February 07, 2019

Dr. Craig Scratchley
School of Engineering Science
Simon Fraser University
Burnaby, BC
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Re: Capstone Project: Functional Specification for Anthem Brakes

Dear Dr. Scratchley,

Please find the functional specification for the Anthem Brakes system below. This document enumerates the functional requirements of the system through three development stages: proof of concept, alpha-prototype, and beta release. The new system comprises an electrically actuated disc brake and an electromagnetic regenerative brake in one integrated package.

The purpose of this document is to showcase the requirements needed for the product from its prototype phase through its pre-production or beta phase. The document will review our high-level requirements before delving into the specific requirements needed for our software and hardware components. Finally, the document will also outline different standards and regulations fitting our project.

Anthem Brakes consists of a team with diverse backgrounds, studying electronics, systems, and computer engineering. If you have any questions or concerns, please contact our chief communication officer, Jason, at jason_wang_10@sfu.ca.

Sincerely,

Jason Wang

Anthem Brakes

Functional Specification

ENSC 405

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Abstract

Our team, *Anthem Brakes,* proposes an alternative solution to the widespread use of hydraulic braking systems. The system is composed of two distinct devices that can work together to offer a fully electronic and regenerative system. This proposal defines the functional specifications of the electronically actuated disk brake and regenerative apparatus. We also will detail the Engineering Safety standards and sustainability advantages.

This information should aid the reader in fully comprehending the purpose, advantage, and challenge in the development of our braking system. The user control will be incorporated into existing braking controls, the actual stopping instrumentation will replace hydraulic lines and pumps, and be integrated into the vehicles' powertrain. The *Anthem Brakes* requirement specifications will be composed of the following:

- Electronic Disk Brake Requirements: material, drag generation, power consumption
- Regenerative Brake Requirements: material, power output and storage
- Software Requirements: feedback and control

Cumulatively, we will outline plans to produce a prototype by April 2019.

Table of Contents

List of Figures and Tables

1. Introduction

1.1 Background

Automotive industries are constantly required to adapt to new technologies across different engineering disciplines. One area where improvements in safety and performance are continuously being achieved is braking. The current trend in braking (making its way from racing, to luxury cars, then finally into the mass market) is a technology called brake-by-wire, where hydraulic pressure at the brake pedal is decoupled from hydraulic pressure at the calipers via electrical signals and separate hydraulic pumps [1].

With constant innovation in electric and hybrid cars, electrical power and control systems are becoming more and more sophisticated. Automotive brakes are progressing toward fully electrical systems, where instead of hydraulic actuation, a “hydraulic-less” electro-mechanical brake (EMB) [2] is in place. The illustration in ***Figure 1*** shows the difference between an electro-mechanical brake (EMB) and a traditional hydraulic brake (EHB). In the latter, braking power comes from a vacuum actuated brake booster and control comes from a hydraulic control unit (HCU) via signals from the vehicle’s electrical control unit (ECU).

