MECHANICAL WATCH

ME251 Course Project
GROUP 7

PRESENTATION FLOW

- Introduction
- Main Watch Sections
- Component Analysis
- Working
- Final Assembly and Design
- Calculations
- Material Analysis
- Conclusion

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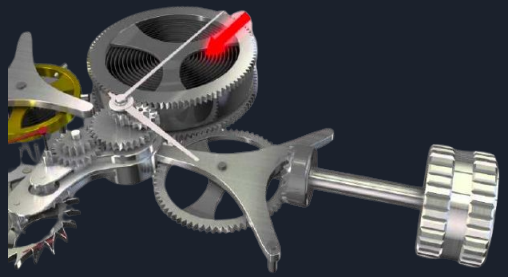
INTRODUCTION

- Mechanical watch functions by mechanical winding to deform the spring and drive a set of gears.
- It has no battery, microchip or circuitry.
- It is primarily driven by the potential energy stored in the spring. This spring must be wound either periodically by hand or via a self winding mechanism.
- These watches can produce accuracy within 2-3 seconds per day.

The watch functioning can be subdivided into three main parts:

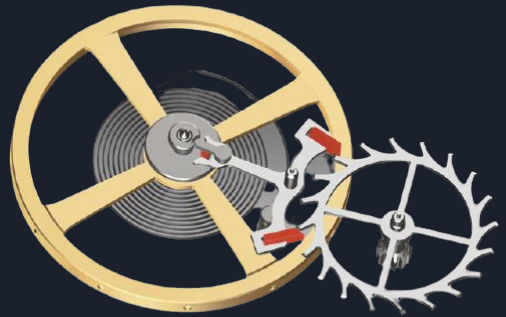
- ➢ Time Setting and Winding
- ➢ Gear Train
- ➢ Escapement

MAIN WATCH SECTIONS



TIME SETTING AND WINDING

WHEEL TRAIN



ESCAPEMENT

1. TIME SETTING AND WINDING

Time Setting and Winding Section-

The time setting and winding section is the foremost part of a mechanical watch which facilitates the interaction between the wearer and watch internal working.

The stem is winded to set the parts in motion. This continues till the mainspring is provided energy to drive the wheel train and manage the time.

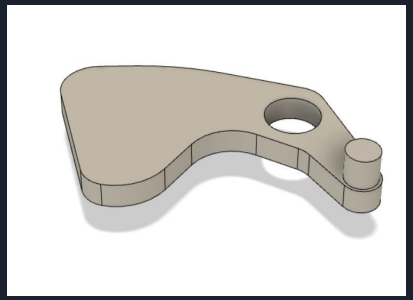
This section majorly consists of the following parts:

- Crown/Winding Stem
- Setting Lever and Jumper
- Sliding Pinion
- Yoke
- Crown Wheel
- Ratchet Wheel
- Mainspring
- Mainspring Barrel
- Barrel Arbor
- Mainspring Click

COMPONENT ANALYSIS

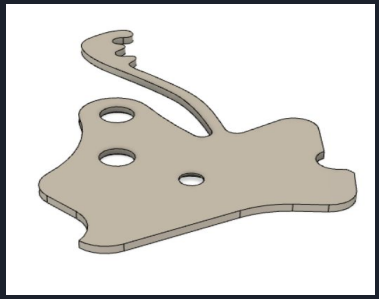
CROWN

- The crown is the main commander center of the watch. It is pushed in to to set the watch parts in motion and initiate the entire working of the assembly.
-It is pushed out to set the time.



SETTING LEVER

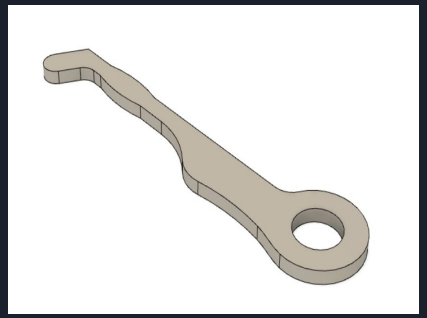
-The setting lever is placed next to the crown in contact with the yoke. For setting time, the lever presses the yoke to move it inwards.
-While winding the crown, the lever works to push the yoke forward.



SETTING JUMPER

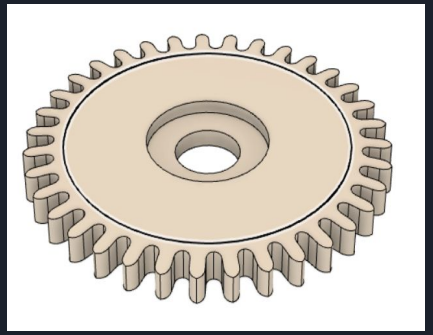
-The setting jumper supports the lever-crown mechanism and holds it in place. The lever clicks on it to and fro.
-The jumper also produces a characteristic click sound while switching modes.

COMPONENT ANALYSIS



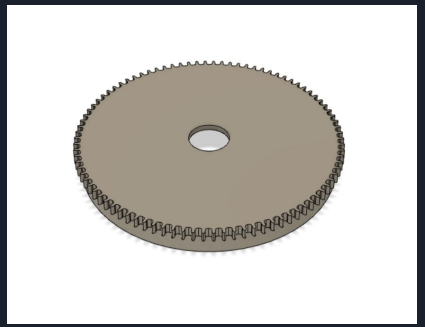
YOKE

- The yoke is placed in contact with the setting jumper and sliding pinion.
-It moves the sliding pinion and has a spring for outward tension.



CROWN WHEEL

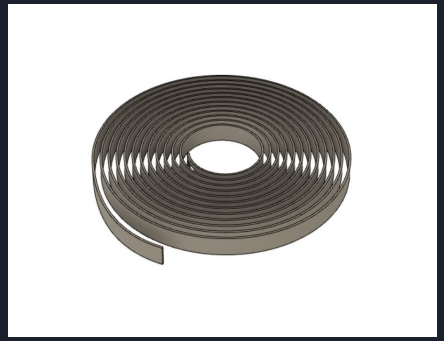
-The crown wheel links the winding system and the mainspring assembly.
-It is driven by the winding stem pinion and drives the ratchet wheel.



MAINSPRING BARREL

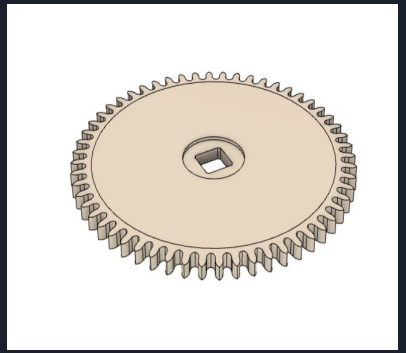
-The mainspring barrel is positioned to ensure the safety of the mainspring in watches.
-The spring is coiled around the arbor and enclosed in the barrel where it is free to turn.

COMPONENT ANALYSIS



MAINSPRING

- The mainspring is used as a power source in watches. While winding the stem, the spring twists on either side and stores energy.
-The force of the spring then turns the clock wheels as it unwinds, followed by another winding.



