Course Project: Manufacturing Process of a Clock
Stage 2 Submission

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Description of Project:

The clock is one of the most successful inventions of all time. It can be seen in analogue form in every household, and a digital form of it is an integral part of every computer-based device, such as laptops, PCs, mobiles. We can also see them in portable forms in the form of wristwatches, and recently smartwatches have become trending, which also builds on the same concept.

A clock is a device that tells time. It is represented as a circular space graduated into 12 different numbers (1-12) making 12 sectors when in analogue form, and a set of numbers in digital form. Everyone knows how to read the time. It needs no introduction. We will be covering analogue clocks as part of this project, and digital clocks tentatively as the project schedule permits.

Applications of a Clock:

As it is evident, clocks are a core part of our life and available everywhere, so their importance cannot be stressed enough. The main feature of a clock is to tell the current time. This is a very helpful way to organize daily life. Nowadays, everyone is involved in a plethora of activities, and it is important to have a way of tracking the duration of them, making sure they don't clash and managing them well. A clock provides access to time, a universally accepted standard to distinguish between events. Using the common notion of time, people can keep a track of events, and designate certain amounts of time to each event. This allows everyone to have a common understanding of the starting and ending of events, a measure of their duration, and a measure of the interval between them.

A clock would mainly be used to know the current daily time, the date, while available as an option in many clocks, is not a traditionally fundamental part of a clock, it is gauged using calendars. So, it aids in daily planning, which is more short-term. For long-term planning, a measure of days, months, and years is required.

A few clocks can even be seen as monuments, Big Ben is the most prominent example. It has become a key part of the representation of London city and is one of the first things that come to mind when someone thinks of London.

Manufacturing Cost of a Clock (approx.):

The manufacturing cost of a clock includes a variety of components, both fixed and variable. Examples of fixed costs involved in the manufacturing process are rent for factory space (or a one-time payment if the land is bought) and electricity/fuel costs (since machines in the factory use the same amount of energy regardless of whether they are actively producing or not).

Examples of variable costs involved in the process are wages paid to workers (since it is likely that new workers may be hired and some old workers leave), amount of capital invested in potential business/machinery expansions, costs of raw materials (which depends on the current market demand for clocks), etc.

Other factors influencing the cost of a clock are the size of the firm (a bigger firm is more likely to experience economies of scale, thereby reducing the average cost of production), type of clock (since a digital clock requires different raw materials compared to an analogue clock or a wristwatch/smartwatch), location of the company (which directly influences costs of local/imported raw materials), etc.

Taking all of these points into account, manufacturing of a simple alarm clock that one may use on a day-to-day basis is found to be approximately between $8 - $12 per clock depending on the output level produced by the firm. A much more extensive cost analysis is discussed in the final section of this report.

Work Distribution (last updated at the time of Stage 4 submission – 26/09/2021)**:**

Stage 2:

Product Description: Gopalan

Product Applications: Sidharth

Approximate Cost: Om

Stage 3:

Design: Gopalan

Components: Om

Engineering Drawing: Sidharth

Stage 4:

Materials: Om

Process Selection: Om (up to digital display), Sidharth (mainspring onwards)

Stage 5:

Manufacturing: Gopalan

Finishing & Coating: Om

Machines & Equipment: Sidharth

Assembly & Inspection: Om, Gopalan

Final Submission:

Cost Analysis: Om

Presentation & Video: All

ME 338 Course Project: Stage 3 Submission

Topic: Manufacturing Process of a Clock

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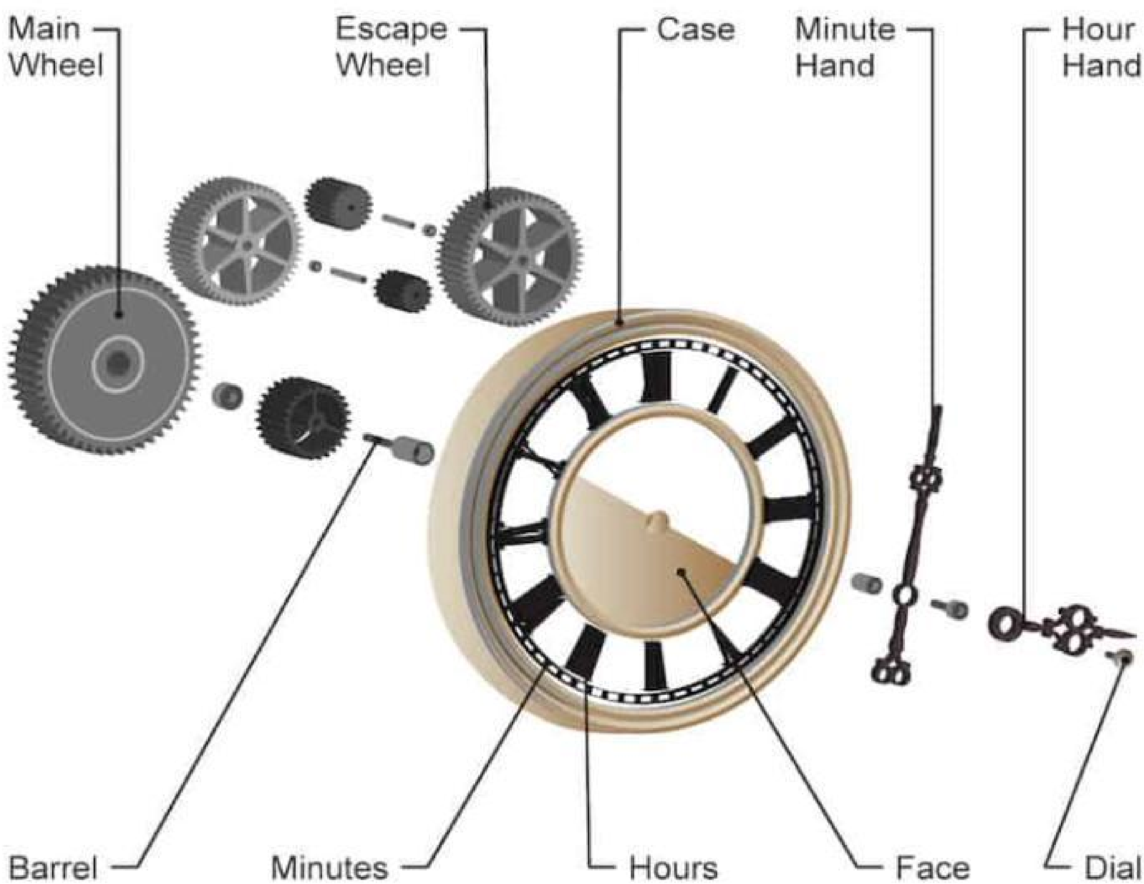
Design:

