FE5 Vehicle Manual

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Startup

1. Turn on LVMS (Low Voltage Machine State)
    a. Dash should turn on, the buzzer should make a noise, and have a purple light on the state LED. If dash not on, double check that the battery is charged and fuses are not blown. If light is not purple, check that the pedal node is plugged in and turned on. Also, check that HV (High Voltage) Request and Drive Request are off.
    b. PEE (Power Electronics Enclosure) should turn on (only the power light should be on)
2. Turn on TSMS (Tractive System MS)
    a. PEE board shutdown circuit indicator should turn on. If it does not, consult shutdown circuit troubleshooting.
3. Turn on HV Request.
    a. Should see dash light turn yellow, indicating that a request for pre-charge is being sent to the motor controller. Shortly after, the pre-charge solid state relay and negative AIR (Accumulator Isolation Relays) should turn on (can be checked by checking LEDs on PEE board), and after that tThe dash light should turn blue.he positive AIR should close and the pre-charge relay should turn off. This sequence is the pre-charge sequence, and is required for starting the vehicle safely.
    b. At this point, you should hear a humming noise and the TSAL should be on.
4. Hold the brake and flip the Drive Request switch
    a. The dash light should turn green and you should hear a long beep from the buzzer. If it enters a fault state, flip the switch back to neutral and try again while pressing the brakes harder.
    b. The car is now ready to drive.

Shutdown

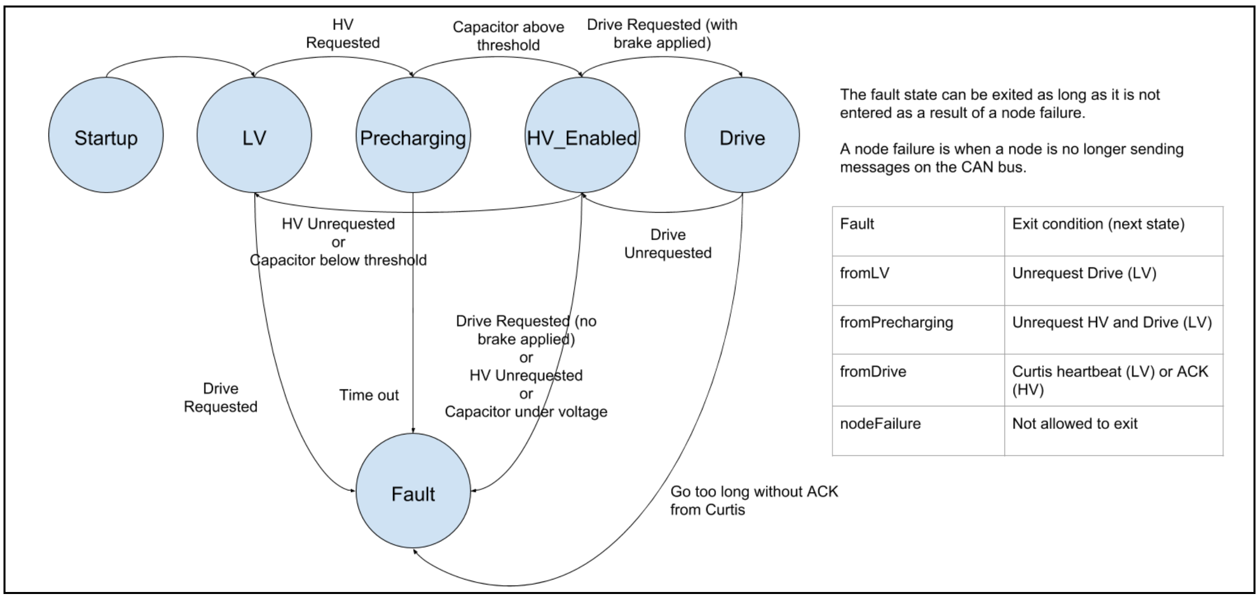
1. Put the car in neutral by flipping the Drive Request switch
    a. Dash light should go back to blue.
2. Turn off HV by flipping the HV Request switch.
    a. Dash light should turn purple. TSAL should turn off after a few seconds. Humming should stop.
3. Turn off HVMS, turn off LVMS.

In an emergency, turn off HV by using any of the e-stops or the TSMS.

Vehicle State

Each node of the vehicle runs a state machine. The vehicle's main state machine is on the dashboard and the tractive system state machine is on the motor controller.

Dashboard State Machine



Startup

The dashboard initializes variables and sounds a short sound to indicate that the LV system is online. Dash light should turn purple.

Precharging

When the HV request switch is enabled, the dashboard's state LED will turn yellow and begin sending set interlock commands to the motor controller. When the motor controller has the interlock set, throttle commands are allowed to move the motor.

