

Ghulam Ishaq Khan Institute of Engineering

Team Techno – Summer Research 2025

BATTLEBOT DOCUMENTATION

"60 Kg Vertical Spinner Battlebot"

Project Head

Danish Shakil
Dayeman Khan

Members

M. Umer Khan
Halar Ahmad
Abdullah

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Executive Summary

This report presents the research and design progress of a 60 kg vertical spinner Battlebot, developed under the leadership of Danish Shakil and Dayeman Khan along with his team as part of Team Techno's Summer Research Program 2025 at GIKI. The purpose of this project is to study, design, and optimize a combat robot for competition within the standard rule frameworks.

The design emphasizes:
A high-energy vertical spinner weapon, capable of delivering over 1400 J of rotational kinetic energy at 2000 RPM.
A robust truss-based chassis, ensuring structural rigidity under repeated high-impact collisions.
An efficient 36 V power system, integrating high-discharge batteries and ESCs for both weapon and drive.
A pulley-based transmission system designed for controlled weapon speed and efficient power transfer.

The project follows an Eight-week timeline:
1. Review of existing Battlebot designs and competition rules.
2. Research on weapon mechanisms and performance feasibility.
3. Drive system evaluation and traction analysis.
4. Power system study, including motor, battery, and controller selection.

By the end of the research phase, the team will have a fully validated CAD model in SolidWorks, complete with weapon, drive, and power simulations. Future stages will involve fabrication, assembly, and live testing which will be completed after the starting of odd semester.

This document consolidates all research findings, calculations, and design justifications to serve as a reference for both the current and future combat robotics projects at GIKI.

1. General Design

1.1 Review of Existing Battlebot Designs and Competition Rules

The design review confirmed that a **vertical spinner with a truss-based chassis** is the most feasible option. It balances offensive power with structural robustness while ensuring compliance with competition rules.

Key Findings from Existing Designs:

- Vertical spinners are among the most effective weapon types.
- They deliver **high kinetic energy impacts** capable of disabling opponents.
- Weaknesses include:
  - Risk of **self-destruction** due to recoil.
  - **Instability** after strong impacts.
  - **High power consumption** during operation.

Competition Rules and Constraints:

- Maximum allowable weight = **60 kg**.
- Mandatory **active weapon kill-switch** for safety.
- Strict **size restrictions** to fit arena entry limits.
- Prohibited weapons include **projectiles, liquids, and fire-based systems**.

1.2 Project Objectives

The primary objective of this project is to design and optimize a Battlebot that balances **offensive weapon power** with **defensive durability and mobility**. Specific objectives include:

- Developing a **4.31 kg vertical spinner weapon** capable of storing and delivering more than **1400 J of kinetic energy** at operating speeds up to 2000 RPM.
- Designing a **robust truss-based chassis** with an 800 mm × 800 mm base that can withstand repeated high-energy impacts.
- Selecting an efficient **36 V electrical power system** capable of supporting both drive and weapon subsystems without overheating or excessive power drain.
- Ensuring smooth **drive performance and traction control** to maintain maneuverability in the arena.
- Completing a **validated CAD model** with simulations in SolidWorks, covering stress distribution, stability, and energy transfer.

These objectives serve as milestones to ensure that the design not only looks feasible on paper but also performs reliably in actual combat scenarios.

1.3 Design Constraints (Weight, Dimensions, Rules)

Design is governed by strict competition constraints. The most critical limitation is the **weight cap of 60 kg**, which requires careful distribution among the weapon system, chassis, drive system, and power electronics. The weapon itself weighs 4.31 kg, while sufficient mass must also be allocated to armor and structural reinforcement to survive enemy attacks.

In terms of **dimensions**, the base has been fixed at **800 mm × 800 mm**, providing stability without exceeding entry limits. Height remains flexible but must accommodate the vertical spinner, pulleys, and drive system while maintaining a low center of gravity to prevent flipping.

Rule-based constraints include the mandatory use of **fail-safe mechanisms** such as power cutoff switch, restrictions against hazardous weapons (fire, explosives, liquids), and the need for modular repair in case of system failures. Additionally, arena-specific considerations such as floor traction, wall rebounds, and corner traps influence both drive and structural design.

Overall, these constraints ensure the design is **competitive yet safe**, maximizing weapon effectiveness while complying with international Battlebot standards.

2. Mechanical Assembly

2.1 Weapon System

The weapon system is the defining feature of this Battlebot and serves as its primary offensive mechanism. The design incorporates a **vertical spinner** weighing **4.31 kg** with a **moment of inertia (MOI) of 0.067 kg·m²**. At its target speed of **1000 RPM**, the spinner can store significant rotational energy, while at higher speeds of **2000 RPM**, it can deliver up to **1467 J of kinetic energy**. This ensures the weapon can disable or severely damage opponent robots in direct contact.