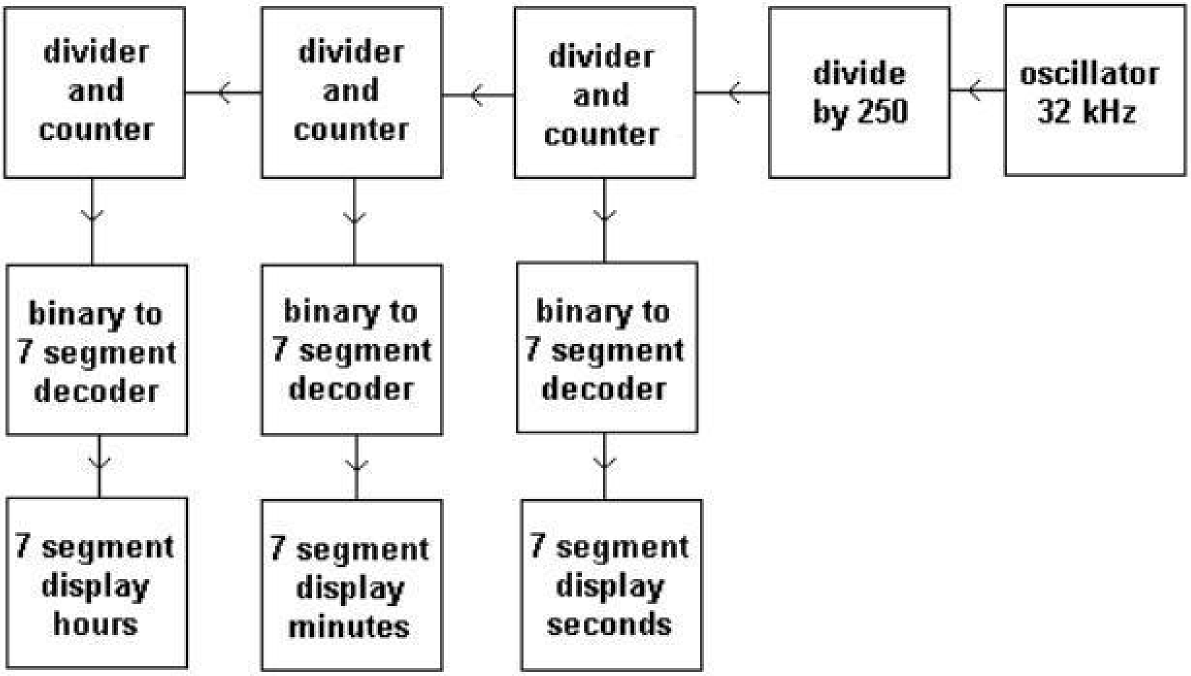
An analogue clock consists of 3 concentric hands: an hour hand, a minute hand and a second hand, which point towards their namesake on a clock-face graduated into 12 different sectors. The face is set in a frame, which contains the gear & spring system associated with the hands, and the power source, which is generally a set of AA or AAA cells.



Exploded View of an Analogue Clock

A digital clock consists of a 7-segment LED/LCD display (or a screen), the power source, and the circuitry along with the crystal using which the circuit determines time.

A Digital Clock



Internal Circuitry of a Digital Clock

Components:

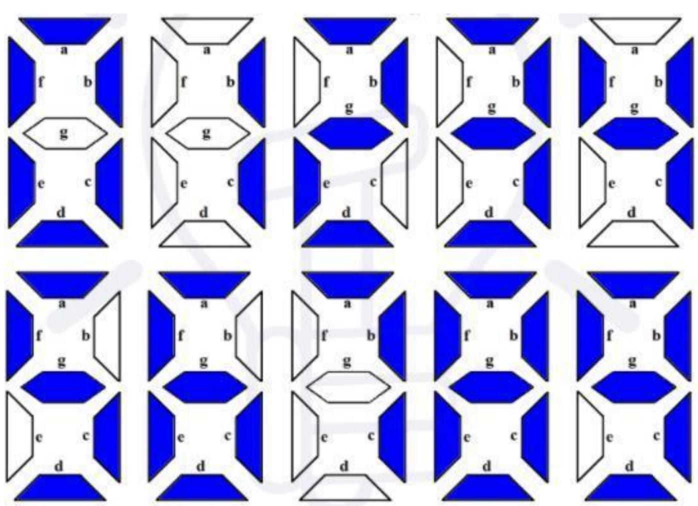
A clock comprises several components, and the nature of these components depends on the type of clock. The parts that immediately come to mind are the visible parts - for an analogue clock, these are the face and arms while for a digital clock, it is the LED display panel. However, it is the components behind the scenes that make the clock actually function. These include the gears/wheels, mainspring, quartz crystal and optionally, a pendulum. All of these components are discussed below in greater detail:

- **Face:** This serves as the main background of a clock. It is generally shaped as a circle, and it contains some basic indicators (such as an hour/minute display) to make it easy to read the time by observing the arms of the clock. Some materials commonly used to manufacture this part include cardboard, acrylic, hardened plastic, painted metal, etc.

