March 7, 2016

Dr. Andrew Rawicz
School of Engineering Science
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Burnaby, BC V5A 1S6

Re: ENSC 440W Design Specification for J2VK's Valvetronic Exhaust Control System

Dear Dr. Rawicz,

The enclosed document is the design specification for J2VK's Valvetronic Exhaust Control System. The goal of the exhaust system is to enhance exhaust volume during enthusiastic driving and decrease exhaust volume whenever appropriate. By designing a control system and integrating it with an exhaust system, J2VK can provide an exhaust system that satisfies a user's driving habits and environments.

The following design specification document will outline the mechanical, hardware and software designs that will be used to implement the initial requirements for J2VK's Valvetronic Exhaust Control System. The document will also explain the design process, system specifications and procedures necessary to bring the exhaust system into fruition. Lastly, the document will highlight a test plan that will ensure the functionality of the exhaust system.

J2VK was founded by four senior engineering students at Simon Fraser University. The team consists of Cheng Ou, Justin Deng, Kenny Sun and Vincent Huang. If you have any questions or comments related to the following design specification please feel free to contact me at jou@sfu.ca.

Best Always,

Cheng Ou
Chief Executive Officer
J2VK

Enclosure: Design Specification for J2VK Valvetronic Exhaust Control System

Design Specification for

J2VK Valvetronic Exhaust Control System

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Date Issued:

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Abstract

This document will discuss the design specification for J2VK's Valvetronic Exhaust Control System. The objective of this document is to explain in detail the mechanical and control systems used to implement the exhaust system, as well as describe in detail J2VK's current and future implementation of the product.

J2VK's Valvetronic Control System consists mainly of two systems:

- Exhaust System - aluminum components, metal control valve, mounting and wiring
- Control System - Arduino Uno programming, tracking throttle input (Throttle-Position-Sensor sensor), and DC motor control

The above main systems of the exhaust will each individually be described in detail on their design logic, function and implementation. To show that the previous functional specification of the product is met, each system will be explored in detail.

To conclude, the following document will also end with a test plan highlighting the necessary test cases to be passed in order for the exhaust system to be functionally sound. The test plan will be consist of individual component testing as well as final integrated system testing.

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Glossary

V	Voltage
A	Ampere
DC	Direct Current
TPS	Throttle Position Sensor
VCC	12V+
GND	Ground
mm	Millimetre
cm	Centimetre
N/m	Newtons per metre
kg	Kilograms
psi	Pascal
rpm	Rotations per minute

1 Introduction

J2VK's Valvetronic Exhaust Control System is an exhaust system that allows for both manual and automatic control of noise levels coming out from the car. The exhaust system has the capability to monitor throttle input from the driver and then adjust a metal flap in the exhaust system to allow for more or less noise to escape from the car. The exhaust system will address the issue where after-market exhaust systems are permanently loud and obnoxious to everyone but the driver. The exhaust system takes into perspective both the driver and pedestrian views; drivers may turn the exhaust valves open during energetic driving in open roads and close the valves in urban areas. If opening or closing the valves seems cumbersome or the driver is easily forgetful, an automatic mode will also be offered that will automate closing and opening the valves depending on throttle input. J2VK's exhaust consists mainly of two systems. The first is the mechanical system which includes the exhaust pipe and metal control valve. The second system is the control system which consists of an Arduino Uno, Throttle-Position-Sensor and a DC motor drive. The following design specification document will thoroughly explore each component used in the systems.

1.1 Scope

This document outlines the design of J2VK's Valvetronic Exhaust Control System. This includes the design approach, logic and potential modifications for future development. This document will also discuss functional requirements from the functional specification that was previously submitted. Finally, test plans with individual test cases for the components used in the system, as well as for the entire completed system, will be discussed to ensure the proper functionality of the exhaust system.

1.2 Intended Audience

The following design specification is intended for all members of J2VK's team. All through the development of the exhaust system, the team can consult this document as a guideline to ensure that all functions of the product are integrated and tested. Test engineers can also refer to this document to ensure that specified functions and design requirements are met.

2 System Overview

J2VK's Valvetronic Exhaust Control System has three operating modes. "Manually Opened", "Manually Closed" and "Automatic" modes. The first two modes are self-explanatory; the exhaust can be manually controlled by buttons that fully opens or closes the metal valve that is in the exhaust pipes. This will be achieved by having an Arduino microcontroller monitor button presses and then send out appropriate signals to a relay. The relay will then allow specific voltage flow to pass through it from the 12V car outlet to the DC motor. To open the control valve the DC motor requires positive voltage flow, and thus the relay will be signaled to allow positive voltage flow. In order to close the control valve, voltage needs to be reversed through the DC motor and so the Arduino board will signal the relay to output the reversed voltage. For the automatic mode, once it is turned on, the Arduino microcontroller board will begin to monitor the voltage signal coming out from the Throttle-Position-Sensor. Depending on the voltage signal that is received from the Throttle-Position-Sensor, as well as the consistency of the signal to reach a specific value in a specific time interval, the valve will open in varying degrees to exhale different decibels of exhaust volume. This will be performed by having the Arduino control the length of time the relay supplies voltage to the DC motor. In order to do this, the Arduino will output a pulse of signal with an extremely small time interval so that the relay will also only operate for that small time interval, resulting in the DC motor being powered just enough to slightly open/close the valve but not enough to do so completely.

