Modeling, Simulating, and Prototyping well-known Mechanisms

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Content:

1.0 Introduction

1.1 Project Description

Our project group modeled, simulated, and prototyped well-known mechanisms that are going to be showcased as examples of several concepts from applied physics and serve an educational purpose by visualizing these concepts for students to understand the application part of their learning better.

1.1.1 Background

We came up with the idea of doing this project because, from our experience, we think that during physics classes, students may need more visual and interactable examples of different physics concepts and events happening in the natural world. Also, it is essential to show where and how these physics concepts and events apply. Below, in the further sections, we describe how these mechanisms relate to more complex engineering constructions that people use daily. This knowledge is significant for future engineering sciences students. These mechanisms will also be good examples of 3D modeling, simulation, and printing. Engineering students can utilize 3D printing technology much more often than they do now, and our project will motivate them to be more creative and aware of the opportunities. We will also provide all necessary research, modeling, and simulation files to whoever needs them as a resource. Having the files, students will be able to edit the models or change the simulation settings, change the materials, and see all the simulation graphs and metrics.

1.1.2 Assumptions and Constraints

Here we describe basic assumptions and constraints in the development of the concept. We assume that we will make every mechanism will be firstly 3D modeled by every part and assembled in software format. All moving parts of the systems will be simulated in SolidWorks to make sure that they work as intended to avoid mistakes during printing and ensure that the mechanism performs correctly when someone interacts.

1.2 Overview of the System

This section provides an executive summary overview of the system. A more detailed description will be provided in Section 3.0

1.2.1 Overview

This subsection provides a high-level overview of the system and its operation. For the project, we made six mechanisms that represent the physics concepts. We will put the stand in one of the Engineering laboratories of the American University of Armenia so that the stand will be accessible to any student or professor for educational purposes.

1.2.2 System Scope

This section gives an estimate of the size and complexity of the system. It defines the system’s external interfaces and enabling systems. All the mechanisms are modeled and simulated in software named SolidWorks which allows doing all the necessary calculations and simulations to ensure that every aspect of the mechanical system was designed correctly to avoid any mistakes during and after the 3D printing. This is critical for us since we want to perform the 3D printing in as few attempts as possible because it will save us a lot of time and filament. As the software for 3D printer we used Zsuite which is the software for the Zortrax 3D printers. In our engineering lab the printer is Zortrax M200 and we mainly used that printer to complete this project

2.0 Documents

2.1 Applicable Documents

This section lists all the documents, models, standards, or other applicable materials, some or all of which will form part of the project's requirements.

The primary documentation that will serve as a foundation for the whole project are the volumes of the book by Ivan Artobolevsky, “Mechanisms In Modern Engineering Design,” particularly volumes II, III, and V. These documentations contain both written and visual information about the mechanisms chosen for this project.

2.2 Reference Documents

Here we provide supplemental information that might be useful in understanding the system or its scenarios.

During the modeling process, we used SolidWorks software to model the mentioned mechanism and used its documentation as a reference.

During the process of prototyping, we used a user manual for 3D printing for reference to make sure that the modeled mechanisms are made correctly because otherwise, it will result in mechanism malfunction.

3.0 Description of System and work process

3.1 Needs, Goals, and Objectives of System

This section describes the needs, goals, and objectives as expectations for the system's capabilities, behavior, and operations. As described earlier, our project's main need is for Engineering Sciences students to have more visual and interactable examples of physics concepts to understand their applications better. As mentioned earlier, the main objective is to model, simulate and prototype these mechanisms and put them on a stand in a university laboratory so that students and professors can use them. The stand will include six mechanisms representing different concepts.

1. Rocker-lever mechanism with a rotating disk.
2. The mechanism of the anti-parallelogram with trailed rod and slide.
3. Crank-slider hammer mechanism A with an elastic link.
4. Crank-slider hammer mechanism B with an elastic link.
5. Punching machine cam mechanism.
6. Three-link cam mechanism of punching hammer.

All these mechanisms were referenced from Mechanisms books (parts 2,3,5).

3.2 Overview of System, Key Settings, and Configurations.

In this section, we describe at a functional level the various elements that will make up the system, including the users and operators. We are going to describe how each mechanism works and what they represent.

Since all mechanisms were modeled in SolidWorks software and are 3D printed with Zortrax 3D printer using the Zsuite software, many things are common for all of them:

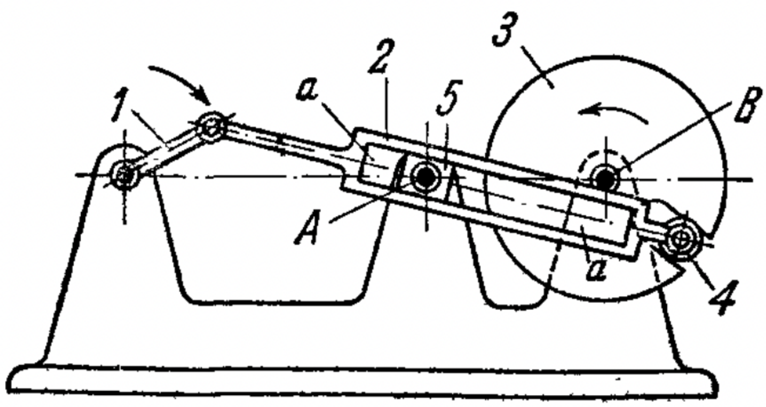
- As a design technique, we implemented fillets in almost all our models to make the mechanisms more appropriate looking and reduce filament usage.

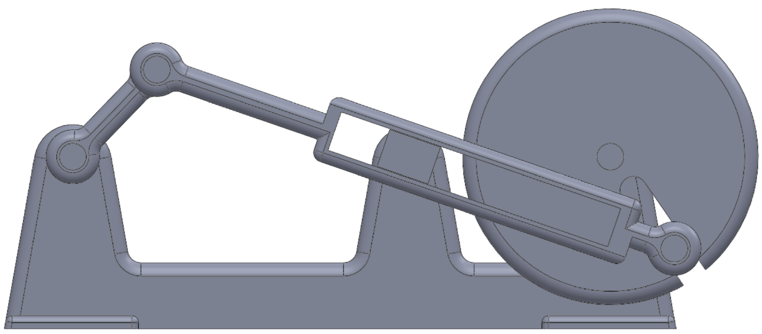
- After the first printing of the parts, we realized that parts like pins and holes did not fit into each other because of the 3D printer inaccuracy, so we decided to make offsets for every part to fit them into each other. We made offsets of approximately 0.2-0.3 mm for the parts where the fit should be tight, for example, for the pin sleeves, which limit the motion of the parts on the pins, and we made offsets 0.5-0.6 mm for the parts where fit should be a loose.
- At the beginning of the planning, we already understood that we needed to limit the movement of parts on the pins along the pin axis. We did research and came up with three main ways to accomplish this task which fitted our models. We used three techniques to limit the movement of the parts on pins along the pin axis.
    - We made hats that have a longer radius than the main part of the pin at one end of each pin so that it can be inserted only from one side and does not fall from the other side:
    - We implemented pin sleeves, which are separate parts similar to a ring. Their outer radius is the same as the radius of the hat mentioned above. The inner radius is similar to the pin's but has an offset described above. These sleeves would be between parts to keep them in the desired position with respect to the other parts so they are aligned correctly.
    - We made small holes to insert a cotter pin to limit the movement from the other end of the pin. Cotter pins are penetrating and coupling mechanical fasteners that are easy to install and remove. They are used to prevent axial movement along a shaft or pin or to secure two components together. Some of the applications of cotter pins are:
        - Limiting parts movement along the ping axis.
        - Connecting piston rods in a crosshead in a steam engine
        - Connecting pedals to sprocket wheels in bicycles
        - Securing bolts and nuts in place
        - Joining the two halves of a flywheel

      Cotter pins can be made of different materials, such as plastic, steel, brass, or Monel, depending on the strength and corrosion resistance required. They come in various shapes and sizes, such as split, circular, or tapered. We used circular-shaped steel-made cotter pins.

In the pages below, each picture and description corresponds to the number from section 3.1, “Needs, Goals, and Objectives of Envisioned System.”

3.2.1 Rocker-lever mechanism with a rotating disk.





Overview

This mechanism represents a standard piston with fixed link 5, rotating around a fixed axis A. It is made in the form of a slider, along which link 2 slides inside slot “a - a”. Link 2 is equipped with a roller 4, which enters the slot of disk 3, rotating around the fixed base B. With the uniform rotation of crank 1, disk 3 rotates unevenly.

Applications

A rocker-lever mechanism with a rotating disk is a type of four-bar linkage that converts continuous rotation into oscillation or reciprocation. It consists of a crank, a coupler, a rocker, and a disk that slides along the coupler. The application of this mechanism mainly comes from its nature of unevenly rotating the pin on the disk. This can be used to generate non-circle-shaped movement which has a lot of applications. Here are some of them:

- Push Mechanism: Since its speed is faster in some sections of the movement than in others, it can be used to push objects.
- Windshield wiper: The crank is driven by a motor and the disk is attached to the wiper blade. The wiper blade oscillates back and forth along the windshield.
- Pumpjack: The crank is driven by an engine and the disk is connected to a rod that pumps oil from a well. The rod reciprocates up and down as the crank rotates.
- Quick-return mechanism: The crank is driven by a power source and the disk is attached to a cutting tool or a press. The tool moves faster in one direction than another, allowing for faster production.