- **Arms:** There are usually 3 arms/hands in a clock - the hour hand, minute hand and the second hand. These are pivoted at the centre of the face and are connected to the wheels in the interior of the clock. The rotation of the hands directly corresponds to the rotation of the wheels.

  Within one hour, the hour hand rotates by 30°, the minute hand rotates through a full 360°, and the second hand rotates by 21600° (i.e., 360° every minute). For ease of identification, the hour hand is usually the thickest and shortest in length. The minute and second hand are usually of a similar length, with the minute hand being thicker than the second hand. They are usually made either of a light metal like aluminium or plastic.

- **Digital Display:** This is the main indicator of time in a digital clock. Each digit is displayed as a combination of 7 LED segments as shown in the figure below. Each segment consists of an LED. One pin of the LEDs is connected to form a common connection to the circuit, while the second pin is connected individually, so the segment glows only when its LED is forward biased.



- **Gears/Wheels:** A clock typically consists of three wheels - the centre wheel, the third wheel and the escape wheel. The centre wheel rotates once per hour, the third wheel rotates once per minute, and the escape wheel is used to control how fast the mainspring unwinds.

- **Mainspring:** This is a spiral torsional spring made of metal ribbon, usually spring steel. It is used to keep track of time by measuring the release of potential energy in the wound-up spring.

  The inner end of the spring is hooked to an axle called the arbor while the outer end is attached to a stationary post. The spring is wound anti-clockwise by turning the arbor, which causes build-up of spring potential energy. After the energy reaches a certain value, the spring and the arbor snap back to their original position, which results in the second hand of the clock moving with a “jerk” in the other (i.e., clockwise) direction.

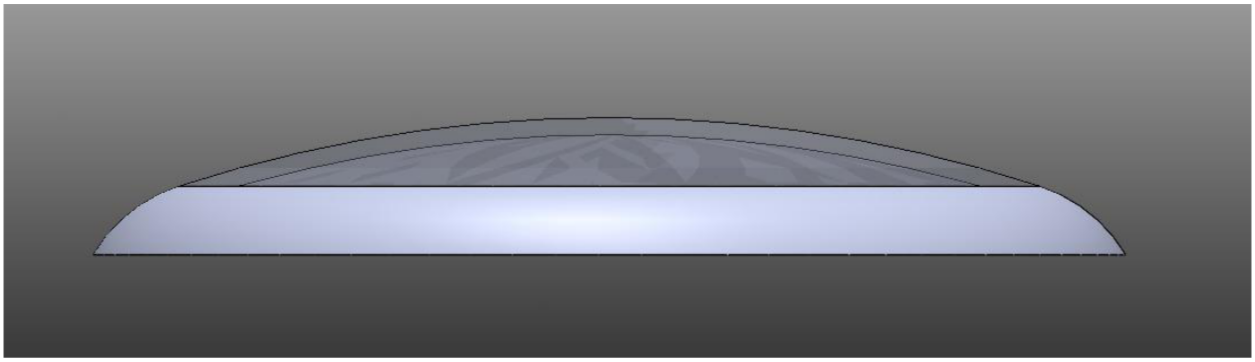
  In more modern clocks, the spring and the arbor are enclosed in a box called the barrel. The pull of the mainspring turns the barrel, which is linked to the wheels through a set of gear teeth.

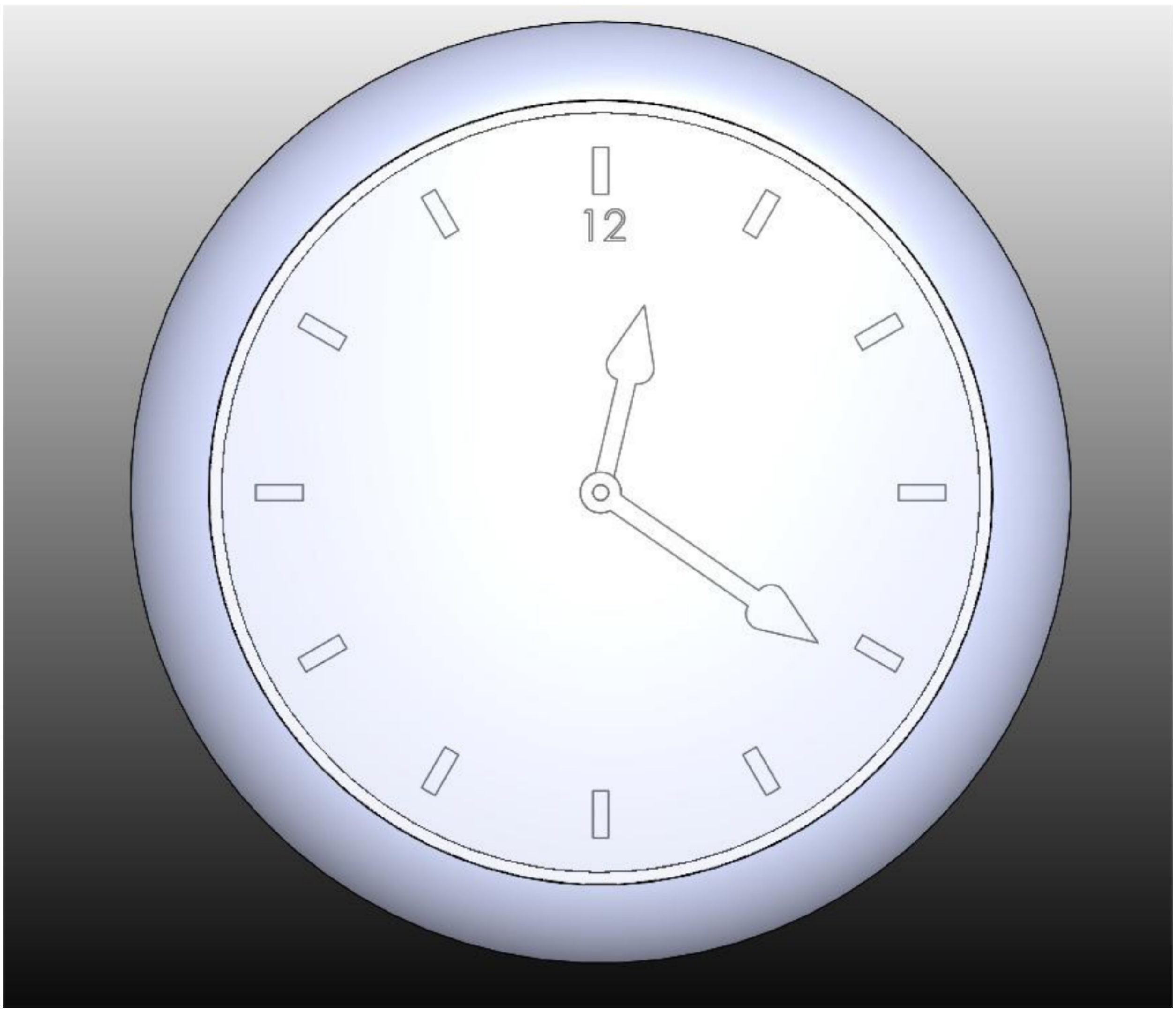
- **Quartz Crystal:** This is used mainly in digital clocks and wrist watches that do not use the gear mechanism. The quartz crystal resonates at an exact natural frequency of 32.768 kHz. The crystal is connected to an AC circuit, which in turn resonates at the same frequency. The rate of oscillation of the AC circuit determines the rate of passage of time.