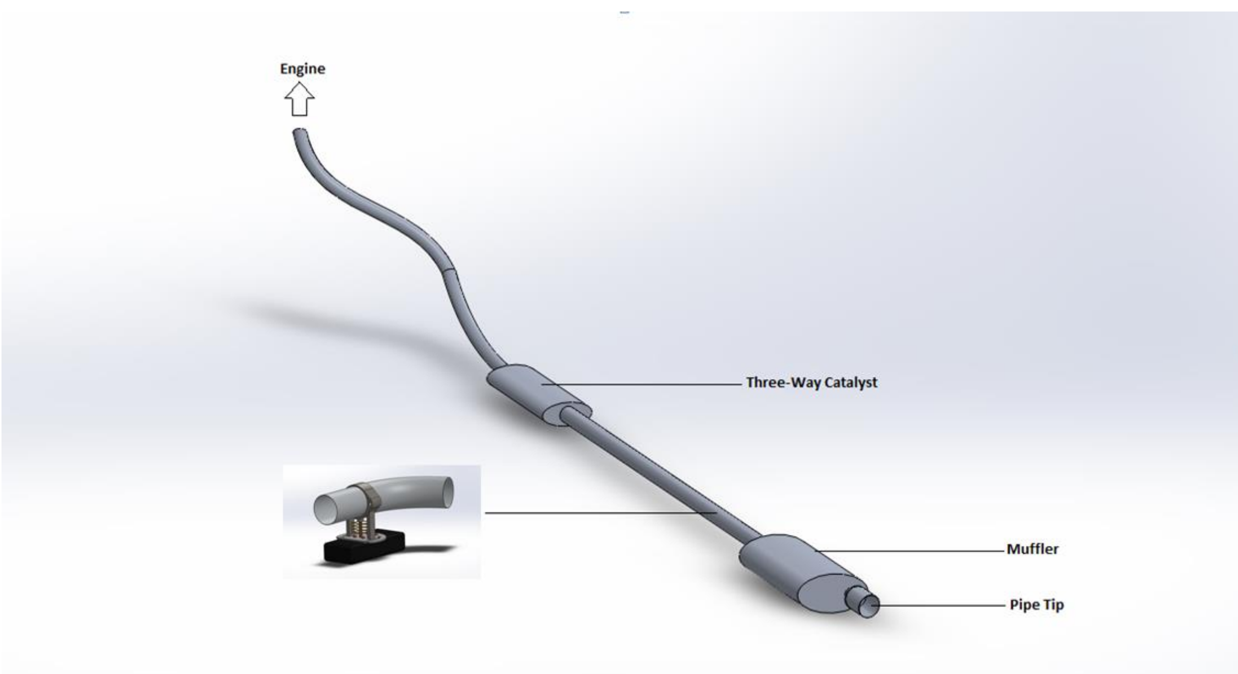

Figure 1: High-Level System Overview

3 Control System

To achieve our goal of intelligently controlling the exhaust valve to open or close, the control system for J2VK's Valvetronic Exhaust Control System prototype consists of the following parts:

1. Arduino Uno microcontroller board
2. Throttle-Position-Sensor (TPS)
3. Buttons
4. Relay
5. Exhaust Control Valve
6. Diode

The Throttle-Position-Sensor is responsible for measuring how far the throttle is being pressed. The Arduino Uno microcontroller board will receive input from the TPS and the buttons and then send output signals to the relay. The relay will control how the battery will provide power to the DC motor in order to open or close the exhaust valve. The following is a block diagram of the overall control system.