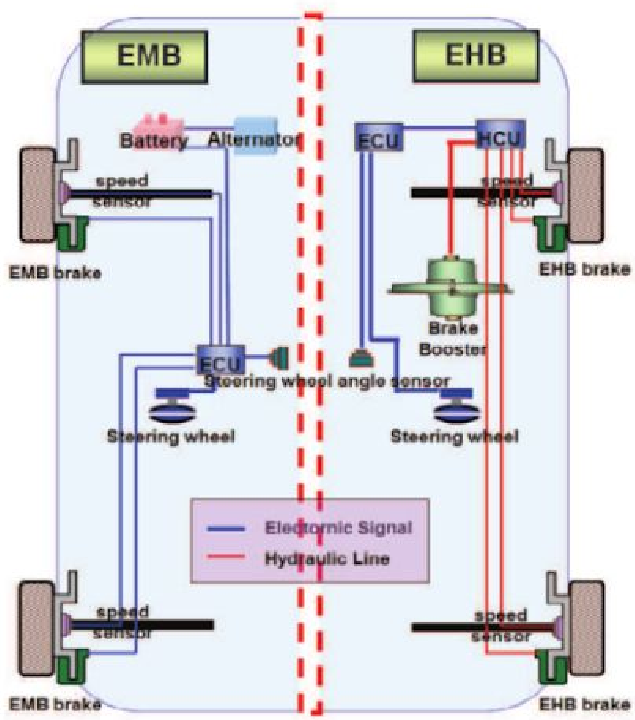

Figure 1: Comparison of Electro-Mechanical Brake (EMB) and Electro-Hydraulic Brake (EHB) [2].

By replacing hydraulic brakes with electrical components, production is simplified and there is an increase in flexibility for component placement. Furthermore, the fast development of battery-powered electric vehicles allows for bidirectional energy flow, which implies that when a vehicle's brake is applied, some kinetic energy can be recaptured [3] (i.e. using a generator). The buzzword typically applied to this mechanism is "regenerative braking."

1.2 Conventions

In this report, functional requirements will be classified according to the production phase in which they should be implemented as shown in **Table 1.1** below.

Symbol	Production Phase
P	Proof of Concept (PoC)
A	Alpha Prototype (engineering)
B	Beta Release (pre-production)

Table 1.1: Requirement classification by production phase

Further, functional requirements will be classified by type according to the document flow. For example, a mechanical, disc brake requirement would be numbered according to the **Mechanical** heading and the **Disc Brake** subheading, so that the numbering system looks like this:

[Type Heading].[Type Subheading].[Requirement Number] - [Production Phase]

That is, if the first requirement under the **Mechanical** heading the **Disc Brake Requirements** subheading (see **Section 3**) were expected to be implemented in the *alpha* stage, it would look like this:

2.2.1-A

2. System Overview

The *Anthem Brakes* system comprises an electrically actuated disc brake for primary stopping power and a secondary regenerative brake that returns power to the vehicle's battery while applying some stopping torque when engaged. The proposed design also features a feedback control system that can interface with a vehicle's main computer (ECU) so that braking can be modulated at each wheel when anti-lock braking (ABS), automatic emergency braking (AEB), or traction control systems come into play.

The brake system will run entirely on a vehicle's native 12VDC power system, and will also include a pedal that replicates the "feel" of a traditional hydraulic braking system. A high-level schematic of the proposed design can be seen in ***Figure 2*** below.

