regulation of the engine's power output relative to the system load is managed by controlling the pressure and velocity of steam entering through the pump.

Below, the most significant parts and systems involved in the engine's operation are explained.

3.1. System of Steam Intake and Steam Exhaust

High-pressure steam enters the valve chest (Figure 4), exerting force on the eccentric strap, which is driven to move linearly with the assistance of the eccentric sheave (Figure 5) affixed to the crankshaft. This crankshaft is segmented into three sections through the integration of two counterweights (Figure 6). Concurrently, the steam is directed through the valve chest towards the cylinder (Figure 7). Upon entering the cylinder, the steam pressure compels the piston to execute a linear motion, characterized by its reciprocal nature, meaning it moves forward and backward. After the steam has fulfilled its role within the cylinder, it is expelled, and the cycle recommences.

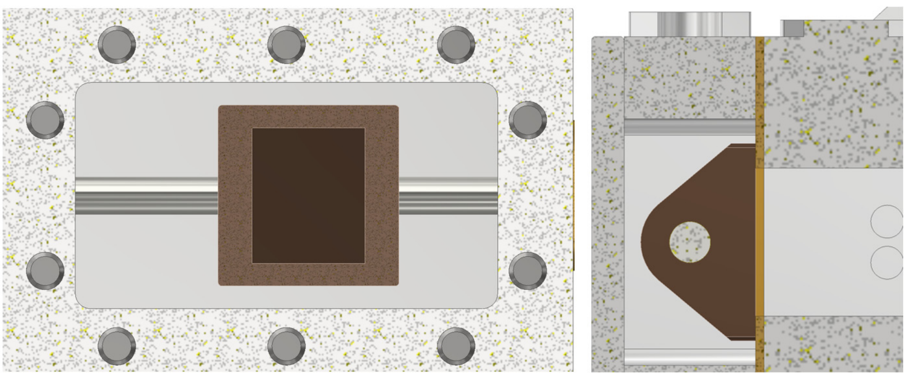

Figure 4. Cross-section of the valve chest showing the slide valve: left view (**left**) and rear view (**right**).

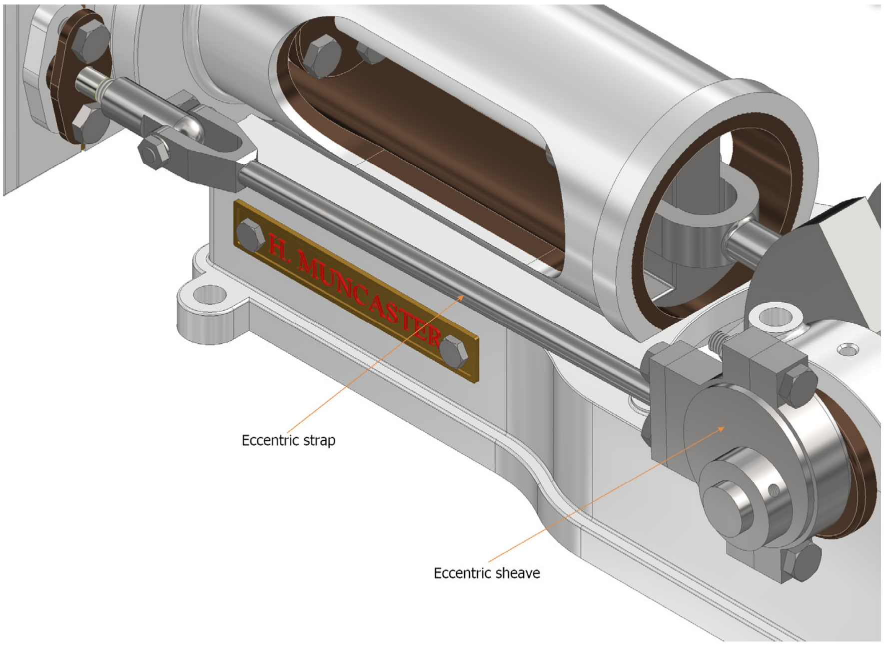

Figure 5. Axonometric view showing the eccentric strap and eccentric sheave.

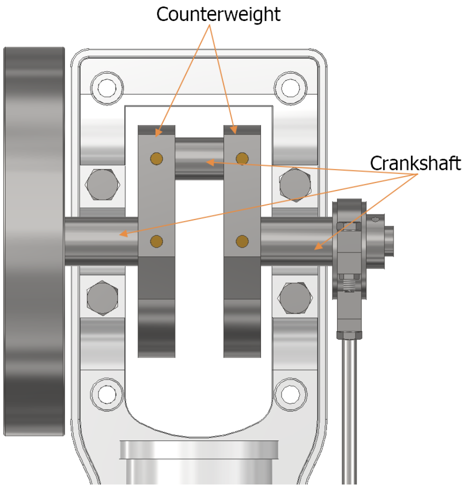

Figure 6. Top view showing the crankshaft and counterweight.

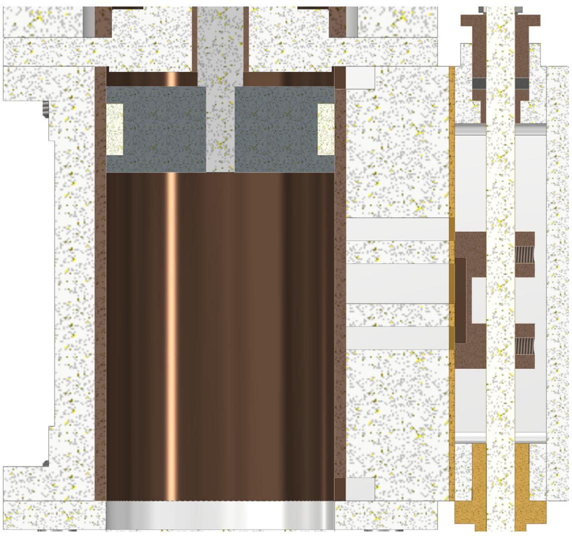

Figure 7. Cross-section of the cylinder and valve chest.

As mentioned previously, operation begins with the entry of high-pressure steam to the cylinder through the slide valve located inside the valve chest, moving the piston downwards with a high-pressure until it reaches the end of its trajectory. Once this end is reached, that is, the bottom dead center, the slide valve moves, leaving another path for the steam to exit the cylinder, performing the exhaust function which makes it possible for the piston not to receive more pressure than necessary on one of its faces. While this exhaust is expelled, high-pressure steam is introduced through another path until the piston reaches its upper dead center, and, again, the sliding valve moves to expel the exhaust, cyclically performing the operation of a double-acting cylinder.

This high-pressure steam must be achieved by increasing the pressure of the steam obtained. To do this, we can increase the number of molecules, increase the temperature, or reduce the volume, but if these three operations are carried out at the same time, the pressure obtained is very high, increasing the efficiency of this steam engine.

3.2. Crosshead

To ensure the optimal functionality of the piston within the cylinder and mitigate abrupt piston movements, a crosshead is employed, which is connected to the piston via a rod (Figure 8). The crosshead plays a crucial role in directing the piston's motion and inhibiting its rotation, thereby preventing transverse forces exerted by the connecting rod from imposing undue lateral stress on the cylinder. The connecting rod spans from the crosshead to the crankshaft. Consequently, the crosshead mechanism is vital for preserving the smooth and efficient operation of the machine as it guides the piston linearly and minimizes excessive wear on the components.

