STAGE MACHINE DESIGN COMPETITION

2022 Clockworks

Indiana University

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Design Specifications

Our team has been hired to create the mechanism for a “crazy clock” effect that will be installed as part of the set. The “crazy clock” will operate at multiple times during the performance – primarily during scene shifts, but potentially at other moments.

Physical Specifications

- The clock is comprised of 3 hands (second, minute, and hour) that rotate on separate axes (*fig. 1)*

Mechanical Specifications

- The hands must be dependent on each other and run by one actuator (motor)
- The clock hands must be mechanically driven but not necessarily motorized
- The clock has the ability to do two movements (see Movement Specifications)
- The mechanism should be as quiet as possible

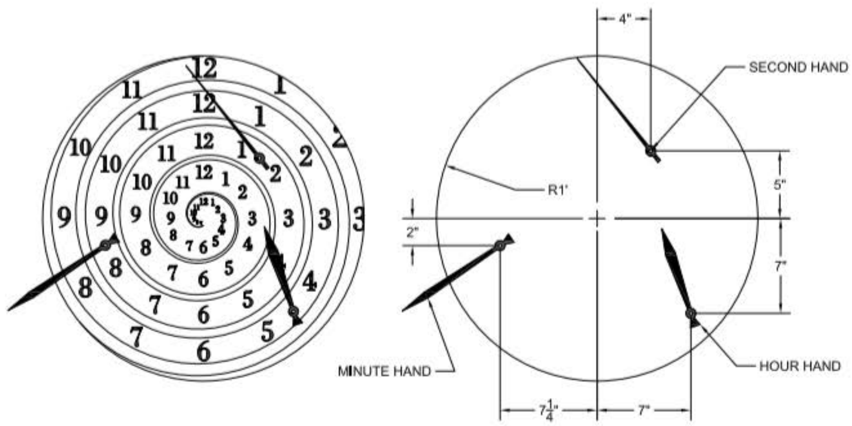

fig. 1

Movement Specifications

Movement 1

- All three hands move in the clockwise direction
- For one revolution of the second hand, the minute hand will rotate 6°
- For one revolution of the minute hand, the hour hand will rotate 30°
- The second hand has an angular velocity of 3 rps
- The initial and final positions of the hands do not matter
- The movement will last for 1 minute
    - 180 revolutions of the second hand
    - 3 revolutions of the minute hand
    - 90° movement of the hour hand

Movement 2

- The second hand and hour hand move in the counterclockwise direction
- The minute hand moves in the clockwise direction
- For one revolution of the second hand, the minute hand will rotate 18°
- For one revolution of the minute hand, the hour hand will rotate 60°
- The second hand has an angular velocity of 1 rps

- The initial and final positions of the hands do not matter
- The movement will last for 1 minute
    - 60 revolutions of the second hand
    - 3 revolutions of the minute hand
    - 180° movement of the hour hand

Provided at Competition

- ⅛" plywood clock hands
- 15A 110-120VAC power
- 100 PSI air pressure through by ¼" tube or quick-connect (must request by May 1)

Other Details

- Artwork does not need to be recreated on the face of the clock
- Teams will have 20 minutes to demonstrate both movements
- No explosives or pyrotechnics

Concept Designs

From the beginning of the design phase, the team understood that we needed to add or subtract an element to switch directions of two of the hands. The team also understood that multiple gears, pulleys, or chains would be required for each of the hands to have a different angular velocity, yet be dependent on one another.

The team began researching and brainstorming various ways to change the direction and velocity of the hands.

Design Option 1: A Shifting Axle

How It Works:

- Establish a single axle in which the motor would run utilizing layers of gears (*fig. 2*)
- The motor shaft will be connected to a system of gears, controlling the hands
- By shifting the axle, the motor shaft can lock into a separate system of gears, changing the direction and velocity of the hands

Pros:

- Single moving part to minimize movement and complexities

Cons:

- Would be difficult to correctly change gear ratios by using minimal space and gears on a single shaft