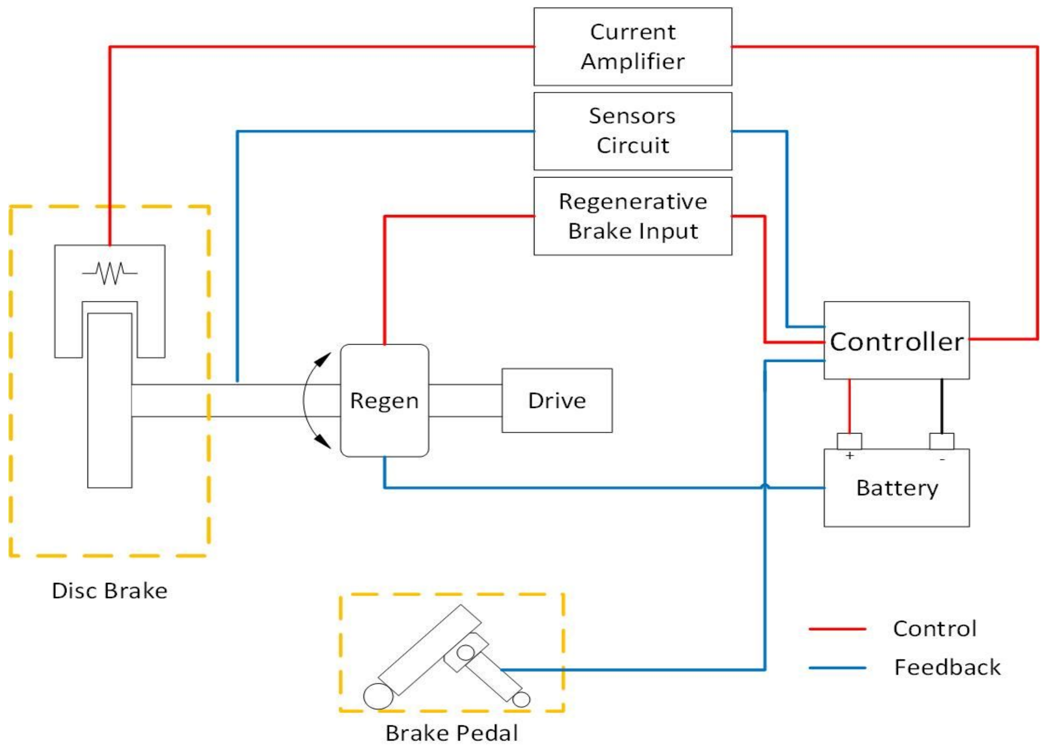

Figure 2: Electric Brake System Schematic

In the schematic, the controller takes driver input (via the brake pedal) and feedback input from the braking system. 12V battery power is channeled to both the disc brake and the regenerative brake via the controller for modulated control.

3. Requirements

This section lays out the proposed requirements for the *Anthem Brakes* system in the three phases of its design development outlined in **Section 1.2** above. The functional requirements are organized by both component (i.e. controller, disc brake, regenerative brake, pedal, power supply, and sensors) and type (i.e. general, mechanical, electrical/hardware, software, and environmental/safety).

3.1 General

3.1.1-P: The system shall consist of an electrically actuated disc brake, a regenerative brake, and a controller.

3.1.2-A: The system shall consist of an electrically actuated disc brake and a regenerative brake, and will have integrated feedback control.

3.1.3-A: The overall weight of the braking system shall not exceed the weight of a fully hydraulic system capable of the same stopping torque.

3.1.4-B: Automated system response time should exceed current industry standards. In an anti-lock braking system (ABS) or automatic emergency braking (AEB) scenario, response time should match or exceed current industry standards.

3.1.5-B: All exterior electrical components and other sensitive areas shall be sealed to IP67 standards or other IP ratings where warranted.

3.1.6-B: The complete system shall have a secondary parking brake that satisfies Transport Canada requirements.

Table 3.1: General functional requirements

3.2 Mechanical

3.2.1 Pedal Requirements

3.2.1-A: The pedal shall have an appropriate "feel" underfoot (i.e. it should feel similar to current hydraulic brake pedals).

3.2.2-A: Braking response should be repeatable and correspond appropriately to pedal movement.

Table 3.2.1: Mechanical requirements - brake pedal

3.2.2 Disc Brake Requirements

3.2.3-P: The clamping force of the proposed system shall meet engineering expectations based on the application of chosen individual components, scalable as production stages progress.

3.2.4-A: The disc brake should be able to consistently meet the initial clamping force target of 4500N.

3.2.5-A: The heat created by the system under normal to extreme driving conditions shall not exceed the tolerances of the individual components.

3.2.6-B: The disc brake should be able to consistently meet the braking torque requirements of the target vehicle.

3.2.7-B: The heat created by the system under extreme driving conditions shall not exceed the tolerances of the individual components, or of surrounding components.

3.2.8-B: The proposed disc brake shall not make an undue amount of noise.

3.2.9-B: Friction wear items shall have a lifespan comparable to existing technology.

Table 3.2.2: Mechanical requirements - disc brake

3.2.3 Regenerative Brake Requirements

3.2.10-P: The proposed component shall provide some measurable braking force on a spinning shaft.

3.2.11-A: The regenerative brake should not create excessive drag when disengaged.