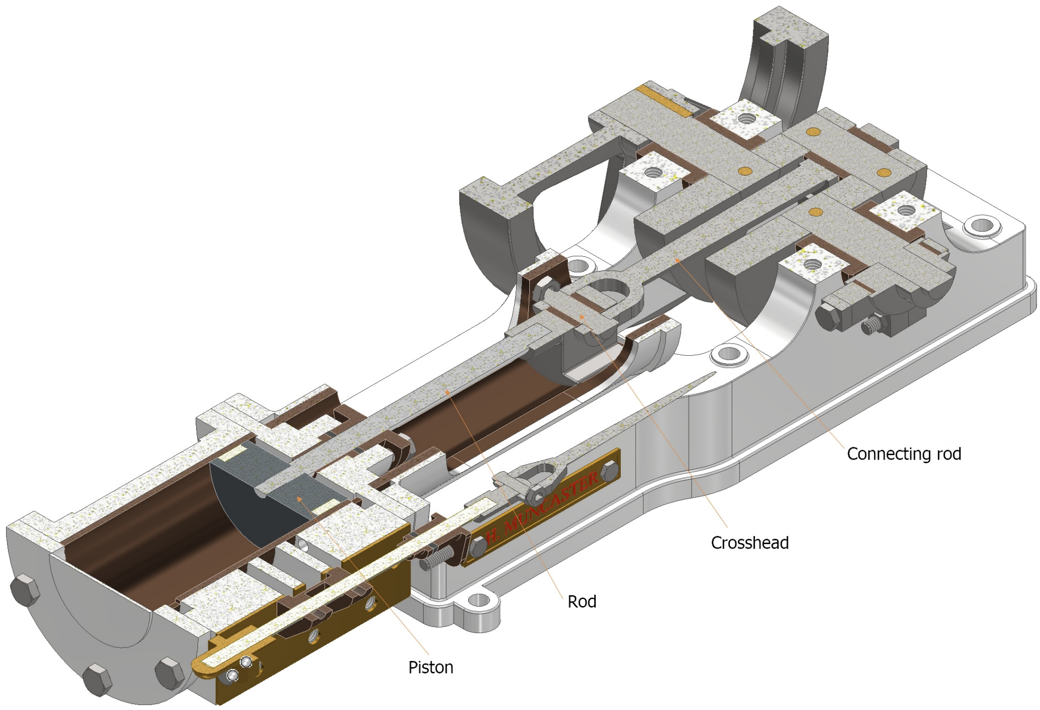

Figure 8. Cross-section of the ensemble: piston, rod, crosshead, and connecting rod.

3.3. Crankshaft Motion and Rotation Mechanism

The barrel guide motion mechanism serves as a mechanical linkage the crosshead to the crankshaft. Its primary function is to maintain the piston's linear motion while enabling the rotation of the crankshaft. As the steam expands, it exerts force on the piston, causing it to move. This motion is then transmitted to the crankshaft via the connecting rod. The crankshaft, in turn, transforms this reciprocating motion into rotational motion, which subsequently drives the flywheel (Figures 9 and 10).

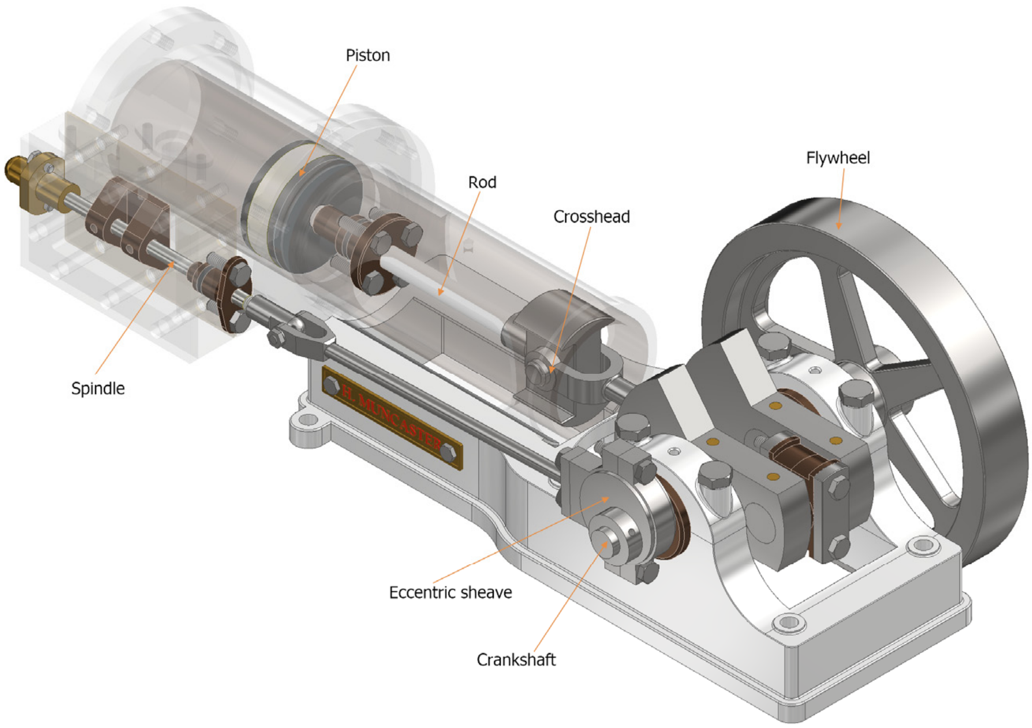

Figure 9. Front view of the necessary elements for the crankshaft motion and rotation mechanism.

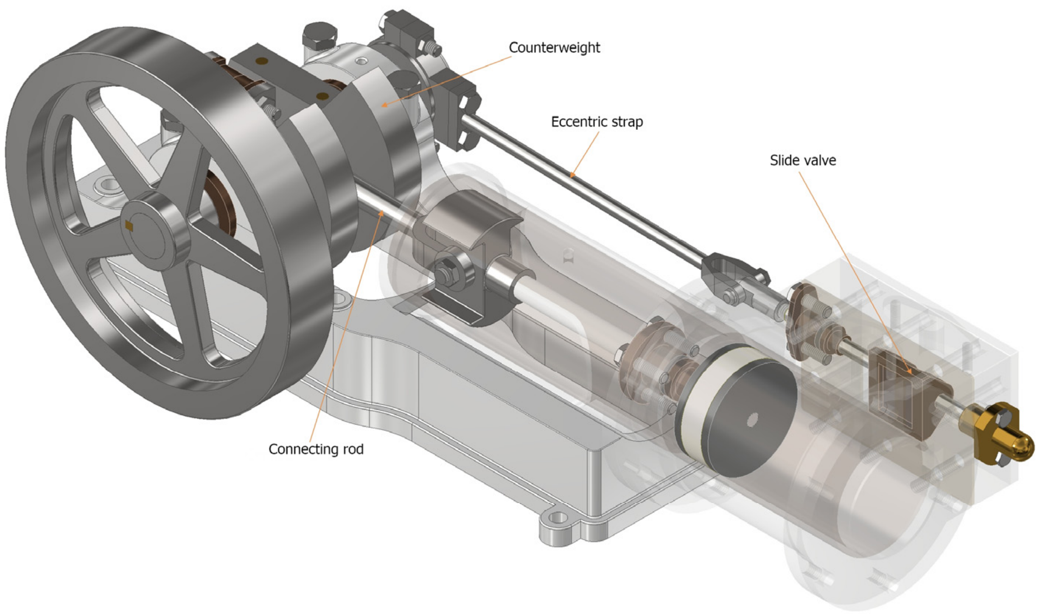

Figure 10. Rear view of the necessary elements for the crankshaft motion and rotation mechanism.