RATCHET WHEEL

-The ratchet wheel is placed on the top of the barrel and is connected to the winding pinion or arbor.
-While winding the crown, the ratchet wheel turns and tightly coils the mainspring, preventing it from unwinding
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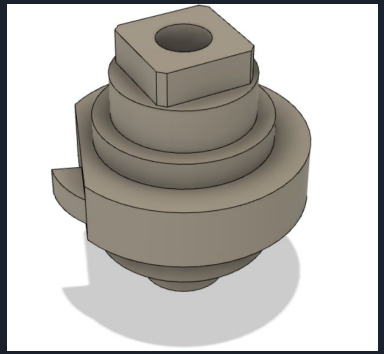
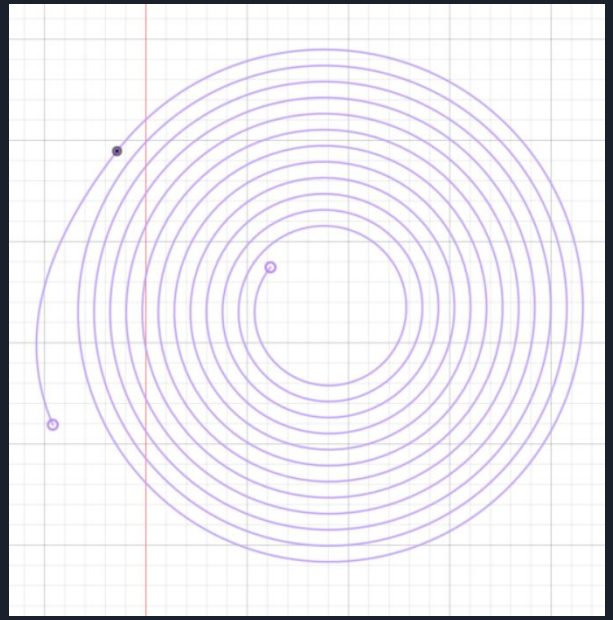


BARREL ARBOR

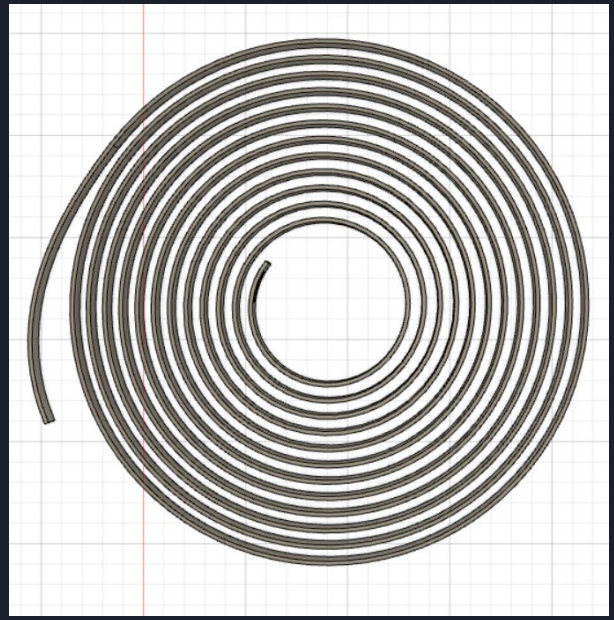
-The barrel arbor supports the barrel and the mainspring.
-It consists of a cylinder, called core and a hook to which inner end of the spring is attached. The upper pivot is cut into a square for fitting the ratchet wheel.

WORKFLOW- PARTS DESIGNING

Mainspring-

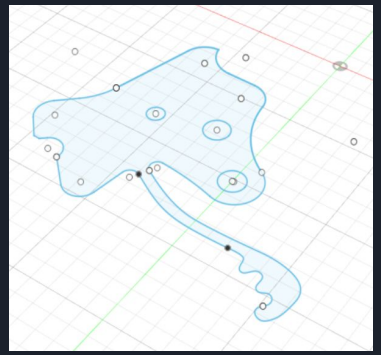


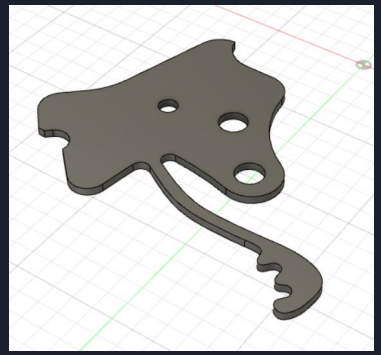
SKETCH DESIGN



FINAL DESIGN

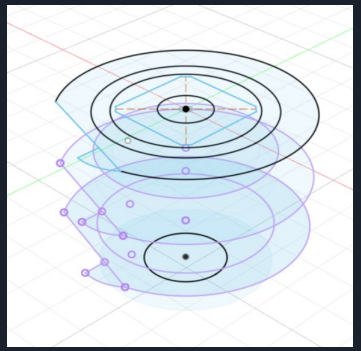
Setting Jumper

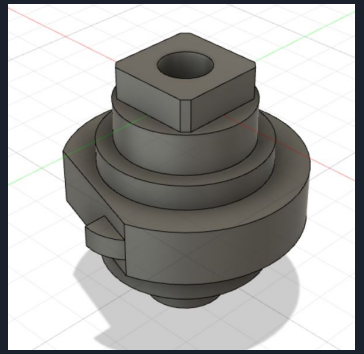




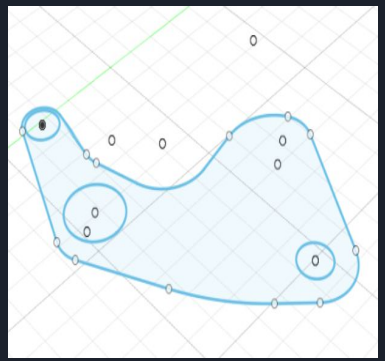
Barrel Arbor

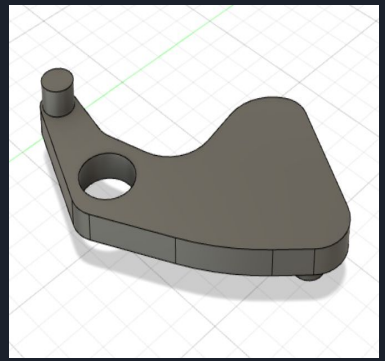
*Only some components are shown.