3.2.12-B: The brake shall have a sealed housing to prevent ingress of water and debris.

Table 3.2.3: Mechanical requirements - regenerative brake

3.3 Electrical and Hardware

3.3.1 Controller Requirements

3.3.1-P: The controller shall provide a pulse width modulated (PWM) signal for braking control.

3.3.2-P: The controller must be able to gather data from the system's sensors with adequate resolution.

3.3.3-A: Braking input signals should be calculated based on speed and torque sensor values when needed.

3.3.4-A: The controller will stop current flow from the regenerative brake to prevent a battery from overcharging when above some voltage threshold.

3.3.5-A: The controller will provide integrated control of both the disc brake and the regenerative brake such that they work in tandem using feedback signals from sensors.

3.3.6-B: When a collision with an obstacle is imminent, the Automatic Emergency Braking (ABE) will be applied and bring the vehicle to a safe halt.

3.3.7-B: The controller manages engagement/disengagement of the regenerative braking system in case of regular/emergency braking, and in the case of abnormal conditions such as overheating, will completely disengage the system.

3.3.8-B: The controller should notify the driver of degraded brake performance or other system faults.

Table 3.3.1: Electrical requirements - controller

3.3.2 Power Supply Requirements

3.3.9-P: The battery capacity should supply enough power for sensors, controller, and brake system for several hours without charging.

3.3.10-A: Power consumption by the proposed braking system shall not exceed 0.1 kWh per mile of driving in city conditions.

Table 3.3.2: Electrical requirements - power supply

3.3.3 Sensor Requirements

3.3.11-P: Feedback sensors shall be provided to measure the speed of the shaft and the braking torque.

3.3.12-A: The strain gauge used to measure torque should be able to withstand the braking torque applied to the system.

3.3.13-A: Sensor signals shall be conditioned with appropriate circuitry for use by the controller.

3.3.14-A: The pedal shall have a position sensor for driver input to the control system.

3.3.15-B: The sensors used should withstand the high temperatures inherent in a braking system.

3.3.16-B: Sensors shall not suffer from interference from nearby components or vehicle vibration.

3.3.17-B: The system should be able to activate backup braking (parking brake) if the primary system fails to supply sufficient braking torque.

3.3.18-B: Thermocouples should be provided to monitor heat.

Table 3.3.3: Electrical requirements - sensors

3.3.4 Disc Brake Requirements

3.3.19-P: The disc brake shall be electrically actuated - i.e., actuation shall occur locally, incorporating minimal moving parts and no hydraulics.

3.3.20-A: The disc brake shall be designed in such a way that it can be modulated via an electrical control signal, mimicking current hydraulic technology.

Table 3.3.4: Electrical requirements - disc brake

3.3.5 Regenerative Brake Requirements

3.3.21-P: The proposed brake shall generate some current to be returned to the vehicle's battery when engaged.

3.3.22-A: The rotating magnetic field (RMF) will be regulated by varying frequency in order to generate predictable and calculated amounts of current for modulated control.

3.3.23-B: The regenerative brake shall be able to induce reverse RMF to slow down the vehicle in emergency situations requiring maximum braking torque.

Table 3.3.5: Electrical requirements - regenerative brake

3.4 Software

3.4.1-P: The control software shall activate regenerative braking and electro-mechanical brakes independently.

3.4.2-P: The software shall provide live readings from the system's sensors for use in development.

3.4.3-A: The software shall determine the appropriate time to use regenerative and electromechanical brakes based on system feedback.

3.4.4-A: The software shall control the flow of power generated by the regenerative brake back into the power system.

3.4.5-A: Fault handling and other safety considerations shall be maintained in the software.

3.4.6-B: The control software shall be able to modulate both the electro-mechanical brake and the regenerative brake independently or in tandem.