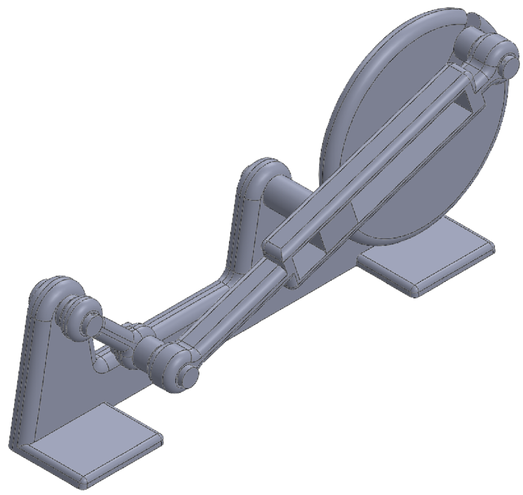
Some advantages and disadvantages of the rocker-lever mechanism are:

- Advantages:
  - It can produce oscillating or reciprocating motion from continuous rotation, which is helpful for many applications such as windshield wipers, pumpjacks, and quick-return mechanisms.
  - It can provide mechanical advantage, which means that it can make lifting or applying pressure easier by reducing the effort required.
  - It can be designed for different requirements and specifications by adjusting the lengths and positions of the links.
- Disadvantages:
  - It may have a limited range of motion or speed depending on the

configuration of the links and joints.

- It may have friction losses or wear and tear at the joints, reducing its efficiency and durability.
- It may not have the mechanical advantage of other types of levers, such as second-order levers or third-order levers.

Our modeling, printing, and assembling experience



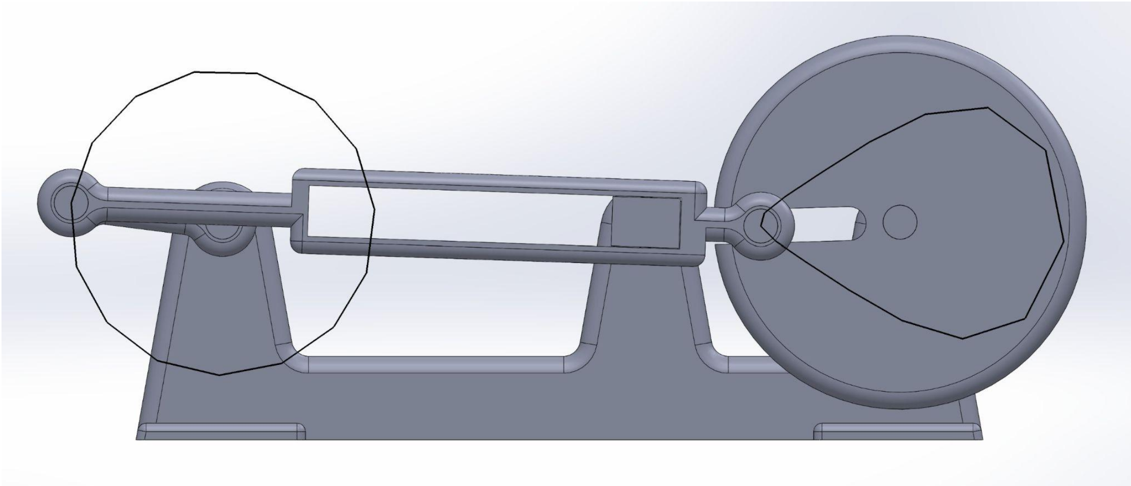
While modeling and simulating, we only had a few problems, except the main part on which everything is fixed and rotating turned out to be bigger than the printer can handle (The printer's dimensions are 200X200X180), so this part was split into two. We fixed them on the stand together and applied some insulating tape.

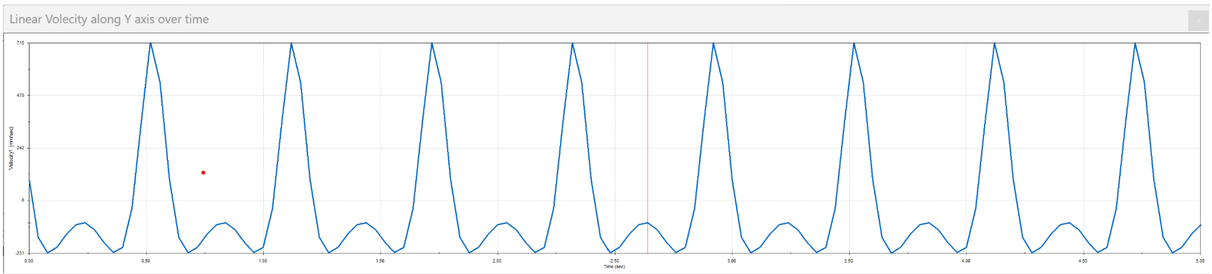
We used several techniques to limit the pins' movement so they do not move back and forth. One was to make one end of the pin wider to limit its movement from one side. Another thing we implemented was to make a sleeve that would go onto the pin and stay between parts to limit the movement.

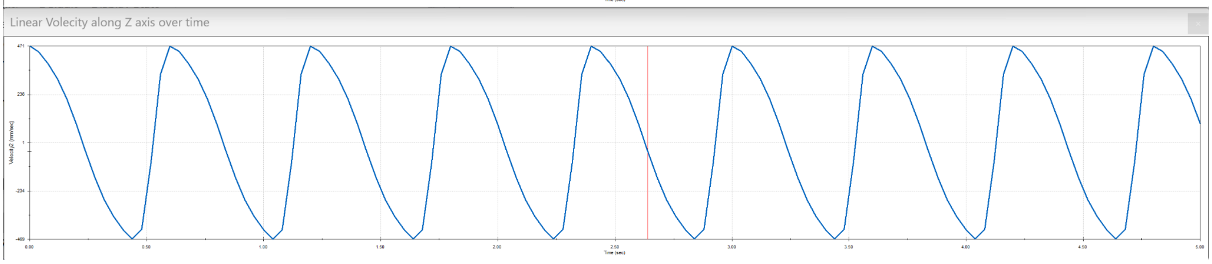
From another end, we used cotter pins to limit the movement, which can be removed if the machine needs to be disassembled. We also implemented holders on the piston to keep it on the same line as rod 2. No other particular approaches were used in this mechanism.

Simulation

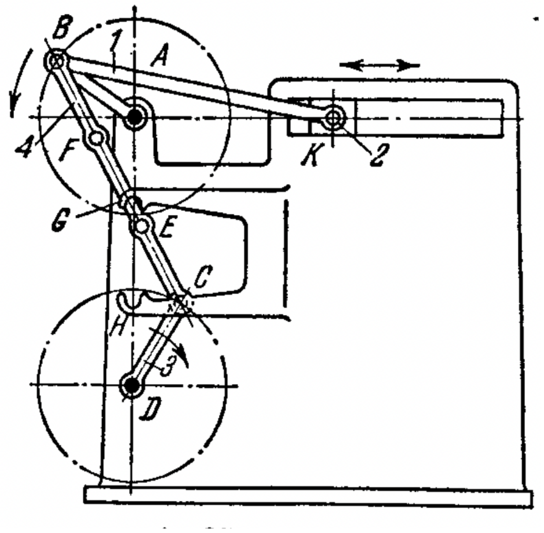
As you can see from the first screenshot below, the pin on the disk follows the path shown. In the next screenshot, you can see the Linear Velocity along Y and Z directions. The Y axis is vertical, and the Z axis is horizontal and is along the mechanism's main part. As you can see from the graphs, the most velocity along the Y-axis is achieved at the very right of the path shown in the first screenshot. This high velocity can be used in the example that was mentioned above. The concept works for the velocity along the Z-axis. The maximum velocity is not as high as along the Y axis, but it reaches the maximum two times during one cycle - at the top and bottom of the path from the first screenshot.

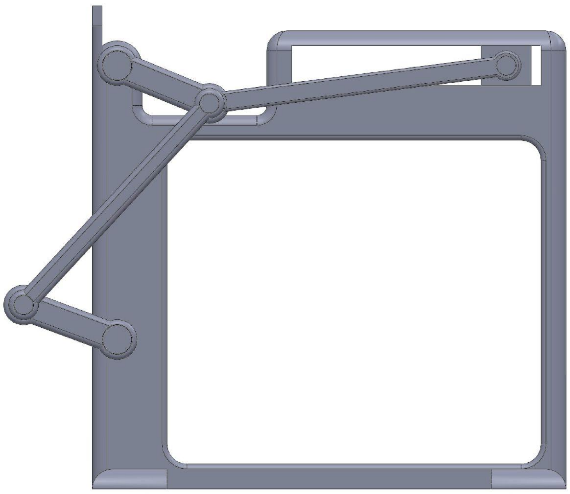






3.2.2 The mechanism of the anti-parallelogram with trailed rod and slide.





Overview

This mechanism also represents a piston mechanism. The lengths of the links of the mechanism satisfy conditions: AB = DC and BC = AD, but the main idea and reason why we are comparing this mechanism to mechanism number 1 since we want the AB < CD in this example to see how this will change the performance of the piston. There is the mechanism of the antiparallelogram ABCD at point B, a connecting rod 1 is attached, which drives slider 2 in a reciprocating motion. With the uniform rotation of crank 3, the crank AB rotates unevenly, which allows the implementation of the complex law of motion of slider 2. Uncertainty in motion antiparallelogram ABCD in the limit positions is eliminated by entering the fingers F and E of link 4 into the grips G and H.