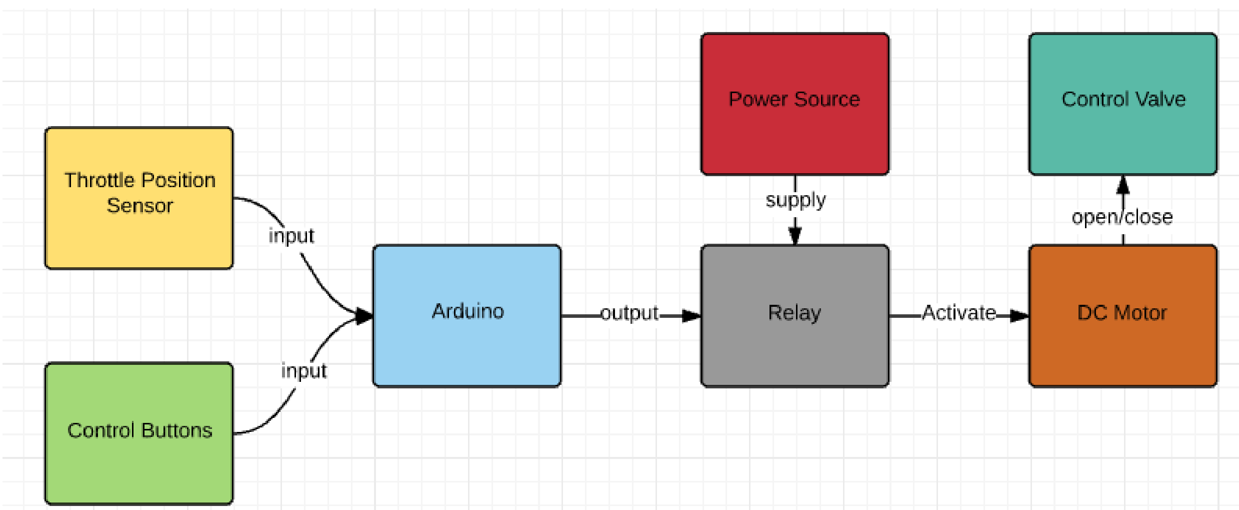

Figure 2: Control System Block Diagram

3.1 Component Specifications

3.1.1 Arduino Uno Microcontroller Board

In order to implement the functions of J2VK's Valvetronic Exhaust Control System, J2VK has decided to use an Arduino Uno R3 Microcontroller board for its easy integration of electronic signals and strong computing capabilities. The Uno is very cheap for its functionality, and the open-source Arduino Software allows for convenient access to many different lessons and tutorials on programming on the Uno. The following figure shows the pin mappings for the Arduino Uno board. The VCC, GND, digital, and analog pins are used as input and outputs for the different connections to other components.

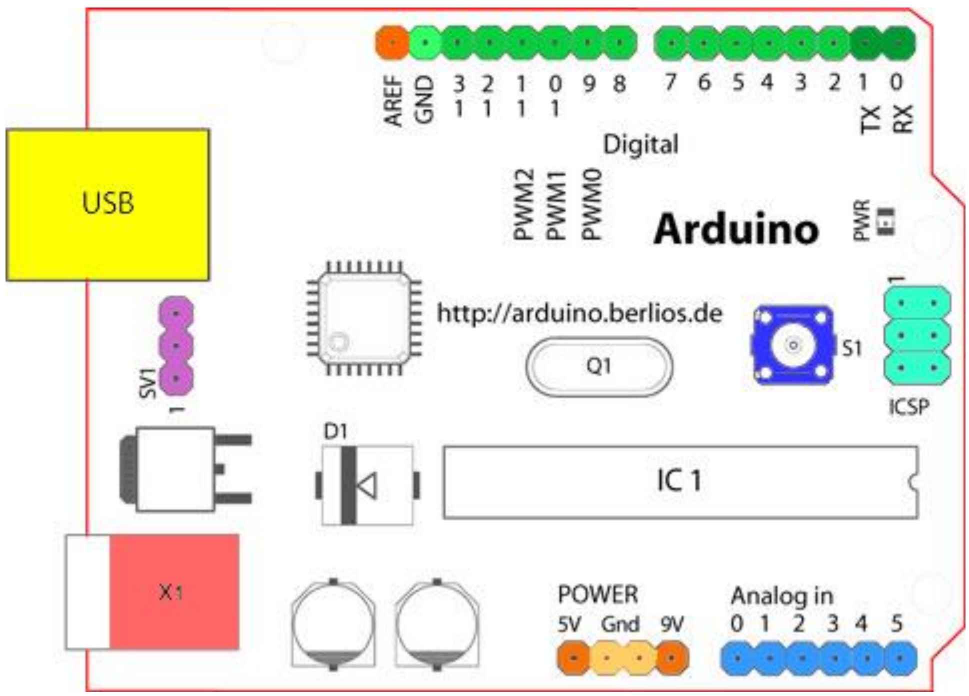

Figure 3: Arduino Uno Microcontroller Mapping [1]

3.1.2 Throttle-Position-Sensor

To meet requirements for detecting the position of the gas pedal, J2VK has decided to use the Throttle-Position-Sensor, because this sensor can accurately measure how far the throttle is being pushed by drivers. The sensor will output a voltage signal, corresponding to throttle input, to the Arduino Uno, which allows the Uno to decide when to open/close the exhaust valve and by how much. Another reason to use the Throttle-Position-Sensor is that this sensor exists in most vehicles already and so the cost of the valvetronic exhaust system will be lower. The following figure shows the Throttle-Position-Sensor and its position in the vehicle.