3.4.7-B: The system's software shall be designed for integration into a vehicle's main computer, such that the braking system can integrate with ABS, AEB, traction control, and steering systems.

Table 3.4: Software requirements

3.5 Environmental/Safety

The Environmental/Safety section addresses requirements for environmental considerations and user safety, both for the system-under-test and for the final product. *Anthem Brakes* will employ cradle to cradle design when designing the product. *Anthem Brakes* will strive to recycle and reuse all the items by the end of the product lifetime. All the products that can be recycled like the metal used to construct the test bench and axle will be recycled at a metal collector. Things like the PCBs will be taken to specific PCB recyclers because of their environmental impact if disposed of inappropriately. The motors and batteries used within the system can be repurposed and reused for any project that needs a motor and battery.

3.5.1-P, A, B: All components shall be presented without loose wires or exposed contacts.

3.5.2-P, A, B: When the system is under test, it shall have an appropriate emergency stop mechanism that stops motion and shuts off all power to the system.

3.5.3-P, A, B: All moving parts (including test apparatus) must be designed appropriately to avoid causing harm or injury.

3.5.4-P, A, B: During development, appropriate signs and lockouts must be used to avoid harm or personal injury.

3.5.5-P, A, B: During development, all hazardous waste is to be disposed of appropriately, and any items that can be recycled shall be dealt with accordingly.

3.5.6-B: There shall be a system in place to make sure enough voltage is present to stop the vehicle, and faults shall occur should the battery drain below a certain voltage threshold.

3.5.7-B: The system will have a visual notification that the parking brake is engaged.

3.5.8-B: The system shall disengage the parking brake automatically in the event that the user is intentionally accelerating or attempting to move the vehicle.

3.5.9-B: The system should prevent the user from driving if one or more safety conditions are not met. These include, but are not limited to electronic failures in any critical systems, insufficient battery power for stopping, and detection of obstacles by the vehicle's sensors.

Table 3.5: Environmental and safety requirements

4. Standards and Regulations

4.1 General

Transport Canada TSD 105: Section on hydraulic and electric brake systems from Transport Canada's *Motor Vehicle Safety Regulations* [5]

B.C. Reg. 26/58: Motor Vehicle Act Regulations provide some characteristics of the brake system for on-road vehicle [6]

Table 4.1: General Standards and Regulations

4.2 Mechanical

IEC TS 61851-3-1 ED1/IEC TS 61851-3-2 ED1: Adheres to reinforced protection for the power supply and components directly connected to it [7]

IEC 60034-30-1, 2014: The motors used shall adhere to the IEC2 efficiency standards [8]

Table 4.2: Mechanical Standards and Regulations

4.3 Electrical

ISO 8820-1:2014: Fuse links used in road vehicle to protect the circuitry used in the brake System [9]

ISO 15118-3:2015: The requirements for controller and sensors to have physical data link that exchange the information with higher level communication [10]

IEC 63110-1 ED1/IEC 63110-2 ED1/IEC 63110-3 ED1: Adheres to charging/discharging protocols [11]

IEC 61643-12 ED3: Surge protection device in place to prevent electrical components [12]

Table 4.3: Electrical Standards and Regulations

4.4 Environmental

ISO 27667:2011: Brake is considered as non-exhaust emission and has an impact on air quality, the composition of the brake pad material must be considered [13]

IEC 62125 ED1: Conforms to environmental standard for insulating control wires and power supply [14]

SOR/2018-196: Prohibition of asbestos in automotive brake pads [15]

Table 4.4: Environmental Standards and Regulations

5. Acceptance Test Plan (Proof of Concept)

This section outlines a test plan for the proof of concept prototype of the *Anthem Brakes* system. The tests enumerated here reflect the PoC requirements from **Section 3**. They have been split up into tests for the disc brake, the regenerative brake, and the controller. These tests have been designed to be pass/fail and to not put undue constraints on the PoC.

