FDD

European Hyperloop Week

Tachyon Hyperloop

March 17, 2024

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Introduction

1.1 FDD.7 Applicant and List of Team Members

1.2 FDD.8 Development Environment and Research Objectives

Parts list:

Teil | Preis | Gewicht | Anzahl | selfmade/outsourced |

1.3 FDD.10 Category for This Application

Mechanical Systems

2.1 Introduction

2.2 Chassis

2.2.1 Overview

Requirements and Constraints

. Detail the main requirements and constraints driving the design.

Concept

. Explain the concept of the subsystem and reasons for its selection.

Size, Components, and Appearance

. Include a table of materials, mass, dimensions, and other relevant factors.

2.2.2 Design Process and Appearance

Requirements Met by the Design

. Outline different requirements to be met by the infrastructure.

Design Rationale

. Detail the design rationale behind the components of the infrastructure.

CAD Models and Technical Drawings

. Present CAD models and technical drawings.

FEM Results

. Present FEM results for worst-case scenarios, including images and values.

Mesh and Boundary Conditions

. Provide details on the type of mesh, boundary conditions, and Free Body Diagrams.

Infrastructure Challenges

. Address thermal expansion, weather resistance, etc.

2.2.3 Manufacturing Process

. Compile a parts list in tabular format, specifying in-house or outsourced production.

2.2.4 Transport and Assembly Process

Transport and Lift Plan

. Describe the transport and lift plan.

Assembly Process

. Describe the assembly process, including integration into subordinate systems.

Timeline and Equipment

. Include a timeline, equipment needed, and workforce details.

2.2.5 Safety Considerations

Safety Factor

. Discuss the safety factor applied.

Worst-Case Scenarios

. Discuss worst-case scenarios and containment plans.

Transport, Storage, and Lifting Requirements

. Requirements as per Section 9.3, especially TS.4. of the R&R.

Physical Stop and Roll-Over Calculations

. Describe the physical stop and roll-over calculations.

2.2.6 FMEA Results Discussion

Risk Assessment

. Preliminary risk assessment for demonstration, transport, and lifting.

FMEA and Risk Mitigation

. Detail FMEA and describe risk mitigation measures.

Simulation Evidence

. Provide evidence of simulations validating theoretical assumptions.

2.2.7 Testing

. Describe testing procedures and provide a preliminary testing plan.

2.2.8 Demonstration

. Outline how the system will be demonstrated if standalone. Rollover and springs.

2.3 Aerodynamics and Shell

2.3.1 Overview

Requirements and Constraints

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Concept

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Size, Components, and Appearance

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2.4 Suspension

2.4.1 Overview

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Concept

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Size, Components, and Appearance

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2.5 Guiding

2.5.1 Overview

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2.6 Brakes

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Traction System

3.0.1 Introduction

This section aims to provide a comprehensive overview of the traction system designed for Tachyon Hyperloop. Emphasis is placed on ensuring the safe design, engineering, and operation of the system. The EMRAX 188 electric motor, alongside its inverter boards, constitutes the core of our traction system, handling both propulsion and energy recuperation efficiently.

3.0.2 Overview

The design of our traction system is driven by several critical requirements and constraints:

- Maximum design speed exceeding demonstration capabilities.
- Targeted average acceleration to achieve optimal performance.
- Compact dimensions to fit within the pod's design constraints.
- A focus on achieving high efficiency and power density.

The choice of the EMRAX 188 motor was motivated by its exceptional power-to-weight ratio and efficiency, making it ideal for our application.

3.0.3 Subsystem Characteristics

Characteristic	Specification
Motor Type	EMRAX 188 Electric Motor
Maximum Power	60 kW
Operating Voltage	490 V DC
Maximum Speed	120 km/h
Average Acceleration	5 m/s^2
Cooling Requirement	Yes, liquid cooling system

Table 3.1: Main characteristics of the Traction subsystem

3.0.4 Theoretical Concepts

The traction system's functionality is rooted in the principles of electromechanical energy conversion. The interaction between the motor's magnetic fields and the track plays a crucial role in propulsion. Free body diagrams, further detailed in subsequent sections, illustrate the forces acting upon the pod during operation.

Moussa :explain the working principle of the PMSM. Shortly include drehstrom.