Applications

Applications of this mechanism are mainly coming from the fact that since pin B is rotating only in the plane to the right of the AD line, this provides uneven movement of the piston; in this case, when it is closer to A pin, the piston moves faster, and while being further from it the speed is low. The model can be modeled so that the logic is opposite and the piston is faster while being further from pin A.

Applications of unevenly moving pistons are:

- In some engines, such as two-stroke engines, the piston also acts as a valve by covering and uncovering ports in the cylinder. This requires the piston to move unevenly to match the timing of the intake and exhaust cycles.
- In some pumps, such as reciprocating pumps, the piston moves unevenly to create a pulsating fluid flow. This can be useful for metering, dosing, or mixing fluids.
- In some compressors, such as scroll compressors, the piston moves unevenly to create a spiral motion of a fluid. This can increase the compression efficiency and reduce noise and vibration.

Here are also some examples of devices that use unevenly moving pistons are:

- Two-stroke engines, which use the piston as a valve to control the intake and exhaust ports in the cylinder.
- Reciprocating pumps, which use the piston to create a pulsating flow of fluid for metering, dosing, or mixing purposes.
- Scroll compressors use the piston to create a spiral fluid motion for efficient compression.
- Wave power generators, which use the piston to convert the kinetic energy of waves into electrical energy.
- Rotary engines use the piston to create a circular fluid motion for power generation.

Possible advantages and disadvantages of unevenly moving pistons are:

- Advantages:
    - Unevenly moving pistons can allow for better timing and control of the intake and exhaust cycles in some engines, such as two-stroke engines.
    - Unevenly moving pistons can create a pulsating or spiral flow of fluid in some pumps and compressors, which can improve the metering, dosing, mixing, or compression efficiency of the fluid.
    - Unevenly moving pistons can reduce the peak pressure and temperature in the cylinder, which can lower the risk of detonation or

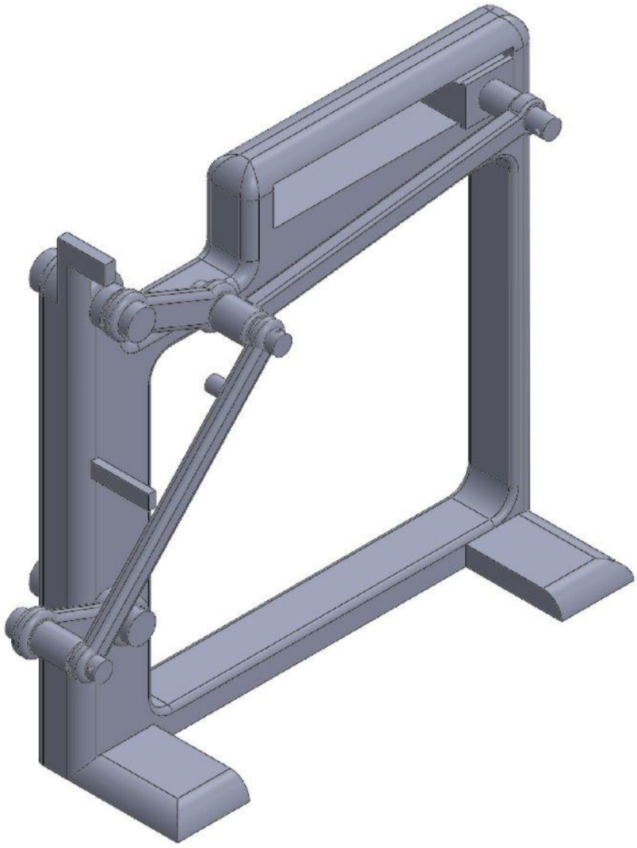
knocking in some engines.

- Disadvantages:
    - Unevenly moving pistons can cause variations in the piston-cylinder mechanism's compression ratio, power output, fuel consumption, noise, vibration, and wear.
    - Unevenly moving pistons can increase the complexity and cost of the piston-cylinder design, construction, and maintenance.
    - Unevenly moving pistons can require additional components or systems to smooth out fluid pulsating or spiral flow in some pumps and compressors.

Optimization

There are also different methods and techniques to control or optimize unevenly moving pistons, depending on the type and purpose of the piston-cylinder device. Some possible ways are:

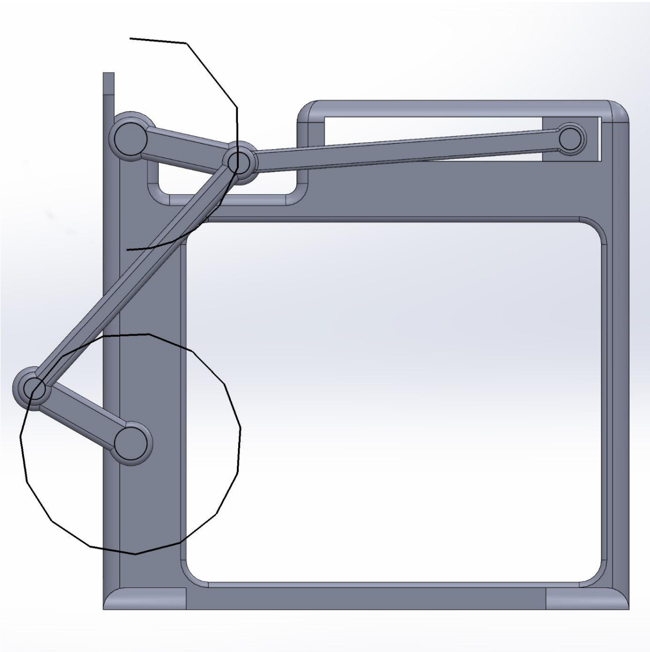
- Using feedback control systems to adjust the force applied on the piston, based on the measurements of the pressure, temperature, velocity, and density of the fluid in the cylinder.
- Using variable valve timing and lift systems to regulate the opening and closing of the intake and exhaust valves in some engines, according to the engine speed and load.
- Depending on the demand and operating conditions, use variable displacement pumps or compressors to change the number of active pistons or cylinders.
- Using different shapes and sizes of pistons, cylinders, connecting rods, and crankshafts to optimize the piston stroke, compression ratio, and fluid flow.
- Using different materials and coatings for pistons, cylinders, rings, and valves to reduce friction, wear, corrosion, and thermal expansion.



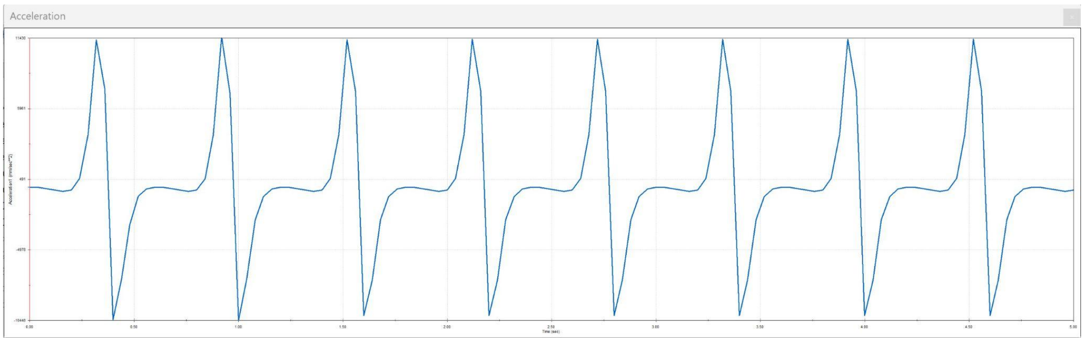
Our modeling, printing, and assembling experience

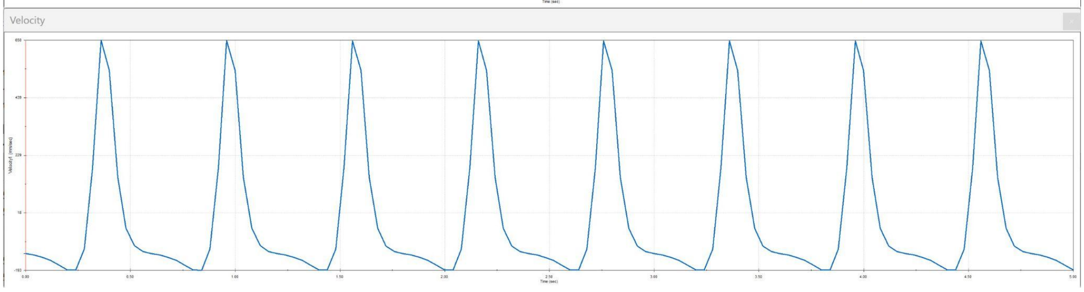
This mechanism fitted onto the printer plate, so we had no significant issues as with the first one. This mechanism was initially designed to have grips that would grab the BC bar, but we changed the design and implemented two movement limiters that would keep the BC bar mainly in the right plain. The mechanism was designed to reduce filament usage as much as possible and make the mechanism lighter. Also, we used the same approach of the pins movement limitations which are one-sided hats, cotter pins, and sleeves between the parts. In one of the places, the sleeve was integrated into the BK part which affected the movement of it on the B pin. Here we also used the same technique of limiting the movement of the piston in the axis perpendicular to the main part by modeling movement limiters on the piston itself as on the previous mechanism.