The alignment of the cylinder and crosshead is crucial for maintaining uniform forces and movements throughout the steam engine. This configuration ensures balanced operation, minimizes vibrations, and enhances the overall efficiency of the engine.

3.4. Design Process for Correct Engine Operation

To enhance the understanding of the steam engine's operation, the design and assembly of various components are elucidated below, with particular emphasis on the constraints applied between them to ensure proper functionality.

It begins by defining all the fixed elements (Figure 11) that support the movement of the mobile elements.

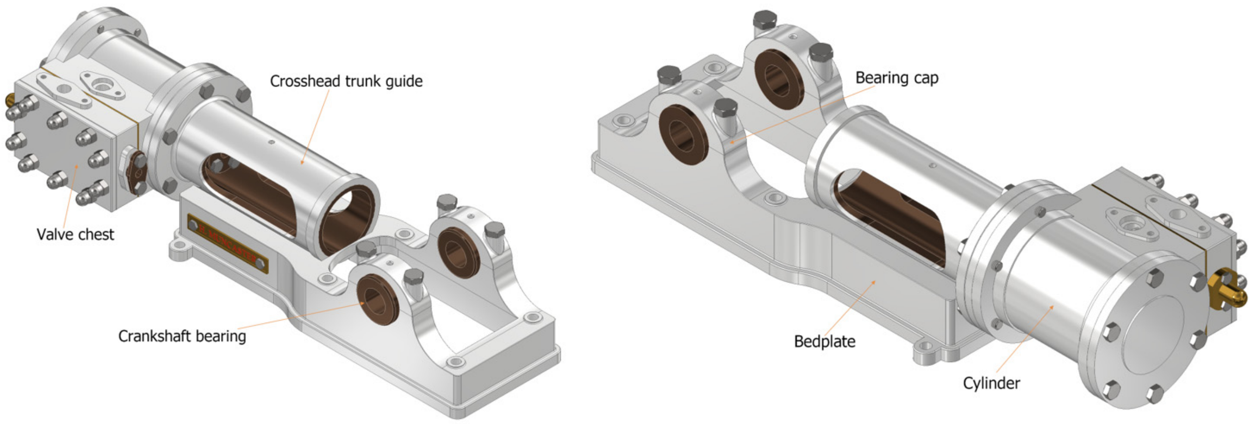

Figure 11. Axonometric view of the fixed elements: front view (**left**) and rear view (**right**).

The majority of fixed elements have a simple design, and their connection has been carried out using cap screws, nuts, and washers. One of the most important fixed elements is the bedplate since it is essential for the crosshead trunk guide to fit perfectly into it and ensure its correct operation, avoiding vibrations. The design of this part of the bench can be seen in Figure 12.

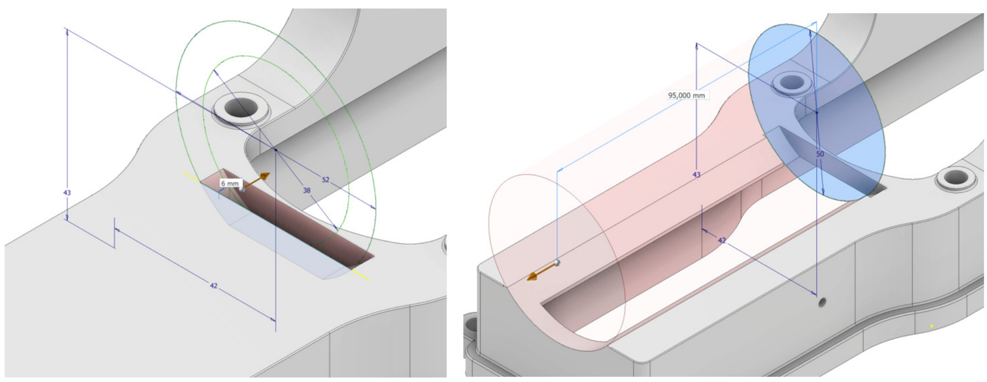

Figure 12. Detailed view of the design of the bedplate: sketch (**left**) and removal operation (**right**).

As can be seen, the design is characterized by having removed material, through Boolean operations, with the same dimensions as the crosshead trunk guide; that is, the negative of it has been made on the bedplate so that it fits perfectly. Thanks to this design of the two pieces, only two constraints have been needed: coincidence (leveling) between the faces and coincidence between the axes (concentricity) of the crosshead trunk guide; and the cylindrical part of the first Boolean operation to remove the material, as mentioned previously (Figure 13).

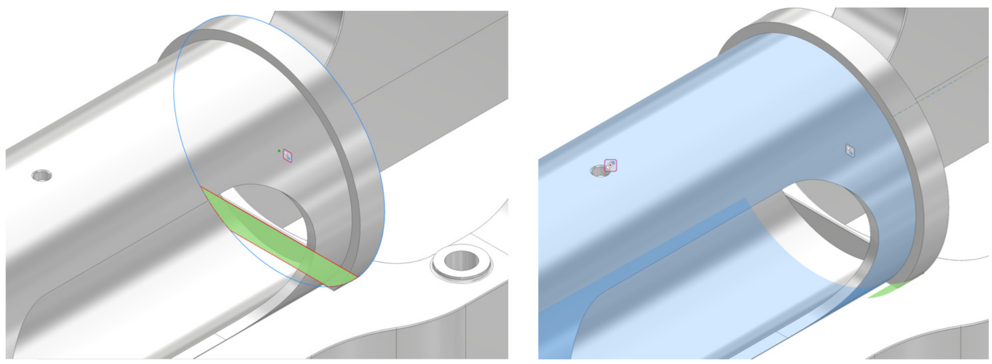

Figure 13. Detailed view of the constraints: coincidence (leveling) (**left**) and coincidence (concentricity) (**right**).

However, during assembly of the moving parts, there may be malfunctions if the parts are not designed and assembled correctly. The moving parts that will carry out the work of the steam engine can be observed in Figure 14.

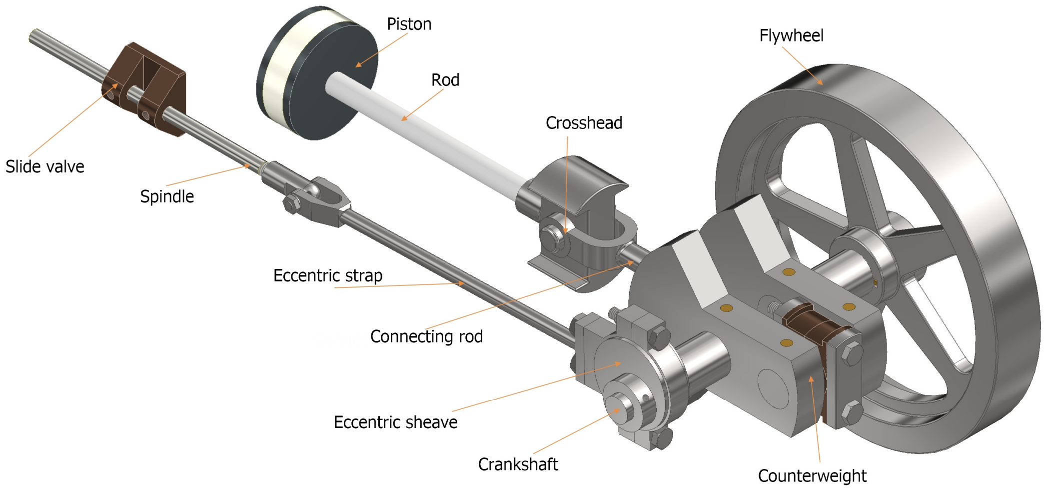

Figure 14. Axonometric view of the moving elements.