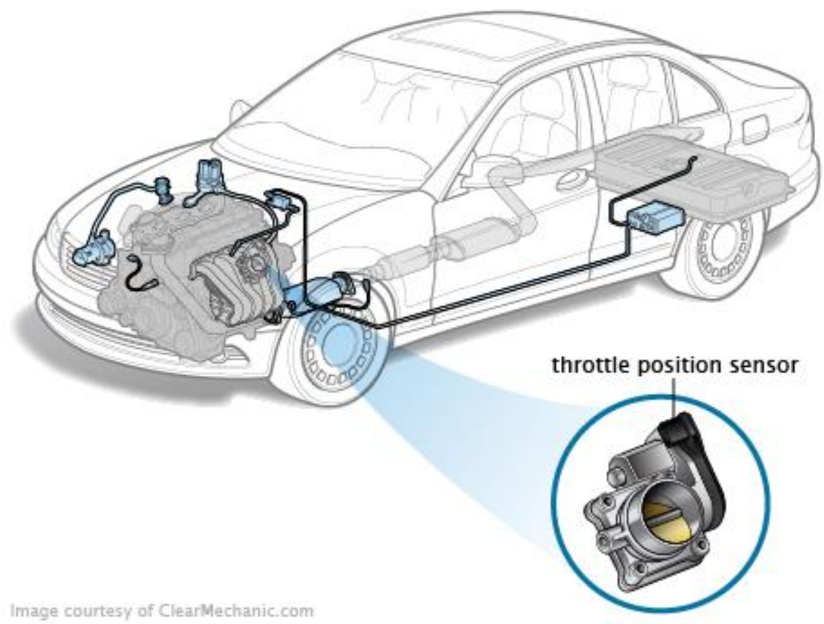

Figure 4: Location of the Throttle-Position-Sensor [2]

Figure 5 shows how the Throttle-Position-Sensor works. When the throttle position moves, the wiper (B) moves to the corresponding position and therefore gives a corresponding output voltage.

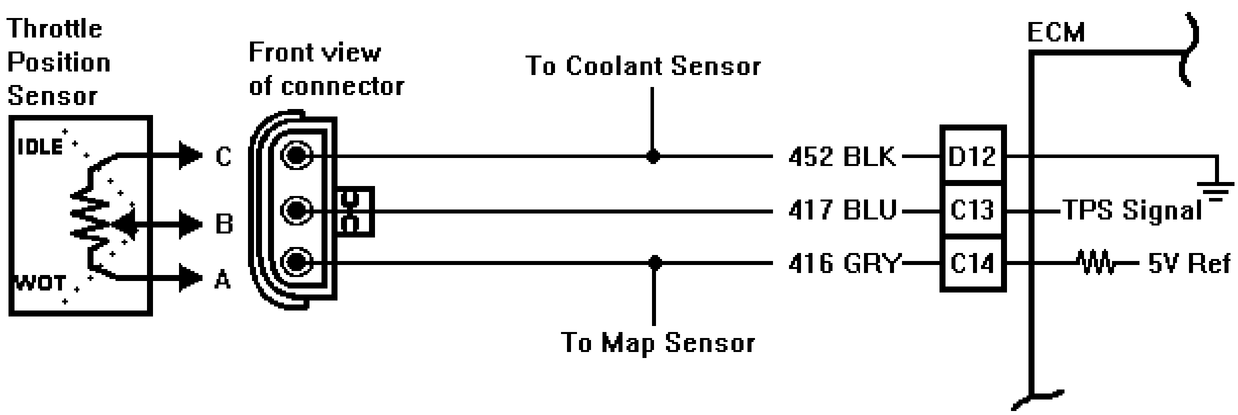

Figure 5: Throttle Position Sensor Internal Design [3]

3.1.3 Buttons

The buttons we will be using will be 8x8 mm so that they may be implemented onto a breadboard. These buttons will be connected to two of the Arduino Uno's many inputs so that the Uno will know when the buttons are depressed. A total of two buttons will be used, one for opening/closing the exhaust valve and one for turning on/off the "Automatic" mode.

Figure 6: Push Button [4]

The following figure shows how the button can be connected with Arduino.

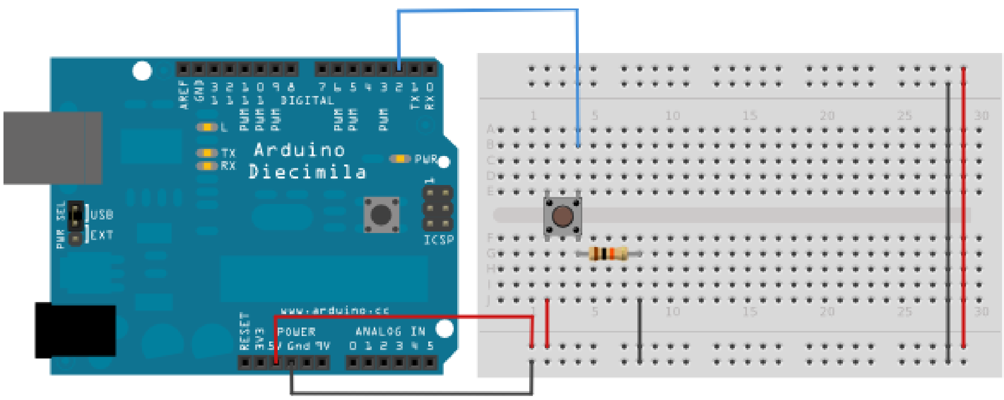

Figure 7: Button connection to Arduino Uno [5]