5.1 Disc Brake

Following the above requirements, the disc brake should provide braking torque to a spinning disc that is scalable to the torque requirements at later development stages (A, B). The following tests provide a benchmark for the PoC design.

Test	Acceptance Condition	Result
Power Consumption	Power consumption under 0.1kWh at continuous load	☐ Pass ☐ Fail
Performance Test	4 stops within 3 minutes without any braking issues	☐ Pass ☐ Fail
Stopping Power	Provides expected stopping torque when engaged, scalable to later development stages	☐ Pass ☐ Fail
Heat Dissipation	Heat generated under load does not surpass the threshold of components	☐ Pass ☐ Fail
Test Bench Robustness	Test bench is rigidly constructed and does not impede component testing	☐ Pass ☐ Fail
Axle Speed	Test bench axle capable of adequate speed to display braking torque (to be determined)	☐ Pass ☐ Fail

Table 5.1: Acceptance test plan - PoC disc brake

5.2 Regenerative Brake

The PoC regenerative brake should be shown to provide some stopping power when engaged as well as providing some amount of current to the battery, these being scalable to the final (A,B) requirements.

Test	Acceptance Condition	Result
Regeneration	Able to generate a measured output current that exceeds input current	☐ Pass ☐ Fail
Stopping Power	Generates measurable torque in the opposite direction of rotation	☐ Pass ☐ Fail
Storing Charge	Regenerated current provides a measurable increase in battery voltage	☐ Pass ☐ Fail

Table 5.2 Acceptance test plan - PoC regenerative brake

5.3 Control System

The PoC control system should be developed as far as possible to provide a template for the final, integrated system. Integration software should be debugged as far as possible without physical actuation. The PoC control system should at least provide a safe and reliable means of actuating the disc brake and the regenerative brake independently, without modulation or feedback.

Test	Acceptance Condition	Result
Disc Brake Actuation	Able to safely engage and disengage the electro-mechanical braking system at a given voltage	☐ Pass ☐ Fail
Regenerative Brake Actuation	Able to safely engage and disengage the electro-mechanical braking system	☐ Pass ☐ Fail
Pulse Frequency	Able to produce a PWM signal with enough resolution (to be determined) for control of brakes in later design stages	☐ Pass ☐ Fail
Sampling	Able to sample input from the proposed sensors at speeds adequate for feedback in later design stages (to be determined)	☐ Pass ☐ Fail
Calculation/Running Speed	Able to take inputs at the desired frequency, process them, and produce outputs in an appropriate amount of time (to be determined)	☐ Pass ☐ Fail

Table 5.3: Acceptance test plan - PoC control system

6. Conclusion

The requirements and specifications outlined in this document specify what *Anthem Brakes* aims to accomplish in the proof of concept, alpha prototype, and beta pre-release development phases. While designing and creating our product we will maintain the cradle to cradle methodology, getting maximum use out of each part and disposing of things appropriately and the end of life cycle.

This braking technology can be employed in any situation requiring high braking torque on a rotating shaft, which allows this product to have a massive target market. We are targeting the automotive industry because of the sheer size of the market and the opportunity to replace the commonly used hydraulic systems that are currently in place. Removing hydraulic fluid from vehicles will remove a short service interval item, and will also get rid of a messy, corrosive fluid that mechanics are constantly disposing of in shops.

Our system will simplify brake maintenance, and it will provide a lighter solution than the current technology. Furthermore, with high speed electric actuation, the *Anthem Brakes* system will be ready for integration with powerful new ECUs and on-board computers, giving vehicle manufacturers full, modulated control over each wheel in emergency and low-traction situations. The new system will also include regenerative braking technology to recharge your battery while on the move, making up for the losses incurred by electrically actuated brakes.

This solution will follow the braking standards of Canada to be viable to deploy into all automotive vehicles. Combining the different skill sets and ideas from our team of engineers to create this product, we believe it has the ability to change the market if given the chance to be deployed.

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