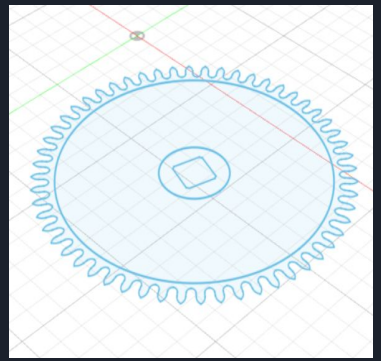


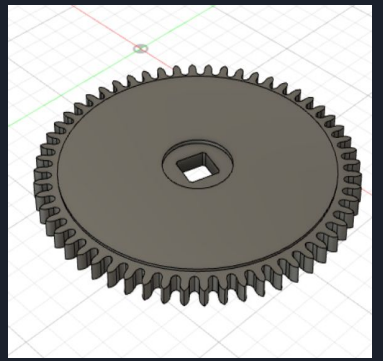
Setting Lever





Ratchet Wheel





PARTS ASSEMBLY-

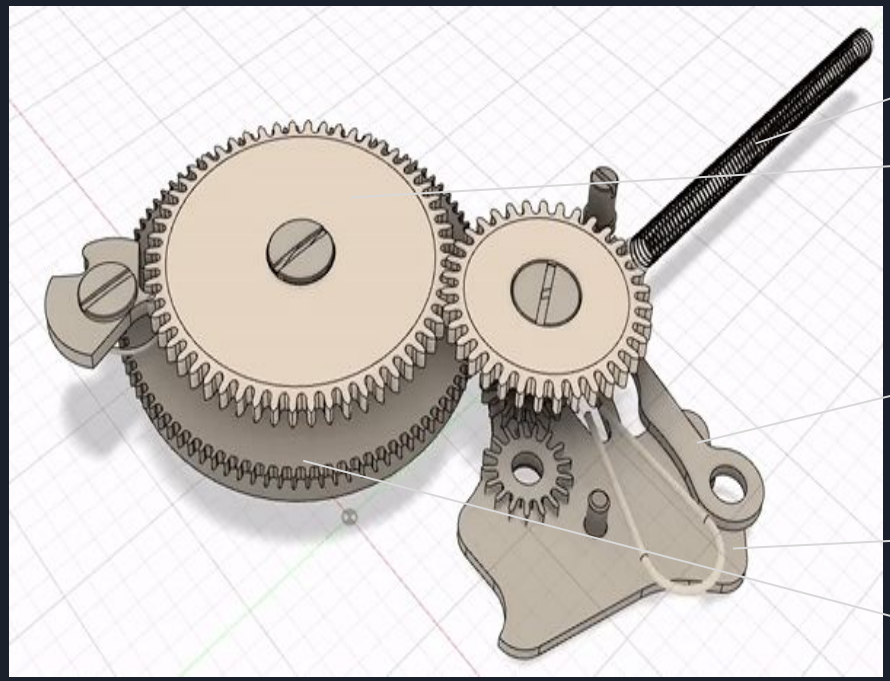
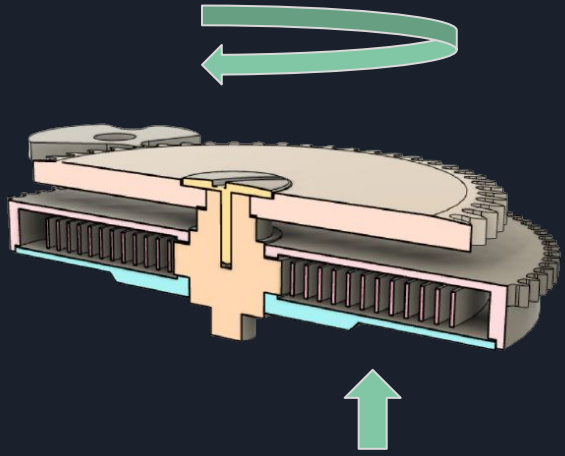


Illustration from our model.

Detailed Working

- The crown is pushed out to set the time, the setting lever clicks onto the indents of setting jumper and also presses the yoke. The yoke moves the sliding pinion towards the time setting gears.
- When the crown is wounded, the sliding pinion motions the connected gears to drive the mainspring.
- The mainspring is connected to the barrel and barrel arbor, also harboring the ratchet wheel.
- The assembly ensures that the entire momentum transferred to spring is released from the barrel to the wheel train.



Mainspring
Sectional View

2. WHEEL TRAIN

Wheel Train and Motion Works-

The Wheel Train of the mechanical watch consists of a set of wheels that transfers torque from the mainspring to the balance wheel in the escapement.

This section majorly consists of the following parts:

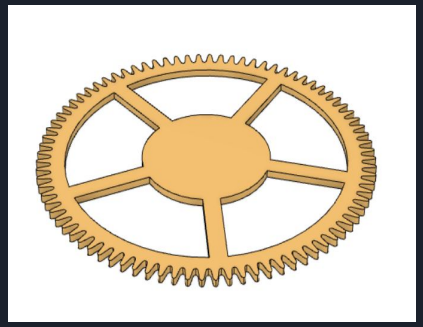
- Center Wheel
- Third Wheel
- Fourth Wheel

Another section of the this sub assembly is Motion Works which powers the watch hands, translating the input from the wheel train into readable time.

This section includes a set of wheels and pinions, major being:

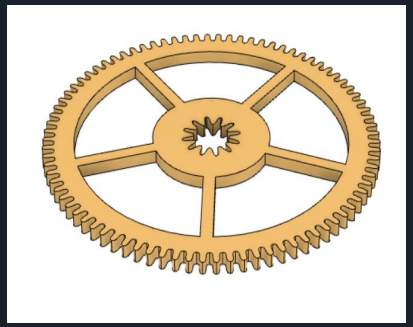
- Minute Wheel
- Hour Wheel
- Canon Pinion

COMPONENT ANALYSIS



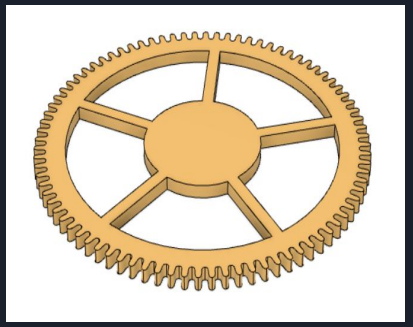
CENTER WHEEL

- The center wheel is driven directly by the mainspring barrel and initiates the wheel train.
-It rotates only once per hour to drive the minute hand of the watch.



THIRD WHEEL

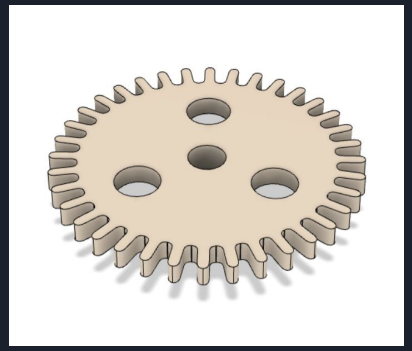
-The third wheel is the interconnection between the center and the fourth wheel.
-It drives the pinion for the fourth wheel.



FOURTH WHEEL

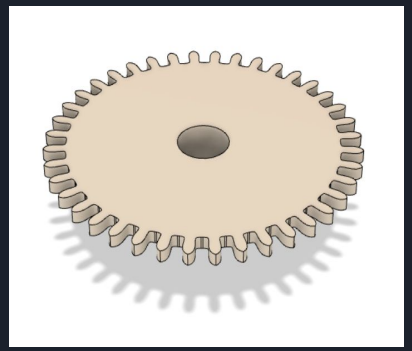
-The fourth wheel drives the escapement wheel and rotates once per minute to drive the seconds hand of the watch.

COMPONENT ANALYSIS



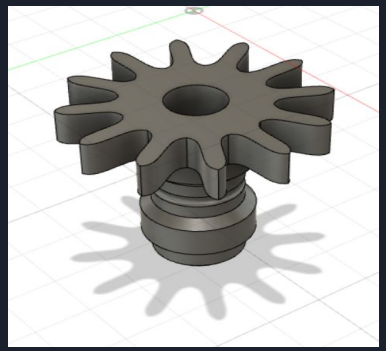
MINUTE WHEEL

- The minute wheel drives the hour wheel which in turn drives the hands of the clock.



HOUR WHEEL

-The hour fits over the shaft of the canon pinion and holds the hour hands.