3.0.5 Design Process and Appearance

- Our CAD models and technical drawings detail the motor's integration with the pod.
- Material selection is justified with an emphasis on durability, efficiency, and thermal management.
- The specific configuration, including dimensions, windings, and air gap, was chosen to optimize performance and fit within the pod's design.
- FEM simulations, including magnetic and mechanical aspects, validate the system's design under various operational conditions.
- Thermal analysis confirms the system operates within safe temperature ranges, with additional cooling mechanisms outlined as necessary.

3.0.6 Control system overview

3.0.7 Manufacturing process

Partlist; measures to make design manufacturable.

3.0.8 Safety Considerations

Safety is paramount, with multiple fail-safes and emergency shutdown protocols in place to protect against overcurrent, overheating, and loss of communication scenarios. The system's design exceeds the required safety factors, ensuring reliability under all operational conditions.

3.0.9 Integration process

Assembling process. Interaction with Electrical, Sense and Control, Mechanical.

3.0.10 Testing

A detailed testing procedure will be documented in the Safety Procedures Documentation (SPD), encompassing both static and dynamic tests to validate the system's performance and safety features.

3.0.11 Demonstration

The traction system's demonstration will showcase its efficiency, acceleration capabilities, and safety features in a controlled environment, emphasizing its readiness for full-scale implementation.

3.0.12 Full-scale Adaptation

Discussion on adapting the current traction system for full-scale hyperloop applications focuses on scalability, efficiency improvements, and integration with larger pod designs.

3.1 Eddy Current Braking

Due to unexpected changes in the team, we decided to halt the development of an eddy current brake, which would have served as an addition to our friction brake, which will conform to the standards of the competition after the redesign that is shown in the respective section.

Electrical Systems

Take a short look at the whole text before starting to write your aprt.

4.1 Introduction

4.1.1 (a) Brief overview with the main points of the HV and LV systems.

4.1.2 (b) List of all discrete electrical subsystems.

We are implementing the following subsystems:

- LV Battery
- HV Battery
- Battery Management System
- Insulation Monitoring Device

4.1.3 (c) Wiring diagram of the HV system.

To Sourajit.

4.2 LV Battery

4.2.1 Overview

(a) Explain the main requirements and constraints that drive the design.
Strict EHW rules
reliability
reusability
lightweight
power of pump, valves etc.

Our general design of this season is inspired by conventional modes of transportation, as we have not had the capacity to start developing a levitation system by this season Thus, we focussed on an electrical system that drives our friction-based motor with excelling acceleration, which is a problem that railway systems frequently face.

In between design and production phase, we received a sponsorship of Leadrive, a local startup for research on automotive power electronics. Furthermore, the institute for electrical systems (ISEA) of our home university offered us assistance in the production of battery cells. Therefore, our workload was eased, which turned out to be favorable because of our lack of team members in the electrical field. This has been a crucial constraint in the design and planning

Column 1	Column 2
Battery Type	Lead-Acid(integrated)
Capacity[Ah]	9
Normial Voltage[V]	12
Cell configuration	2s
Maximum discharge current (lower limit) [A]	10
Weight per cell [Kg]	2,7
Dimensions per cell (L x W x H)[mm]	151 x 65 x 94

process of the electrical department since the last season. Only shortly before submitting the ITD, we were able to make an estimation of realistic goals for the new team.

4.2.2 Electrical and mechanical design process

(a) Present Schematics or logic diagrams of the boards.

(b) Present temperature simulations for vacuum conditions.

For our heat simulations, we used the software of ANSYS. By vacuum conditions, we assumed the lack of gas flow, which eliminates the cooling heat flow from winds. The simulation tool solves the heat transfer equation $\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)$ by discretizing through Finite-Element-Methods.

4.2.3 Description of subsystem control

(a) Briefly reference the control systems of the boards, which should be explained in the levitation or propulsion subsection respectively.

We configure the BMS prior to the competition.

4.2.4 Electrical system characteristics

4.2.5 Interface with other system

(a) Briefly reference the communication protocols or control mechanisms of the boards, which should be explained in the respective Sense and Control subsection.
All the electric subsystems are located within the pod.

LV battery does not communicate. Its sensor data gets picked up by thermal system.

4.2.6 Final system description

Batteries

For the Fermion, we are using two distinct power networks for the high voltage system and low voltage system. Low voltage network is at 24 Volt and high voltage network is at 444 Volt nominally.

