2022 Stage Machine Design Competition Design Proposal

Purdue University

Flynn Botkin

Szczesny Lipinski

Mason Trenaman

Tabitha Wimsett

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Design Proposal

The Process

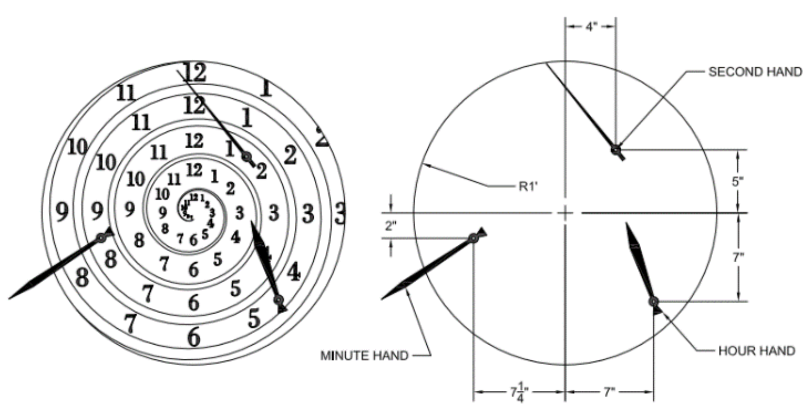
While the SMDC challenge this year only consists of two motion profiles for one singular function, the task itself is mechanically complex. Because of this, extensive research and thought went into how the team approached this design proposal. The team started by establishing a design specification based on the competition information provided. Next, concept designs were produced by each member of the team. These concepts varied from designs based on existing clock mechanisms to novel and atypical solutions. Based on criteria derived from the design specification, the team compared each concept using a decision matrix. After several matrix iterations, a winning solution was chosen.

Design Specification

We have been hired to develop a mechanism for a “crazy clock” effect for a production of *All in the Timing*. The clock will operate multiple times during the performance, mostly during scene shifts with the potential for use during other moments. Three hands on separate axes with dependencies on each other will make up the clock. For this production, the design team envisions two different sets of movements.

Physical Specifications:

- Clock contains 3 hands that rotate on separate axes.
- While the clock hands must be mechanically driven, they do not have to be motorized.
- Single actuator can be used to drive all 3 hands.
- Mechanisms should be as quiet as possible.
- There will be time during the production to make any adjustments to the mechanism necessary to allow for changes in direction and velocity.
- Clock hands will be constructed out of 1/8” plywood
- Weight variance of plywood hands is marginal.
- No restriction for the thickness or weight of the clock.
- Designers prefer not to see the mechanism from the front.



Operational/Movement Specifications:

- The hour hand movement should be dependent on the minute hand.
- The minute hand should be dependent on the second hand.
- Hand cranks are acceptable.
- Clock Movement 1:
    - All 3 clock hands will move in the clockwise direction as seen from audience.
    - For each single revolution of the second hand, the minute had will move a total of 6 degrees.
    - For each single revolution of the minute hand, the hour hand will move a total of 30 degrees.
    - The second hand should have an angular velocity of 3 revolutions per second.
    - The initial and final positions of the hands do not matter.
    - Total movement should last 1 minute: 180 full revolutions of the second hand, 1 revolution of the minute hand, and 180 degrees of movement of the hour hand.
- Clock Movement 2:
    - The second and hour hand will move counterclockwise as seen from the audience.
    - Minute hand will move in clockwise
    - For each single revolution of the second hand, the minute hand will move 18 degrees
    - For each single revolution of the minute hand, the hour hand will move a total of 60 degrees.
    - Second hand should have an angular velocity of 1 revolution per second.
    - The initial and final positions do not matter.
    - The movement should last 1 minute: 60 full revolutions of the second hand, 3 revolutions of the minute hand, and 180 degrees of movement for the hour hand.

