ABU ROBOCON 2022, India

DESIGN DETAILS DOCUMENT

Pimpri Chinchwad College of Engineering, Pune

R1 Robot

A. ***Overall dimensions*** *($L \times W \times H$):*

1) ***At start:*** $(800 \times 840 \times 1610)$*mm*
2) ***During game time:*** $(800 \times 840 \times 1610)$*mm*

B. ***Estimated Weight:*** *21 kg*

C. ***Material Used:*** *Al6061, Mild steel, AISI304, Plywood, Nylon 66, Polypropylene, Carbon Fiber, PU, Rubber.*

D. ***Type of Drive:***

Four-wheel Swerve drive is selected because of its **fast and precise movement**. Traction wheels each driven by a BLDC motor, provide better friction and **high acceleration**. These wheels are steered individually to enhance control and mobility. This is a **semi-autonomous** drive controlled wirelessly via a PS4 controller with **feedback** from **gyroscope** and **laser distance sensors (class 2)**.

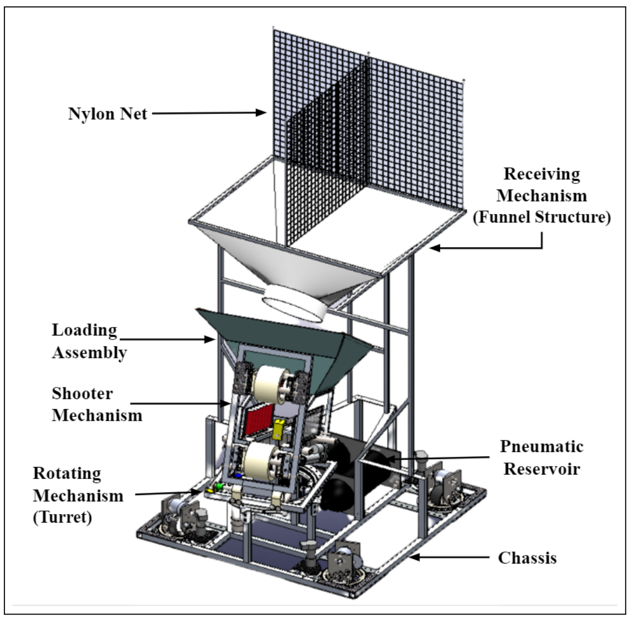

Fig. 1: **R1 Robot**

I. Seeker

Lagori Breaking

Introduction:

The **objective of the task** *is to break the Lagori pile during the break shot time from R1SZ using seeker balls*. A **shooter mechanism** comprising of two nylon wheels, each driven by a BLDC motor, is used for shooting the ball. A pneumatic piston pushes the pre-loaded seeker balls to the shooter mechanism. *(refer Fig. 3)*

Working:

1) During the setting time, the piston is in actuated state and the three seeker balls are loaded onto the loading assembly of Seeker R1 (**Rule 1.13**).
2) The piston is retracted so that the ball to be launched lands on the guideway from the loading assembly.
3) The wheels start to rotate gaining momentum, followed by the piston actuation, forcing the ball towards the wheels.
4) Ball is sucked and thrown out immediately by the wheels. The piston retracts allowing the next ball to land on the guideway.

This process is illustrated below

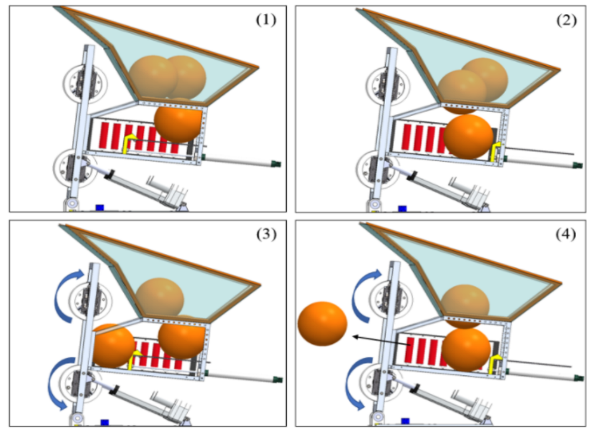

Fig. 2: **Working of Shooter Mechanism**

Calculations/ Justification:

The dimensions and design of the loading assembly **(trapezoidal structure)** are chosen considering that all the pre-loaded balls fit all together and can be **loaded one at a time** onto the guideway as per **Rule 2.2.4**.