  Quartz occurs naturally as a mineral (or can also be artificially manufactured), but it cannot be directly used in this form. For the crystal to resonate at exactly 32.768 kHz, it must be machined very precisely. Any errors can lead to a different value of resonant frequency, which would make the crystal unsuitable for use in a clock.

- **Pendulum:** Some antique clocks use a pendulum system to keep time. It comprises a weight that hangs from a pulley mechanism and swings at an exact rate of one second. The pulley is internally connected to the wheels, so the arms of the clock may move. Galvanized steel is commonly used in pendulums since it is cheap and has a low coefficient of thermal expansion.

Engineering Drawings:

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ME 338 Course Project: Stage 4 Submission

Topic: Manufacturing Process of a Clock

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Materials:

The materials used in a clock are heavily dependent on the type of clock in consideration. For example, a digital watch lacks certain components like gears, hands, etc while a mechanical watch lacks a digital display and perhaps a touchscreen. This essentially means that different materials must be used in both of them to account for their usage.

The main factors influencing the selection of a material in any manufacturing process, amongst many others, are suitable properties required for the application, availability, cost (assembly equipment/labour, material, tooling, energy cost) and environmental concerns. There may be many materials suitable for the application, out of which only a few have to be chosen after taking all these points into consideration.

The table on the next page discusses the most common materials used in various parts of a clock in much greater detail, along with several reasons as to what makes the materials suitable for their respective application.

Part	Material(s) Used	Properties
Case/Housing	Stainless Steel (most commonly used is SAE 316L)	- significant carbon content which increases toughness & strength - significant chromium content, which increases resistance to scratches & wear by corrosion - visually appealing surface finish - heavy for use in wrist watches (density: 7.9 g/cm^3) - high hardness leads to difficulties in shaping operations
	Aluminium alloys (50-60% aluminium oxide)	- economical and easily available - very high formability for machining operations - relatively high hardness & strength for its low density
	Wood (commonly used in antique wall clocks)	- readily available and extremely economical - various types of wood to choose from based on consumer preference - highly brittle and very low formability, needs to be machined using classic sawing, grinding and planing
	Other Composites (suitable for use in pocket watches/alarm clocks)	- carbon composites: low density, high strength; low scratch resistance - ceramics: high scratch resistance; risk of breakage due to low pliancy - plastics: highly machinable, low density, economical, reasonably tough; environmental concerns
Face	Toughened plastics	- low-cost machining & easier to print/etch time display (i.e., hour display) - relatively more brittle compared to ceramics
	Ceramics	- resistant to cracks and medium-heavy mechanical damage, leading to better protection for internal components
Arms	Aluminium (and other light metals)	- low density allows for smaller torque requirements for the internal gear mechanism, leading to overall energy efficiency - high ductility allows for manufacture of thin arms
	Plastic	- lighter and more economical compared to metals

Digital Display	LEDs	- semiconductor wafers & epitaxial layers: combination of gallium, arsenic, phosphor compounds (different excitation frequencies corresponding to different colours) - lead frames/pins: metal electroplated with alkaline low-cyanide silver - thin gold filament to provide connection between the two pins - small plastic mould to seal the assembly
	Integrated Circuit	- provides independent control of LEDs in 7-segment display using pins that define bias of each LED - silicon dioxide: insulator and dielectric material (high availability, high stability due to diamond-like structure and high forward voltage, moderate energy band gap) - arsenic/boron, gallium/phosphor: N and P-type dopants (due to having 5 and 3 valence electrons respectively)
Gears/Wheels	Steel/Cast Iron	- high strength-to-weight ratio - ability to enhance physical properties through heat treatment & other chemical methods - competitive pricing
	Toughened Plastics	- economical and easy to source & manufacture - suitable for smaller clocks (eg: alarm clocks) - lower life span compared to metallic gears
	Brass/Bronze	- relative softness of alloys leads to easier machining as well as lower friction coefficients - longer lifespan compared to plastic gears
	Powdered Metals (iron-nickel steel)	- low friction coefficients leading to lower energy losses from gear teeth - suitable for smaller gears in mechanical clocks (linked to knobs for changing time manually) - requires precision tooling & high pressures for smaller gears