Competition Specifications

- Total of 20 minutes to demonstrate both moves.
- 1/8” Plywood clock hands will be provided after registration
- We have access to the equipment in the trap room.
- Materials in the shop can be used with permission from shop supervisor.
- Clock Mechanism will have to stand alone.
- Access to 15A 110-120VAC power
- Access to 100 psi by ¼” tube or quick-connect

Timeline:

- Written proposal due by February 15th
- Competition on May 7th

Concept Designs

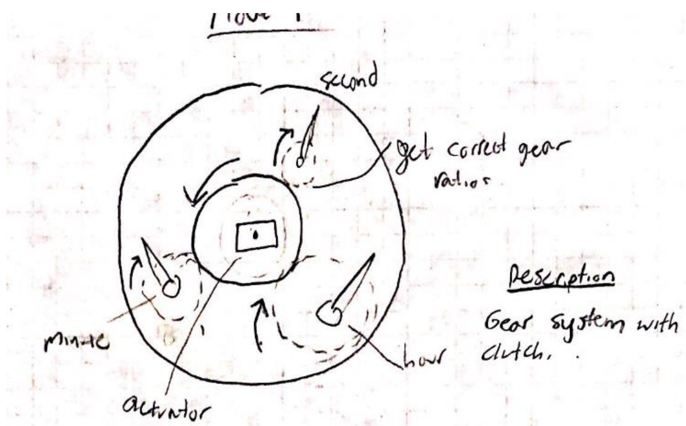
Research

At the beginning of the concept design phase, team members performed individual research. A variety of approaches were explored by team members, including researching traditional mechanical clocks, examining various gears and hardware from McMaster Carr, watching videos of different mechanical clock builds and designs, exploring Bernard water clocks, and reviewing the textbook *Mechanical Design for the Stage* by Alan Hendrickson. The main influence on the final design was a video about a motorized monitor lift using timing belts and pulleys. The idea to use timing belts and pulleys brought the possibility of belt drivers to move pulleys into the minds of the team.

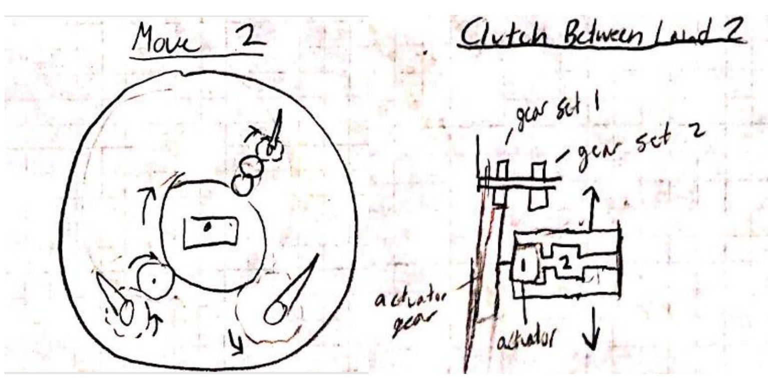
Concepts

Concept 1: Gear system with clutch between moves 1 and 2

First move:



Second Move:



How it works:

- A gear pattern for each move is created
- The gear sets are stacked onto each other
- A clutch system on the actuator is used to clutch between moves 1 and 2

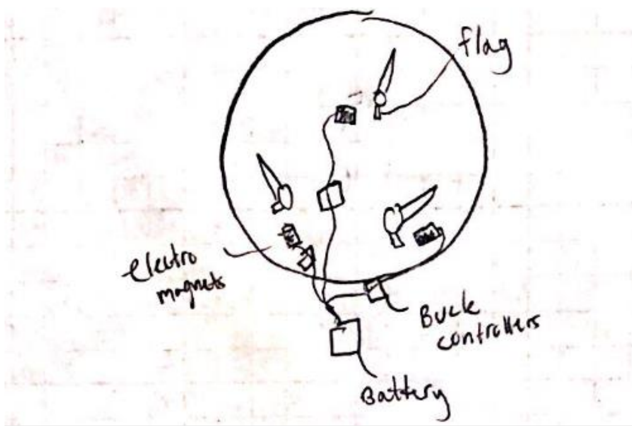
Pros:

- Less mechanically complex than other designs
- Well-designed gears will be close to exact
- One driving component
- Compact

Cons:

- Clutch adds complexity
- More transition time required for clutch (repeated clutch term)
- Complex gear ratios
- Gears will require a lot of manufacturing/prototyping

Concept 2: Electromagnetic Flag system



How it works:

- Electromagnets spin hands by pointing at a magnetic flag.
- Direction controlled by polarity; speed controlled by current.