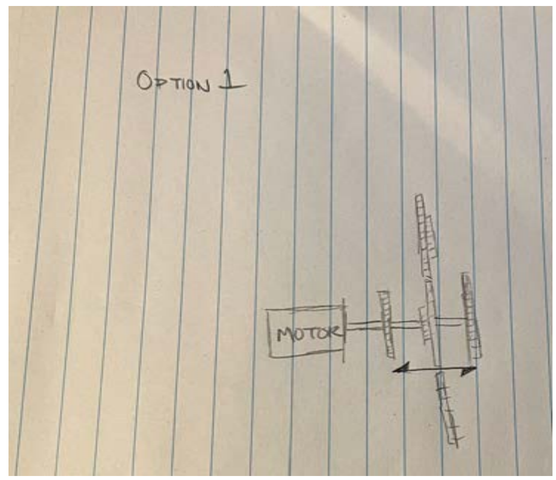

fig. 2

Design Option 2: The Pegboard

How It Works:

- Use a “pegboard” system to place gears
- Would use predetermined holes to move gear shafts in place for each movement (*fig. 3*)

Pros:

- Easily adjust and slot gears into different configurations to achieve the needed ratios

Cons:

- Large potential for human error due to the complexity of the moves
- Lack of available space for the required movement of the gears

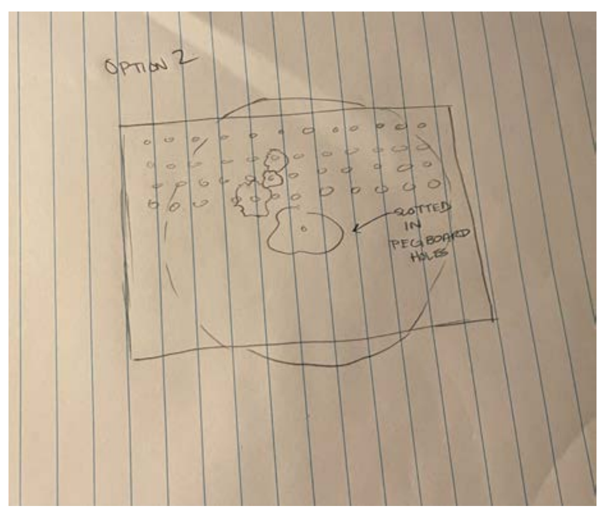

fig. 3

Design Option 3: Bike Chains

How It Works:

- Use bike chain to "shift gears" between movements (*fig. 4*)
- Utilizing the gear shift mechanism on a bike in order to change gear ratios
- The bike chains would move from a single shaft with multiple gears reaching out to their respective clock hands
- The chain(s) would shift to create the various movements

Pros:

- Simple movement

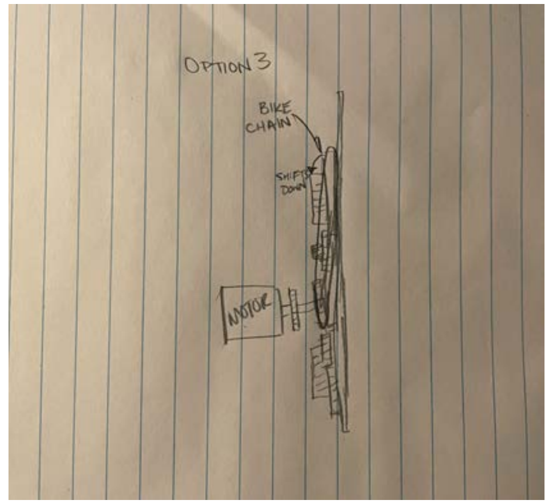

fig. 4

Cons:

- Maintaining the appropriate tension of the chain could cause error
- Sound could prove to be an issue
- Difficult to change direction of only the hour and second hand due to the limited ability to add or remove extra components

Design Option 4: The Watch Pin

How It Works:

- Similar to the mechanics of a watch pin engaging and disengaging
- When our "pin" (a gear shaft with 2 different gears on it) is engaged, it will create movement one
- Moving the pin outwards would shift the second gear on the shaft in place to create movement 2 (*fig. 5*)

Pros:

- Limited moving parts

Cons:

- Would be difficult to correctly change gear ratios needed for movement 1 and movement 2 due to the limited ability to add or remove extra components