Additionally, when the interlock command is received by the motor controller, a pre-charge sequence will begin.

HV Enabled

In this state, the positive and negative AIRs are closed. The dash light should turn blue.

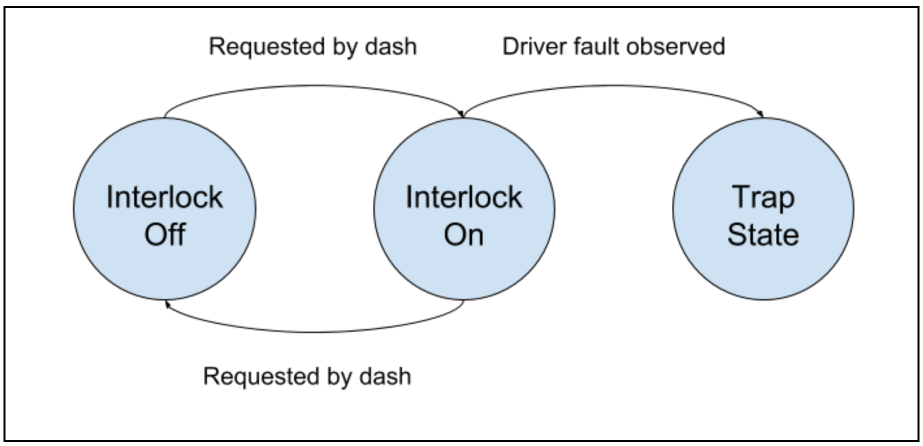
Drive

In this state, the dashboard passes along throttle positions from the pedal node to the motor controller. Only in this state can the motor be moved.

Fault

The fault state is used to indicate to the driver that something has gone wrong.

Motor Controller



Interlock Off

The negative AIR is kept open, and the interlock is cleared.

Interlock On

The negative AIR is kept closed, and the interlock is set. Bounds checking is performed on the requested throttle values in this state as well. When the dash is in the HV or Drive state, the motor controller is in the Interlock On state.

Trap State

This state keeps AIRs safe in case of faults. This will be further explained in the motor controller section.

Dashboard

The dashboard is the heart of the LV system. While running the vehicle state machine as outlined previously, the dashboard helps coordinate between the driver's requests, the pedal node, and the motor controller.

Typically, the dashboard is redesigned each year. However, the core functionality always remains the same.

Motor Controller

The motor controller we use is a Curtis 1239E. There are several oddities about this controller which I will outline in this section.

pre-charge

The battery is electrically isolated from the rest of the system by two accumulator isolation relays, or AIRs. Additionally, the motor controller has a large capacitor. An uncharged capacitor acts like an electric short. If the AIRs are both closed without first pre-charging this capacitor, a huge amount of current will flow, possibly causing arcs to form as the contactors close and welding them shut. To prevent this, a pre-charge routine is used.

First, the negative AIR and pre-charge relay are closed. Importantly, when this is done, the battery is able to charge the motor controller's capacitor through a large current limiting resistor. Once the capacitor is charged to approximately 90% of the battery's total voltage, the positive AIR is closed and the pre-charge relay is opened.

The Curtis motor controller's pre-charge routine is less than ideal. This model of the motor controller has a low voltage logic side which is completely isolated from the high voltage side. Therefore, the controller does not know the pack's current voltage while precharging. In pseudocode, the routine looks like:

```
while (capacitor_voltage < 87.5% of nominal_pack_voltage)
{
        wait
}
```

Note that nominal_pack_voltage is a user set parameter of the controller. The value 87.5% is used to ensure that the routine works when the pack is at a wide variety of voltage levels.

In 2018, FE5's development was halted by a bug in the Curtis pre-charge routine. The pre-charge was taking longer than one second, the maximum allowed by the controller, and instead of timing out, the controller was proceeding to close the main contactor (B+ AIR). This caused the positive AIR to weld shut. Not realizing what had happened, the car was quickly reset. This time, when the negative AIR was closed to begin precharging ,the positive AIR was already closed, due to the weld, effectively connecting both AIRs to a discharged capacitor. This blew the main pack fuse, and destroyed both AIRs. Our contact at Curtis helped us find a solution to lengthen the time the controller allowed for precharging, and this was an effective workaround.

Drivers

The controller's drivers are used to control the AIRs. The selection of AIRs is intentional and outlined below.

Driver2 controls the negative AIR because it can supply enough current to keep it closed.

Driver5 (PD) controls the positive AIR. Curtis has Driver1 as the main contactor by default, but we map it to Driver5 because Driver1's current limit is too low to close the positive AIR.