For better understanding, the complete assembly of all moving parts will be divided into three subassemblies. The first subassembly will be the flywheel, with the crankshaft and its counterweights. The second will be the one formed by the spindle and the slide valve with the eccentric strap and the eccentric sheave. The third subassembly will be the piston with the rod, and this with the connecting rod by means of the crosshead.

First of all, two types of pins that will be necessary for the first subassembly must be designed: type 1 pin (Figure 15, left) and type 2 pin (Figure 15, right).

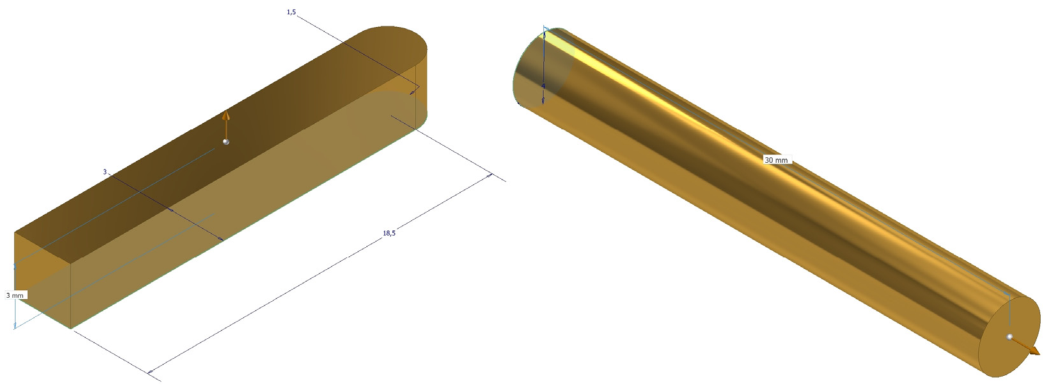

Figure 15. Pins for connection: type 1 pin (**left**) and type 2 pin (**right**).

To explain the first subassembly, we will begin by explaining the design of the crankshaft. The design of the three parts of the crankshaft is based on circumferences that have been extruded to turn them into solid pieces, but each of them will have holes to make the necessary assemblies.

Of the three parts of the crankshaft, the first of them is exposed (Figure 16), specifically the one that will be attached to the flywheel through the type 1 pin and to one of the counterweights thanks to the type 2 pin.

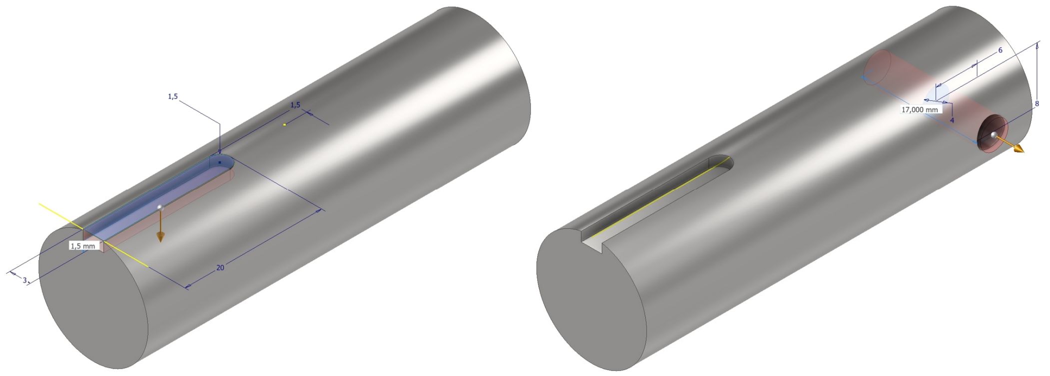

Figure 16. Design of the first part of the crankshaft: removal for type 1 pin link (**left**) and removal for type 2 pin link (**right**).

The central part of the crankshaft (Figure 17) joins the two counterweights thanks to the type 2 pins.

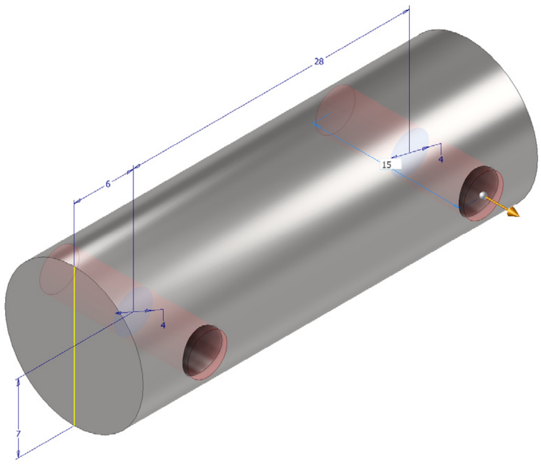

Figure 17. Design of the second part of the crankshaft.

And finally, the third part of the crankshaft (Figure 18) will be joined to the second counterweight and to the eccentric sheave using the type 2 pin.

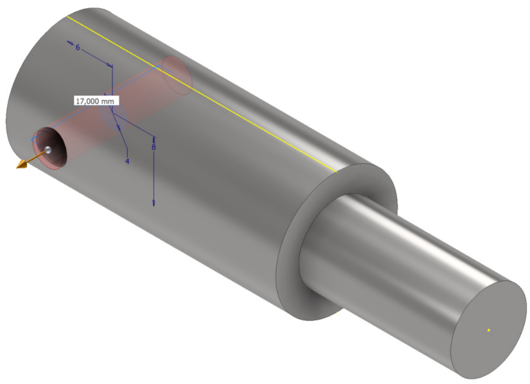

Figure 18. Design of the third part of the crankshaft.

Furthermore, it will be necessary to design the two counterweights (Figure 19), which will be joined together by the second part of the crankshaft, and each of them will be joined to the first and last part of the crankshaft, respectively. All these connections will be made using type 2 pins.

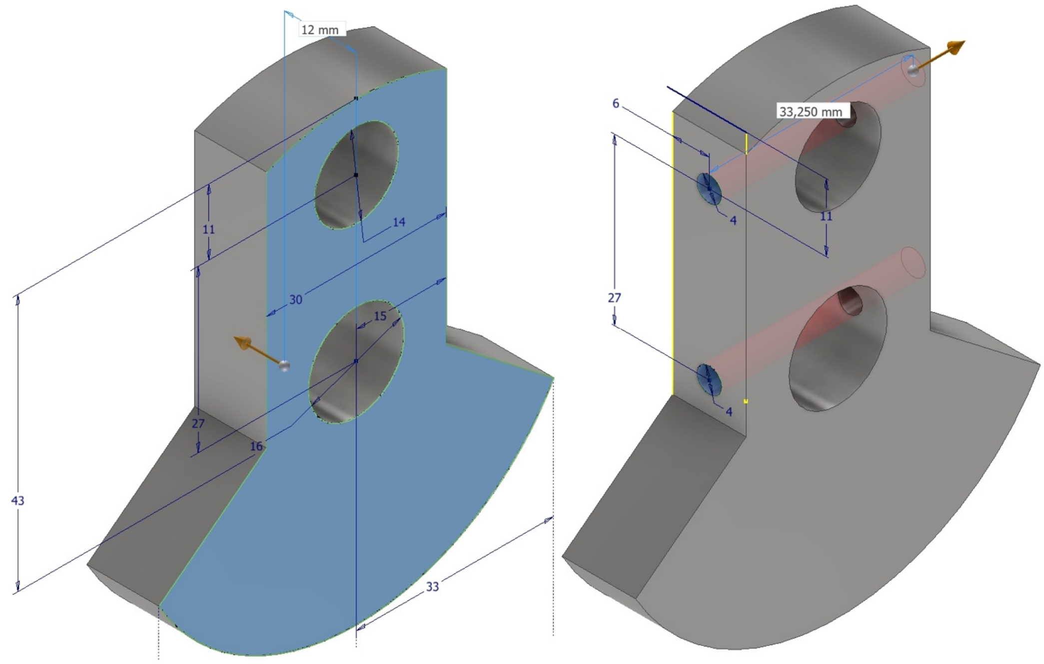

Figure 19. Design of the counterweight: sketch and removal for crankshaft link (**left**) and sketch and removal for type 2 pin link (**right**).