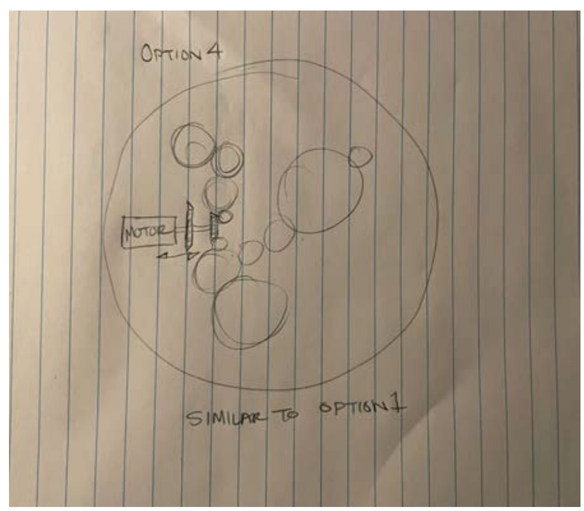

fig. 5

Final Design

After discussing the pros and cons of the other design concepts, the team decided to combine elements of the watch pin design and the bike chain design. We wanted to minimize the number of elements that shifted between movement 1 and movement 2. This would both reduce the likelihood of human error and reduce the time it takes to prepare for the second movement. We knew that the simplest way to change the direction of the hands was to add a single gear and wanted to come up with a way to insert this extra gear into the system without having to physically adjust everything else.

How It Works

- The clock consists of various gears and chain
- A motor is directly connected to the minute hand, set to 3 rpm, locking it at a constant speed
- Through a combination of chains and gears, the speeds of the second hand and the hour hand are established
- One system of gears is set directly on the axle of the minute hand, connected via chain to the gears creating the ratio needed to get the speed for the second and hour hand (*fig. 6*)
- The gear attached to the chain is able to shift via a tracking piece to create Movement 2 (*fig. 7*)
  - The chain maintains tension while allowing two extra gears to be added to the system to change both the direction and the angular velocity for the second and hour hands
- This pivot/gear shift will be done manually to ensure proper placement
- All gears, shafts, and clock pieces will be 3D printed using MakerBot Replicator with the MakerBot print software