Mainspring	Invar (Fe-Ni36%)	- high dimensional stability due to very low thermal coefficient of expansion, leading to better time accuracy in varying temperature conditions - high ductility for use in precision instruments/parts
	Spring steel (SAE 1070, 1095)	- hardened and tempered steel with high elasticity - more suitable for use in larger clocks due to relatively lower ductility compared to iron-nickel alloys
Quartz Crystal	Quartz	- distinctive quality of oscillating at a very precise frequency when stimulated by alternating current (natural frequency differs based on size and shape) - requires extremely precise machining to reach the desired frequency (32,768 kHz for clocks) - second most naturally occurring mineral
Pendulum	Galvanized Steel/Brass	- ease of production and machining - resistance to wear by corrosion - low coefficient of thermal expansion leading to better time accuracy

While the above table includes the most common materials used in mechanical as well as digital clocks, there are a few other types of clocks which use slightly different working mechanisms and hence, different materials. Similar to how pendulum clocks use a gear mechanism and crystal-based clocks use quartz crystals for timekeeping, atomic watches use atomic interactions between Cesium-133 atoms while magnetic watches use a ball-bearing mechanism.

In an atomic clock, each of the Cesium-133 atoms have one of two possible energy states depending on the surrounding magnetic field (referred to as hyperfine levels). A very high frequency alternating current is used to oscillate the magnetic field, which in turn influences the energy state of the atoms. When the magnetic field is flipped, all the atoms move from one energy state to the other. This allows for very precise time measurement - in fact, atomic clocks are so accurate that the SI system defines one second as the amount of time it takes for a Cs-133 atom to oscillate exactly 9,192,631,770 times.

Magnetic wrist watches use a modified version of the gear mechanism. The ticking motion of the gears is used to internally move small neodymium magnets, each of which move a ball bearing around the circumference of the watch in a circular track. Given the limited space on a wrist watch, there are usually only two ball bearings corresponding to the hour and minute indicators. This type of design makes it very easy to tell the time by simply touching the face of the watch and sensing the position of the ball bearings, which is suitable for people with vision impairments.

Process Selection:

As we have seen, manufacturing a clock involves a variety of different components. Since the nature of these components is very different, it follows that they cannot all be manufactured using the same set of manufacturing processes. In general, the larger parts corresponding to the exterior of the clock are manufactured by bulk cutting processes, while the interior parts require more precise machining.

1. **Case/Housing:**

   Since this is the largest part of the clock, it is relatively easier to manufacture using bulk machining processes such as shaping or milling. To avoid a lot of wastage, the initial workpieces must be of approximately the same size as the manufacturing specifications, with some allowance for machining. This can be done by solidifying molten metal in moulds of a specific size and shape, and by chainsawing machines in case of wood.

   The machining processes are generally carried out using curved ball nose-shaped tools to give the case a fine surface finish. Very often, products require further finishing to get rid of any anomalies introduced by machining (eg: narrow circular tracks produced in the direction of the directrix). The most commonly used processes for this are electroplating and/or painting due to their affordability and bulk processing ability.

   Wooden cases are most often manufactured manually by carpenters, since high-speed machining processes are likely to fracture wooden workpieces due to large shear stresses. They can then be easily polished manually using lacquer or varnish, depending on the type of finish desired. This is also why many wood-based clocks are more expensive compared to their metallic counterparts.

2. **Face:**

   The face of a clock is perhaps the simplest piece to manufacture, since it most often is just a thin square slab or circular disc made of plastic/ceramic. This can be achieved very easily by shaping or milling processes using a tool with large surface area for bulk machining. However, care must be taken to keep machining speeds relatively low, since both plastics as well as ceramics are relatively brittle.

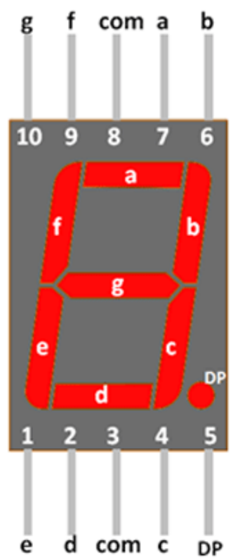
   It gets more complicated when the face has to be of specific colour(s). This often requires high-temperature processes where plastics/ceramics become relatively more porous and allow dyes to pass into the material. A simple alternative to this would be simply spray-painting the faces (ideal for smaller clocks where it is more economical per unit manufactured), but high-temperature dyeing generally offers better visual results as well as better wear resistance.

3. **Arms:**

   The arms of a clock are relatively smaller components compared to the case and face. Since they are relatively thin, care must be taken that they are not bent in any way while manufacturing. A very common process used to manufacture such thin components is pressing, which essentially involves the action of high pressure to reduce the material thickness. To attach the arms about the central pivoting shaft, the process of punching is used.

4. **Digital Display:**

The production of a digital display mainly involves constructing the LED circuit on top of the integrated circuit (which is manufactured by squeezing semiconductor wafers under high pressure). The pinout diagram below is a schematic representation of the circuit which defines the bias of the LEDs. Each of the 7 LEDs is linked to one of the terminals labelled a – g, while the remaining three ports are used for connections to the AC circuit.