To finish the first subassembly, the flywheel remains to be designed (Figure 20). The only important detail for correct assembly is the Boolean operation of removing material with the shape of the type 1 pin so the assembly between the flywheel and the first part of the crankshaft is optimal.

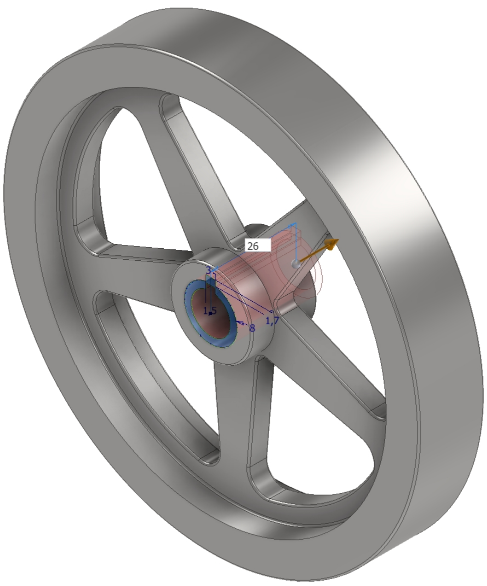

Figure 20. Design of the flywheel.

Figure 21 shows the result of the first subassembly with its respective constraints for its correct operation. The types of constraints used have been those of coincidence of a leveling type between the faces that must be aligned, and those of concentricity-type coincidence between the cylindrical bodies and the holes made for them.

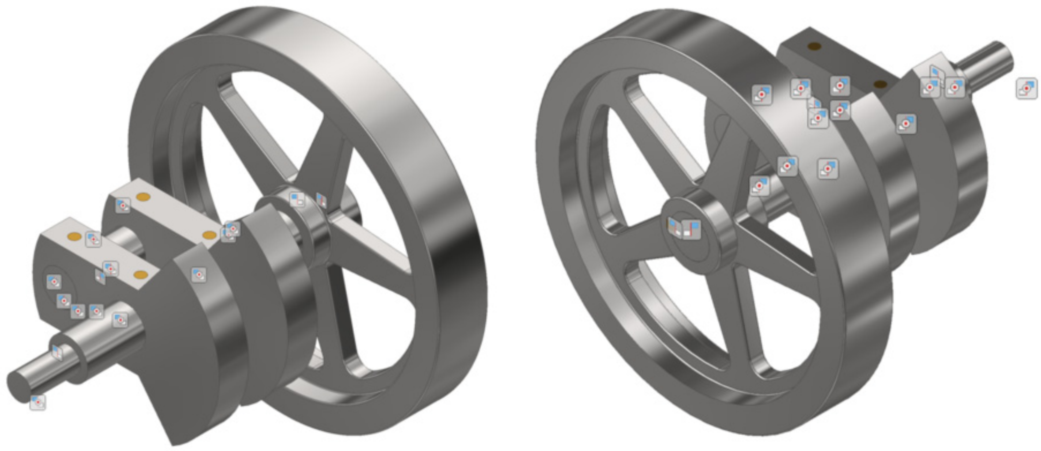

Figure 21. First subassembly: front view (**left**) and rear view (**right**).

On the other hand, the second subassembly will begin with the design of the spindle (Figure 22), the most important part being the one that is assembled with the eccentric strap (Figure 23).

Figure 22. Spindle.

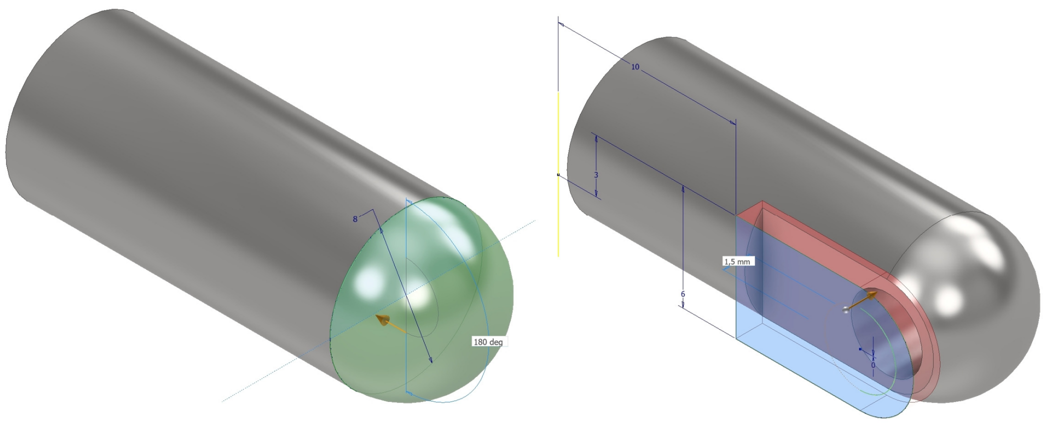

Figure 23. Design of the spindle: design of the half sphere (**left**) and sketch and removal operation (**right**).

Along the spindle, the slide valve will be assembled (Figure 24) thanks to the creation of a plane and the use of a leveling-type constraint between that plane and the face of the slide valve.

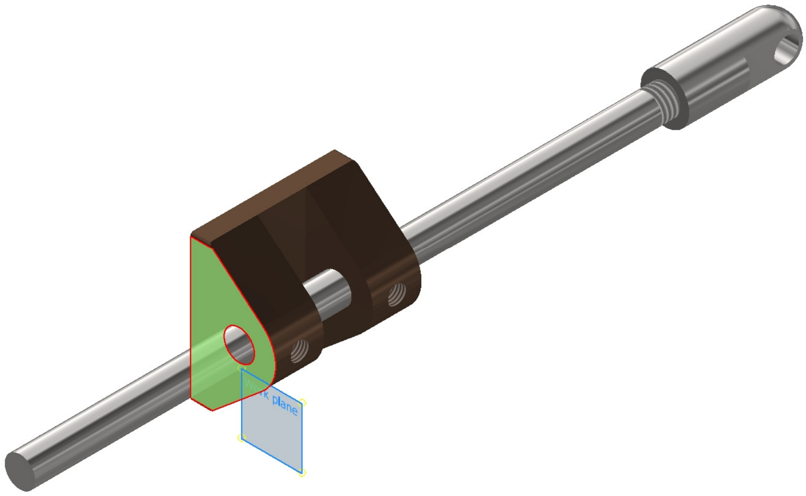

Figure 24. Assembly of the slide valve and spindle.

Figure 25 shows the design of the slide valve, where the most relevant operations will be the Boolean operations to remove material for subsequent assembly with the other parts (Figure 25, left) and to guarantee correct operation at the time of steam intake and exhaust (Figure 25, right).