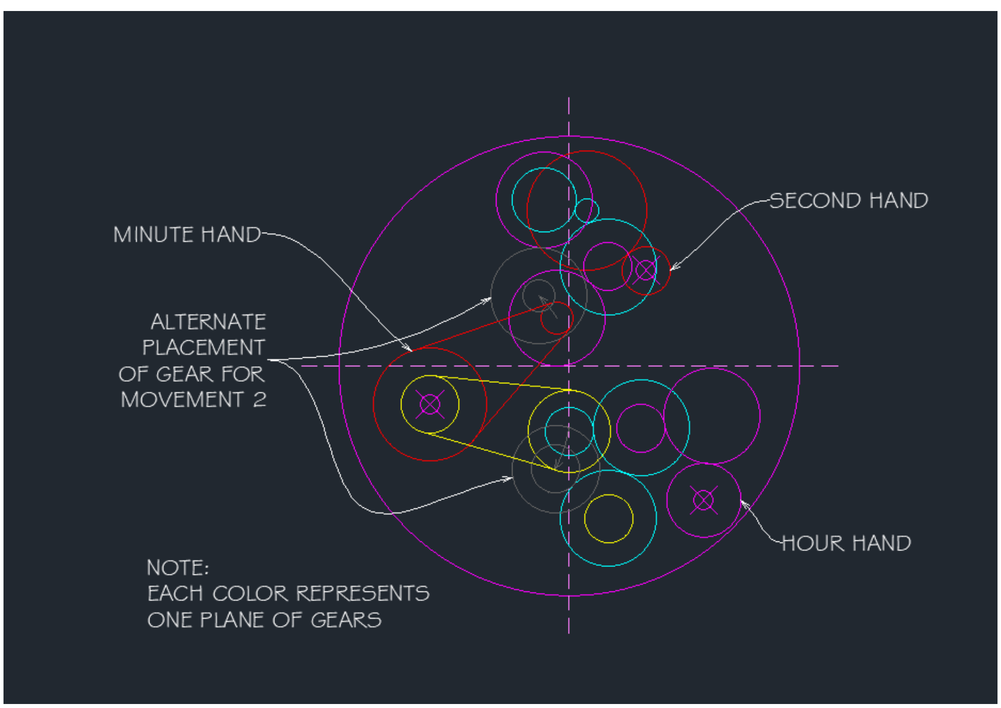

fig. 6

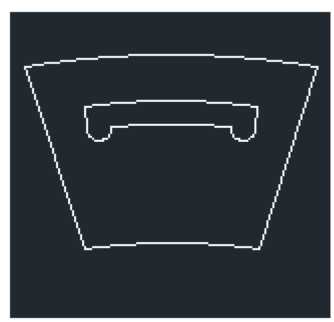

fig. 7

Pros

- Fast changeover
    - Very few pieces will have to shift to get both movements
    - No speed adjustment necessary in the motor
- Limited potential for human error
    - Adding a chain to the gears that shift help maintain tension, keeping the gears in place
    - The operator will only be touching the two gears attached to the chain, the rest of the system is precisely placed
    - These two gears are on a track that allows for very little movement outside of the specific needs for the change
- Accuracy
    - Layered gears allow us to control ratios and, in turn, speed
    - 3D printing gives us the exact gears we require

Possible Challenges and Solutions

- Manual shifting does leave room for human error
    - Will be mitigated by adding notches within the tracks established on the backing piece
- Precision is a necessity, leaving little room for misplacement
    - Purposeful construction of the backing piece will help alleviate any misplacement error
    - Once pieces are correctly placed, they will not need to be moved
- Chain can create too much sound
    - Inside of clock can be padded with foam to dampen any sound
    - Different chain materials will be explored

Cost Analysis

- By 3D printing our gears, we greatly decrease the cost of the design
- The elements that would not be 3D printed include:
    - The clock face
    - The backing piece/gear casing
    - The chain
    - The motor
- All of these elements, except for the motor and chain can be constructed with pine or plywood

Next Steps

Our team has calculated the various ratios that are needed to complete the movements assigned. By using an online software (geargenerator.com), we have confirmed our math and will use this information to help guide us in the gears that we print (*fig. 8*).

The elements that we will be further developing include:

- Creating a method to keep the axles secure, but able to rotate with the gears
- Designing how the tracking system sits within the build
- Exploring various chain materials and their pros and cons (plastic, metal, etc.)

Our team will be spending the next three months conducting research and development as we prototype different gears and how the tracking system works. We will be using rough prints of gears in order to establish which gears we need. Once we have tested and confirmed our gears, we will do a final, fine print.

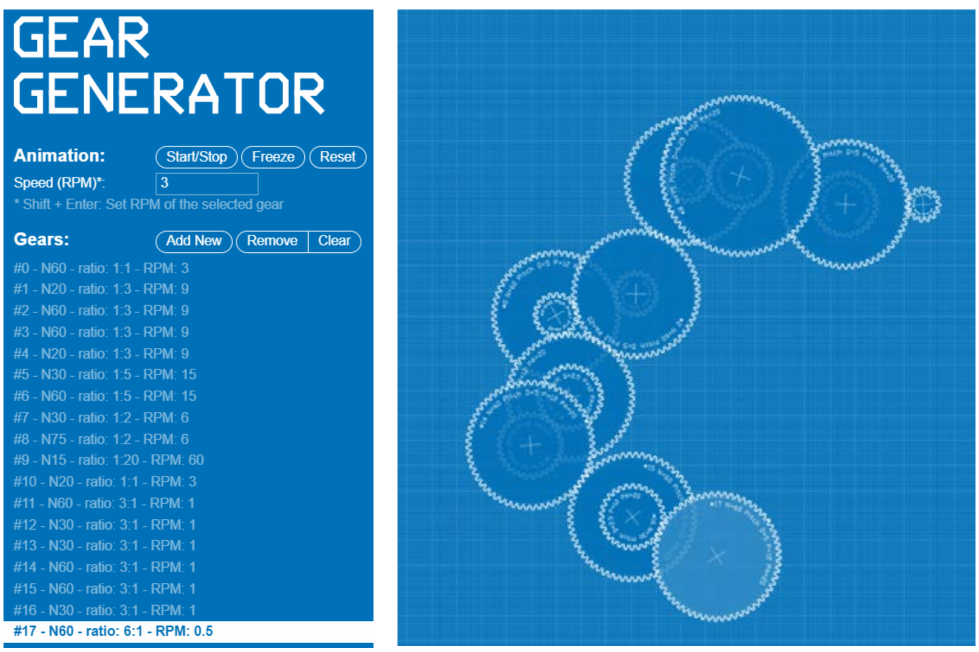

fig. 8