The weapon is constructed from **high-strength steel (density ~8000 kg/m³)** to balance durability and energy transfer. The outer ring diameter of **152 mm** and inner diameter of **135 mm** were optimized to maximize MOI without exceeding the weight cap. This geometry ensures that most of the weapon's mass is concentrated at the perimeter, producing stronger impacts.

CAD modeling in SolidWorks has been used to analyze stress distribution, while simulation tests confirmed that the weapon's geometry minimizes deformation during high-speed rotation. Provisions for replacement and modular repair have also been considered, allowing the weapon to be swapped or repaired between matches.

2.2 Drive System

The drive system is designed to provide both **high torque for pushing power** and **sufficient speed for maneuverability** in the arena. Stability and mobility are critical since a weapon-only design cannot win without effective control.

The drive motors are selected to run efficiently at **36 V**, powered by a high-discharge battery. Careful attention has been given to **traction**, ensuring that the wheels have sufficient grip to counteract weapon recoil. The chassis design distributes weight evenly over the wheels, keeping the **center of gravity low** to prevent flipping or instability during sudden turns.

A balance between **speed and torque** has been prioritized. High torque allows the robot to resist pushing matches and recover quickly after weapon impacts, while moderate speed ensures effective navigation around the arena. Simulation of traction and stability was conducted in SolidWorks Motion Analysis to validate these choices.

2.3 Pulley & Transmission

The weapon is driven via a **pulley and belt transmission system** to regulate speed and ensure smooth power transfer from the motor. The small pulley diameter is **60 mm**, with a **center-to-center pulley spacing of 0.254 m**. The system operates at a **belt speed of 6.3 m/s**, allowing efficient transmission while minimizing belt slip.

This arrangement offers flexibility in tuning weapon RPM. By adjusting pulley ratios, the team can prioritize either higher torque (for durability against impacts) or higher speed (for maximum energy delivery). The use of a belt drive also provides a natural "shock absorption" effect, protecting the motor from sudden impact loads transmitted through the weapon.

Key considerations included **belt material selection** for durability, **alignment of pulley axes** to prevent slippage, and ensuring **safety guards** around the transmission system comply with competition safety standards.

2.4 Structural Frame

The structural frame is the foundation of the Battlebot. The chosen design is an **800 mm × 800 mm truss-based chassis**, offering an excellent balance between weight and strength. A truss

framework distributes forces evenly across members, reducing stress concentrations and improving resistance against bending or twisting during combat impacts.

Material selection for the chassis prioritizes **lightweight alloys** with high yield strength, ensuring durability without exceeding the 60 kg total weight cap. Load simulations were conducted in SolidWorks to evaluate the ability of the frame to withstand both static and dynamic forces, particularly at the points of weapon mounting and wheel attachments.

A modular design approach has been applied to the chassis, allowing for **easy replacement of damaged sections**. The flat, wide base improves stability and ensures that the vertical spinner operates effectively without tipping the robot.

3. Power System

The power system is the **backbone of the Battlebot**, supplying energy to both the weapon and the drive subsystems. It must be designed for **reliability, efficiency, and safety** under high-stress competition conditions where sudden current surges and prolonged loads are common. The choice of a **36 V system** strikes a balance between compact battery size, manageable current levels, and sufficient power delivery for both offensive and defensive maneuvers.

3.1 Operating Voltage Selection (36 V)

The decision to operate at **36 V** stems from performance and safety trade-offs. Lower-voltage systems (e.g., 12 V or 24 V) would require higher currents to achieve the same power, resulting in **thicker wires, higher resistive losses, and overheating risks**. Conversely, extremely high-voltage systems (48 V or more) increase complexity and pose safety hazards.

A **36 V configuration** provides:

- **Optimal motor efficiency**, allowing the weapon and drive motors to operate in their recommended voltage ranges.
- **Reduced current draw**, minimizing I^2R losses and preventing wire overheating.
- **Compatibility** with commercially available ESCs (Electronic Speed Controllers) designed for combat robotics.

This voltage level ensures that both **burst power for weapon acceleration** and **continuous power for driving** can be delivered without system instability.

3.2 Battery Selection and Requirements

The battery is the heart of the power system. For this design, **high-discharge lithium-polymer (Li-Po) packs** are the most suitable option due to their **high energy density, low weight, and ability to deliver rapid bursts of current**.

Key requirements include:

- **Voltage:** Nominal 36 V (achieved by connecting multiple Li-Po cells in series).
- **Capacity:** Sufficient to power a full 3-minute match with reserves for weapon spin-up and drive. Typical range: **5–8 Ah** depending on current draw.
- **Discharge Rate (C-rating):** High enough to manage **instantaneous current surges** when the spinner accelerates from rest.
- **From Factor:** Compact size for integration into the chassis without affecting weight distribution.