Simulation

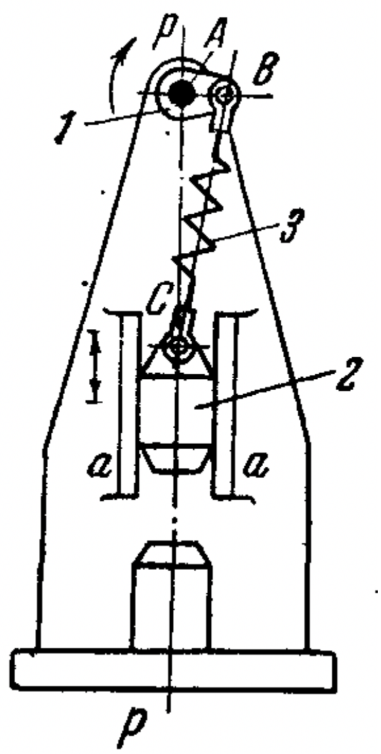


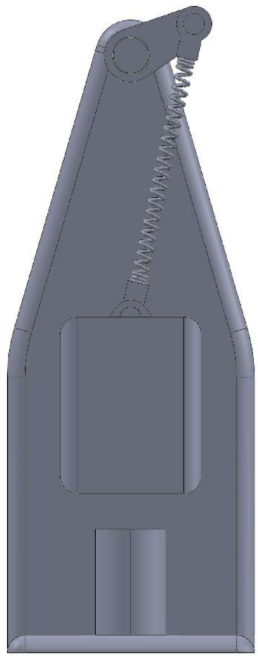
In this mechanism as stated above the upper pin is moving along the semicircle to the right plane of the BC bar and the below pin is making a full rotation and the force of hand or the motor rotation is applied to it. You can see the path in the screenshot. In the Graphs below you can see the Acceleration and the Velocity of the piston. As you can see from the Velocity graph, the piston is moving unevenly and its speed is increasing closer to the center of the bar. The purpose of having the slot for the piston so long is that it is possible to make the mechanism also do the same action in the reverse direction - move the piston to the right part of the slot.





3.2.3 Crank-slider hammer mechanism with an elastic link.





Overview

In this mechanism, Crank 1 revolves around axis A. Slider 2 moves in fixed guides a - a. Point B of crank 1 and point C of slider 2 are connected by a spring link 3. When crank 1 rotates, slider 2, under the influence of spring link 3, oscillates in the direction of the p-p axis. The main idea of this mechanism comes from its elastic link 3. Because of that, it is possible to put an object of any size under the slider (hammer), and the mechanism will not break.

Applications

A crank-slider hammer mechanism with an elastic link is a planar mechanism consisting of a crank, a coupler, and a slider. The coupler is flexible and can deform under the action of external forces. The slider is a hammer that can strike an object or a surface. This mechanism can be used for various applications, such as:

- **Dynamic analysis and testing** of materials or structures. The slider can apply impact loads to the test specimen and measure the resulting response.

The flexibility of the coupler can affect the contact force and the vibration of the mechanism.
- **Piezoelectric actuation and control** of the mechanism. The coupler can be equipped with piezoelectric layers that can generate electric signals or deform under applied voltages. These signals can be used to control the slider or the crank's motion or suppress the coupler's vibration.

The advantage of piezoelectric actuators in these mechanisms is the high-speed operation and performance of machines or equipment. The mechanism can be used to achieve high operating speeds, superior reliability, and accurate performance in various industrial or commercial applications.

The flexibility of the coupler affects the performance of the mechanism in several ways:

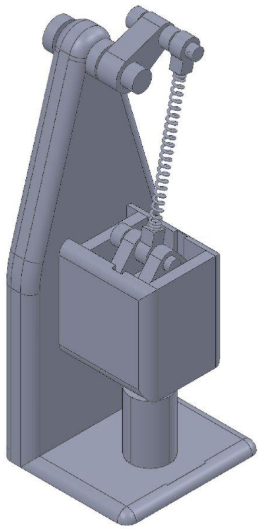
- It can reduce the impact forces and vibrations caused by the clearance in the joints. The flexible coupler can act as a suspension for the mechanism and absorb some of the energy during contact.
- It can change the natural frequencies and modes of vibration of the mechanism. The flexible coupler can deform under the action of external forces, and its shape can vary during motion.
- It can influence the accuracy and precision of the slider position and velocity. The flexible coupler can introduce errors and uncertainties in the mechanical response due to its deformation and nonlinear behavior.

Optimization

Depending on the desired performance and objectives, there are different ways to control or minimize the effects of the flexible coupler in the crank-slider mechanism.

- Using piezoelectric actuators to apply input signals to the flexible coupler and suppress its vibrations. Piezoelectric actuators are intelligent materials that convert electrical energy into mechanical deformation and vice versa.

Our modeling, printing, and assembling experience



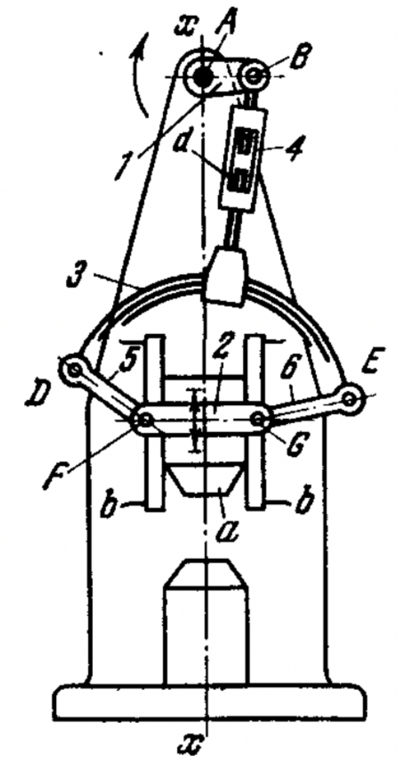
During modeling this mechanism, we used knowledge gained from the conference we attended about simulating springs in Solidworks. We had no significant issues with the mechanism parts, which were supposed to be 3D printed. The part that needed the most attention here was the spring that was used as a method of making the link elastic. In the initial scheme, it is shown that there is a directing link inside the spring that would prevent the spring from deforming in the perpendicular axis while the mechanism work. However, since we were limited to 3D-printed parts, we did not find a suitable solution, so it was decided not to use such directing link. Another problem was finding the spring of the correct stiffness and size.

As you can see, the spring does not have much stiffness. One of the takeaways from assembling this kind of mechanism which we will also show in the next one, is that we should have considered the high amount of friction between 3D printed parts and needed more directing parts for the slider. As you will be able to see from the assembled part, the slider is changing its angle a bit while being pulled up. We also made rails that would keep the slider in place. We made them circle shaped, which we realized was a mistake during the assembling since the angle of the slider changed while the mechanism was working.

Simulation

For this mechanism, we do not have clear simulation results that will depict the real motion of the piston (slider) as it is connected to an elastic link (spring). This made it difficult to get clear results in SolidWorks motion analysis since the spring is moving in the horizontal direction and also rotating.

3.2.4 Different approach for crank-slider hammer with an elastic link.

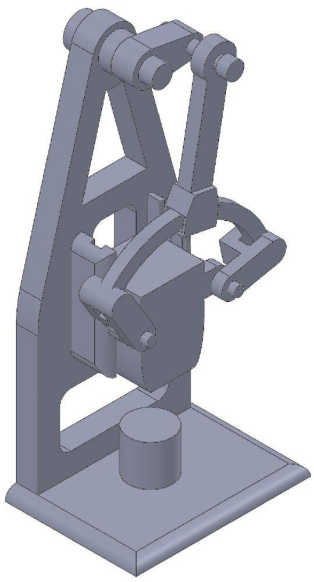


Overview

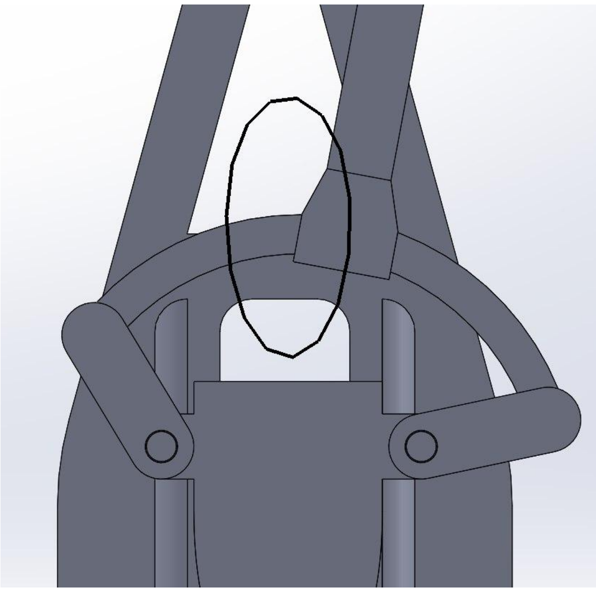
Striker (slider) “a” slides in cap movable guides “b - b.” Rigidly connected with the striker on traverse 2, which is part of the rotational pairs F and G with links 5 and 6. Res-Azora 3 at points D and E are connected to links 5 and 6 and is rigidly connected to connecting rod 4 with threads, which is part of the rotational pair B with crank 1, rotating around a fixed axis A. When crank 1 rotates, striker 2, under the influence of spring 3, oscillates in the direction of the “x - x” axis. Rod with threads 4 has a wind control device A for changing the amplitude of the vibrations of the striker.