3.1.4 Relay

In order to make sure that the control valve's DC motor is properly powered, we chose a SRD-05VDC-SL-C 2 Relay Module to receive signals from the Uno and control how much power goes to the motor. The relay will allow the Uno to control the power flow from the car power outlet to the DC motor. To open the control valve, a voltage of 12V will be supplied to the DC motor. Similarly, to close the control valve the relay will reverse the power being given to the motor (-12V).

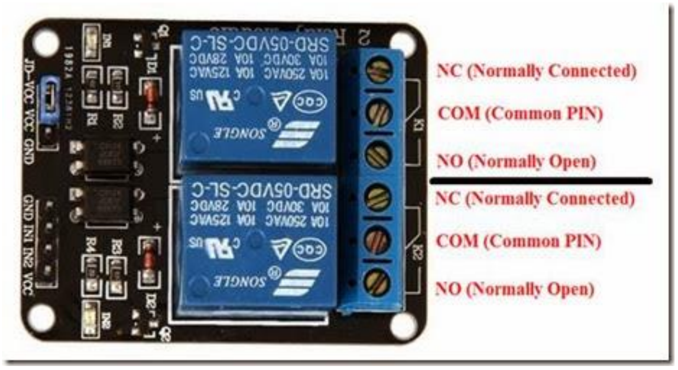

Figure 8: SRD-05VDC-SL-C 2 Relay Module [6]

The reason we chose this relay component is because we needed two relays to control the motor, due to the fact that the voltage needs to flow in two different directions. When both relays' NC pins are connected to the negative port of the battery, the motor is in a stable state; when one of the relays' NO pins connect to the positive port of the battery and the other relay's NC pin connects to the negative port of the battery, the motor rotates in one direction; when one of the relays' NC pins connect to the positive port of the battery and the other relay's NO pin connects to the negative port of the battery, the motor rotates in the other direction. The following figure shows how the relay controls the motor's direction.

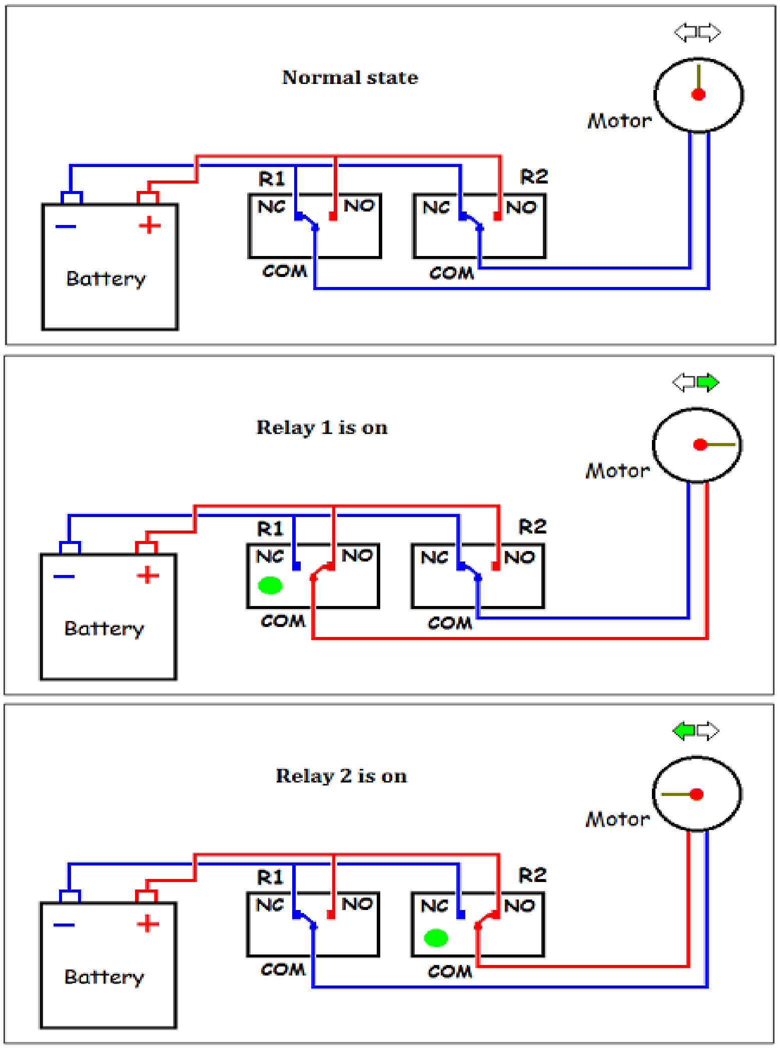

Figure 9: Battery-Relay-Motor Schematic [7]