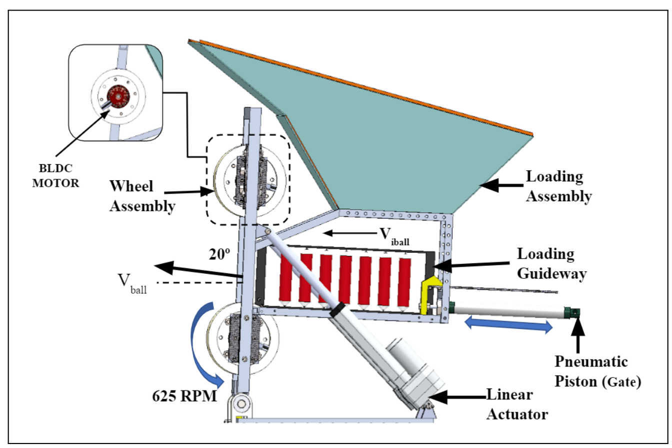

Fig. 3: **Lagori Shooter and Ball Loading Mechanism**

This loading assembly comprises of a **piston (stroke length 200*mm*** and **bore ϕ20*mm***) that serves as a gate between the loading assembly and the guideway. This piston generates a force of $112N$ (at $0.4N/mm^2$) to provide initial velocity (v_{iball}) = *0.2m/s* to the ball before getting sucked by the wheels. This guideway is lined with an **array of rollers** for smooth passage of the ball.

According to the team's game plan, to break the entire pile of mass (M_l) $\approx$ 1.5*kg* [*density* (d_l) = 14 kg/m^3] using one shot, the ball hits the lagori disc of ϕ500*mm*.

The minimum required displacement of lagori pile $(s_l) = 260mm$.

Assuming lagori breaking time (t_l) = 0.4s, using the kinematic equation, $\boxed{a_l = 3.25m/s^2}$ The coefficient of friction sunmica-sunmica (μ_s) is practically determined to be 0.2 (**Rule 1.17**).

Thus, minimum velocity of the ball (v_{fball}) required to break the lagori pile using the law of conservation of energy,

$$\frac{1}{2} \times M_{ball} \times (v_{fball})^2 = [(\mu_s \times M_l \times g) + (M_l \times a_l)] \times s_l$$

was calculated to be 4.5*m/s*. The distance between the shooter mechanism and lagori pile (x) is 3.5*m*. The mechanism is mounted at a height (y) of 0.52*m* from the ground. To calculate the required launch velocity of ball (v_{ball}), The launch angle (θ) is considered as 20°. Using Projectile Equation,

$$y = xtan\theta - \frac{gx^2}{2u^2cos^2\theta} \qquad ...(i)$$

We get $\boxed{v_{ball} = 7.06m/s\ (25.4km/hr)}$ $> v_{fball}$ ensures that lagori pile is broken and **Rule 2.1.10** is followed.

To provide the above v_{ball}, the wheel of mass (M_{wheel}) = 600g and ϕ120*mm* is used. The v_{iwheel} is calculated by law of conservation of momentum. Considering losses,

$$v_{fwheel} = 0.9v_{iwheel}$$

$$2 \times M_{wheel} \times v_{iwheel} + M_{ball} \times v_{iball} = 2 \times M_{wheel} \times v_{fwheel} + M_{ball} \times v_{ball} \qquad ...(ii)$$

$$\boxed{v_{iwheel} = 11m/s(1846\text{rpm})}$$

To meet this RPM requirement, a **BLDC motor** of **320KV** which can provide **1920 rpm at 6V** is selected.