Our modeling, printing, and assembling experience

Applications and optimizations for this mechanism are mainly the same as for the previous one since the main logic remains the same: the slider “a” is not rigidly connected to the rod 4. We did not use the technique with threads for the rod 4 since we were limited to the 3D printed parts, so instead we just used a straight, rigid link as you can see in the screenshots below. As the flexible part had big problems finding the elastic part as the flexible mechanism so we used a flexible piece of metal that would fit inside the holes of the part replacing the threaded rod and the holes on the DF EG parts. In the Solidworks, we made it as a usual extrude to represent the movement. These parts were also modified to be centered with part 4 and being able to hold the flexible metal. In this mechanism, we also had the problem of the slider changing the angle while the mechanism work as in the previous one so we made it so that it is fully stitched to the back of the main part and the rails are square shaped to prevent rotation.

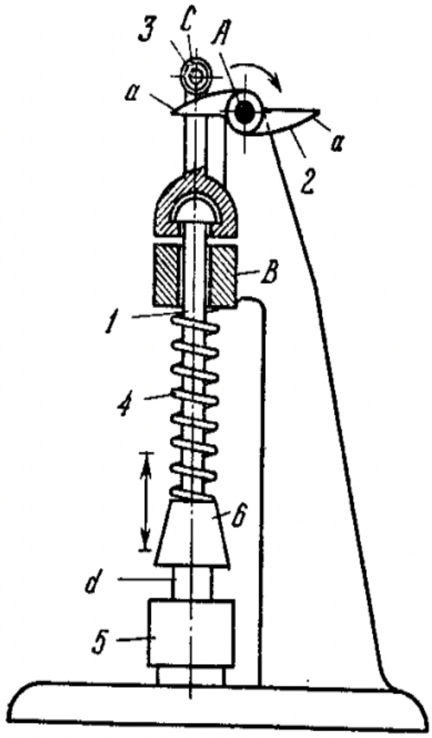


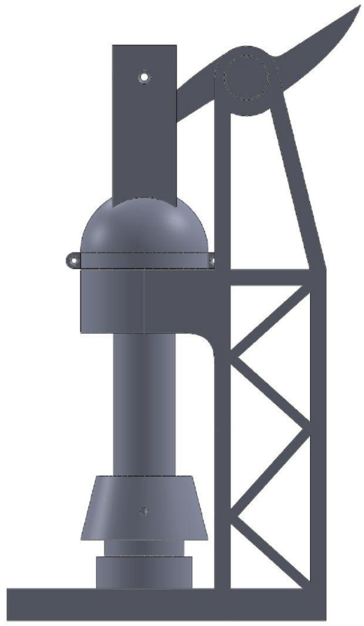
Simulation



In the screenshot, you can see the path of the central part of the end rod 4. In the real model, since it is not sticked with the elastic element, it is sliding left to right, but the path remains the same. For this mechanism, also, it was quite difficult to get motion graphs that would depict the mechanism's true motion as it is also connected to an elastic link.

3.2.5 Punching machine cam mechanism.





Overview

Cam 2, rotating around a fixed axis A, consists of two parts with profiled sections a. Rod 1 with hitter 6 moves progressively in a fixed guide B. Bar 1 has a roller 3 rotating around axis C, which periodically is in contact with one of the profiles and of cam 2. After leaving the contact, rod 1 falls under the weight of hitter 6 and spring 4 and hits the workpiece d lying on a fixed base 5. For a full cycle movement of the mechanism, rod 1 has two periods of rise and two periods of fall.

A cam is a rotating or sliding piece in a mechanical linkage that transforms rotary motion into linear or oscillating motion. It has a curved profile or groove that strikes a lever or follower at one or more points on its circular path. The follower is a lever that makes contact with the cam and moves according to the shape of the cam profile. A cam can produce different types of motion for the follower, such as rise, dwell, return, and fall. A cam mechanism usually consists of two moving elements, the cam, and the follower, mounted on a fixed frame. A cam mechanism can be classified by the shape of the cam, the type of the follower, and the way of locking. A cam mechanism can be used for various applications that require a complex or intermittent motion for the follower. This mechanism can also be used with a spring as it is shown in the scheme between parts B and 6. In this case, pin A and cam 2 can be made of different materials because of the high load on that detail, and also part 6-d should be attached to bar 1 not to come out because of the spring.

Applications

A punching machine cam mechanism is a device that uses a cam to convert the rotary motion of a motor into the linear motion of a punch tool. Using mechanical power, it is used for making holes or cutting shapes in sheet metals or nonmetals. Applications for punching machine cam mechanisms are:

- Punch press machine: A machine that uses a cam to drive a punch tool to make holes or blanks in metal sheets. It is suitable for mass production and can run at high speed.
- Stamping machine: A machine that uses a cam to drive a stamp tool to imprint patterns or logos on metal sheets. It can be used for making labels, badges, coins, etc.
- Forming machine: A machine that uses a cam to drive a forming tool to bend or shape metal sheets into desired forms. It can be used for making brackets, hinges, clips, etc.
- Embossing machine: A machine that uses a cam to drive an embossing tool to create raised or sunken designs on metal sheets. It can be used for making decorative items, jewelry, cards, etc.

Some of the advantages of using a cam mechanism are:

- It has a simple, compact, and easy-to-design structure, making it widely used in various machines and devices.
- It can produce any desired motion for the follower by designing the cam profile.

- It can achieve high-speed and accurate motion transmission with minimal backlash.

Some of the disadvantages of using a cam mechanism are:

- It has high wear and tear due to point or line contact between the cam and the follower, which requires lubrication and maintenance.
- Processing the cam profile is difficult and costly, especially for complex shapes and curves.
- It has limited stroke and force transmission capacity for the follower.

Since our mechanism is a punching machine here some of the advantages of using a it with cam mechanism are:

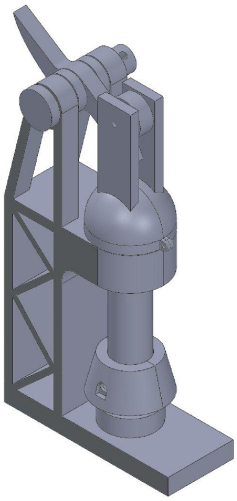
- It can produce holes or shapes in metal sheets with high speed and accuracy.
- It can achieve different motions for the punch tool by designing the cam profile accordingly.
- It is more economical and reliable than pneumatic or hydraulic systems.

Disadvantages of using a punching machine cam mechanism are:

- It has high wear and tear due to point or line contact between the cam and the rod or the punch tool, which requires lubrication and maintenance.
- Processing the cam profile is difficult and costly, especially for complex shapes and curves.
- It has limited stroke and force transmission capacity for the punch tool.

Our modeling, printing, and assembling experience

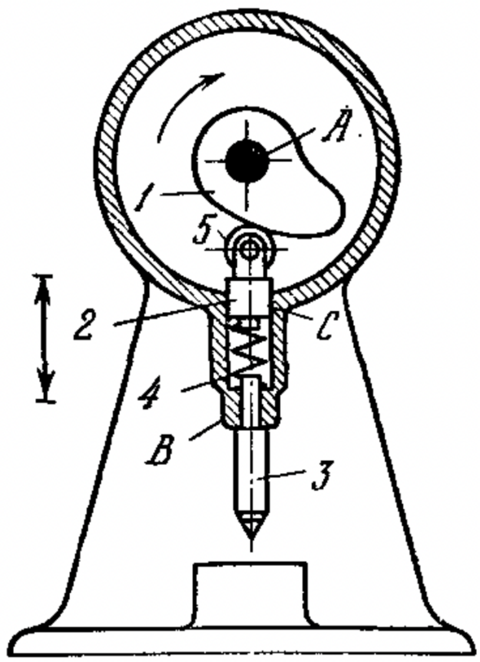
As you can see from the model it is shorter than the one on the scheme, because of the 3D printer dimensions and also we didn't want to make the punching rod too long because it would make it fragile. In this mechanism, we implemented triangular-shaped wholes to make the main part of the mechanism at the same time hard to brake and lightweight. As shown in the scheme the upper part of the punching rod is inside a semicircular structure which allows disassembling of the mechanism if needed. As mentioned in the explanation part of this mechanism, we decided not to use a spring because of the high load on the parts. Still, if the spring is not very stiff, the bottom of the striker rod is stuck with the main hole through which its working, and the cam is made out of different material it would be possible to use it with a spring.