3.1.5 Exhaust Control Valve

In order for the exhaust system's noise to be manipulated a control valve within the exhaust is necessary. The control valve will hinder, block or allow airflow through it and will be powered by a 12V socket inside the vehicle. As previously stated above, the relay will facilitate the power that goes to the control valve so then it may be completely opened, completely closed, or partially opened.

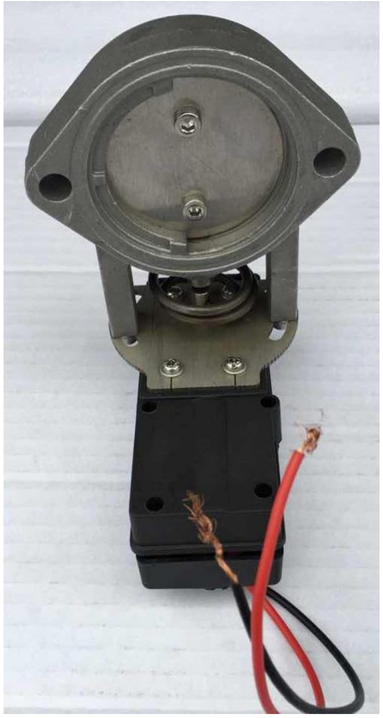

Figure 10: Control Valve for Exhaust System

3.1.6 Diode

The diode within the circuit will ensure that power being supplied from the 12V socket will only travel in one direction and will not reverse direction in such a way that will damage the motor.

Figure 11: Diode [8]

The following flowchart more descriptively shows how our control system works for J2VK's Valvetronic Exhaust Control System.

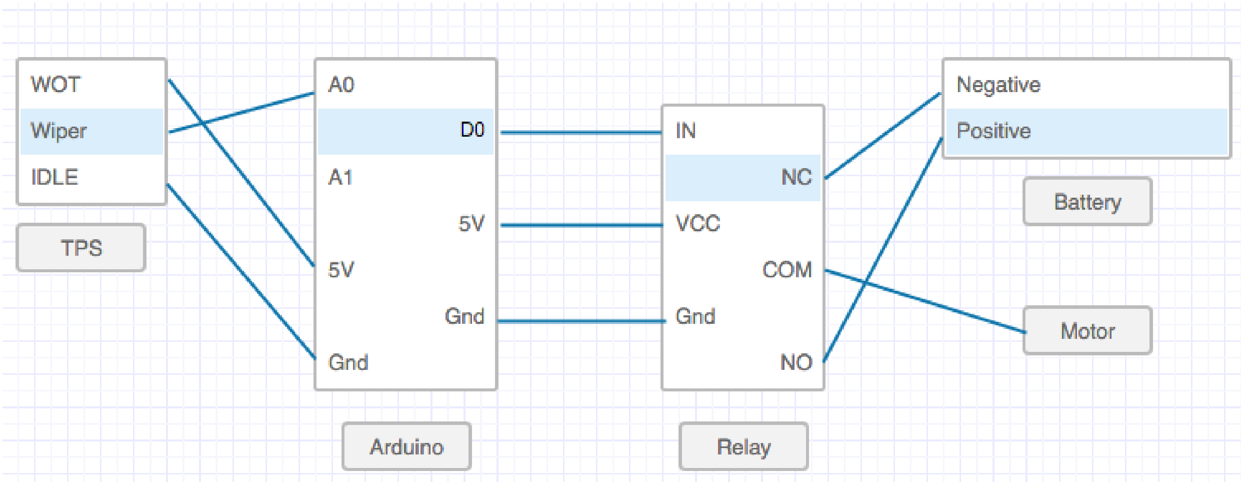

Figure 12: Working Process Flow Chat

4 Mechanical System

The mechanical system grants the valvetronic exhaust system the ability to physically adjust the exhaust system sound. This part will state the design details of the mechanical system. The specifications of the mechanical components, gear box, smart valve, overall structure and prototyping will be discussed.