Driver4 controls the solid state pre-charge relay. The pre-charge relay is controlled by photomos, which is slow and could be compromised by the lower quality PWM signals of the other drivers.

Driver Fault checking

It is important to enable fault checking on the appropriate drivers. Otherwise, welded contactors may result. Consider the following scenario:

1. The vehicle pre-charges successfully.
2. An E-Stop is pressed, forcing the AIRs to open. The motor controller does not know about this because fault checking is disabled.
3. The E-Stop is released, allowing the AIRs to close again (without pre-charge protection). The AIRs weld shut.

These checks should be enabled for the main contactor (PD) and the negative AIR (Driver2). These checks will not interact well with the photomos of the pre-charge relay.

Pedal Node

The pedal node is absolutely necessary for the safe functioning of the vehicle.

APPS

The accelerator pedal position sensor uses two separate sensors. If the sensors read differently by 10% or more, the pedal node will cut power to the motor.

BSE

The brake system encoder is used to track the position of the brake.

APPS / Brake Plausibility Check

If the brakes are actuated and the APPS is signaling a throttle request greater than 25%, the pedal node cuts power to the motor until the APPS signals 5% or less pedal travel.

BSPD

The Brake System Plausibility Device is a seperate non-programmable check which is performed to ensure that the brake and throttle are not requested simultaneously. A signal is generated by the current sensor when a certain amount of current is flowing, which is combined with the BSE information to open the shutdown circuit. This can only be reset by turning the car off and on again.

Throttle Chain

The throttle chain consists of all the steps involved in transferring a throttle request from the pedal to the motor.

1. Driver
2. Pedal (two separate sensors)
3. Pedal node
    a. Reads the sensors and checks for plausibility
4. Dashboard
    a. Based on the state of the vehicle, may or may not send a request to the motor controller
5. Motor controller
    a. Based on the interlock state, may or may not send the request to the motor

A good design goal might be to shorten this chain by removing the dashboard. This might reduce latency, and will certainly reduce the load on the CAN bus.

Calibration

To calibrate the pedals push the reset button on the pedal node, in FE5 this is the button closest to the corner. This will cause the pedal node code to enter the calibration section. Once the button is pushed a timer begins and you must push both pedals through their entire range of motion to calibrate the internal potentiometers. In the span of about 5 seconds be sure to move each pedal through its entire range of motion at least 3 times. Once this process is complete cycle KSI and check the values sent from the pedal node over CAN to confirm that the sensors have been calibrated.

Battery Management System (BMS)

The BMS is responsible for ensuring the safe and healthy operation of the battery pack.

The BMS slave boards are primarily used for data collection. They do not do any “thinking”, but are instead report cell voltage and temperature readings back to the master. The master sifts through these readings and looks for cells which are out of normal operating voltage or temperature. If such problems are found, the BMS OK signal is turned off, and the shutdown circuit is opened.

Balancing

An important part of keeping a battery healthy is balancing the cells. As the cells are charged and discharged, they may come to have slightly different voltages. When balancing, the master looks for cells which are more than 15mV away from the lowest operating cell, and discharges the high cells through the LTC6811-2 ICs. During this process, the slave boards will become quite warm (because of the discharging), and thermistors on the boards are used to keep temperatures within safe operating ranges.

Broken Thermistors

Unfortunately, not every thermistor used in the BMS is fully functioning. Because of this, the BMS master ignores some thermistor readings. Enough readings are still used to meet the requirements of the rules.

Tools

PSOC

- PSOC Creator
    - Make sure that all teammates are using the same version of PSOC Creator. Compatibility issues can arise.
- Debugger
    - The debugger should be plugged into your computer first. Then, use Debug -> Select Debug Target to ensure that you have the right power settings applied.
    - Make sure to check that “External” power is selected if you will be using an external power supply. Otherwise, you could damage the debugger or PSOC.
    - Be careful when plugging in the debugger, several debuggers have been ruined by plugging them in a pin over.
- Dev kits

    - Use the dev kits to develop your understanding of embedded system design and PSOC. Practice before you implement things for real.

Motor Controller

Use a Curtis 1309 to connect to the motor controller for all of the functions listed below.

- 1314
    - This is the program you will use for changing motor parameters and checking for faults. This software is essential to working with the motor controller.
- WinVCL
    - This program allows you to build and flash new firmware for the motor controller. This is also essential.
- TACT
    - This is a logging software used at Curtis. If you are having problems getting your VCL running, use TACT to debug.
    - Can also be used to log data if you have a laptop you are willing to put in the car.

CAN Analyser

- The CAN Analyser Mini can be used to read data off the CAN bus and send messages.
- Make sure you design the wire harness with a way to plug this device in.

Resources

- Read the rules
- Read the ESF