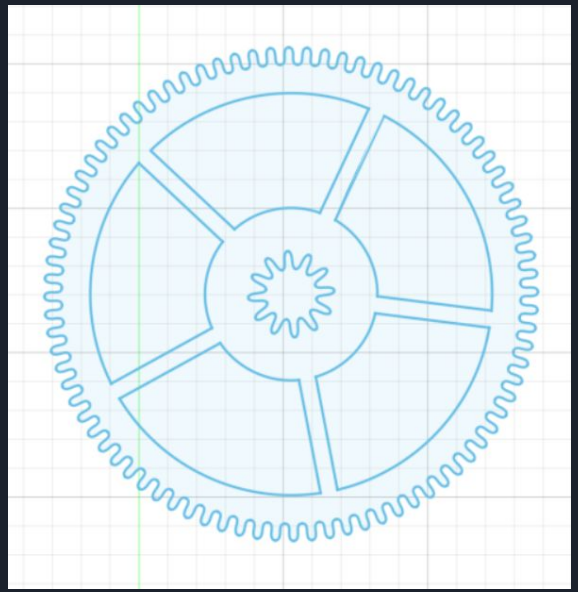


CANON PINION

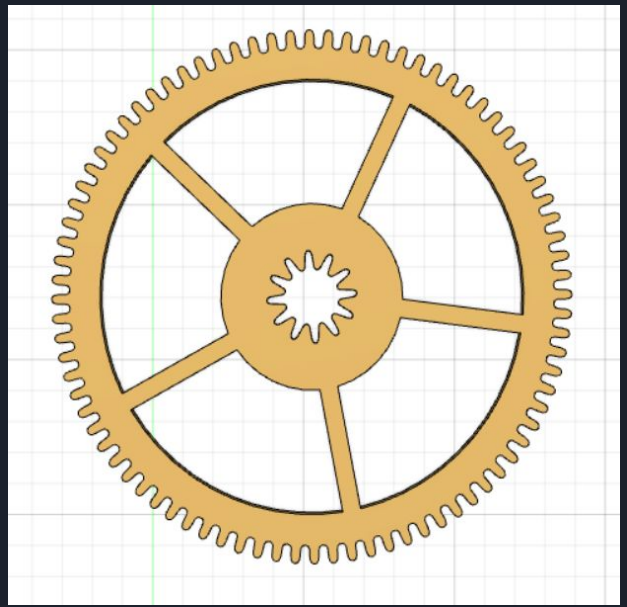
-The canon pinion holds the hour wheel which in turn holds the hour hand. The minute hand is fitted to the shaft of the canon pinion.

WORKFLOW- PARTS DESIGNING

Third Wheel-

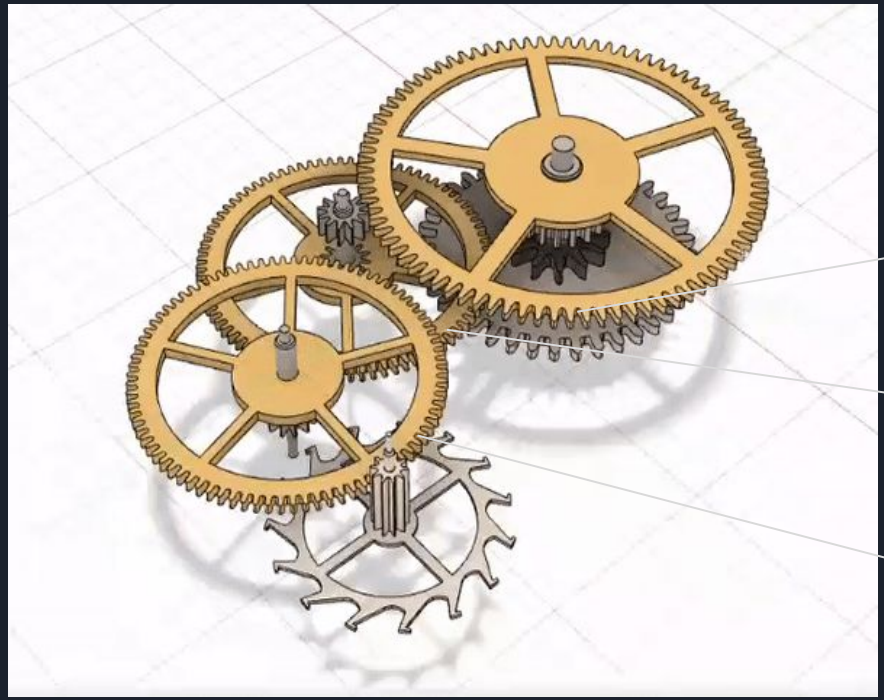


SKETCH DESIGN



FINAL DESIGN

PARTS ASSEMBLY-

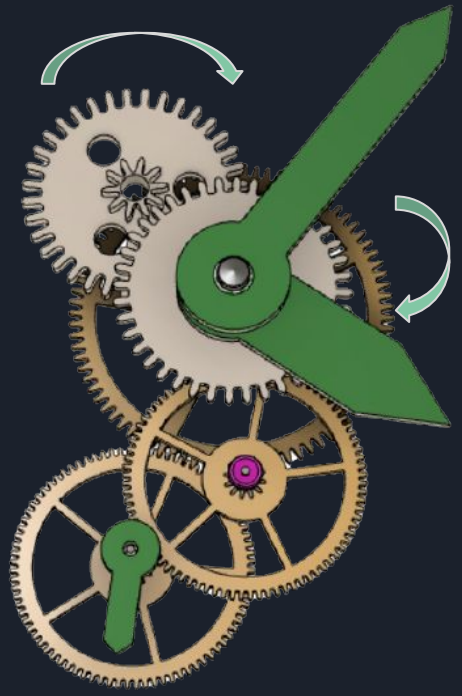


Detailed Working

- The center wheel of the wheel train is driven directly by the mainspring barrel, rotating once per hour, thus setting the minute hand of the watch in continuous motion.

- The third wheel flows power to the fourth wheel, which rotates once per minute, thus powering the seconds hand of the watch.

- Each gear of the assembly is attached to a central axis and a set of pinions to provide the necessary alignment.



3. ESCAPEMENT

Escapement in the watch-

The escapement in watches is a mechanical linkage that regulates the release of mainspring energy in precise time increments, ensuring that the mainspring doesn't release all of it power at once.

The entire assembly works to transfer periodic impulses to the balance wheel to compensate for the lost energy and thereby keep it in continuous oscillation.

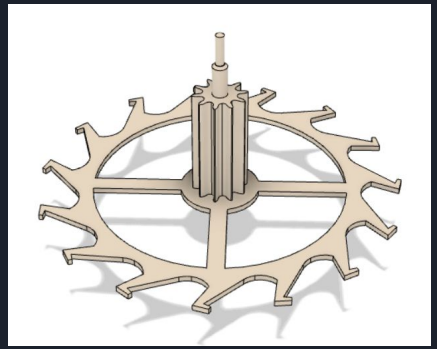
The Escapement majorly consists of the following two parts:

- Escape Wheel
- Pallet Fork

This is connected in line with other sets of parts namely:

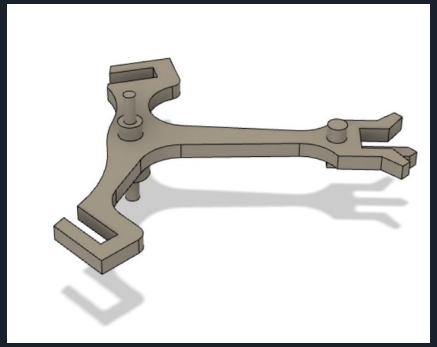
- Balance Wheel
- Hairspring
- Regulators
- Supporting Rollers
- Incabaloc

COMPONENT ANALYSIS



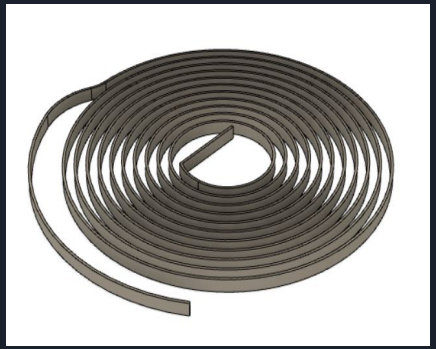
ESCAPE WHEEL

- The escape wheel is geared to the watch's wheel train which rotates as a consequence of torque given from the mainspring.
-It has specially shaped teeth to interact with the jewels of pallet fork.