Sometimes, in a bid to reduce manufacturing costs, manufacturers may use tinted glass or ceramic panels to cover the display instead of using coloured LEDs.

5. **Mainspring:**

There is a five-step process for the manufacturing of springs. First, the spring needs to be coiled, which can be achieved by using either cold winding or hot winding. Cold winding involves simply winding a wire that is at room temperature around a shaft. If we heat the wire, it will be easier to deform it (lesser force required as flexibility increases), so hot winding is preferred for springs. Commonly in the industry, before bending, the metal is heated to increase wire flexibility and coiled when hot. Next, it is quenched in oil to cool it down and to keep the shape in place.

For the second step, the built-up stresses are in the wire, the spring is heated to a set temperature and then cooled slowly. The spring is then strengthened to decrease metal fatigue. Next, setting is done by completely compressing the spring multiple times to keep it stable and keep the length constant. In the final step, to prevent corrosion, the spring is coated with chromium/zinc.

6. **Gear/Wheels:**

   Hobbing and milling process can be used for manufacturing gears. In this process, the workpiece is fed at a constant rate while the cutting tool (hob) rotates. It is also a type of milling process. The hob does a series of cuts to produce external gear teeth. Similar to the manufacturing process of mainspring (second step), the material is heated to relieve the built-up stresses and then cooled. Grinding may be used to provide a smoother finish.

7. **Quartz Crystal:**

   The quartz crystals need to be artificially grown under controlled conditions, as naturally occurring quartz is not suitable according to the quality needs of the resonator. After growing the crystal, the faces are accurately ground to accurately define the X, Y, and Z axes.

   High-precision cutters are then used to cut the quartz crystal into small flat plates. These slices through the crystal need to be made slightly thicker than that required for the finished crystal.

   Now these can then be further cut into smaller blanks which are then lapped to bring them closer to the required thickness. As the lapping process is abrasive, it damages the crystal lattice on the surface of the crystal. This not only lets in gas molecules and other impurities later that will cause ageing, but it also directly causes changes with time.

   Once the lapping forms have been embraced, the surfaces of the precious stone are chemically carved. This gives a really much better wrap up to the crystal and gives less opportunity for chemical entrance afterward. In any case the surface of the crystal has to be exceptionally carefully washed after the chemical carving to expel all follows of outside chemicals.

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ME 338 Course Project: Stage 5 Submission

Topic: Manufacturing Process of a Clock

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Manufacturing: Processes have been described in the Stage 4 Report. The following summarizes the manufacturing of a generic clock.

1. **Metal:** Large parts such as the frame, face, gears, etc. are made using large-scale machining processes such as casting to create the workpiece of appropriate dimension, and subsequent shaping/milling to remove material to create the finished part. Words/numbers are embossed/engraved onto the part. However, smaller parts such as the spring and the clock arms are produced by special processes called winding(hot/cold) and pressing(and subsequent punching[shearing]) respectively.

2. **Wood:** High-precision cutting(sawing) and engraving are used to create the main wooden parts of a clock such as the frame, face and perhaps the pendulum. High feed rate/cutting speed machining processes are uncommon, since wood does not have the material properties required to withstand the forces without fracturing/breaking. Wooden clocks are usually more difficult to produce, as smaller parts like the arms cannot be large-scale manufactured efficiently. These are usually cut or carved manually.

3. **Plastics:** Thermo-setting polymer materials are usually moulded and cast into the required shape. This is more scalable, economical and efficient than metal product casting and machining.

4. **Glass:** Glass products such as the face-cover, or occasionally, a glass clock are made by cutting of a glass plate, and by hot blowing of glass respectively.

5. **Quartz:** Produced by artificial crystallization to frequency specifics, then laser-cut to extremely thin flat plates, and chemical treatment to the surface is finally applied for use in the clock.

Finishing & Coatings:

Finishing is one of the final stages in the manufacturing pipeline, where the raw product is processed further to make it visually more appealing as well as to coat it with other materials for increased resistance to mechanical damage. The processes and materials used in the finishing stage will often differ greatly depending on the type of clock produced.

Let us start with wooden clocks, since these have been in production for as long as 300 years, and there has not been much innovation in the finishing processes for wooden products in recent years. Due to a general lack of mechanization for producing wooden clocks, the raw manufactured product generally has a lot of rough edges, as shown in the picture below:

Raw manufactured outer case for wooden clocks

There are various relatively inexpensive processes that are used for finishing of wooden clocks:

1. **Sanding:** The workpiece is mounted on a movable L-shaped plate and the facets are pressed lightly against a disc sander which rotates at a high velocity. To prevent burn marks on the workpiece, the grinding is done in short cycles. Often after this process (or after final assembly), the case is further polished manually using finer sandpaper to remove any smaller facets or saw marks remaining on the surface.

Grinding a wooden workpiece against a disc sander

2. **Varnishing:** This is mainly used as a secondary process after the clock has been polished by sandpaper. Several materials including bush oil, lacquer, and polyurethanes can be used for this process. It essentially involves very thin coats of these materials over the wooden surface in a circular motion using a soft cloth. For further polish, the workpiece is sanded using a 320-grit sandpaper between successive coats. Applying such types of varnish over the casing of the clock not only makes it more visually appealing but also masks any small surface irregularities that may have remained after the sanding process.

Most modern clocks and wristwatches are now made of metal. Due to its very nature, metal clocks require a very high degree of surface finish, since even the smallest of surface irregularities can easily be spotted and leads to loss of visual appeal. Further, any cracks or pores in the outer surface may also lead to internal rusting of the casing. The major processes used for finishing of metal clocks are:

1. **Electroplating:** This is probably the most common method used for the finishing process. Electroplating is often used in the case of gold plating, since making the entire body out of gold is very expensive and requires different machining techniques, since gold is a relatively soft metal. Wrist watches are often plated with nickel and chromium alloys for a better surface finish as well as resistance to corrosion.