Pros:

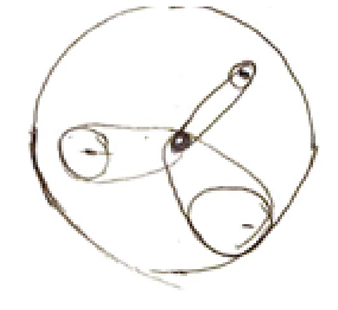
- Little to no mechanical components
- No need for an actuator
- Compact
- Little manufacturing needed

Cons:

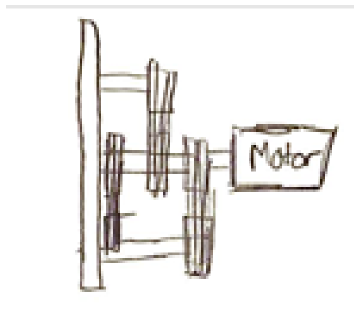
- Substantial amount of testing would be required to tune accurately
- Wiring intensive
- Several batteries needed
- Not mechanically bound- more likely to be inconsistent

Concept 3: Belt drivers

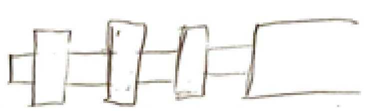
First move:



Back view

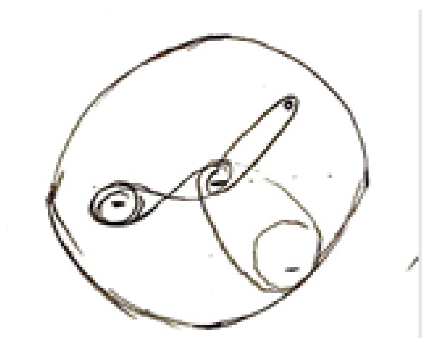


Side View



Driver shaft with pulleys

Second Move:



How it works:

- Belt connects to a pulley or wheel at each clock hand
- For second move: Minute hand belt will be in a figure eight configuration
- Hand pulleys switched

Pros:

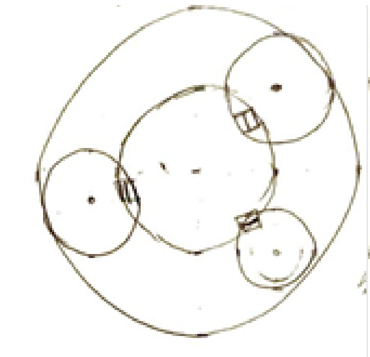
- Simple
- Easy to build

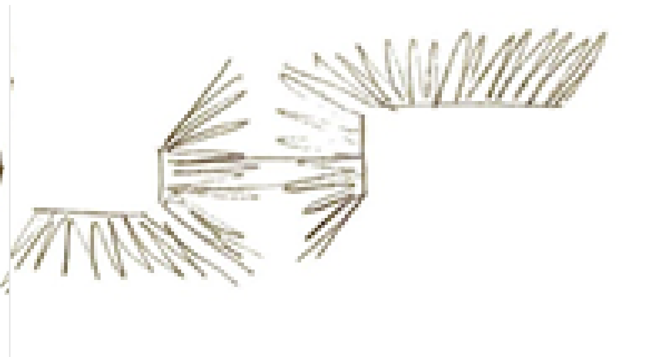
Cons:

- Figure eight will likely involve specialty pulleys and guides
- Pulleys or wheel require specific friction and tension conditions to work properly
- Potential for belt to have a higher failure rate

Concept 4: Bevel gears

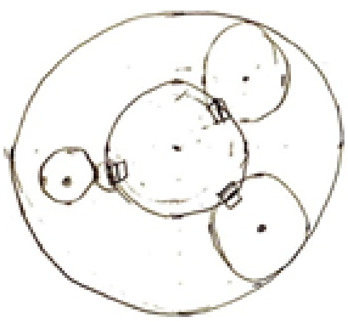
First Move:





Back view Bevel Gear Connection

Second Move:



Back View Added Bevel Gear Connection

How it works:

- Centrally driven gear rotates sets of bevel gears connected to each gear driving each clock hand
- Gear connections using two bevel gears to connect top center gear and bottom gears driving hands
- For second move: All lower gears switched
- For second move: Extra gear added to change rotation direction of minute hand
- Extra gear added is a combination of a bevel gear and traditional mechanical gear

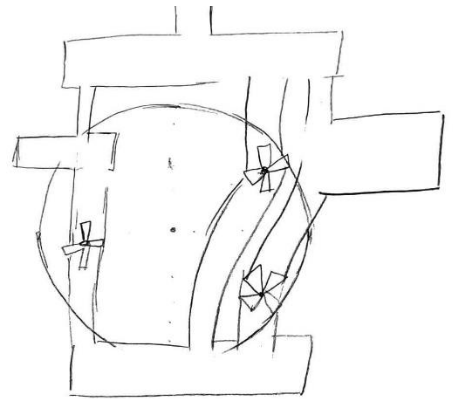
Pros:

- Creative and different use of gears

Cons:

- Double bevel gear might be complicated to manufacture
- Combination gear requires special build
- Overly complicated

Concept 5: Hydraulic or sand driven



How it works:

- Series of tubes, holes, and tanks to manipulate a controlled substance such as water or sand
- Similar to a water clock
- Substance falling turns wheels at rates determined
- Second movement would require a different set of tubes and tanks

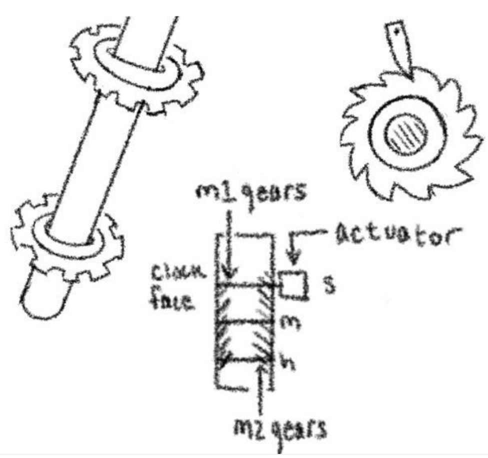
Pros:

- Easy to change directions
- Not dependent on a powered actuator

Cons:

- Considerably harder to control
- Heavy
- Precision and speed of rotation require more complicated calculations
- Substantial testing required for fine tuning

Concept 6: Ratcheted Gears



How it works:

- Two sets of gears run on one shaft turned by an actuator
- Gears are ratcheted in opposite directions so that only one moves at a time, allowing the two different required movements
- Inner part of the ratcheted gears is free to rotate no matter which way the shaft is rotating so that the system does not fail
- Friction or a grab mechanism between inner and outer part of gear so outer part turns when unlocked

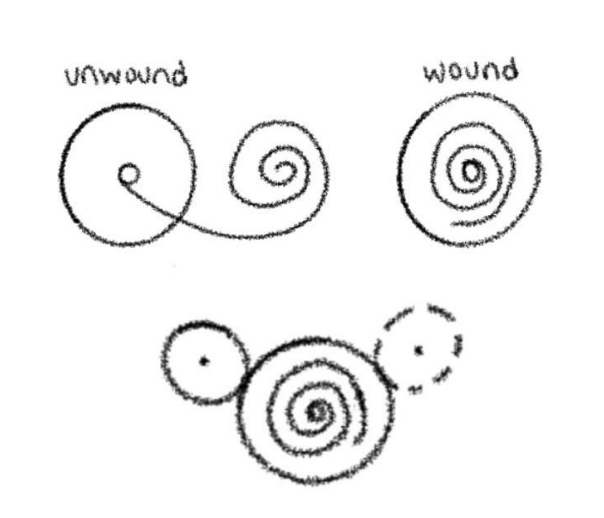
Pros:

- Little to no time required to switch between movements
- Gears can be enclosed to prevent foreign object interference
- Can be run using any actuator that facilitates rotation

Cons:

- Ratchets could click loudly
- Inner rotating piece may fail to turn outer gear if grab mechanism fails

Concept 7: Steel Spring



How it works:

- Steel curved band is wound tightly, causing it to unwind when released
- This works as an actuator by turning whatever the spring is wound around
- To have two movements, the pieces interacting with the spring can be switched out during transition