PALLET FORK

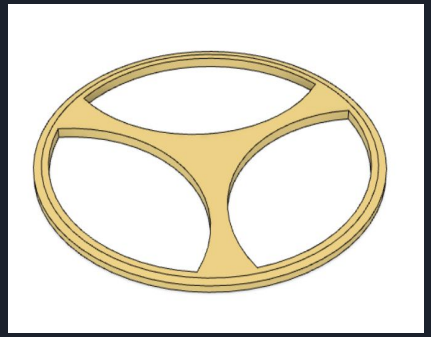
-The pallet fork consists of pallets which lock the escape wheel to release its one tooth at a time and causes the fork to move to and fro.
-This gives energy to and oscillates the balance wheel.



HAIRSPRING

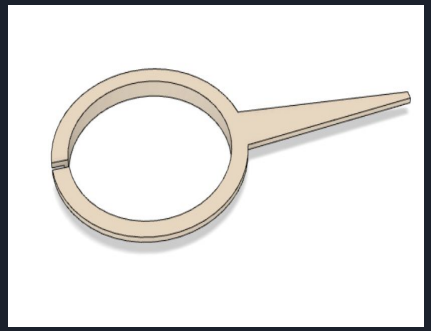
-The hairspring causes the balance wheel to oscillate with a resonant frequency.
-It tightens in one direction and releases energy to push balance back to equilibrium expanding to push it in other direction.

COMPONENT ANALYSIS



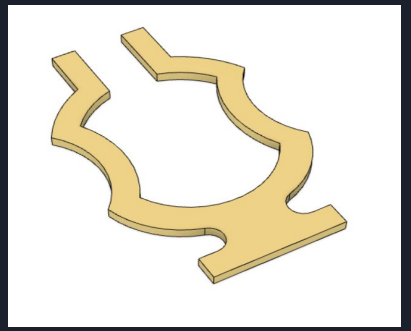
BALANCE WHEEL

- The balance wheel is the timekeeping device which rotates back and forth in coordination with other attached parts.
-Each swing of the wheel allows the gear train to advance a set amount, moving the hands forward.



REGULATORS

-The regulator on the spring is used to adjust the rate of the watch. It has two curb pins to adjust the effective length of the spring.
-It also controls the stiffness, spring constant and the wheel period to adjust the running rate.

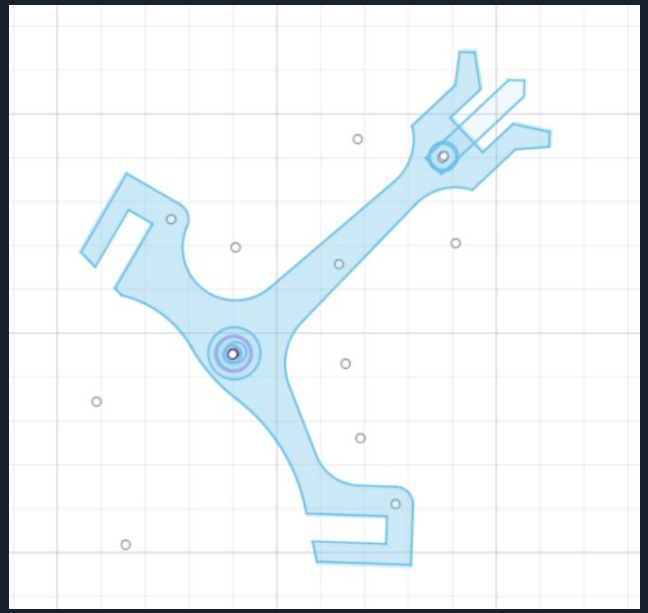


INCABALOC

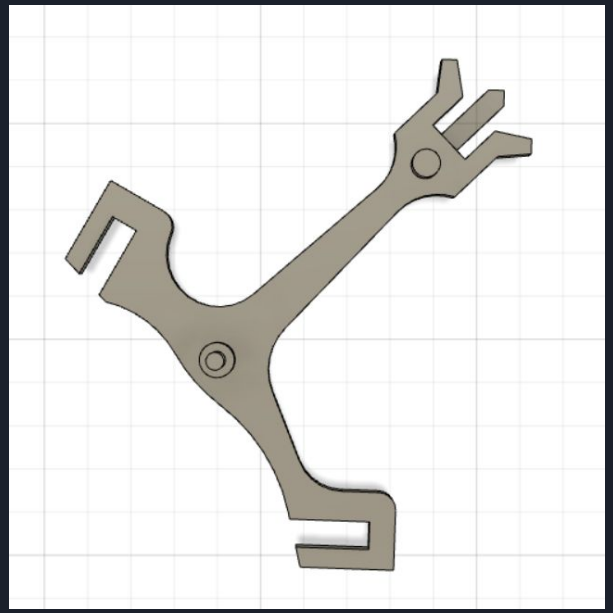
-The incabaloc is a shock resistant part, which protect the delicate parts attached.
-It allows the entire balance to move briefly when shock occurs, and then transfers the force away to lower and more stronger parts of the watch.