Low Voltage Network:
Our low voltage battery network consists of 6 Lithium-Polymer batteries connected in series, thus having the voltage of the low power system set at around 24V. It powers the entire sensing, control and telemetry system.

4.2.7 Manufacturing process

Our PCB Design

PCBs

Prototyping: Prototype PCBs are fabricated in the FabLab associated with our university. The FabLab provides access to PCB manufacturing equipment and materials, enabling the rapid production of prototypes for initial testing and design validation. Once the PCBs are fabricated, they are assembled manually by our team members.

Production: We ordered our final PCBs from JLCPCB, a leading PCB manufacturing service. In addition to JLCPCB, we also collaborate with Würth Elektronik who produce PCBs in Germany, aligning with our goal of sustainability.

Batteries

We produced the battery packs in cooperation with the ISEA (Institute for Power Electronics and Electrical Drives) at RWTH, whose experience helped us to assemble more efficienciently and more safely, as we had a considerable high voltage system. The casing will consist of polycarbonate. Polycarbonate is a material that is durable , lightweight nature, and impact resistance

4.2.8 Testing

We started testing software.

4.3 High Voltage Energy Storage

4.3.1 Overview

(a) Explain the main requirements and constraints that drive the design.

Our general design of this season is inspired by conventional modes of transportation, as we have not had the capacity to start developing a levitation system by this season Thus, we focussed on an electrical system that drives our friction-based motor with excelling acceleration, which is a problem that railway systems frequently face.

In between design and production phase, we received a sponsorship of Leadrive, a local startup for research on automotive power electronics. Furthermore, the institute for electrical systems (ISEA) of our home university offered us assistance in the production of battery cells. Therefore, our workload was eased, which turned out to be favorable because of our lack of team members in the electrical field. This has been a crucial constraint in the design and planning process of the electrical department since the last season. Only shortly before submitting the ITD, we were able to make an estimation of realistic goals for the new team.

This year, we would like to set the path for magnetic levitation in the future, relying on an active system inside the vehicles. This was taken into consideration when designing the power dimensions, keeping plenty of overhead for the future, which aligns with our goal of sustainability. By having reusable modules, the design process of the upcoming years will be simplified.

Our project has been significantly bolstered by the generous support and endorsement from leading industry giants, which has considerably alleviated our financial burdens and propelled our initiative towards groundbreaking achievements.

Altium has been instrumental, providing us with cutting-edge PCB design software valued at approximately €10,000. This invaluable resource has empowered our team to design highly complex and efficient circuit boards, essential for the intricate electronics that drive our hyperloop prototype.

Festo, renowned for their pneumatic and automation solutions, contributed a suite of components and systems worth over €15,000. Their support has enhanced our prototype's propulsion and control systems, enabling precise maneuverability and stability at high velocities.

Mouser Electronics stepped in with a crucial contribution, supplying us with electronic components and parts worth about €20,000. This vast array of high-quality components has been pivotal in assembling our prototype's electrical systems, ensuring reliability and performance.

Würth Elektronik provided essential PCB materials and expertise, along with a donation of specialized components valued at €12,000. Their contributions have significantly optimized our prototype's power distribution and structural integrity.

Leadrive offered their advanced inverter technology, a contribution that not only included hardware valued at €18,000 but also critical technical support. This has dramatically improved our prototype's efficiency and power management capabilities.

Vector Informatik has generously supplied software licenses and technical support for vehicle communication systems, with a contribution valued at €8,000. This support has been crucial in implementing robust and reliable communication systems within our prototype.

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All the electric subsystems are located within the pod.

From | To	LV Battery	HV Battery	BMS	Traction Inverter	Motor	Cooling System
LV Battery	-	-	Powers	Powers control system	-	Powers pump and control system
HV Battery	-	-	Connects to	Provides power	-	-
BMS	-	-	Controls	-	-	-
Traction Inverter	-	-	-	-	Propels	X
Motor	-	-	-	-	-	-
Cooling System	-	-	-	Cooling	Cooling	Cooling (implicitly)

Table 4.1: Physical connection matrix

From \ To	LV Battery	HV Battery	BMS	Traction Inverter	Motor	Cooling System	Brakes Controller	Telemetry Unit
LV Battery	-	-	-	-	-	-	-	-
HV Battery	-	-	Discharge rate, voltage level	-	-	-	-	-
BMS	controls	controls	-	-	-	-	-	sends data
Traction Inverter	-	-	-	-	-	-	-	sends data
Motor	-	-	-	-	-	-	-	-
Cooling System	-	-	-	-	-	-	-	sends data
Brakes Controller	-	-	-	-	-	-	-	sends data
Telemetry Unit	-	-	updates limits	sends commands	-	sends target rates	sends commands	-