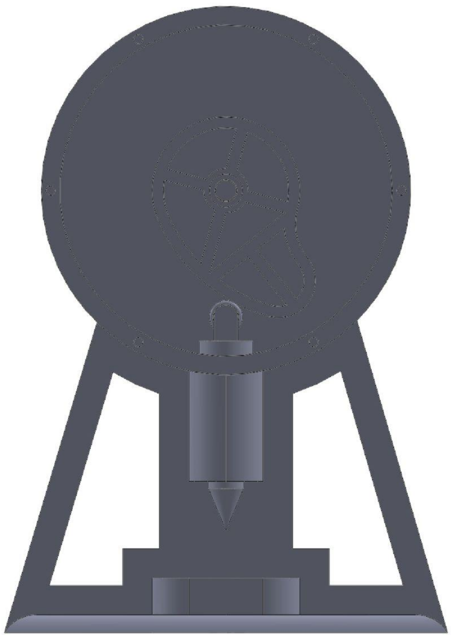


Simulation

In this mechanism, we could not simulate its movement in SolidWorks since we could not correctly simulate the cam rotating and pushing the punching part firstly up and then realising it downwards. Inside the software, the moment of the cam realizing the cam is infinitely short, so it wan’t possible to correctly simulate the velocity and acceleration of the striker.

3.2.6 Three-link cam mechanism of punching hammer.





Overview

Cam 1 rotates around a fixed axis A. Tool 3, which pierces the product, moves in a fixed guide B. Pusher 2, move-reciprocating in a fixed guide C, has a roller 5 rolling along the profile of cam 1. Between tool 3 and pusher 2, there is a spring 4. When the cam rotates 1 pusher compressing the spring chin 4, strikes tool 3, which pierces the product.

Applications

Applications of cam mechanisms are:

- Automotive engines: Cams play a vital role in internal combustion engines, controlling the opening and closing of valves.
- Textile machinery: Cams drive various mechanisms in textile machines, including looms and spinning frames.
- Printing presses: Cams control the precise movements of printing elements in printing presses.
- Door lock mechanisms: Cams can lock and unlock doors by rotating a key or

a knob.

- Stamping/hammering machines: Cams can produce intermittent linear motion of a punch or a hammer that strikes a workpiece.

Cam mechanisms have advantages and disadvantages, depending on the type, design, and application of the cam and follower:

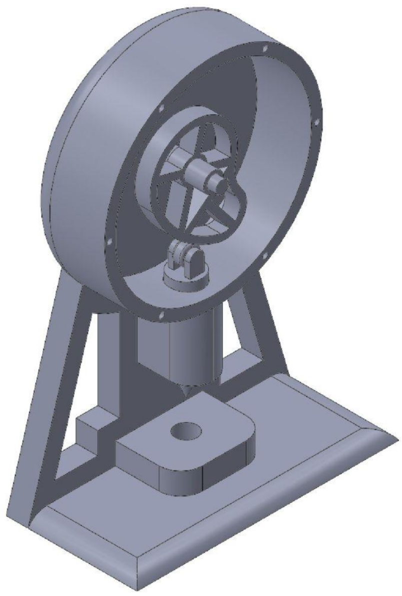
- Cams can produce a range of linear motion: Cam and follower mechanisms can be used to produce linear motion with different stroke lengths and velocities.
- Precision can be achieved: High levels of precision can be achieved using a high-quality cam mechanism. This is why cams are used in applications where tolerances are tight and precision is key, such as engines and in timing applications.
- Compact systems: Cam and follower mechanisms can reduce the number of mechanical components used within a system. They can do this through their ability to produce a range of different forms of motion by using small spaces and a small number of components.
- They can convert types of motion: Cam and follower mechanisms are used in a wide range of mechanical systems as they can convert types of mechanical motion. They can produce linear motion and convert rotational motion into other forms such as oscillating motion or vice versa.

Some of the disadvantages are:

- They can wear: Cam and follower mechanisms use mechanical parts which use friction to achieve their outcomes. Any mechanical system that uses friction can wear, so the transmission force that should be applied to a cam mechanism should be relatively low. Some applications that can handle high levels of transmission force but these are usually expensive mechanisms that have been designed for a specific application.
- High manufacturing costs: The accuracy of the cam profile is high, and it needs to be printed by 3D printer or processed by a CNC machine tool. This increases the manufacturing costs and complexity of cam mechanisms.
- Size limitation: Cams are limited by size and shape, which may restrict their

application in some situations. For example, a snail or drop cam can only work by rotating in one direction.

- Maintenance/checks are required: Cams and followers need regular maintenance and checks to ensure they are working correctly and safely. They may need lubrication, adjustment, or replacement over time.



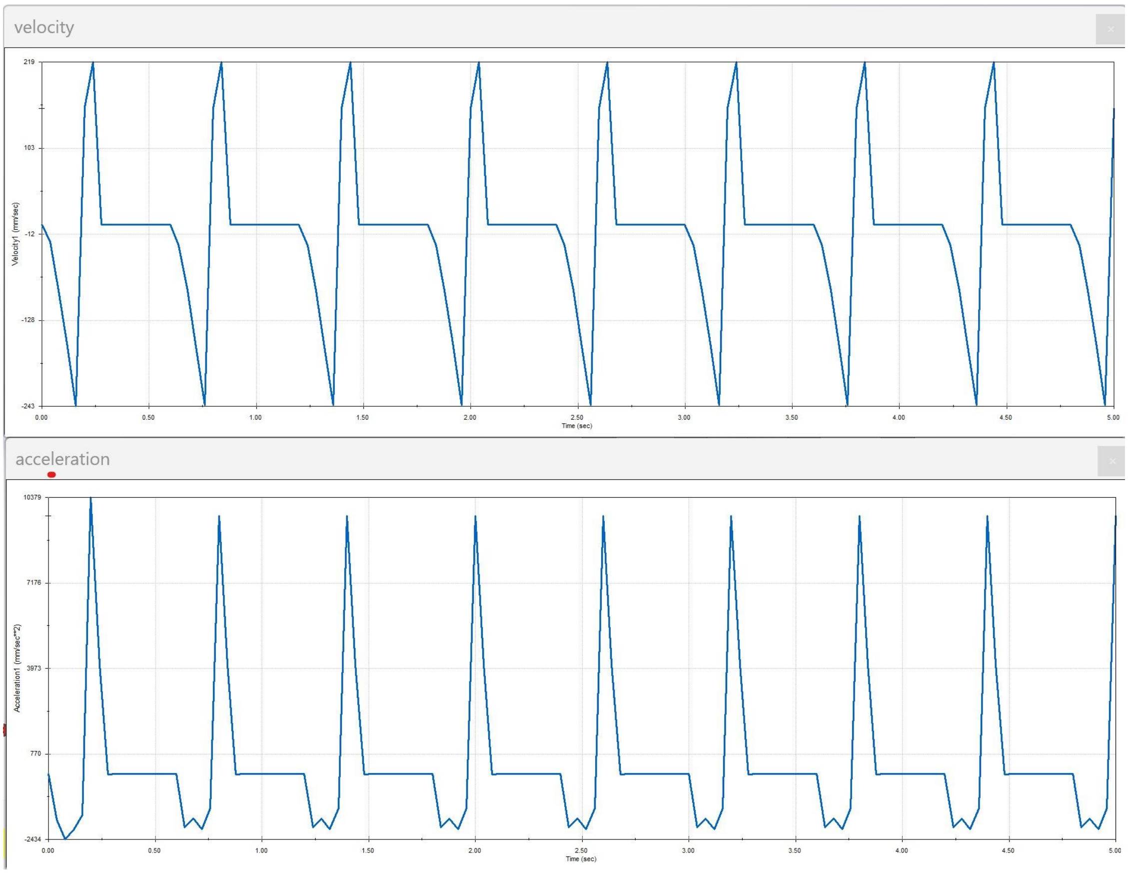
Our modeling, printing, and assembling experience

During work on this mechanism, we didn’t have significant issues. The roller at the top of the striker was inserted by brute force between two tight circle-shaped holders. The spring is put inside the hole and its bottom part is held by the top of the thinner part of the hole. As you can see from the model, there is also a hole at the very bottom part of the mechanism, this was done to enable physical instruments access to the hole of the striker to make it wider in case the offsets are not enough. There are also holes on the main part and the part that makes the striker go down to reduce the wait and filament usage. Also, the rotating part was made thinner and the sleeves were made to put it on the same line as the roller.

The spring that we found is a bit tight, but it ideally fits the hole, and the concept is represented very clearly.