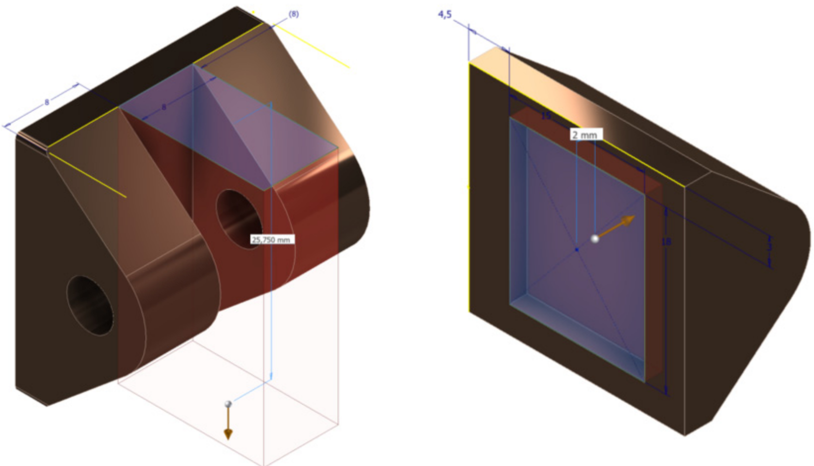

Figure 25. Design of the slide valve: removal operation to reduce weight (**left**) and removal operation for its correct working (**right**).

In a similar manner, as a notable design aspect, the eccentric sheave (Figure 26) determines the distance at which the main hole is located, through which the crankshaft will be placed so that the rotation movement is eccentric.

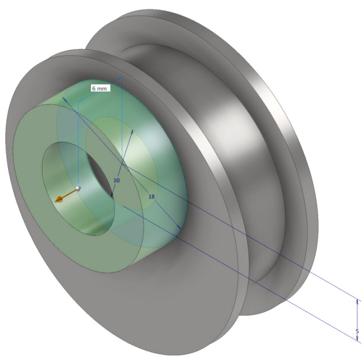

Figure 26. Design of the eccentric sheave.

Finally, we will detail the design of the eccentric strap (Figure 27). The first part (Figure 28) will be the one that will be assembled to the eccentric sheave, with its respective joint for correct assembly, and the second part (Figure 29) will be the one necessary for correct assembly with the spindle.

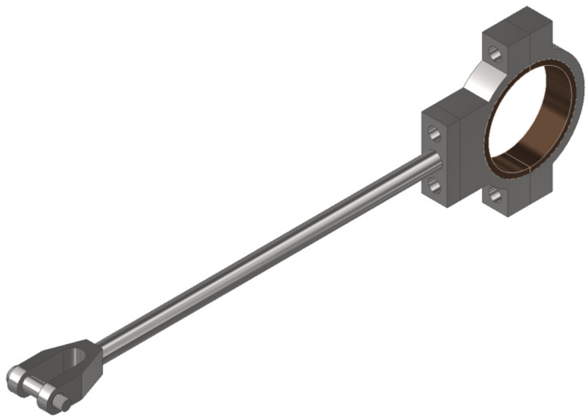

Figure 27. Eccentric strap.

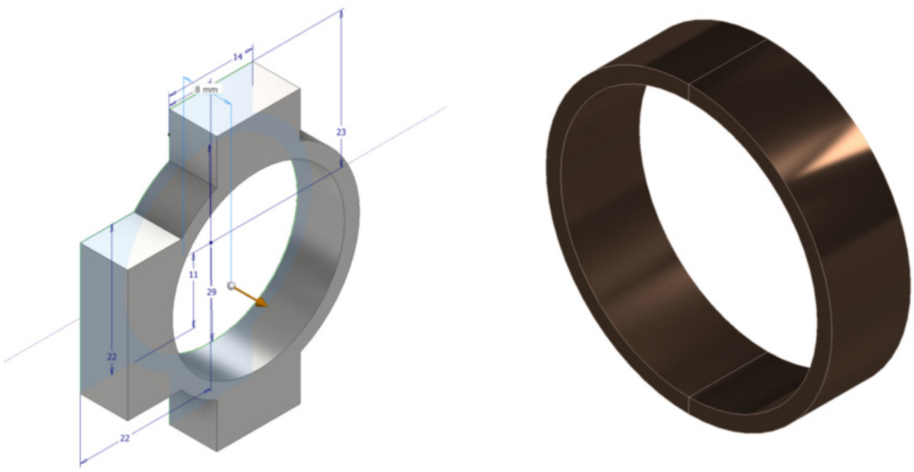

Figure 28. First stage of the design of the eccentric strap: sketch and extrude operation (**left**) and design of eccentric strap joint (**right**).

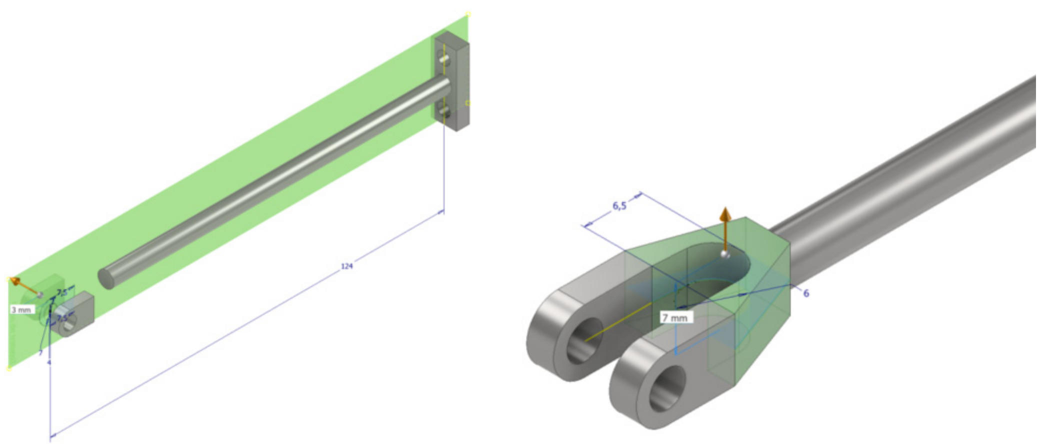

Figure 29. Second stage of the design of the eccentric strap: sketch and extrude operation (**left**) and sketch and extrude operation (**right**).

With all the elements of this subassembly, we will proceed to discuss the necessary constraints for its correct assembly and operation (Figure 30). All the necessary constraints that will be applied will be those of concentricity between the cylindrical elements and their respective holes, and those of leveling between faces that must be in contact. In this subassembly, the most important constraints will be the leveling ones between the internal face of the eccentric sheave and the external face of the eccentric strap, as well as another new constraint, i.e., the tangency one between the inner face of the eccentric strap joint and the outer face of the central body of the eccentric sheave.

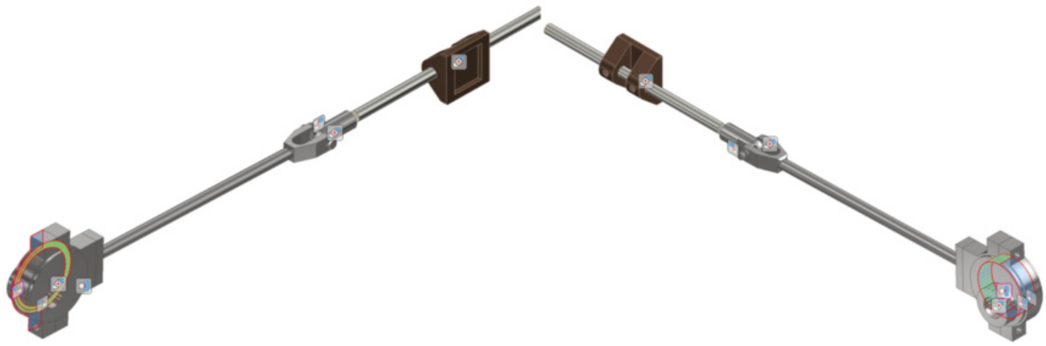

Figure 30. Second subassembly: front view (**left**) and rear view (**right**).