Safety considerations include:

- **Over-current protection** via fuses or ESC current limits.
- **Thermal monitoring** to prevent overheating during repeated matches.
- **Battery quick-change capability**, allowing rapid swap-outs between rounds.

3.3 Electronic Speed Controllers (ESCs)

ESCs function as the **interface between batteries and motors**, regulating speed, torque, and direction. For the Battlebot:

- **Weapon ESC:** Must support **high current spikes** during weapon spin-up and regenerative braking when the spinner slows down. Selection was made for an ESC rated at **over 100 A continuous discharge** with active cooling.
- **Drive ESCs:** Each drive motor has an independent ESC to allow for precise steering via differential control. These ESCs are optimized for **torque stability** and must withstand continuous current during pushing matches.

Key considerations include **programmability** (tuning acceleration curves), **failsafe modes** (emergency stop compliance), and **thermal performance** (heat sinks or fans).

3.4 Power Distribution and Wiring

A well-organized power distribution system is essential to avoid bottlenecks. The layout includes:

- **Main Power Bus:** A central hub that distributes 36 V to ESCs and auxiliary electronics.
- **Kill-Switch Integration:** A mandatory safety feature that instantly cuts power to the weapon while preserving drive control if required by rules.
- **Wiring:** High-gauge silicone-coated wires are used to manage surge currents without significant voltage drops. Connectors are rated **well above peak current demand** to prevent failures mid-match.

3.5 Safety and Reliability Considerations

Given the extreme stresses of combat robotics, safety is as important as performance. The power system incorporates:

- **Hardwired kill-switch** (rule compliance).
- **Overcurrent protection** for ESCs and batteries.
- **Secure battery housing**, isolated from the weapon bay to reduce fire risk in case of puncture.
- **Shock mounting** for electronics to protect against vibrations and impacts.

Additionally, modularity was prioritized. Each subsystem (drive, weapon, power) can be independently disconnected and serviced, ensuring quick repairs between matches.

The 36 V Li-Po based power system ensures **high efficiency, stable power delivery, and compliance with competition safety rules**. Its modular, reliable, and high-discharge design provides the necessary foundation for both the vertical spinner's destructive energy and the drive system's agility.

4. Calculations & Analysis

Accurate calculations form the backbone of the design process. This section consolidates the analytical work conducted for the weapon, transmission, and power subsystems to validate feasibility and performance.

4.1 Weapon Energy Calculations

Vertical spinner energy storage

The vertical spinner is the BattleBot's primary offensive system. Its destructive ability is defined by the rotational kinetic energy stored in the weapon.

Formula:
$E = \frac{1}{2} \cdot I \cdot \omega^2$

Where:

- E = Rotational Kinetic Energy (Joules)
- I = Moment of Inertia ($kg \cdot m^2$)
- ω = Angular Velocity (rad/s)

Given:

- Moment of Inertia, $I = 0.067085\ kg \cdot m^2$
- Mass of weapon = 4.31 kg
- Target speed = 1000 RPM
- Maximum speed = 2000 RPM

Conversion (RPM to rad/s):
$\omega = (2\pi N) / 60$

For 2000 RPM:
$\omega = (2\pi \times 2000) / 60 = 209.44$ rad/s

Energy stored:
$E = \frac{1}{2} \times 0.067085 \times (209.44)^2 \approx$ **1467.85 J**

Conclusion:
The weapon stores approximately **1468 J of energy** at 2000 RPM, which is sufficient to damage or disable opponents by tearing off armor or destabilizing their drive systems.

4.2 Pulley & Belt Transmission Calculations

Pulley–belt system for weapon motor

The weapon motor drives the spinner through a pulley–belt system. Proper sizing ensures the weapon reaches its target speed while minimizing slip.

Given:

- Small sheave diameter = 60 mm (radius = 0.03 m)
- Pulley center-to-center spacing = 0.254 m
- Belt speed = 6.3 m/s

Relationship:
$V = r \cdot \omega$

Where:

- V = Belt speed (m/s)
- r = Pulley radius (m)
- ω = Angular velocity (rad/s)

Calculation of pulley angular velocity:
$\omega = V / r = 6.3 / 0.03 = 210$ rad/s ≈ 2000 RPM

Conclusion:
The pulley ratio is correctly designed to achieve the target weapon speed of ~2000 RPM, validating the transmission sizing

4.3 Power Requirements

Power relationship:
$P = \tau \cdot \omega$

Where:
P = Power (W)

τ = Torque (N·m)
ω = Angular velocity (rad/s)

Given:
Power to rotate blade = 0.22 kW = 220 W
RPM = 2000

Calculate angular velocity:
$\omega = 2\pi \cdot RPM / 60 = 2\pi \cdot 2000 / 60 = 209.44$ rad/s

Required torque:
$\tau = P / \omega = 220 / 209.44 \approx$ **1.05 N·m**

Conclusion:
The motor must consistently deliver approximately **1.05 N·m** of torque at **2000 RPM** to sustain the weapon spin.