Simulation

In the below graph you can see the velocity and acceleration of the pin with the shape of the cam that we chose for the mechanism and with the default settings of the spring simulation:



3.3 Interfaces

In this section, we describe the system's interfaces with any other systems that are external to the project. It may also include high-level interfaces between the major envisioned elements of the system. Interfaces may include mechanical, electrical, human user/operator, fluid, radio frequency, data, or other types of interactions.

For the prototyping of the mentioned mechanisms, we used a 3D printer. We will also need human interaction with the mentioned mechanisms as they need to be put into motion to display the mentioned physics concepts.

SolidWorks is a 3D CAD design software. It is used by engineers and designers to create, analyze, and manage various types of products and projects. SolidWorks offers a range of tools and features to help you with design, simulation, manufacturing, data management, and more. We used Solidworks software for modeling the parts and simulating them in the assembly and exporting them as animations.

Another software we used is the Zsuite software, a slicing and 3D printing farm management software designed for Zortrax devices. It allows to convert 3D files into models that can be printed with Zortrax 3D printers. It also offers features such as automatic mesh repair, editable supports, rotation optimization, hollow infill, overhang highlighting, and more. We used the software to understand if the parts can be placed onto the 3D printer plate, and edit the mesh pattern of the parts and the infill. We also described more details settings at the beginning of section “3”.

3.4 Modes of Operations

In this section, the various modes or configurations that the system accomplishes and its purpose throughout its life cycle are presented. This may include modes in the development of the system, such as for testing or training, as well as various modes needed during its operational and disposal phases.

All the chosen mechanisms have two modes of operation.

The first mode is when the mechanism is at rest, meaning none of its parts are in motion at any given moment. In this mode, there is no external interaction between the mechanism and the human.

The second mode is when the mechanism is put into motion, meaning that at least one part of the mechanism is in motion at any given moment. In this mode, there is initial interaction between the mechanism and the human. This mode is used to showcase how a particular mechanism works and the physical concept it displays.

3.5 Proposed Capabilities

Here we want to describe the various capabilities that the system provides. These capabilities cover the entire life cycle of the system's operation, including special capabilities needed for the verification/validation of the system, its capabilities during its intended operations, and any exceptional capabilities needed during the decommissioning or disposal process. As one of the proposed capabilities of our system, we consider the ability to fully reproduce the physical concept that the mechanism is showing. The mechanisms are made of filament and are strong enough to last for a long time of frequent usage. The parts have a certain degree of freedom and are able to move without any interference inside that degree.

4.0 Physical Environment

In this section, we describe the environment that the system performs in throughout its life cycle, including integration, tests, and transportation. This may include off-nominal temperatures, pressures, radiation, winds, and other atmospheric, space, or aquatic conditions. A description of whether the system needs to operate, tolerate degraded performance, or just survive in these conditions should be noted.

The primary physical environment for the mechanisms will be one of the laboratories at AUA. Therefore, the mechanisms are expected to operate under normal room temperatures without any risk of damage due to temperature fluctuations. It is imperative that students who interact with the mechanisms exercise caution and avoid applying excessive pressure, as we have limitations on the amount of filament we can use with a high mesh value. Furthermore, we have concerns that the models may become damaged under pressure. It is critical to avoid dropping the mechanism, as most of the 3D-printed parts were manufactured with an infill of 30%, which is sufficient for motion demonstrations but can be broken when dropped on the floor. Our team experienced such an incident while assembling mechanism number 4. We accidentally dropped it on the floor, and the pins, printed with an infill of 30%, broke, requiring us to reprint them. Additionally, the 3D-printed parts cannot resist significant angular pressure. For this reason, parts on which pressure is applied, or which are long and thin, are printed with an infill of 50% which makes it harder to break them.

5.0 Support Environment

This section describes how the system will be supported after being fielded. This includes how operational planning is performed and how commanding or other uploads is determined and provided, as required.

The mechanisms will be supported by project group members who will monitor the system's performance in the field and ensure it functions optimally. We will work closely with the students and professors, in particular, to ensure that the system is meeting their needs. We will also be responsible for providing explanations and support to the students in case they are interested. This includes providing students the software files and tutorials for them to understand how the mechanisms are built. This will help their introduction to the 3D modeling topic and how what they learn is applied.

3D printed mechanisms can be supported by a wide range of environments. Depending on the size and complexity of the mechanism, different environments can be used to ensure stability and accuracy. These include:

1. Computer-Aided Design (CAD) programs: CAD programs allow us to create 3D models of their mechanisms, which can then be printed out. This ensures that all parts of the mechanism are accurately and precisely printed, which is essential for proper functioning.

2. 3D printer software: 3D printing software is used to control the printer and ensure

that all parts of the mechanism are printed out correctly. This allows us to customize the 3D prints, ensuring that the mechanisms are of high quality.

3. 3D printers: 3D printers are used to print out 3D mechanisms. Some 3D printers are specifically designed for printing out 3D parts, allowing us to create complex and intricate parts with ease.

4. Materials: Different materials can be used to create 3D-printed mechanisms. We used Zortrax filament for 3D printing most of the parts. The parts that are not 3D printable are the elastic elements, so we found them from the external market. This includes springs on mechanisms #3, and #6 and the elastic link on mechanisms #4.

5. Support structures: Support structures hold the mechanism in place while it is being printed. Support structures are typically made of plastic or other materials, and they can be easily removed once the mechanism is finished.

6. Finishing techniques: Finishing techniques such as sanding and polishing can be used to improve the overall quality of the mechanism. This ensures that the mechanisms part fit into each other and they are smooth and precise, which is essential for proper functioning.

7 After all the mechanisms are ready, they are placed on a stand made of wood. There are also schemas and explanations of every mechanism stuck near their placement position.

6.0 Operational Scenarios, Use Cases, and/or Design Reference Missions

6.1 Nominal Conditions

These are scenarios and use cases that cover how the envisioned system will operate under normal circumstances where there are no problems or anomalies taking place.

In the case of nominal conditions described in point 4.0 Physical Environment, each mechanism consists of several parts each of which has degrees of freedom. In nominal conditions, each of these parts should be able to maintain its degrees of freedom. Considering correct usage as nominal conditions mechanisms will be able to last for a long time without any critical damage, deformation, or misfunction. We also consider the correct usage of the mechanism as a nominal condition since there is a designated interactable part on each mechanism that will make them function properly.

The nominal conditions of a 3D printed mechanism also depend on the printer and materials used. Generally, 3D-printed mechanisms need to be designed for the specific printer and materials being used for the best performance. Some considerations include layer thickness, wall thickness, infill settings, surface finish, and post-processing. The nominal conditions for a 3D-printed mechanism may also differ depending on the type of motion and load it needs to support.

6.2 Off-Nominal Conditions

These scenarios cover cases where some condition has occurred that will need the system to perform in a way that is different from usual. The mechanisms may malfunction in the environment outside of the designated physical location mentioned in 4.0 Physical Environment.

1. Poor dimensional accuracy: 3D printing is a process that involves melting and extruding filament to construct an object layer-by-layer. This can lead to variations in the size of the final product, which may not meet the exact dimensions specified in the design.

2. Poor surface finish: 3D printed parts have a rough surface finish due to the layers of filament being extruded. This can make them prone to wear and tear over time. 3. Poor material strength: 3D-printed parts are often made from plastic or other thermoplastic materials, which can be weaker than traditionally manufactured parts.

3. Poor layer adhesion: Due to the layer-by-layer construction of 3D printing, the layers may not adhere properly, resulting in weak spots in the overall structure.

4. Warping: Warping occurs due to uneven cooling of the 3D printed layers, which can lead to distortion in the final product.

5. High pressure is applied to the mechanism. Students who will use them should be very careful applying hand pressure on the parts, especially on the ones that are long and thin.

6. High temperature. The filament cannot resist very high temperatures, it can melt and deform. After cooling down the shape will remain deformed, so no high-temperature environment or object should be near the mechanisms.

7.0 Impact Considerations

This section describes the potential impacts, both positive and negative, on the environment and other areas.

7.1 Environmental Impacts

This section describes how the envisioned system could impact the environment of the local area, state, country, and worldwide as appropriate for the system's intended purpose. This includes the possibility of generating any orbital debris, potential contamination of other planetary bodies or atmosphere, and the generation of hazardous wastes that will need disposal on Earth and other factors. Impacts should cover the entire life cycle of the system from development through disposal.

A 3D printing filament is a type of thermoplastic of which objects are made when 3D printing. While 3D printing is a revolutionary technology that is changing the way products are developed, manufactured, and used, there are environmental concerns associated with the production and disposal of 3D printing filaments.

The production of 3D printing filaments requires the use of energy and natural resources. The manufacturing process of these filaments uses fossil fuels, which impact the environment, as they are a non-renewable resource and produce harmful emissions.

The disposal of 3D printing filaments has a significant impact on the environment. The plastic or polymers used to make these filaments are non-biodegradable, meaning they will not decompose in the environment and instead will remain in landfills for centuries. Additionally, 3D printing filaments can release toxic chemicals into the environment if not disposed of properly.

To reduce the environmental impact of 3D printing filaments, consumers should be aware of the environmental impact of their purchases and look for filaments made of recycled or biodegradable materials. Additionally, consumers should adequately dispose of 3D printing filaments by taking them to a recycling facility or a hazardous waste management facility.