4.1 Components Specifications

4.1.1 Modelcraft 12V High Performance Gearbox Motor

In order to operate the control valve's lever, a 12V/1300 rpm motor is used to control the valve's lever to move in a 0 - 90 degree range. Below is the performance chart of the motor:

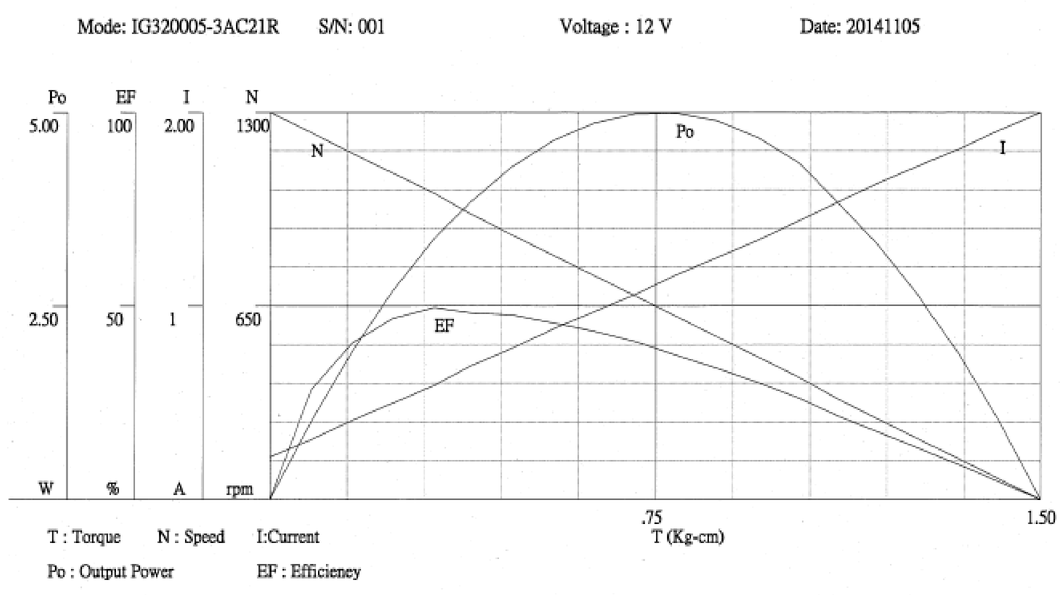

Figure 13: Performance Chart of Gearbox Motor [9]

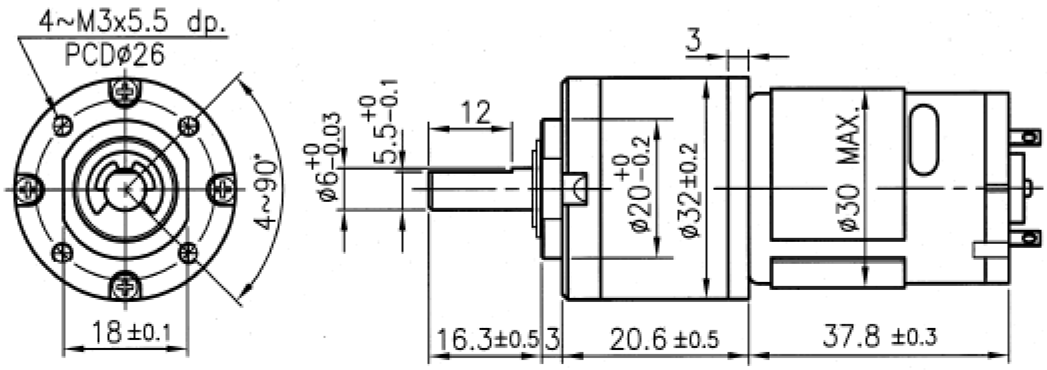

Figure 14: Dimensions of the Gearbox Motor [9]

Based on our exhaust product's requirement, the motor should provide enough torque, at least 0.1N/m with the 12V power supply in a normal vehicle, at low rpm in order to avoid overheat. Also, in order for the entire mechanical system to not exceed 5kgs the motor should be very light and small in dimensions. The motor should also come with its own transmission system to enlarge the torque with a low end gear ratio.

4.1.2 Steel/Aluminum Valve

The valve should be very light to reduce the overall weight of the exhaust system, and so its dimensions will be constrained to a maximum 10x10x20 cm in size. Also, the torque needed to twist the valve should be less than 0.08 torque; less than the normal load of the motor.

4.1.3 Pipes

The pipes we use in the exhaust system must be light and capable of withstanding high working temperatures. So we chose Drawn Aluminum Bare Tube 2024 T3 with a diameter of 1.75 inches.