II. Hitter
Ball Receiving and Hitting Ball on Head

Introduction:

The **objective of the task** *is to receive hitter balls from R2 and hit the opponent team's Ball On Head (BOH) to displace it*. A **net structure** receives the ball and guides it into the loading assembly. Hitting the opponent's BOH is achieved through the **shooter mechanism** (same as 'Lagori breaking'). This mechanism is mounted on a **rotating mechanism (turret)** *(refer Fig. 5)* consisting of bearings, which are connected to a gear assembly, driven by a DC motor, that rotates the mechanism about its vertical axis. The **launch angle** is adjusted by two **linear actuators** *(refer Fig. 3)*.

Working:

1) The hitter balls are received from R2 into the receiving mechanism and loaded sequentially onto the guideway.
2) The wheels spin with the required velocity, to gain momentum.
3) The turret mechanism rotates the shooter mechanism and the linear actuator sets the launching angle computed based on the required trajectory with respect to the opponent's BOH.
4) The ball is shot by the shooter mechanism, to displace the BOH.

This process is illustrated below

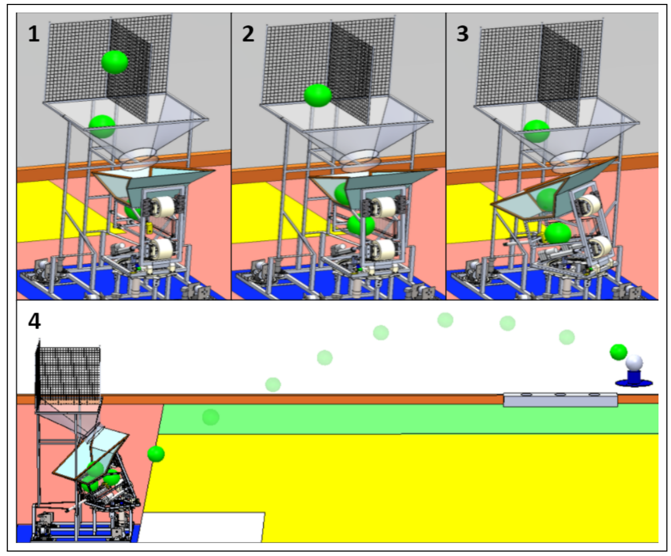

Fig. 4: **Working of ball recieving and hitting BOH**

Calculations/ Justification:

The **T-shaped nylon net structure** of the receiving mechanism is designed to receive the balls thrown from either of the ball areas without changing the orientation of R1. **Nylon net** is preferred as it is lightweight and provides **sufficient damping**. The ball from the receiving mechanism is guided to the loading assembly through a funnel structure *(refer Fig. 3)*.

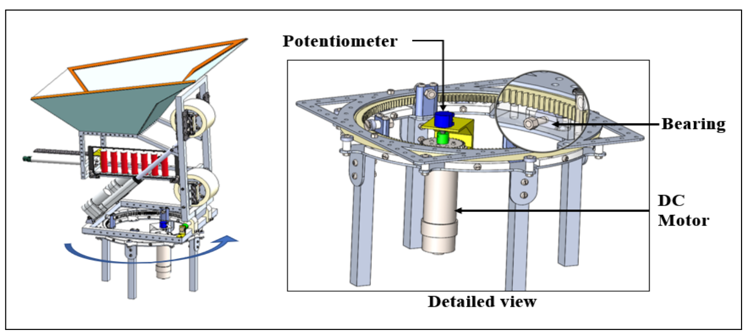

Fig. 5: **Rotating mechanism (Turret)**

The **turret** covers a **wide range of lagori area** to shoot from R1SZ**.** The bearings are used to provide smooth rotation. Entire assembly *(refer Fig. 3)* has a mass (M_{sa}) of 6.5kg. The radius of the rotating assembly (r_t) is 160*mm*. Hence, the torque required to rotate entire assembly(τ) (Considering (μ) = 0.3.) is,

$$\tau = \mu \times M_{sa} \times g \times r_t = 0.3 \times 6.5 \times 9.81 \times 0.16 = \boxed{3.06\text{Nm}}$$