Table 4.2: Data connection matrix

The phsyical connection matrix is as following:

The data connection matrix is as following. All communication between boards are via CAN, if not specified otherwise:

4.3.6 Final system description

Battery Cells

High Voltage Network:

Our high voltage battery will make use of lithium-ion polymer technology. We use 120 pouch-format cells from Shenzhen GrePow Battery Co. Ltd rated at 45C maximum discharge that we plan to connect in series. The finished package (main battery pack) will be assembled by the team. We are going to connect the 120 cells connected in series and that will have 1 parallel line. This will roughly have 504 Volt at max (using $120 * 4.2V = 504V$) which provides sufficient electricity to power the motor. The battery pack will provide up to 350 Amps of DC current available to the inverter. However, neither the inverter nor the motor is not rated for such high currents nominally.

Therefore, the maximum output current of the HV Battery will be rated at 200 A maximum (peak) and 100 A continuous.

We will stack 30 cells in series per pack and then stack 4 of them to get the full battery pack. No we won't.

BMS

Our battery management system

The Orion BMS 2, connected to the HV battery, protects it and improves its life, efficiency.

Operational Mechanics

The Orion BMS 2 facilitates real-time monitoring and management of each cell within the HV battery pack, which consists of 120 lithium-ion polymer cells arranged in a series configuration to achieve a nominal voltage of 504V. This arrangement necessitates precise control and monitoring to prevent overcharging, deep discharging, and to ensure balanced cell voltages, all of which are within the Orion BMS 2's capabilities.

1. **Cell Voltage Monitoring and Balancing:** The BMS continuously monitors the voltage of each cell, ensuring that all cells operate within their safe voltage range. Cell balancing is performed to equalize the charge across all cells, thereby enhancing the battery pack's overall efficiency and lifespan.

2. **Temperature Monitoring:** Given the high energy density of the HV battery pack, thermal management is paramount. The Orion BMS 2 monitors the temperature of individual cells and the battery pack as a whole, activating cooling measures when necessary and preventing operation under extreme temperatures that could damage the battery or compromise safety. The Orion BMS 2 itself tracks the temperature of 8 individual cells. 28 other cells are measured by the Thermal Controller.

3. **State of Charge (SoC) and State of Health (SoH) Estimation:** SoC and SoH estimations are important for optimal battery utilization and health maintenance. The Orion BMS 2 employs advanced algorithms to provide these estimates, ensuring that the battery's capacity is used efficiently.

The integration of the Orion BMS 2 encompasses several safety mechanisms designed to protect the battery pack, the hyperloop pod, and its occupants:

1. **Overcurrent and Short Circuit Protection:** By monitoring the current flowing in and out of the battery pack, the Orion BMS 2 can detect overcurrent conditions and short circuits, initiating immediate shutdown procedures to prevent damage and ensure safety.

2. **High and Low Voltage Protection:** The BMS prevents the battery from exceeding its maximum voltage during charging and dropping below its minimum voltage during discharge, thereby avoiding scenarios that could lead to reduced battery life or safety hazards.

3. **Thermal Runaway Prevention:** Through its temperature monitoring capabilities, the Orion BMS 2 can detect the onset of thermal runaway—a dangerous condition where one cell's failure can lead to a cascading failure of adjacent cells—and take corrective actions to isolate the problem and mitigate potential damage.

Efficiency Enhancements

By optimizing the operational parameters of the HV battery pack, the Orion BMS 2 contributes significantly to the efficiency and performance of the hyperloop prototype:

1. **Energy Optimization:** By ensuring that all cells are balanced and operate within their optimal voltage and temperature ranges, the BMS maximizes the energy extracted from the battery pack, contributing to the hyperloop's range and speed capabilities.

2. **Lifecycle Extension:** Through diligent monitoring and management, the Orion BMS 2 extends the useful life of the HV battery pack, reducing the environmental impact and operational costs associated with battery replacement.

3. **Predictive Maintenance:** By providing detailed data on the SoC and SoH, the Orion BMS 2 enables predictive maintenance, allowing for timely interventions that prevent unscheduled downtimes and extend the battery's lifespan.