4.4 Drive System Considerations

The motors must balance torque and speed:

- High torque ensures **traction and pushing power** against opponents.
- Speed must allow **maneuverability** without compromising stability.

Assumptions:

- Bot mass = **60 kg**
- Friction coefficient with arena floor = ~0.7
- Max tractive force:

$F=\mu \cdot m \cdot g$
$F = 0.7 \times 60 \times 9.81 \approx$ **412 N**

defines the **maximum usable drive force** before wheels slip. Drive motors are therefore sized to approach, but do not exceed this traction limit.

4.5 Power Budget & Efficiency

- Weapon motor: **220 W continuous**, higher during spin-up.
- Drive motors: Estimated **150–200 W combined**.

- Total peak system demand: **~500 W**.

The **36 V Li-Po battery system** was selected to comfortably supply this demand while leaving headroom for current surges. Losses from **belt slip, ESC inefficiency, and resistive wiring** reduce efficiency to ~85%, which has been factored into battery capacity planning.

- Weapon energy: **1468 J at 2000 RPM**
- Pulley system: Correctly sized for target speed
- Required torque: **~1.05 N·m** at full power
- Drive traction limit: **~412 N**
- Total system power demand: **~500 W**

These calculations validate that the design is feasible, efficient, and within competition constraints.

5. Troubleshooting & Future Work

Designing a combat robot involves anticipating failure modes and preparing mitigation strategies. While simulations and calculations provide confidence, real-world testing often exposes new challenges. This section outlines expected issues, troubleshooting strategies, and proposed future improvements.

5.1 Anticipated Challenges

1. **Weapon Recoil and Self-Destruction**
    - High-energy impacts from the vertical spinner may cause significant recoil, leading to loss of stability or internal damage.
    - Risk: The bot could destabilize after delivering a strong hit, making it vulnerable to counterattacks.
2. **Overheating of Motors and ESCs**
    - Continuous operation of the drive system and weapon at peak loads may cause excessive heat buildup in motors and controllers.
    - Risk: Thermal shutdown or component damage during matches.
3. **Belt Slippage in Transmission**

- At extremely high RPMs, the belt may slip or wear out quickly, reducing efficiency of power transfer.
- Risk: Reduced weapon performance or sudden loss of weapon functionality.

4. **Structural Damage to Chassis**
    - Despite the truss-based frame, repeated impacts can cause deformation or failure at joints and welds.
    - Risk: Progressive weakening of the structure across matches.
5. **Battery and Power System Stress**
    - High discharge currents may exceed safe limits during weapon spin-up, reducing battery life or causing swelling.
    - Risk: Shortened operational life or safety hazards.

5.2 Proposed Solutions

- **Weapon Recoil:** Incorporate shock-absorbing mounts between the weapon and chassis. Fine-tune the weapon RPM for optimal balance between destructive energy and recoil control.
- **Overheating:** Use forced air cooling or heatsinks on ESCs and motors. Monitor real-time temperature with sensors. Consider short spin bursts instead of continuous operation.
- **Belt Slippage:** Use high-friction timing belts or multiple belt configurations. Apply proper tensioning and guard covers to prevent derailment.
- **Chassis Reinforcement:** Reinforce critical joints with gussets and high-grade fasteners. Use replaceable armor panels for sacrificial protection.
- **Battery Safety:** Employ Li-Po safe bags and rigid enclosures. Use batteries with higher discharge ratings than calculated needs, providing headroom. Add fuses to protect against current surges.

5.3 Future Work

1. **Advanced Control Systems**
    - Integration of sensors and feedback systems for improved maneuverability. Gyroscopes and accelerometers could help stabilize the bot after heavy impacts.
2. **Weapon Optimization**

- Exploring interchangeable weapons (drum, bar, or wedge attachments) for adaptability against different opponents.

3. **Material Upgrades**
    - Testing lightweight composites such as carbon fiber or titanium to reduce chassis weight while improving strength.
4. **Energy Recovery Systems**
    - Investigating regenerative breaking in the weapon system to recharge the battery during spin-down, improving efficiency.
5. **Automation and AI Assistance**
    - In long-term development, incorporating semi-autonomous decision-making systems to assist drivers with strategy and rapid reaction during combat.

The project team has identified possible **mechanical, electrical, and thermal challenges**. Troubleshooting strategies focus on **reliability and modularity**, while future work highlights opportunities to adopt **advanced materials, adaptive weapons, and smarter control systems** for next-generation designs.