   Electroplating is a very efficient process since it is very easy to control the rate of material deposition, which makes is much easier to produce very thin coats, especially in the case of precious metals like gold. However, this also makes it susceptible to wear over time.

2. **Filling:** This is often seen as an alternative to electroplating with the additional advantage of wear resistance. To account for filling, there are a bunch of small cavities that are intentionally left in the base metal, usually cast iron or steel, during the manufacturing process. The secondary metal (eg: gold, chromium, etc) is then filled in the cavities and over the case in several layers. This may leave some stray marks on the surface, which can be removed by exposing it to mild chemical reagents that dissolve the metal and remove surface irregularities.

   This has the advantage of providing greater strength to the casing, but also tends to make it denser as well as more expensive to manufacture.

3. **Physical Vapour Deposition (PVD):** This is a relatively modern process which is mainly meant for tackling the shortcomings of traditional electroplating. During PVD, the target (i.e., the material to be deposited) is initially in a solid or liquid phase. It is bombarded by a high-energy source, such as a beam of electrons or ions. This leads to dislodging of metal ions from the surface, converting them to a vaporized state.

   The vaporized metal is then transported through a duct into a vacuum chamber. In some cases, the metal may be reacted with gases such as oxygen, nitrogen, or methane. This leads to the formation of metal oxides, nitrides or carbides which, in some cases, leads to additional strength of the final coating.

   Finally, the metal is deposited onto the surface of the casing. This is done by inducing the watch casing with a charge opposite to that of the metal ions, which allows the metal to be easily deposited onto the casing. Due to vaporized coating process, the coats produced by PVD have a controllable thickness as well as a very fine surface finish, which means that it does not need any further processing.

4. **Diamond Like Carbon Coating (DLC):** During DLC, the product is placed on a rotating carousel inside an evacuated vacuum chamber. It is then scrubbed using a high-energy beam of relatively inert ions such as argon to clean the surface and remove any micro-oxides that may interfere with the coating process.

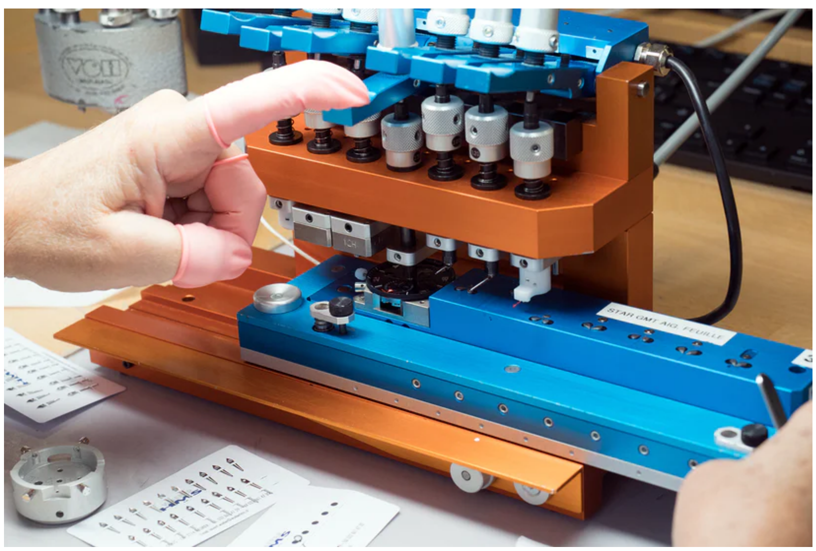
During the coating phase, a carbon-carrying gas (usually methane) is introduced in the chamber. The gas is then ionized by auxiliary anodes. This leads to separation of carbon and hydrogen atoms — a process known as cracking. The ionized atoms are then deposited over the surface of the carousel by electrostatic attraction, which leads to formation of an amorphous carbon, or diamond-like carbon, film.

Machines & Equipment:

1. **3D Printer:** For making a prototype, after the design has been made on software it is 3D printed. The material is generally kept transparent, and this prototype helps get a sense of the tactile qualities and proportions of the watch.

2. **Vacuum Chamber:** The quartz crystal that is grown by artificial treatment is kept in a vacuum chamber while manufacturing to work most effectively.

3. **Press Machine**: The placement of hands of the watch are very important. Poor hand placement can produce issues such as hands slipping on their posts and becoming misaligned, hands simply falling off if the watch gets bumped, and ultimately even stopping because the hands are binding against each other, or rubbing against the glass or the dial.



The press machine is used to place the hands quickly and accurately. This machine is very specific to a particular watch design and is expensive, but guarantees precision and consistency, which is crucial as explained above.

4. **Computer Numerical Control (CNC) Machine**: In these machines, we can give a set of coordinates as input and the workpiece head moves through those coordinates precisely, giving very accurate control over the path and ultimately the cutting of the workpiece. It is used in a lot of modern machining processes, and naturally in watch making also. These are used to cut out parts in certain required shapes from metal sheets.

5. **Spring Vibration Tool:** As mentioned in Stage 4, the mainspring needs to be vibrated to determine the active length. In this machine, the spring is pinned to the collet - the part of the balance staff to which the innermost coil of the spring is attached, using epoxy or laser spot-welding.

Inside the tool is a reference balance, which beats at a pre-set frequency (generally 2.5 Hz). The spring is placed above it, and you start the reference balance swinging by pushing the lever at 6:00 to the left. The balance to be timed is also started, and the frequencies are compared and adjusted for any mismatches.