WORKFLOW- PARTS DESIGNING

Pallet Fork

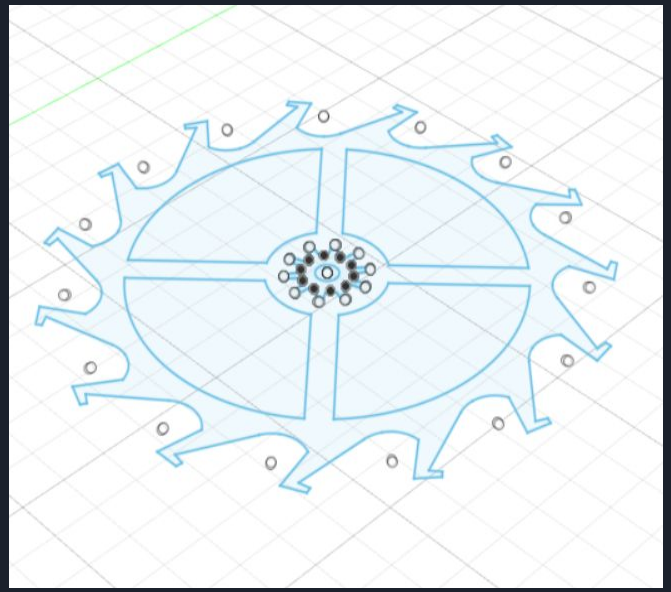


SKETCH DESIGN

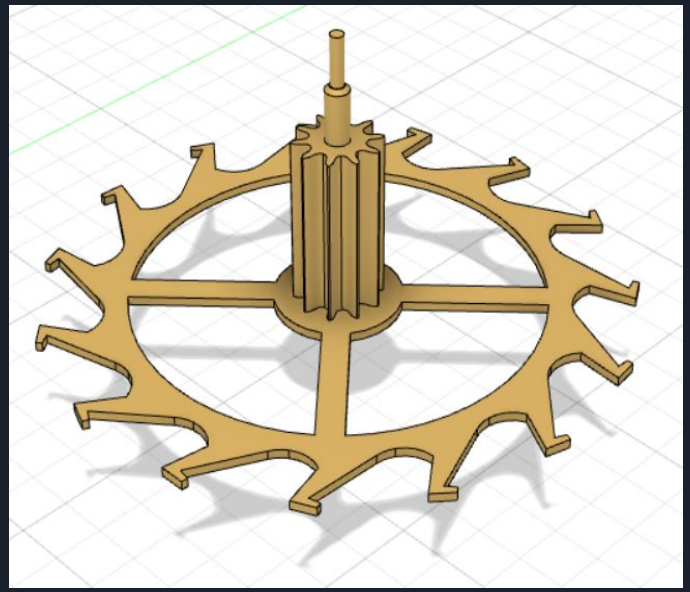


FINAL DESIGN

Escape Wheel

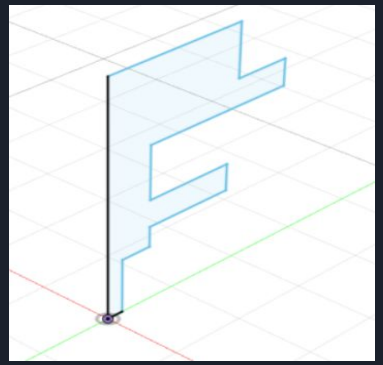


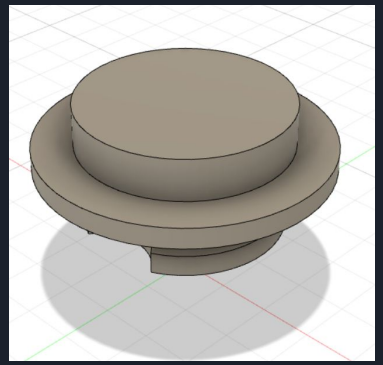
SKETCH DESIGN



FINAL DESIGN

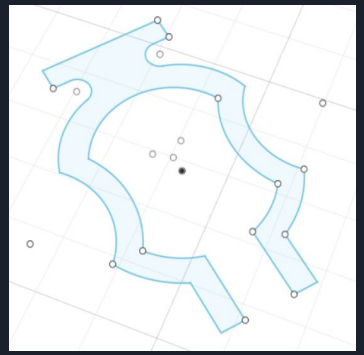
Winding Pinion

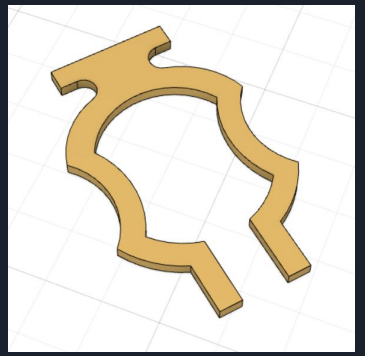




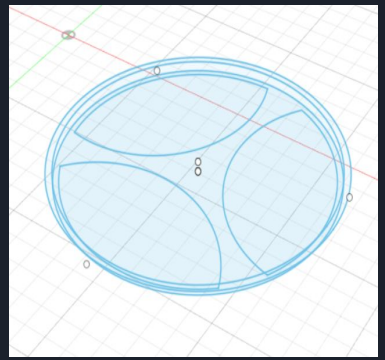
Incabaloc

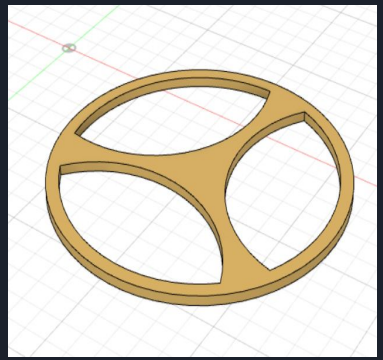
**Only some components are shown.*



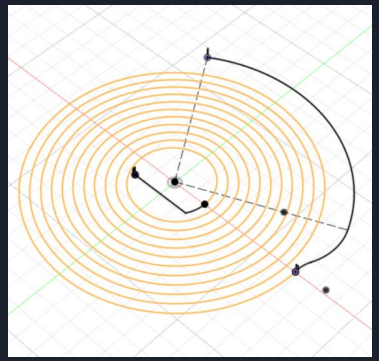


Balance Wheel

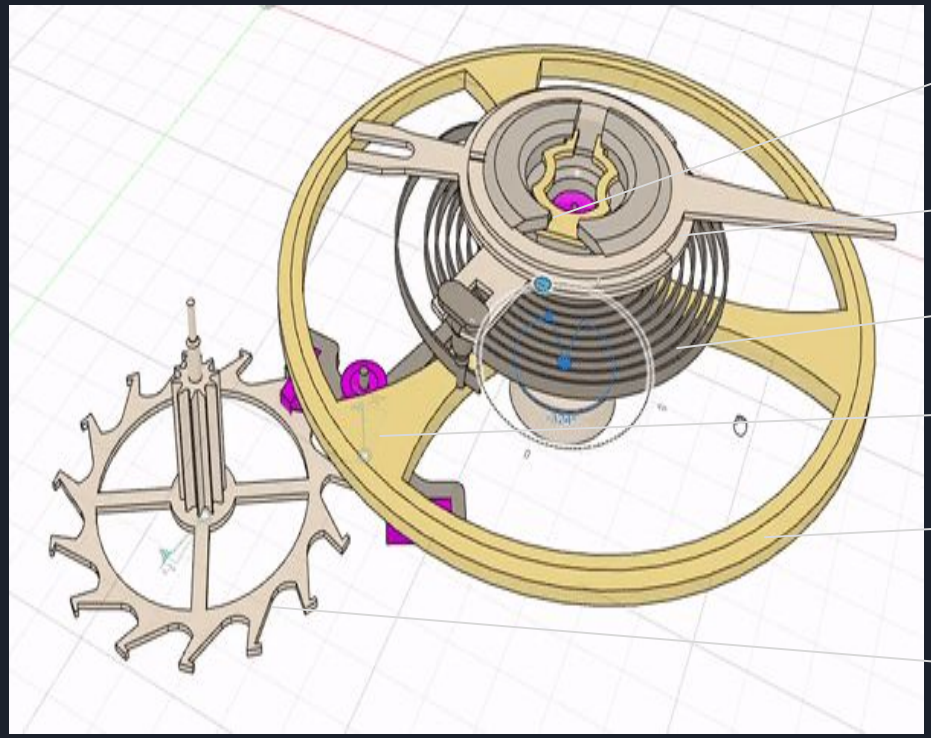




Hairspring

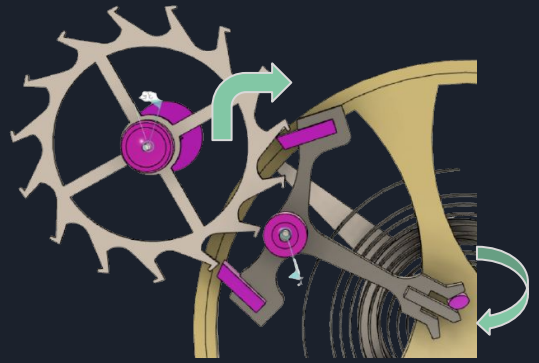


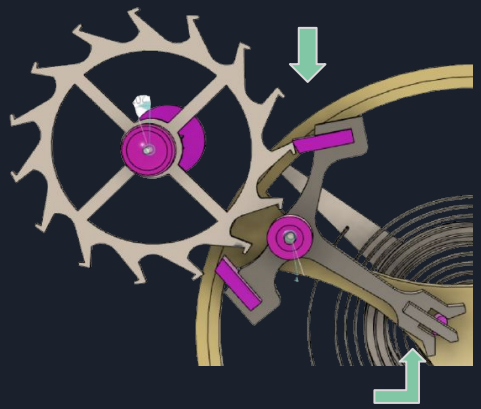
PARTS ASSEMBLY-



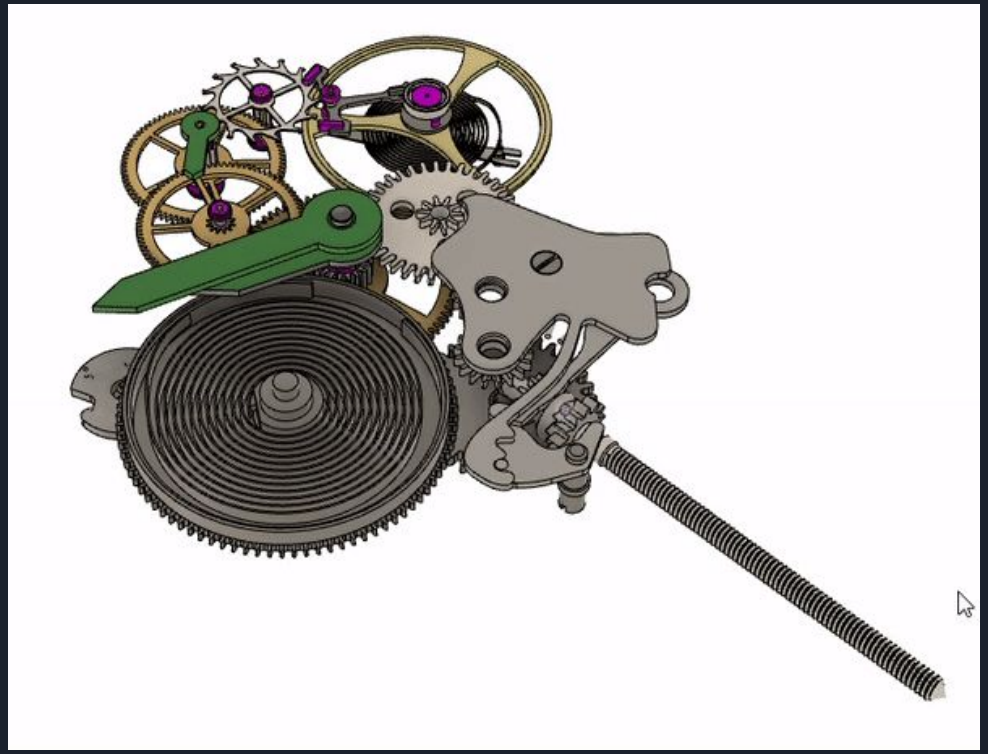
Detailed Working

- Considering Escapement as unit, the escape wheel pushes the pallet fork which consequently flicks a section on the balance wheel.
- The pallet transfers the rotary motion of the escape wheel into a back and forth motion of the pallet.
- The pallet fork then drives the curb pin which causes a vibratory motion of the balance wheel.
- The rotation of balance wheel is managed by regular contraction and relaxation of the hairspring.