To meet this torque requirement, a **DC motor** with **torque 4*Nm*** is used. Considering various locations of the opponent's Seeker R2, the launch angle and hitting range changes. To vary the launch angle of $0-43°$ (w.r.t. horizontal) a **linear actuator (stroke length 200*mm*)** is selected.

According to the team's game plan, we aim to hit the BOH in the range of 2-6*m*. To ensure that the **Rule 2.1.13** is not violated, the permissible velocity of the ball 8.2*m/s* (29.52*km/hr*) is considered. The relation between the launch angle and the required range at the hitting height of 1.35*m* has been plotted in MATLAB using a projectile equation.

The required RPM of nylon wheels is calculated using equation *[eqn-(ii)]* Hence, a **BLDC motor** of **320*KV*** providing **2240 *rpm* (at 7*V*)** is selected.

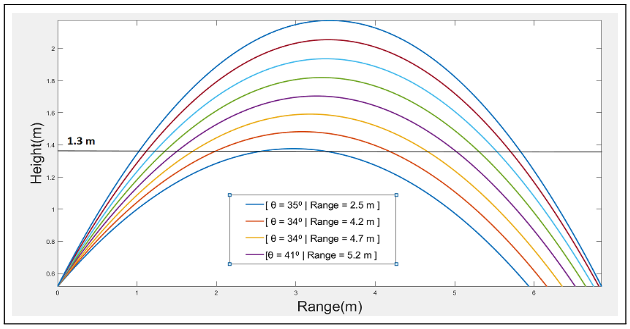

Fig. 6: **Graph of Projectile Height vs Range**

R2 Robot

A. ***Overall dimensions**-Excluding BOH $(L \times W \times H)$:*

1) ***At start:*** $(940 \times 920 \times 1216)mm$

2) ***During game time:*** $(1240 \times 960 \times 1216)mm$

B. ***Estimated Weight:*** *27 kg*

C. ***Material Used:*** *AISI304, Al6061, Nylon 66, Glass Fiber, Carbon Fiber, Mild Steel, Acrylic, Wood, Rubber.*

D. ***Type of Drive:***

Four-wheel Omni drive is selected as its rich maneuverability will help R2 to move swiftly. This is a **semi-autonomous** drive controlled wirelessly via a PS4 controller with **feedback** from **gyroscope** and **laser distance sensors (class 2)**.

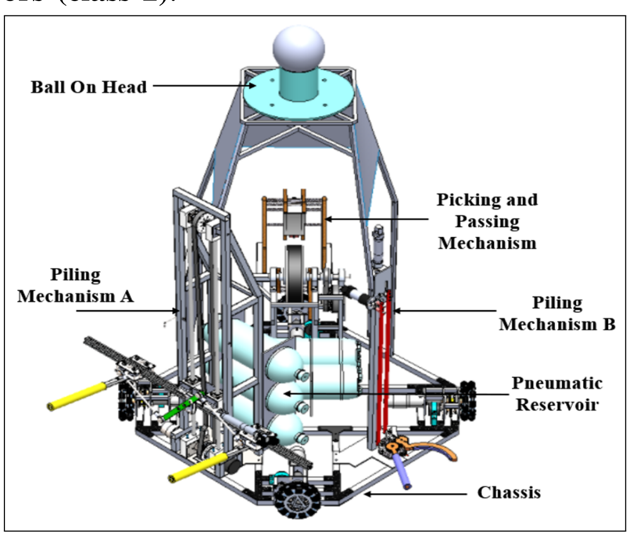

Fig. 7: **R2 Robot**

III. Seeker
Piling Up the Lagori Discs

Introduction **:**

The **objective of the task** *is to pick the fallen lagori discs inside the lagori area and pile them in the required sequence over the lagori base.* According to team's game plan, this task is achieved using two mechanisms :

1) **Piling Mechanism (A)** for Picking and placing the **bottom 4 lagori discs** over the lagori base.
2) **Piling Mechanism (B)** to pick the **topmost lagori (200*mm*)** and place it over the lagori pile.