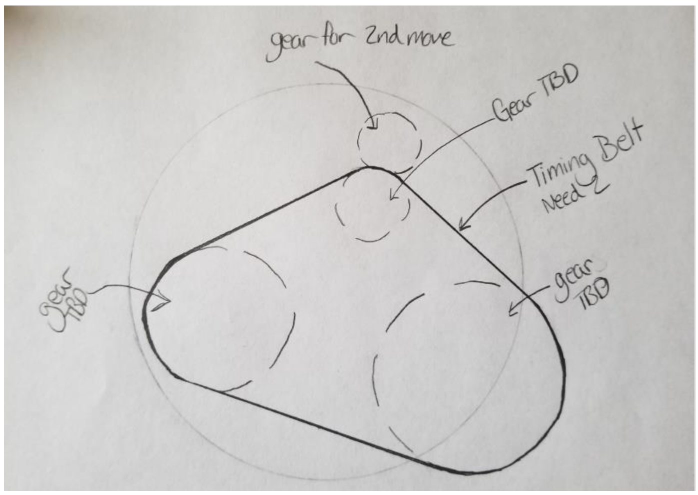
Pros:

- Does not require motor/pneumatics

Cons:

- Requires significant amount of time to start (winding)
- May not be consistent

Concept 8: Timing Belt



How it works:

- Each hand will have a different sized gear ensuring the proper timing
- Timing belt will be used to drive the three gears
- Second timing belt and one additional gear will be used to achieve the second move

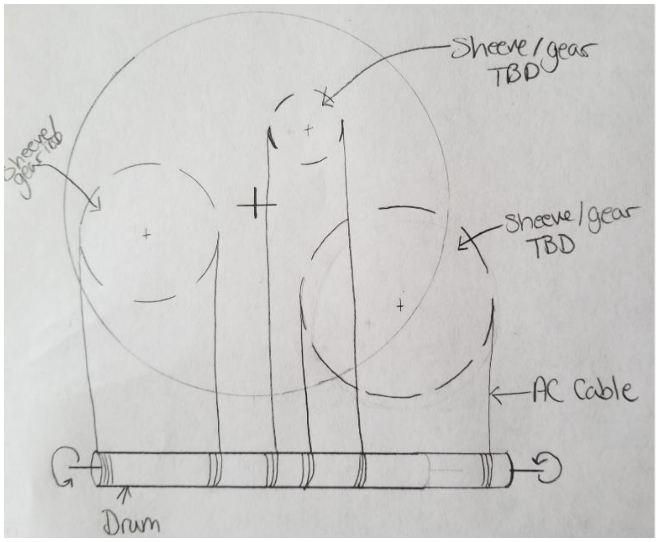
Pros:

- Quick change between movements
- Simple and efficient set up
- Could be motorized or manual

Cons:

- Requires a high amount of precision where the timing belt and gears interact

Concept 9: Drum



How it works:

- Three different sized sheeves or gears are used to ensure proper timing
- AC cable would be connected to a long drum
- As drum rotates, the sheeves will spin
- To achieve the second movement: ac cable would have to be wrapped in the opposite direction

Pros:

- “Out of the box” solution
- Fairly simple to achieve
- Could be motorized or manual

Cons:

- Timing could be a challenge.
- AC Cable may slide over the sheeve instead of rotating it.
- Mechanism is large and not easily hidden

Evaluation

After analyzing the various concept designs, the team created a decision matrix. The team started by developing a list of criteria based on their understanding of the challenge. Given what the team learned from the design specification, criteria such as consistency of mechanism, build ability, speed of transition, and complexity of calculations were used. After finalizing the criteria, a weight of priority was used to rank how well each concept design met the criteria.