- The hairspring properties are in turn managed by the regulators.
- The assembly also has incabaloc to provide a shock absorbent mechanism and protect it during impact.





FINAL ASSEMBLY



Our final working model is as shown on the left.

The combined assembly is made by providing appropriate joints and motion links.

The clock hands are driven to give time.

❖ OUTER DESIGN

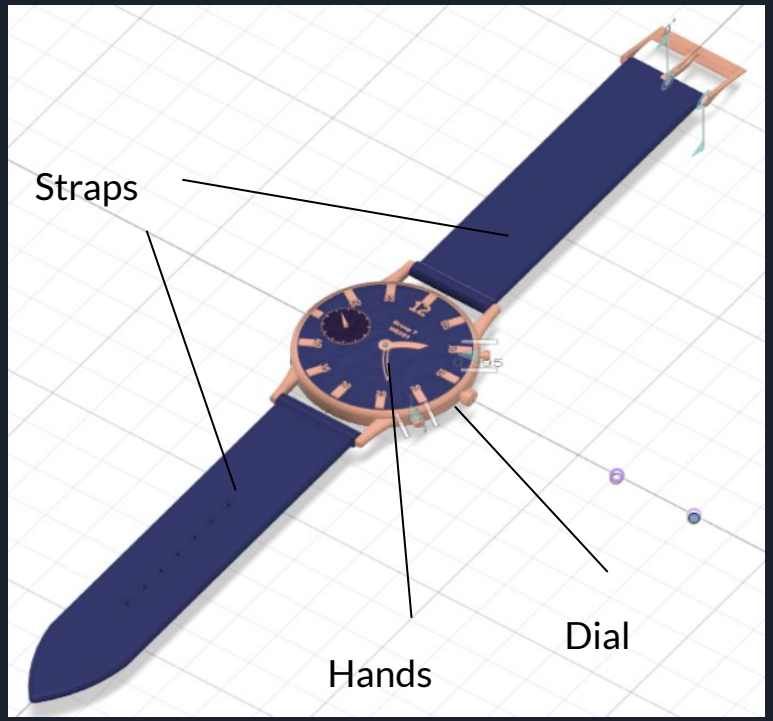
Exterior Components

The watch exterior consists of following listed parts:

- Outer case
- Dial
- Wearing Straps
- Watch Hands

The parts are designed with the following dimensions:

- Dial : dia = 38mm
- Outer case : dia = 40mm
- Outer case height : 6.5mm
- Glass thickness : 1.5mm
- Strap width : 20mm



Calculations

The mechanical watch consists of a number of gears with different teeth count resulting in different rates of revolution of each gear.

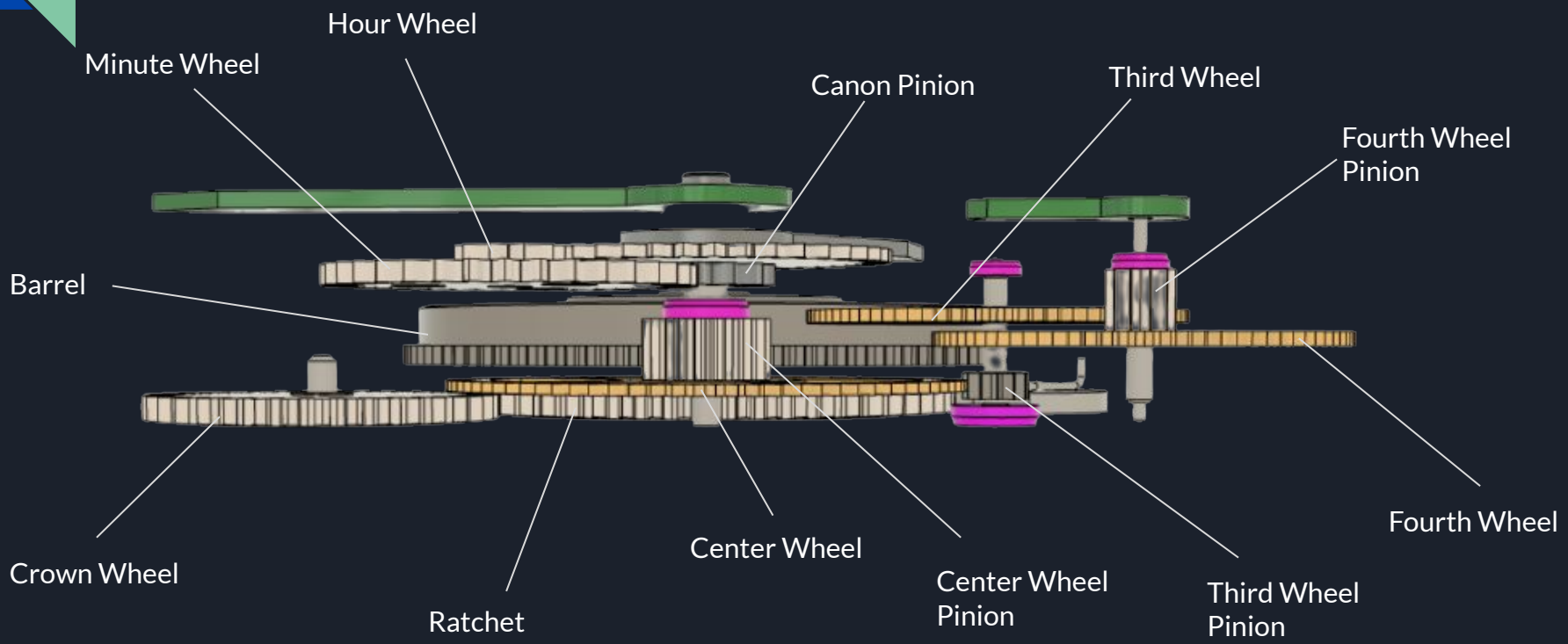
- The dependance of rate of revolution (w) on teeth for two connected gears can be given by the **Gear Ratio formula** :

$$GearRatio = W1/W2 = N2/N1$$

- The **Module** of the gear represents the size of the gear tooth. It depends on Pitch circle diameter and number of teeth and is given as:

➢ Module= Pitch Circle Diameter/Number of Teeth

Systematic Gear Assembly



Gear Type	Teeth (N)	Pitch Diameter(d)(in mm)	Module(d/N)
Crown Wheel	13	8.42	0.65
Ratchet	56	13.06	0.24
MainSpring Barrel	90	15.98	0.18
Centre Wheel Pinion	18	2.67	0.15
Centre Wheel	84	11.5	0.14
Third Wheel Pinion	12	1.2	0.10
Third Wheel	84	8.35	0.10
Fourth Wheel Pinion	12	1.2	0.10
Hour Wheel	40	7.95	0.20
Minute Wheel	36	7.45	0.20
Canon Pinion	12	2.486	0.20

Gear Links

- The ***crown wheel*** drives the ***ratchet*** forming LINK 1.
- The ***mainspring barrel*** drives the ***center wheel pinion*** forming LINK 2.
- The ***center wheel pinion*** drives the ***third wheel*** forming LINK 3.
- The ***center wheel*** drives the ***third wheel pinion*** forming LINK 4.
- The ***third wheel*** drives the ***fourth wheel pinion*** forming LINK 5.
- The ***canon pinion*** drives the ***minute wheel*** forming LINK 6.
- The ***minute wheel*** pinion drives the ***hour wheel*** forming LINK 7.

Gear Ratios

- The ***crown wheel*** and ***ratchet*** have gear ratio 13:56
- The ***mainspring barrel*** and ***center wheel pinion*** have gear ratio 90:18
- The ***center wheel pinion*** and ***third wheel*** have gear ratio 18:84
- The ***third wheel pinion*** and ***center wheel*** have gear ratio 84:12
- The ***third wheel*** and ***fourth wheel pinion*** have gear ratio 84:12
- The ***canon pinion*** and ***minute wheel*** have gear ratio 12:36
- The ***minute wheel*** pinion drives the ***hour wheel*** have gear ratio 10:40

Frequency Analysis

In watches, one vibration/beat is single swing of balance wheel, which is one-half of an oscillation or semi oscillation.

The frequency is taken in Hertz or Beats Per Hour(BPH), for number of oscillations and semi-oscillations per second respectively.

-A watch with frequency 4Hz, makes 4 oscillations or 8 beats per second.

-Equivalent to, 8*60*60=28800 Beats per hour.

The most common frequencies of watch are 2.5, 3, 4 and 5 Hz or 18,000, 21,600, 28,800 and 36,000 BPH respectively.

A balance wheel's period of oscillation (T in seconds), time required for one complete cycle or two beats is:

$$T = 2\Pi\sqrt{\frac{I}{K}}$$

-- I is the moment of inertia of wheel

-- K is the stiffness of hairspring

The pallets strike the teeth of escape wheel to make 'tick' noise.
Each increasing escape wheel rotation is a beat.

Accuracy

- The higher the frequency of the watch, the more balance wheel will oscillate in a second, the more **precise** the watch will be with smoother movement of the hands.
- However, too high frequency can wear out the movement and reduce the autonomy of power.
- A watch with frequency 4Hz or 28,800 BPH has an accuracy of +-20 seconds.

Duration of watch

The exact duration of run for a mechanical movement is calculated with the formula:

n2 = (n1 * z1) / z2

z1 = Number of barrel teeth

z2 = Number of center pinion leaves

n1 = Number of revolutions of the barrel

n2 = Number of revolutions of the center pinion (duration of run)

MATERIAL ANALYSIS

List of materials used in manufacturing of different parts of watch are:

Component Name	**Material**	**Component Name**	**Material**
Strap	Leather	All internal gears	Brass
Dial	Brass	Pinions	Stainless Steel
Mainspring	Spring Steel	Third Wheel	Bronze
Jewel	Sapphire	Escape Wheel	Aluminium
Hands	Plastic	Setting Lever	Steel
Pallet Fork	Ruby Jewel	Crown	Stainless Steel
Hairspring	Nivarox (Fe, Ni alloy)	Yoke and Sliding Pinion	Cast Iron
All Bridge	Titanium	Exterior Casing	Stainless Steel

Material analysis in detail-

- **Hairspring: (Nivarox)**: Its notable property is that its coefficient of elasticity is remarkably constant with temperature. Hairsprings made of this alloy have a spring constant that does not vary with temperature, allowing the watch's balance wheel, its timekeeping element, to keep better time.
- **Balance wheel(Invar):** The balance wheel of a watch is made of invar. Invar is a nickel iron alloy. It shows a very little coefficient of linear expansion. So, the change of its length varies very slightly with the change in temperature. Thus time given by this watch is more accurate over a very long range of temperature.
- **Pallet fork**: In watches, it is typically made of nickel-plated brass, unlike the escape wheel, and features two jewels on its ends, which are the pallet stones. These synthetic jewels mitigate friction as the fork and escape wheel connect.
- **Watch Cover** : It is the outer cover that contains all the internal parts. It is made up of alloys and stainless steel so that the internal parts remain protected from bumps, dirt, dust moisture and rust.
- **Dial**: It is the base plate that is made up of brass-copper-zinc alloy which contains numbers, indexes and surface design.

Material analysis in detail-

- **Escape Wheel** : It is made up of aluminium because of its ability to withstand wear of the escape wheel teeth under the impact and friction of the pallet. Also steel prevent an escape wheel from magnetic influences that would impair the accurate or proper running of the watch, and which will be able to withstand wear from the action of the pallet thereon.
- **Jewel Bearing**: Jewel bearings are made from precious gems such as rubies, sapphires, and other types of corundum (a form of aluminum oxide). These materials are among the hardest substances on Earth, which imbues jewel bearings with extreme resistance. They have a low coefficient of friction and do not readily wear down, even in extreme environments, hence provide smooth movement of internal parts.
- **Dial Cover** : It is made up of convex crystal glass which is three times stronger than regular glass and is scratch resistant.
- **Watch Straps** : Leather is used to make the watch straps as it is durable, elastic, long-lasting, care-free and environment friendly.
- **Wheel Train** : Gears and pinions comprise the Wheel train. Gears are usually made of brass and pinions are small gears usually made of steel. They are riveted together when used in a Wheel train.

CONCLUSION

We are thankful to ***Prof. Nachiketa Tiwari***, our instructor-in-charge and ***Prof. Bishakh Bhattacharya***, our course instructor for providing all possible guidance and support during the project.

We are also thankful to our all the TAs of this course for helping us throughout the project.

This was, till date, a comprehensive learnable experience and a fruitful application of our knowledge.