Finally, the third subassembly begins with the design of the piston (Figure 31) and the connecting rod (Figure 32).

Figure 31. Piston.

Figure 32. Rod.

However, the most important part of this third subassembly is the crosshead (Figure 33), which will be responsible for acting as a connecting element between the piston and the connecting rod.

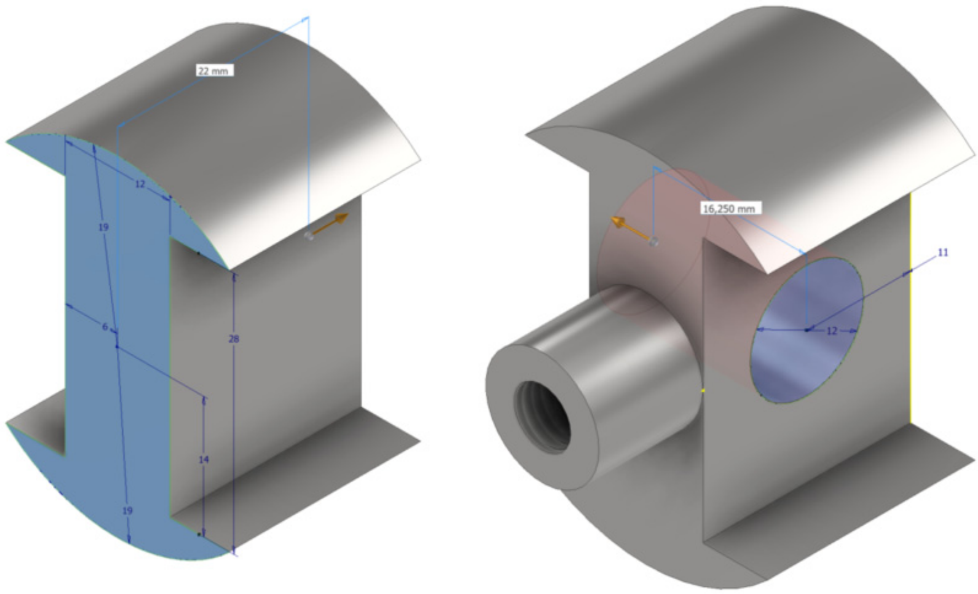

Figure 33. Design of the crosshead: sketch and extrude operation (**left**) and removal operation (**right**).

The connecting rod (Figure 34) has been designed in two stages: in the first, the main body is attached to the crosshead (Figure 35); and in the second, the head is attached to the crankshaft (Figure 36).

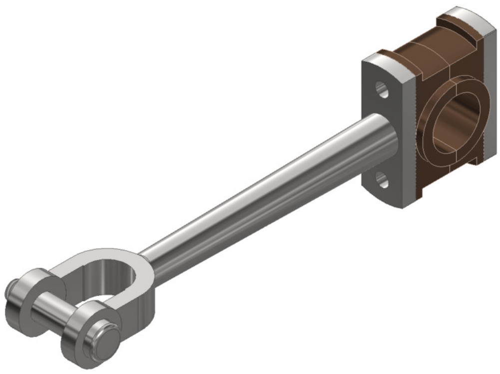

Figure 34. Connecting rod.

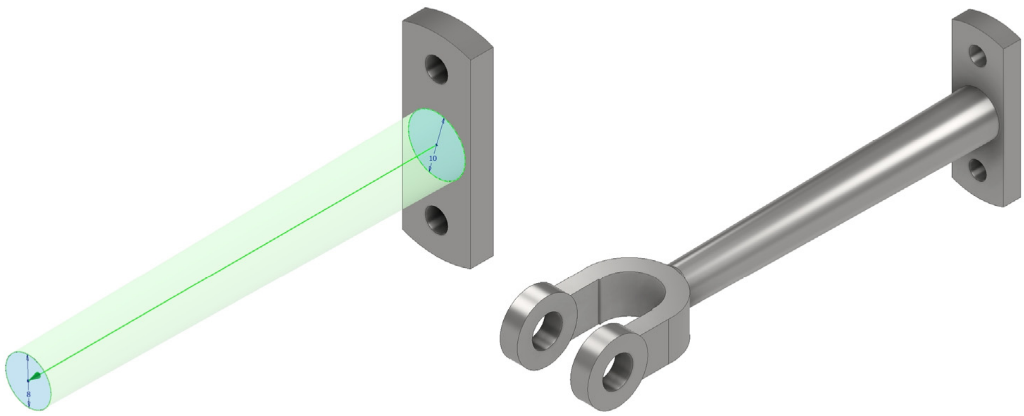

Figure 35. First stage of the design of the connecting rod: sketch and extrude of the loft (**left**) and final result (**right**).

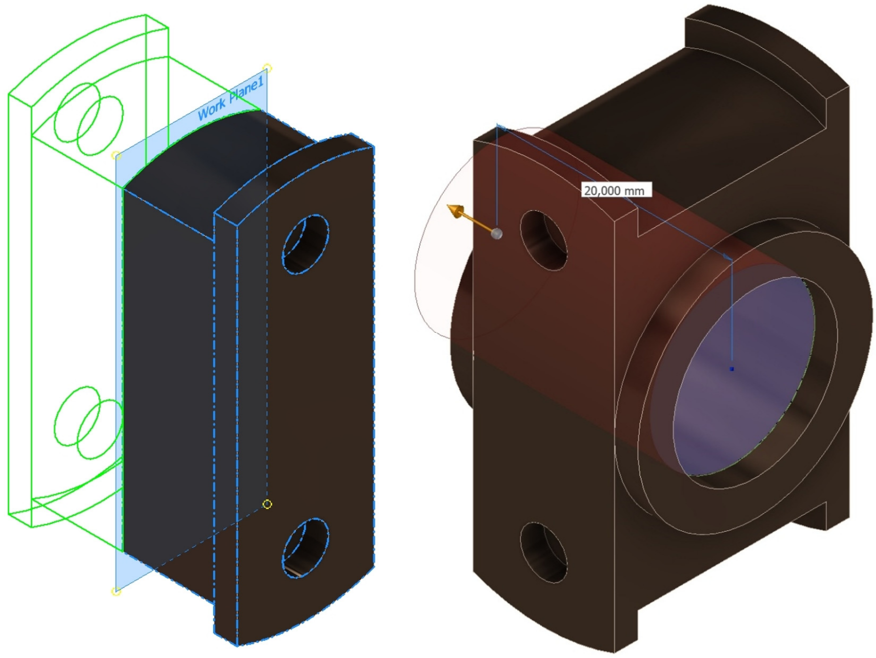

Figure 36. Second stage of the design of the connecting rod: symmetry operation (**left**) and removal operation (**right**).

With all the elements of the third subassembly (Figure 37), we will proceed to discuss the necessary constraints for its correct assembly and operation. All the necessary constraints applied are those of concentricity between cylindrical elements and their respective holes, and those of leveling between faces that must be in contact. In this third subassembly, the most important constraints will be the concentricity between the piston connecting rod and the inlet hole made in the crosshead and between the crosshead hole and the connecting rod, whose connection will be given by a cap screw.