Conclusion

The integration of the Orion BMS 2 with the HV battery pack in our hyperloop prototype represents a critical step towards ensuring the system's safety, efficiency, and reliability. Through its comprehensive monitoring and management capabilities, the Orion BMS 2 ensures that the HV battery pack operates within its optimal parameters, significantly contributing to the prototype's overall performance and safety profile. As we progress towards the final stages of the FDD, the detailed exploration of the Orion BMS 2's functionalities underscores our commitment to leveraging advanced technologies for the enhancement of hyperloop transportation systems.

4.3.7 Manufacturing process

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For our heat simulations, we used the software of ANSYS. By vacuum conditions, we assumed the lack of gas flow, which eliminates the cooling heat flow from winds. The simulation tool solves the heat transfer equation $\frac{\partial T}{\partial t} = \alpha \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2} \right)$ by discretizing through Finite-Element-Methods.

4.4.3 Description of subsystem control

(a) Briefly reference the control systems of the boards, which should be explained in the levitation or propulsion subsection respectively.

We configure the BMS prior to the competition.

Column 1	Column 2
Battery Type	Lead-Acid(integrated)
Capacity[Ah]	9
Normial Voltage[V]	12
Cell configuration	2s
Maximum discharge current (lower limit) [A]	10
Weight per cell [Kg]	2,7
Dimensions per cell (L x W x H)[mm]	151 x 65 x 94

4.4.4 Electrical system characteristics

Parameter	MIN	NOM	MAX	Unit	Conditions
Ambient Temp. for Operation (T_{AMB})	-40	-	90	°C	-
Ambient Temp. for Storage (T_{STO})	-40	-	85	°C	-
Relative Humidity	0	-	95	%	-
Flow Rate of Coolant (V_{CLNT})	8	12	16	l/min	Derating @ $8 \sim 12$ l/min
Inlet Temp. of Coolant (T_{CLNT})	-40	-	85	°C	Derating @ $65 \sim 85$°C
Cooling Inlet Pressure (P_{INLET})	-	-	2.5	bar	-
Pressure Drop between Cooling Inlet and Outlet (P_{DROP})	-	0.25	-	bar	$T_{\text{CLNT}} = 65°C$, $V_{\text{CLNT}} = 12$ l/min
Input Voltage (V_{DC})	260	600	850	V	Full operation @ $450 - 800$V
Input Current (I_{DC})	-	200	-	A	Continuous
Peak Input Current (I_{DCPK})	-	300	-	A	For max t_{PK} duration
Output Voltage (V_{AC})	-	400	-	Vrms	-
Output Current (I_{AC})	-	-	200	Arms	Continuous
Peak Output Current (I_{ACPK})	-	-	300	Arms	For max t_{PK} duration
Output Power (S_{AC})	-	135	-	kVA	Continuous
Peak Output Power (S_{ACPK})	-	200	-	-	For max t_{PK} duration
Peak Duration (t_{PK})	-	-	60	s	-
Input Voltage for Control (V_{BAT})	6	-	36	V	Full functional @ $8 - 32$V (control board)
Max. Efficiency (η)	97	-	-	%	-
Torque Control Accuracy (ϵ_{TRQ})	-	-	3	%	Torque > 100Nm
	-	-	3	Nm	Torque < 100Nm
Torque Control Speed (t_{TRQ})	-	-	100	ms	-
Speed Control Accuracy (ϵ_{SPD})	-	-	30	rpm	-

Table 4.3: 800V Single Inverter Specifications

4.4.5 Interface with other system

(a) Briefly reference the communication protocols or control mechanisms of the boards, which should be explained in the respective Sense and Control subsection.
All the electric subsystems are located within the pod.