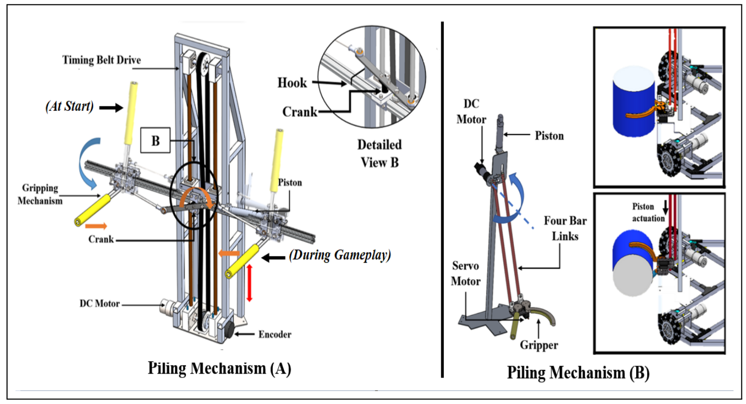

Fig. 8: **Piling Mechanisms**

Piling Mechanism (A)

Introduction:

Piling Mechanism (A) consists of a **parallel gripper based on double slider crank mechanism**. The gripper picks the four lagori discs of diameters 500*mm*, 425*mm*, 350*mm* and 275*mm* respectively. It comprises of two gripping links mounted on rollers that slide over an aluminium extrusion profile. These links are connected to a piston actuated crank via two connecting rods. This gripping assembly is mounted on a **belt drive** for **vertical motion** upto the required height using a DC motor with an encoder feedback. *(refer Fig. 8)*

Working:

1) Seeker R2 navigates towards the fallen lagori disc in the lagori area and aligns the gripper for picking.
2) The pneumatic piston actuates closing the gripper to grip the lagori disc.
3) Gripped disc is lifted to required height while R2 moves towards the lagori base and aligns with it.
4) The lagori disc is released on the base from the gripper by retracting the piston.

This process is illustrated using Fig. 9.

Calculations/ Justification:

Initially, to fit within the dimensions of R2SZ as per **Rule 3.4.1** the gripping mechanism is folded inwards by resting onto a hook *(refer Fig. 8)*. After the game begins, it disengages from the hook by lowering it with the help of belt driven assembly. This hook is mounted in such a way that the gripping mechanism is rested on it unless any external force is applied, hence, no other actuator is required for this process. After the disengagement, due to gravity, the hook does not interrupt the vertical motion.