7.2 Organizational Impacts

Here we describe how the envisioned system will impact existing or future organizational aspects. As described in the previous sections, these mechanisms will be used for educational purposes. Professors can use these mechanisms as showcases of different physics concepts. This will help students to understand better the application of what they; earn during physics classes at the American University of Armenia which will also lead them through the engineering sphere to understand which part of engineering they want to focus on. Also, 3D printing has the potential to revolutionize the way products and mechanisms are designed and manufactured. It can drastically reduce the cost and time associated with creating complex parts and mechanisms, enabling new levels of customization and efficiency.

The most significant organizational impact of 3D printing is the reduction in the need for large investments in tooling and inventory. By printing parts on-demand as needed, we can eliminate the need for large spare parts. Additionally, 3D printing allows for the creation of custom parts and mechanisms, allowing us to tailor our products to the requirements better.

On the manufacturing side, 3D printing drastically reduces the time and cost of prototyping. This allows companies to quickly create and test new parts without expensive tooling and inventory. Additionally, 3D printing allows companies to quickly adjust their designs in response to customer feedback, giving them an edge over competitors.

Finally, 3D printing can potentially reduce the amount of waste generated during the manufacturing process, as 3D-printed parts are made directly from CAD models without the need for excess material. This can significantly reduce the environmental impact of manufacturing.

7.3 Scientific/Technical Impacts

This subsection describes the anticipated scientific or technical impact of a successful mission or deployment, what scientific questions will be answered, what knowledge gaps will be filled, and what services will be provided.

The 3D printing of mechanisms can provide various benefits, including faster development cycles, lower costs, and improved product performance.

Faster development cycles: 3D printing can be used to quickly produce prototypes and functional parts, allowing engineers to quickly iterate designs to explore different options and identify the best solution.

Lower costs: 3D printing eliminates the need for expensive tooling and can reduce material waste, making it an attractive option for low-volume production.

Improved product performance: 3D printing allows for complex geometries and internal structures that are impossible to produce using traditional manufacturing processes. This allows engineers to create parts with improved strength, performance, and functionality.

8.0 Risks and Potential Issues

This section describes any risks and potential issues associated with the envisioned system's development, operations, or disposal. Also includes concerns/risks with the project schedule, staffing support, or implementation approach.

3D printing technology offers a wide array of capabilities that can provide tremendous benefits, such as the ability to create custom components and reduce the cost of prototyping rapidly. However, 3D printing can introduce a variety of risks and potential issues when it comes to creating a 3D-printed mechanism.

One of the major risks associated with 3D printing is the potential for parts to fail due to material properties. 3D-printed parts are usually made from thermoplastics, which are not as strong or durable as traditionally machined parts. As a result, complex mechanisms may not be able to handle the stresses and strains of the environment or application. Additionally, the surface finish of 3D printed parts can be below that of machined parts, which can affect performance and cause problems such as increased friction or wear.

Another potential issue with 3D-printed parts is the accuracy of the design. 3D printing works by depositing layers of material on top of each other, which can cause parts to warp or be misaligned. This can lead to misaligned parts and reduced performance, or worse, the failure of the mechanism. Furthermore, 3D printing can have difficulty producing parts with tight tolerances, leading to performance issues. We had this problem while we were printing and assembling the mechanisms. Most of the offsets we created for the section of the parts that should fit into each other were misaligned and it led to some amount of physical work done on the parts to make them aligned.

Finally, 3D-printed parts can be time-consuming and expensive to create. Depending on the complexity of the part and the type of 3D printer being used, it can take hours or even days to create a part. Additionally, 3D printing can require a large amount of material, which can add to the cost of the part.

3D printing is an incredibly powerful technology and can provide a wide range of benefits. However, there are a variety of risks and potential issues that must be taken into consideration, such as material properties, design accuracy, and cost.

9.0 Conferences

9.1 Tips and Tricks for CSWP

We attended this conference to get more knowledge on SolidWorks, the software that is in the backbone of our project. The conference was about tricks and tips while working with SolidWorks. While it was mainly focused around the certification that SolidWorks provides, CDWP (Certified SolidWroks Professional), we were able to learn a lot of new features that SolidWorks has to offer. Here are the main things that we learnt. Some of them help during one’s day to day SolidWorks experience, and make it easier and faster, while others have distinct implementations, some of which we used during our project:

Using keyboard shortcuts: SolidWorks has many keyboard shortcuts that can help ytoou work faster and more efficiently.

Using configurations: Configurations can be used to create variations of a part or assembly within the same file. This can be useful for creating different versions of a product or accommodating different manufacturing processes.

Using reference geometry: SolidWorks offers many tools for creating reference geometry, such as planes, axes, and points. These tools can help create accurate and complex models more easily.

Customizing the toolbar: One can customize their SolidWorks toolbar by adding or removing commands that they frequently use. This can help one access the commands they need more quickly.

Using mates carefully: Mates are used to constrain parts in an assembly. Use mates carefully and thoughtfully, as over-constraining a part can lead to errors and unexpected behavior.

Utilizing the mouse gestures: SolidWorks has built-in mouse gestures that can be used to perform common tasks quickly.

Understanding design intent: When creating parts and assemblies in SolidWorks, it's important to understand design intent. This means designing with future changes in mind and creating models that are flexible and adaptable.

9.2 BOM management in SOLIDWORKS

This conference was all about BOM (Bill of Materials) in SolidWorks. It refers to the process of creating and managing lists of components in a CAD assembly. A BOM is a list of parts or components that are required to build a product. It can include details such as part numbers, quantities, and descriptions.

In SOLIDWORKS, you can create a BOM using the "Bill of Materials" tool. This tool allows you to customize the appearance and contents of the BOM, such as hiding or showing specific columns, grouping components, and adding custom properties. You can also choose to link the BOM to the CAD assembly, so any changes made will automatically update the BOM.

- One of the benefits of using SOLIDWORKS for BOM management is that it provides a streamlined workflow for creating and managing BOMs. You can easily export BOMs to Excel, Word, or other formats, and you can also use SOLIDWORKS PDM (Product Data Management) to manage and control BOM revisions.

- During this conference we learnt a lot about Bill of Material in SolidWorks, some of the best features are listed below. We have implemented some of the below mentioned features in our project as well:

- Best practices for creating BOMs: The conference covered best practices for creating BOMs (Bill of Materials) in SolidWorks,such as structuring the BOM, adding custom properties, and linking the BOM to other parts of the design.

- Tips for managing large assemblies: Assemblies with a large number of parts can be difficult to manage. The conference covered tips and techniques for managing these assemblies.

- Managing revisions and changes: Revisions and changes to a design can impact the BOM. The conference covered strategies for managing revisions and changes to ensure the BOM stays up to date.

- BOM export and collaboration: The conference may have covered how to export BOMs from SolidWorks and collaborate with other stakeholders, such as suppliers or manufacturers. This could includes exporting BOMs in different formats, sharing BOM data via the cloud, or integrating BOM data with procurement systems.

- BOM for documentation and regulatory compliance: BOMs are often used for documentation and regulatory compliance. The conference discussed how to create BOMs that meet regulatory requirements and how to use BOM data for documentation purposes.

9.3 Modeling Springs Accurately with Multibody Dynamics

Modeling springs accurately with multi-body dynamics is an important aspect of simulating the behavior of mechanical systems that incorporate springs. Multibody dynamics software, such as SolidWorks Simulation, can create models of complex mechanical systems and analyze their behavior under different conditions.

When it comes to modeling springs accurately, there are a few key factors to consider. Here are some tips for modeling springs accurately with multibody dynamics:

- Choose the appropriate spring type: There are several types of springs, including compression springs, tension springs, torsion springs, and leaf springs. It's important to choose the appropriate spring type for the specific application, as each type behaves differently and requires different modeling approaches.
- Define the spring properties: When modeling a spring, it's important to accurately define its physical properties, such as the spring rate, free length, and maximum deflection. These properties will determine how the spring behaves in the simulation.
- Use the appropriate contact conditions: Springs typically interact with other components in the mechanical system, such as the housing or the component that the spring is attached to. It's essential to use the appropriate contact conditions to model the interaction between the spring and these components accurately.
- Use multibody dynamics software: Multibody dynamics software can provide advanced tools for modeling springs accurately, including the ability to define complex nonlinear behaviors and simulate the effects of damping and friction.

Modeling springs accurately with multi-body dynamics requires careful attention to detail and a thorough understanding of the physical properties and behavior of the spring. With the right tools and approach, however, it is possible to create highly accurate models of mechanical systems that incorporate springs.

10.0 References

Mechanisms in Modern Engineering Design, Volume 2:

Mechanisms in Modern Engineering Design, Volume 2.pdf

Mechanisms in Modern Engineering Design, Volume 3:

Mechanisms in Modern Engineering Design, Volume 3.pdf

Mechanisms in Modern Engineering Design, Volume 5:

Mechanisms in Modern Engineering Design, Volume 5.pdf

SolidWorks: SolidWorks_manual.pdf

ZSuite: z-suite-manual.pdf