The phsyical connection matrix is as following:

The data connection matrix is as following. All communication between boards are via CAN, if not specified otherwise:

From | To	LV Battery	HV Battery	BMS	Traction Inverter	Motor	Cooling System
LV Battery	-	-	Powers	Powers control system	-	Powers pump and control system
HV Battery	-	-	Connects to	Provides power	-	-
BMS	-	-	Controls	-	-	-
Traction Inverter	-	-	-	-	Propels	X
Motor	-	-	-	-	-	-
Cooling System	-	-	-	Cooling	Cooling	Cooling (implicitly)

Table 4.4: Physical connection matrix

From \ To	LV Battery	HV Battery	BMS	Traction Inverter	Motor	Cooling System	Brakes Controller	Telemetry Unit
LV Battery	-	-	-	-	-	-	-	-
HV Battery	-	-	Discharge rate, voltage level	-	-	-	-	-
BMS	controls	controls	-	-	-	-	-	sends data
Traction Inverter	-	-	-	-	-	-	-	sends data
Motor	-	-	-	-	-	-	-	-
Cooling System	-	-	-	-	-	-	-	sends data
Brakes Controller	-	-	-	-	-	-	-	sends data
Telemetry Unit	-	-	updates limits	sends commands	-	sends target rates	sends commands	-

Table 4.5: Data connection matrix

4.4.6 Final system description

4.4.7 Manufacturing process

Our PCB Design

PCBs

Prototyping: Prototype PCBs are fabricated in the FabLab associated with our university. The FabLab provides access to PCB manufacturing equipment and materials, enabling the rapid production of prototypes for initial testing and design validation. Once the PCBs are fabricated, they are assembled manually by our team members.

Production: We ordered our final PCBs from JLCPCB, a leading PCB manufacturing service. In addition to JLCPCB, we also collaborate with Würth Elektronik who produce PCBs in Germany, aligning with our goal of sustainability.

Inverter

The inverter is a product from Leadrive used as an OEM product in automotive and mobility industry.

Support from Leadrive: The development of the inverter system is supported by Leadrive, a company specializing in advanced inverter technology. Their expertise significantly contributes to the optimization of our propulsion system. Collaboration with Formula Student Team of FH Aachen: Additionally, we collaborate with the Formula Student Team of FH Aachen, benefiting from their practical experience in electric vehicle design and inverter application. This partnership enriches our project with valuable insights into inverter integration and performance enhancement.

4.4.8 Testing

We started testing software.

4.5 Sensing and Control

4.5.1 Introduction

Our S&C part consists of a

- Braking Controller, using a TMS
- Thermal (Cooling) Controller
- Telemetry Device
- CAN Bus
- GUI/Logging system

FDD.9 Budget, Funding, and Manufacturing Methods

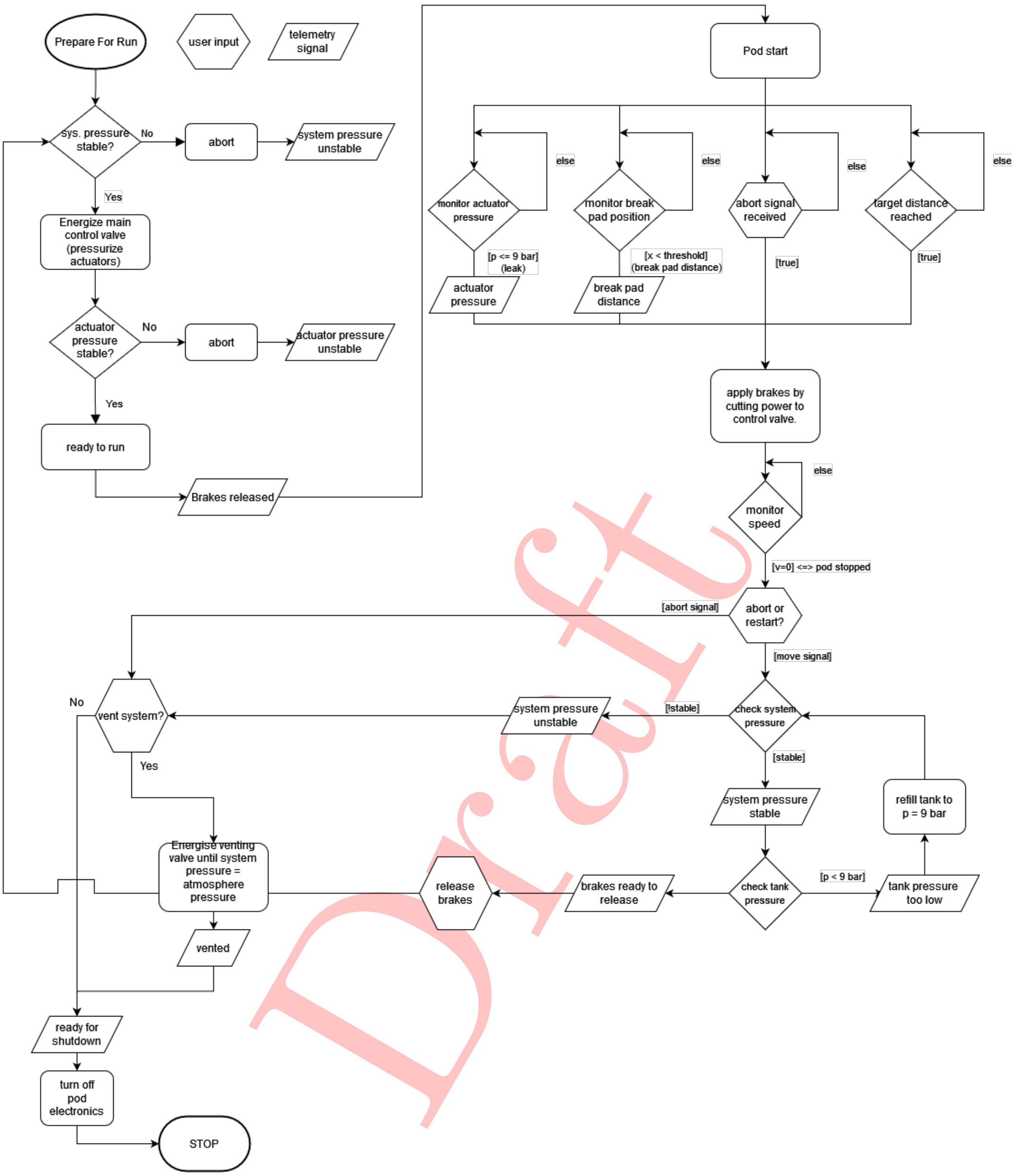
Due to our sponsoring agreements with Mouser, Wurth and . We were able to receive