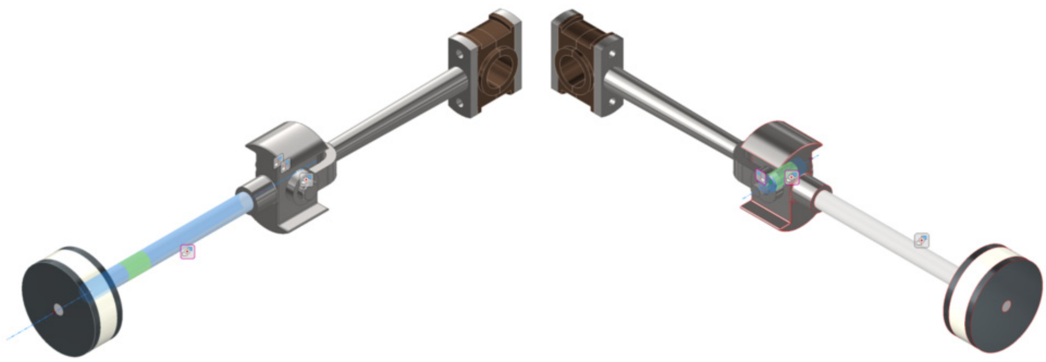

Figure 37. Third subassembly: front view (**left**) and rear view (**right**).

At last, a virtual simulation showcasing the functionality of the invention has been produced in mp4 format, spanning 67 s in duration (accessible as supplementary material). This simulation owes its existence to the Inventor Studio module integrated within Autodesk Inventor Professional 2024. It serves as a conduit for readers to gain a comprehensive understanding of both the design and functionality of this noteworthy historical invention. In the following, a brief explanation of the benchmarking functions involved in the simulation that demonstrates the operation of the inventions is presented.

First, the duration of the animation and the desired speed profile must be selected. In this case, a constant speed was established to avoid abrupt changes in the animation's velocity. Next, the camera must be created, with as many cameras as needed for the required views. For example, if a top view and an axonometric view are desired, both cameras with their respective views must be created. Therefore, each camera must be animated, specifying its movement. In this case, all camera views were animated to rotate around the engine, specifically rotating around the machine's *Z*-axis.

Once all camera-related tasks are completed, the components which are the moving parts of the invention must be animated. This is achieved using a series of angular constraints between some components, allowing them to move according to real movements when the animate option is selected. In this case, simply applying an angular constraint between the flywheel's XZ plane and the general XZ plane (parallel to the bedplate) is enough to recreate its operation.

Additionally, some components can be blurred for proper visualization while they are working. For example, the valve chest, the cylinder block, and the crosshead trunk guide can be blurred to allow for clear visualization of internal elements, such as the piston, the slide valve, the rod, the connecting rod, and the crosshead, while they are operating.

Finally, the animation is rendered by choosing the desired quality based on the frames per second and the number of iterations, with the number of iterations being directly related to the video quality; that is, a higher number of iterations results in a higher quality video.

4. Conclusions

This study presents the outcomes of a sophisticated geometric modeling procedure aimed at producing an accurate 3D CAD representation of a single-cylinder horizontal steam engine with a crosshead trunk guide, originally designed by Henry Muncaster. This task was accomplished using Autodesk Inventor Professional 2024 software.

The process commenced with the original drawings of the invention, as published in Model Engineer magazine in 1957 and later reproduced by Julius de Waal. These drawings were drafted in the decimal metric system, displaying orthographic projections of various components along with their respective dimensions. Nevertheless, the modeling process encountered several challenges due to the absence of dimensions for certain components and inaccuracies in others.

The primary challenge stemmed from the lack of operational documentation for the invention. Consequently, this research pursued a dual objective: first, to hypothesize the potential functionality of the invention based on a 3D CAD model created using engineering graphics techniques, necessitating a detailed understanding and the application of various mechanical engineering components; and second, to develop a realistic virtual simulation that clearly demonstrates its operation. To achieve this, a series of dimensional, geometric, and movement constraints were applied to the 3D CAD model to ensure coherence and functionality. Upon completion of the 3D CAD model, comprehensive graphic documentation, including assembly plans and perspectives, was produced to facilitate functional analysis.

Ultimately, the geometric modeling process enabled the determination of the correct alignment of the cylinder and the crosshead. This alignment is crucial for ensuring uniform force distribution and movement within the steam engine, which, in turn, enhances operational balance, reduces vibrations, and improves overall efficiency.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/sym16060722/s1, Video S1: Virtual Recreation.

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References

1. Inkster, I. (Ed.) *History of Technology*; Bloomsbury Academic: London, UK, 2004; Volume 25.
2. Stokes, P.R. Piston steam engine innovation. *Proc. Inst. Mech. Eng. Part A J. Power Energy* **1996**, *210*, 95–98. [CrossRef]
3. Thoendel, E. Simulation model of the thermodynamic cycle of a three-cylinder double-acting steam engine. *Chem. Prod. Process Model.* **2008**, *3*, 21. [CrossRef]
4. Yatsuzuka, S.; Niiyama, Y.; Fukuda, K.; Muramatsu, K.; Shikazono, N. Experimental and numerical evaluation of liquid-piston steam engine. *Energy* **2015**, *87*, 1–9. [CrossRef]
5. Wang, Y.; Zhou, Z.J.; Zhou, J.H.; Liu, J.Z.; Wang, Z.H.; Cen, K.F. Micro Newcomen steam engine using two-phase working fluid. *Energy* **2011**, *36*, 917–921. [CrossRef]
6. Who was Henry Muncaster? Available online: https://modelengineeringwebsite.com/Henry_Muncaster.html (accessed on 28 May 2024).
7. Muncaster, H. *Model Stationary Engines—Their Design and Construction*; TEE Publishing Ltd.: Oxford, UK, 1912.
8. Rojas-Sola, J.I.; Barranco-Molina, J.C. Engineering drawing applied to the study of the design of a two-cylinder entablature steam engine with parallel motion crosshead. *Symmetry* **2024**, *16*, 578. [CrossRef]
9. Westbury, E.T. The Muncaster steam-engine models: Horizontal stationary engines. *Model Eng.* **1957**, *116*, 488–490, 515.
10. Single-Cylinder Horizontal Steam Engine with a Crosshead Trunk Guide. Available online: https://modelengineeringwebsite.com/Muncaster_4c_mill_engine.html (accessed on 28 May 2024).
11. Principles of Seville on Virtual Archaeology. Available online: https://icomos.es/wp-content/uploads/2020/06/Seville-Principles-IN-ES-FR.pdf (accessed on 28 May 2024).
12. London Charter. Available online: https://londoncharter.org (accessed on 28 May 2024).
13. Rojas-Sola, J.I.; Gutiérrez-Antúnez, J.F. Analysis of the design of Henry Muncaster′ two-cylinder compound vertical steam engine with speed control. *Appl. Sci.* **2023**, *13*, 9150. [CrossRef]
14. Rojas-Sola, J.I.; Aguilera-García, A. Virtual and augmented reality: Applications for the learning of technical historical heritage. *Comput. Appl. Eng. Educ.* **2018**, *13*, 1725–1733. [CrossRef]
15. Shih, R.H.; Jumper, L. *Parametric Modeling with Autodesk Inventor 2024*; SDC Publications: Mission, KS, USA, 2023.