6. **Polishing Wheel**: This tool is used for polishing the lever. It is very important to polish the fork of the level, as it is the only point directly in contact with the balance and rest of the watch. If the fork is properly polished, it will transmit energy to the balance more efficiently, and it will also allow the balance to unlock the pallets from the escape wheel

with as little energy loss as possible. The polishing wheel is used along with two steel plates (for bending), to ensure precise dimensions are achieved.

7. **Polishing sticks**: For movement finishing, hand-finishing is preferred over using lasers. Polishing sticks made from the woody stem of the yellow gentian are used for polishing flanks and bevels.

Assembly and Inspection:

1. **Part Inspection:** Before assembling the final product, each of the parts undergo a final quality check to filter out potentially faulty components. This is usually manual, since mechanized quality checks can often lead to false positives. Plastic/metal machined parts are also sometimes subjected to random ultrasound/X-ray inspections to test the general performance of the machines involved in the manufacturing processes, and to weed out specific problems to fix in the pipeline.

2. **Assembly:**
   Following the pre-assembly quality check, the central dial is fitted manually. Next, the hour, minute and second hands are fitted over the dial using a semi-automatic process over a Lecureux line (a type of assembly line containing specialized workstations, where parts are added in stages to a semi-finished product).

   The assembly line is manually monitored at each workstation through infrared/ultrasound displays to check for assembly errors. Any faulty assemblies are removed from the line and corrected manually. After fitting the dial and hands, the casing and glasses are cleaned under compressed air and vacuum. The case back is then fastened to the front casing. In case of wrist watches, the body of the watch is sent over for strap assembly.

3. **Finished Product Inspection:** Finally, the finished product is put aside for about 24-48 hours to check whether it runs properly. To save time as well as cost, manufacturers often make multiple test models to check for impact resistance, water resistance, material strength, etc. After the assembly process is complete, the clock is then sent for packaging and transport.

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ME 338 Course Project: Final Submission

Topic: Manufacturing Process of a Clock

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Cost Analysis:

Now that we have discussed the entire manufacturing process right from the materials & process selection to the techniques used for manufacturing specific parts of a clock, let us take a brief look at the costs incurred during manufacturing. Of course, the costs a company incurs will greatly differ based on the type as well as the amount of watches they produce.

The cost analysis in this section is done by assuming a local manufacturing unit which sells electronic quartz clocks at a rate of around 750 units per month.

We first consider the fixed costs, i.e. the costs that are either one-time or do not need to be paid regularly (eg: rent, electricity per month, etc). Given that the manufacturing process of clocks has become more and more automized over the years, we can proceed with an initial assumption that fixed costs as well as labour costs will be much lower compared to the cost of setting up and operating machines & other equipment.

Sr. No.	Description	Quantity	Cost (₹)
1	Quartz clock tester	3	60000
2	Digital multimeter (3 ½ digit)	4	14000
3	Electrification cost (taken 10% of equipment cost)		7400
4	Office equipment, furniture		25000
5	Tools, jigs, soldering stations, etc		10000
6	Pre-operative expenses		10000

The analysis of the variable costs is a little more involved since there are many factors, like labour costs (wages will be different due to difference in job position), raw material requirement (will change with demand, here assumed to be 7500 units per month), utilities (power, water, etc) and contingency expenses (such as rent, telephone charges, etc).

1. **Staff and labour costs:**

Sr. No.	Designation	No. of people	Salary (₹)	Total (₹)
1	Manager	1	5000	5000
2	Sales/service assistance	1	2000	2000
3	Clerk/typist	1	2000	2000
4	Peon/watchman	1	1500	1500
5	Skilled labour	3	2500	7500
6	Semi-skilled labour	2	2000	4000

This gives us a total of ₹22,000 for labour costs. After including 15% of the total salary as prerequisites, the cost of labour totals to ₹25,300.

2. **Raw material requirement:**

Sr. No.	Description	Cost per unit (₹)	Total for 750 units (₹)
1	Quartz	250	187500
2	Materials for case, hands, dials	350	262500

Hence, the rough total for raw materials (assuming production of 750 clocks per month) is ₹4,50,000.

3. **Utilities:**

Sr. No.	Description	Cost (₹)
1	Power	250
2	Water	350

The cost incurred by the company for utilities per month is ₹2200.

4. **Other contingency expenses:**

Sr. No.	Description	Cost (₹)
1	Rent	4000

2	Postage and stationery	2000
3	Telephone/fax charges	1000
4	Repair and maintenance	1000
5	Transport & conveyance charges	6000
6	Advertisement & publicity	5000
7	Insurance & taxes	300
8	Consumable stores	2000
9	Allowance for miscellaneous expenditure	1000

Hence the rough cost for contingent expenses for the company is around ₹22,300 per month. Hence, the aggregate cost of manufacturing from (1), (2), (3) and (4) is around ₹4,99,500. Thus, the total recurring expenses per year are as follows:

Sr. No.	**Description**	**Cost (₹)**
1	Total recurring expenditure	5994000
2	Depreciation of equipment & machinery (10% of the fixed cost of machines & equipment)	7400
3	Depreciation of tools, jigs, fixtures (25% of associated fixed cost)	2500
4	Depreciation of office equipment (10% of associated fixed cost)	5000
5	Interest on capital investment (~16% of total capital investment)	260000
	Total cost of production per annum	**6269000**

Thus, the company spends around ₹62,69,000 per annum (besides the fixed cost). Assuming each clock sell at a price of ₹800, the total revenue from 9000 clocks sold over one year is ₹72,00,000 which results in a total profit of around ₹9,31,000.

Of course, as stated earlier in this section, all the costs are taken assuming a local manufacturer. The costs are likely to vary a lot depending on the size of the company. However, since the basic manufacturing pipeline remains the same, it is fairly reasonable to assume that other companies also encounter a similar nature of manufacturing costs. Hence, the same type of analysis can be applied to any other manufacturer.

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