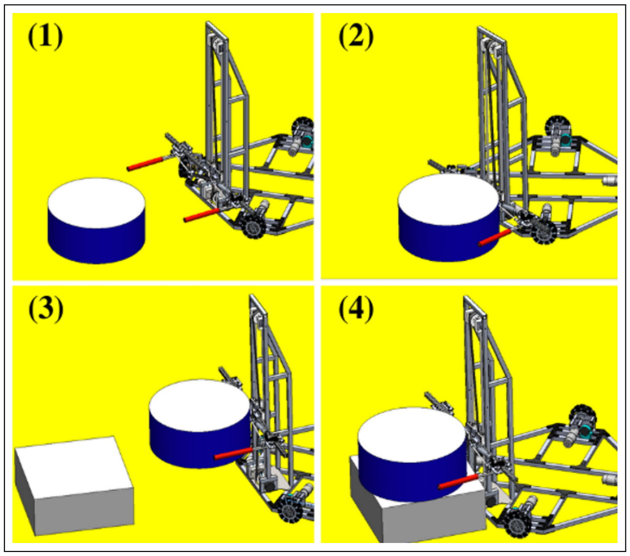

Fig. 9: **Working of Piling Mechanism (A)**

The **double slider crank mechanism** provides the required horizontal gripping motion with a **single actuator**. The quick actuation of the pneumatic piston results in fast gripping. According to team's gameplan, to pick the 4 lagori discs, a gripping range of 270*mm* to 600*mm* is required. Hence, length of crank was tested for various lengths and an optimal length of 220*mm* was finalized. Accordingly, the length of connecting rods were taken to be 190*mm*.

To lift the pile of 4 lagori discs [(W_d)=13.97*N*], $F_g(\textit{gripping force}) > \frac{W_d \times FOS}{\mu}$. i.e. $\boxed{F_g > 52.38N}$ (considering μ=0.4 for PU foam and FOS =1.5).

To satisfy this force requirement, a **pneumatic piston** of **stroke length 100*mm*** and **bore Ø20*mm***, operated at $0.3N/mm^2$, which generates a force of 84*N*, is selected. Considering this force is applied to the lagori disc, an analysis of 500*mm* disc was carried out to ensure that the disc is gripped without damaging it following the **Rule 5.2.**

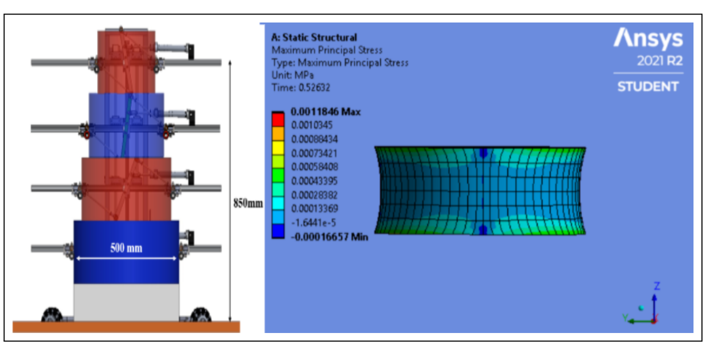

Fig. 10: **Gripping analysis**

The vertical motion of the gripper has a maximum range of 850*mm* w.r.t. ground so as to pile the four discs at the respective heights.

Considering the weight of the gripper assembly(W_G) to be *24.52N*, the *Tension on the timing belt* = W_G + W_d = *24.52* + *13.97* = $\boxed{38.49N}$.

Torque required to lift the entire assembly is calculated as, $\textit{Torque} = \textit{Tension} \times R_{pulley} \times \textit{FOS} = 38.49 \times 0.03 \times 2 = \boxed{2.309\ Nm}$. To satisfy the requirement, a **DC motor** with **4*Nm* torque** is selected. The **Timing belt** and **encoder feedback** aids in accurate vertical positioning for piling each Lagori disc at its desired height.

PILING MECHANISM (B)

Introduction:

Piling Mechanism (B) consists of a **servo actuated angular gripper** which is mounted on a **four-bar linkage** used to pick and place the lagori disc of diameter 200*mm*. In case the disc is fallen over its curved surface, the angular gripper is oriented w.r.t. lagori disc using a pneumatic piston. This linkage is rotated using a DC motor to lift the gripped lagori to the required height *(refer Fig 8)*.

Working:

1) Seeker R2 moves towards the fallen lagori disc and aligns the gripper according to the orientation of the 200*mm* lagori disc.
2) The gripper grips the lagori disc by actuating the servo motor.
3) The gripped lagori is lifted to the desired height by rotating the four-bar linkage.
4) Seeker R2 navigates to the lagori pile and releases the lagori on the top of it to achieve the **Perfect Lagori** .