4.5.2 Technical Description and Constraints

FDD.11 Technical Specifications

All sensors

The software follow a simple state:



FDD.17 Design Constraints

The

FDD.18 Performance Requirements

We designed with a failure-proof

FDD.19 Integration with Other Systems

The friction brakes, the cooling pump and the motor are controlled through our system.

4.5.3 Objectives and Design Approach

FDD.12 Design Objectives

FDD.15 Innovative Aspects

We are able to measure the vibrations of our chassis in different places, proving our mechanical simulations.

FDD.16 Design Approach

4.5.4 Safety

FDD.13 Safety Considerations

FDD.14 Safety Testing and Compliance

4.5.5 Parts List (FDD.21)

Parts list:

Table 4.6: Parts List

Amount	**Name**	**Company, (Serial Number)**	**Dime**
1	Power Inverter	Leadrive EV0019	
1	Motor	Emrax 188AC	
2	HV Battery Pack	GrePow	
2	LV Battery Packs	KingLong	
32	Additional Temperature Sensors (NTC, 10k Ohm)	Company	

4.6 Additional considerations when writing the document for specific subsystems

Sources:

- https://link.springer.com/article/10.1007/s40789-022-00494-0 BMS System Reliability
-

Safety - 30 pages max

We have the following safety hazards:

- Pneumatic Braking Systems
- Heavy systems
- Cooling and Thermal Systems
- High voltage Batteries and protections

5.1 FDD.25 Technical Description for Compliance

5.2 FDD.26 Preliminary Risk Assessment for Demonstration

5.3 FDD.27 (FMEA)

5.3.1 Mechanical Systems FMEA

5.3.2 Electrical Systems FMEA

5.3.3 Traction Systems FMEA

5.3.4 Sense and Control Systems FMEA

5.3.5 Risk Mitigation Measures

5.4 FDD.28 Energy Storage Types and Components

5.5 FDD.29 Transport, Storage, and Lifting Requirements

5.5.1 FDD.26 Preliminary Risk Assessment for Transport and Lifting

5.5.2 Transport and Storage Logistics

Testing and Demonstration

6.1 FDD.32 Manufacturing and Testing Procedure

6.1.1 Aim and Objectives

6.1.2 Test Description

6.1.3 Testing Infrastructure and Setup

6.1.4 FDD.33 Preliminary Testing Plan

6.2 FDD.20 Demonstration Plan

6.2.1 FDD.22 CAD Renders of Demonstration Setup

6.2.2 FDD.23 Equipment and Infrastructure List

6.2.3 FDD.24 Use of Own Infrastructure