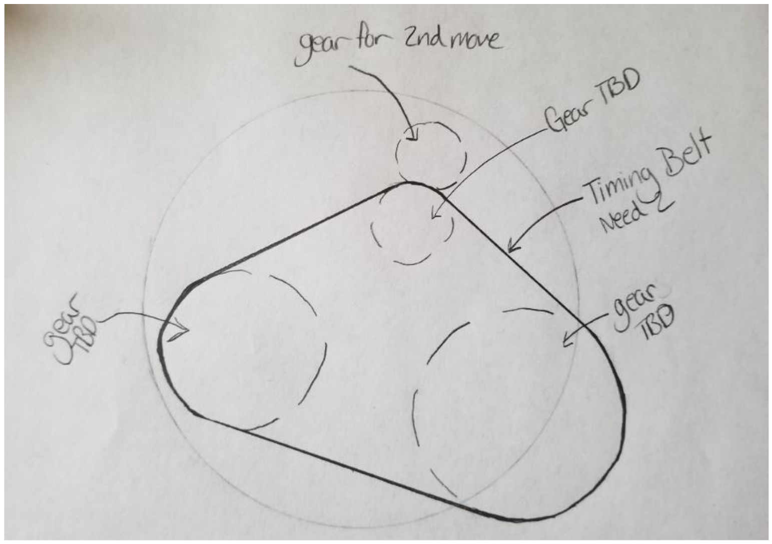
CLOCK MECHANISM WEIGHTED DECISION MATRIX [ALL CONCEPTS]											
Criteria	Driven by Single Actuator	Noise Level	Speed of Transition	Speed of Load-In	Elegance	Buildability	Complexity of Calculations	Precision of Mechanism	Consitency of Mechanism	Ease of Transition	TOTAL:
Weight: 1-5	**5**	**1**	**3**	**2**	**3**	**4**	**2**	**5**	**5**	**2**	
Gears with Clutch	0	2	-2	0	-1	3	0	0	1	-2	**6**
Electromagnetic Flags	-5	5	0	-1	0	2	-3	-3	-3	0	**-50**
Belt Drivers	0	1	-2	0	-2	1	0	-3	-2	-2	**-36**
Bevel Gears	0	2	-3	0	-1	-2	0	0	0	-2	**-22**
Hydraulic Driven	-3	-2	-3	-2	-1	-4	-5	-1	-3	-4	**-87**
Racheted Gears	0	0	0	0	0	0	0	0	0	0	**0**
Steel Spring	0	0	-3	-2	0	-4	-4	-3	-3	-3	**-73**
Timing Belt	0	1	-1	0	-1	5	2	-1	-1	-2	**5**
Drum	0	1	-3	-1	-1	2	-2	-1	-3	-3	**-35**

Each team member created separate decision matrices using the weighted criteria. After discussing the findings, the team decided to create a single matrix together using the concept that scored highest, ratcheted gears, as a baseline. Based on the matrix, it was discovered that two other concept designs scored slightly higher than the ratcheted gears.

CLOCK MECHANISM WEIGHTED DECISION MATRIX													
Criteria	Driven by Single Actuator	Noise Level	Speed of Transition	Speed of Load-In	Elegance	Buildability	Complexity of Calculations	Precision of Mechanism	Consitency of Mechanism	Ease of Transition	Complexity of Mechanism	Creativity of Design	TOTAL:
Weight	**5**	**1**	**3**	**2**	**3**	**4**	**2**	**5**	**5**	**2**	**5**	**1**	
Gears with Clutch	10	5	8	10	6	5	6	8	8	6	5	5	271
Racheted Gears	10	2	10	10	6	3	6	8	8	8	2	10	260
Timing Belt	10	8	8	10	7	8	8	6	7	6	8	7	295

After further discussion, the team decided to create one more matrix with additional criteria comparing the top three designs. Additional criteria such as creativity of design and complexity of mechanism were added. Based on the final decision matrix, the team was able to definitively choose a concept design to move forward with.

Final Design



The final design chosen was concept 8, the timing belt design. The team felt that this design is the most accomplishable given the constraints of our project timeline and resources. The design will use a timing belt tensioned around pulleys that have been manufactured to the correct gear ratio. Each pivot will contain two stacked pullies to account for the two different motion profiles. The team will be designing a belt quick release system so the transition time between move 1 and 2 will be minimal.

Moving Forward

Moving forward, each team member will perform the calculations to determine the gear ratios for each move. A 3D model will be made with the calculated gear ratios to determine the appropriate belt length. Next, the team will start exploring existing belt drivers and hardware. Depending on availability, the team is prepared to pivot to building a custom belt driver if needed. After that, gears/wheels/pulleys will be fabricated, and the belts will be added. The physical clock face will be built, and the hands will be cut out using the CNC Router. Testing can then begin.