This process is illustrated below

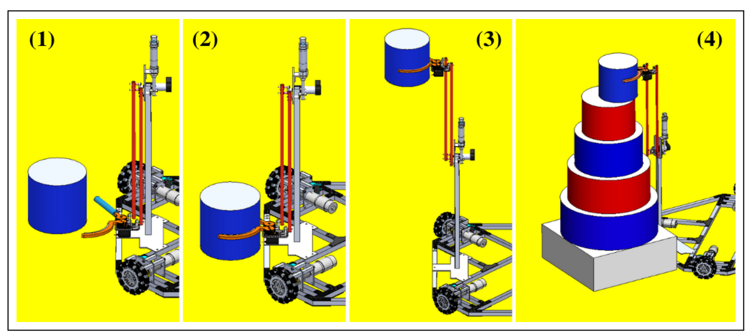

Fig. 11: **Working of Piling Mechanism (B)**

Calculations/ Justification:

The **four bar linkage** is used because it **maintains** the **same orientation of gripper during rotation**. The dimension of arm is selected as 550*mm* to achieve the required height of 1121*mm* for piling the lagori disc without violating **Rule 3.4.2**. The mass of the lagori disc (M_L) is 0.087*kg*, hence torque (τ_g) required to grip the lagori disc is calculated as:

$$\tau_g = M_L \times g \times r_l \times \textit{FOS} = 0.087 \times 9.81 \times 0.1 \times 2 = \boxed{0.17\ Nm}$$

To satisfy the requirement, a **servo motor** with **0.98*Nm* torque** is selected for gripping.

To pick the lagori in any orientation, a **pneumatic piston** of **50*mm* stroke length** and **bore ϕ12*mm*** is selected which is capable of orienting the gripper w.r.t. lagori. The total mass of gripper along with the lagori disc (M_T) is 0.75*kg*. Torque (τ_L) required to lift this assembly is calculated as,

$$\tau_L = M_T \times g \times r = 0.75 \times 9.81 \times 0.57 = \boxed{4.19Nm}$$

Hence, a **DC motor** of **6.8*Nm* torque** is selected to lift and pile the disc over the lagori pile.

IV. Hitter Ball Picking and Passing

Introduction:

The **objective of the task** *is to pick and pass hitter balls from ball rack to Hitter R1*. According to the team's game plan, the hitter ball is picked and directly passed from the ball rack to receiving mechanism on Hitter R1 ***(FAQ1_2.2-3)***. A **belt driven roller assembly** for picking the ball and a **rotating flywheel** for passing is used to achieve this task. The roller assembly includes two rollers connected by a timing belt, in which **one roller** is driven by a **BLDC motor 1**. Similarly, the **flywheel** is driven by **BLDC motor 2** through a timing belt drive to launch the ball towards Hitter R1.

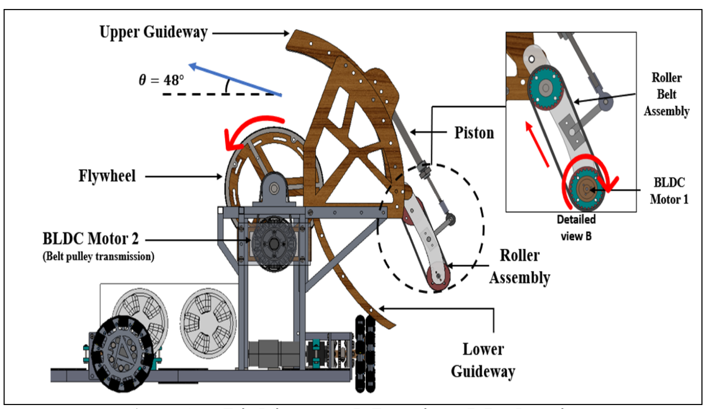

Fig. 12: **Picking and Passing Mechanism**

Working:

1) Hitter R2 navigates to the ball rack and aligns itself, aiming towards the receiving mechanism. The piston attached to the roller assembly is retracted, lifting it to avoid contact with the hitter ball.
2) The flywheel and the roller assembly begin to rotate to gain momentum. The piston is actuated, lowering the roller assembly to make contact with the ball.
3) The rotating rollers pull the ball towards the flywheel with the help of the lower guideway
4) The ball is launched by the rotating flywheel towards Hitter R1 with the help of upper guideway and Hitter R2 moves to the next ball.

This process is illustrated using Fig. 13.

Calculations/ Justification:

This mechanism is preferred for picking and shooting because of its **high precision, consistency and compact size**. The roller assembly picks the ball from above which provides **quick alignment**.

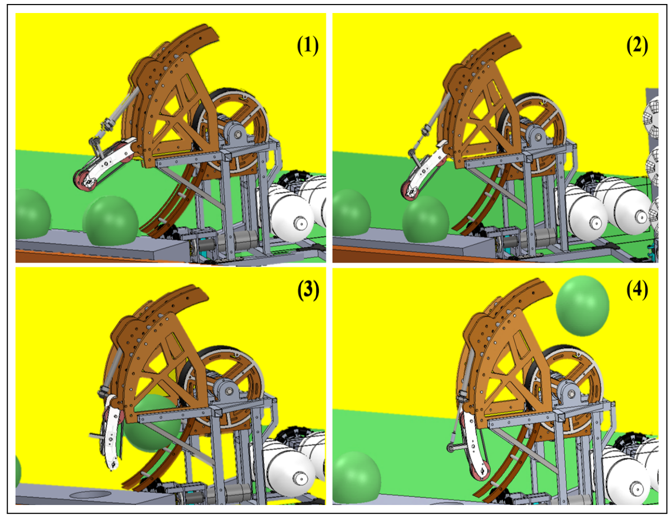

Fig. 13: **Working of Picking and Passing Mechanism**

To lift the ball from ball rack to flywheel at a height of 200*mm*, the required velocity of ball(v_{hb}) is calculated as $\boxed{1.98m/s}$, using the law of conservation of energy. Therefore, the required roller velocity (v_r) is calculated using law of conservation of momentum,

$$(M_b.v_{hb})_i + 2 \times (M_r.v_r)_i = (M_b.v_{hb})_f + 2 \times (M_r.v_r)_f$$

$$\boxed{\therefore v_r = 14.66m/s}$$

The radius of roller is 25*mm*, hence the required rpm is 5601*rpm*. To meet this requirement the **BLDC motor 1** of **930*KV*** providing **7440*rpm* (at 8*V*)** is selected.

The receiving mechanism is at a distance (x_{pass}) of 7*m* from the ball rack and at a height (yf_{pass}) of 1.3*m* from the ground. Considering the launch angle (θ) as 48°, the initial velocity (v_{fhball}) required to pass the ball is calculated using **equation (i)** $\boxed{v_{fhball}=8.2m/s}$ (29.52*kmph*). It ensures that **Rule 2.1.10** is followed.

The flywheel is designed in such a way that its mass is distributed along its rim. The radius (r_{fw}) of 100*mm* keeps the ball in contact for maximum duration. This ensures maximum momentum transfer. Considering mass of flywheel (M_{fw}) = 1.4*kg*, using law of conservation of momentum, the required flywheel velocity is calculated. Considering v_{wf} = 0.9×v$_{wi}$,

$$(M_b.v_{hb})_i + (M_{fw}.v_w)_i = (M_b.v_{fhball})_f + (m_w.v_w)_f$$

$$\boxed{\therefore v_{wi} = 8.88m/s = 848rpm}$$

The torque required to rotate the flywheel is given by $\tau_{fw} = m_{fw} \times g \times r_{fw} = 1.4 \times 9.81 \times 0.1 = \boxed{1.37Nm}$. To meet this requirement, the **BLDC motor 2** of **100*KV*** providing **900*rpm* (at 9*V*)** is selected.

The upper guideway concentric to the flywheel provides the required trajectory of the ball before launching. The overall design of mechanism ensures that the ball is continuously in contact with the rotating parts of the mechanism to provide high acceleration during the task time.

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