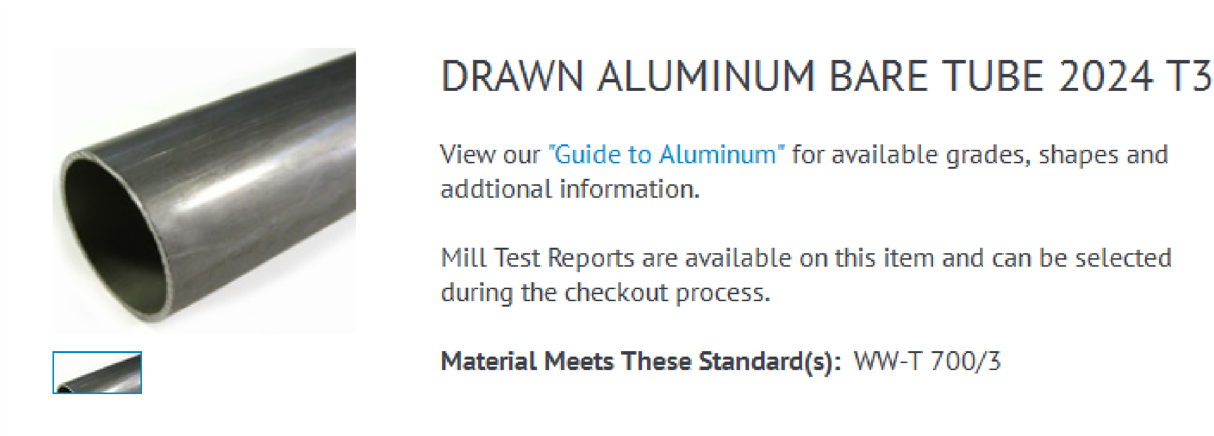

Figure 15: Aluminum Pipe [10]

4.1.4 12V Car Adapter

In order to meet the requirement of powering our exhaust system with 12V, a universal 12V car adapter socket will be used as the power source of our product. The control valve will be powered by this power source. Since all cars have 12V power sockets, making our product work with them will greatly increase our products flexibility and compatibility.

Figure 16: 12V Power Socket in Cars [11]

4.2 Mounting and Wiring

The prototype of our exhaust system was designed using Solidworks. The aluminum pipe is welded on the control valve frame and installed onto the car as a branch of the exhaust system. The electric DC motor is in the black box in the figure. The motor will rotate the control valve through a gear box attached to one end of the motor. The copper alloy spring is used to create a power lag that can help the valve fit onto the frame of the car without any gaps. The following figure shows the Solidworks design of our valvetronic exhaust system.

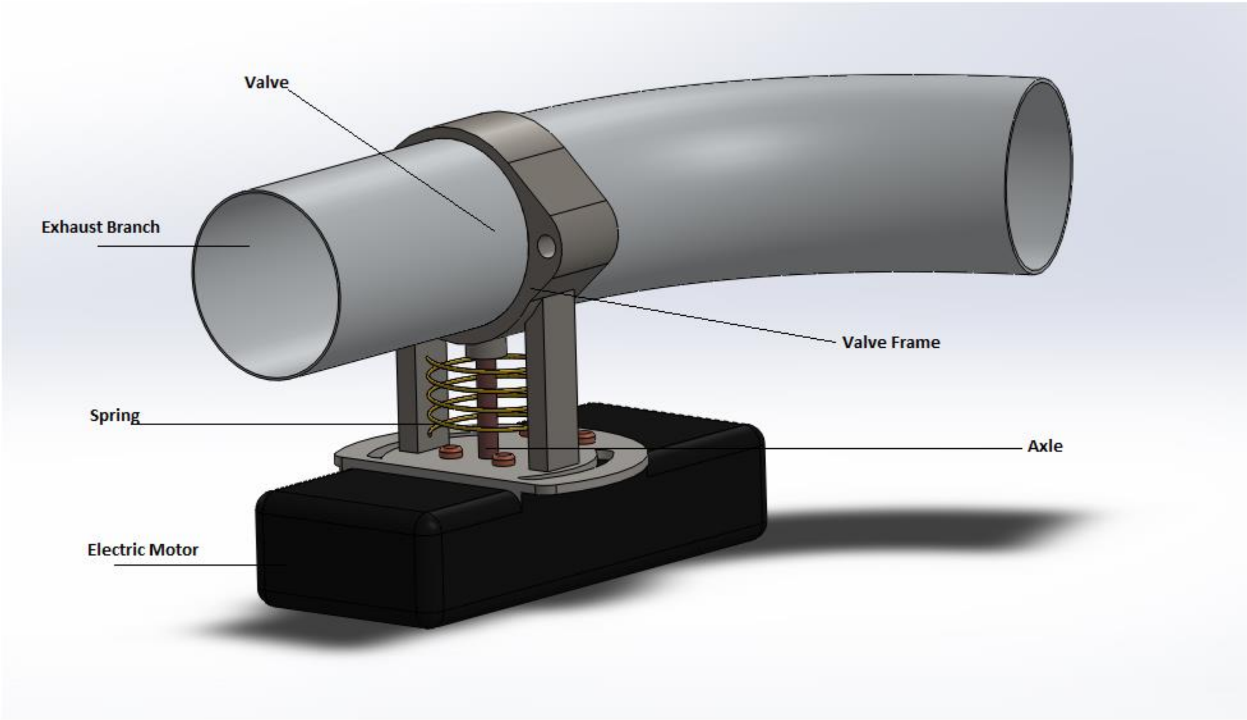

Figure 17: Exhaust System Prototype (Mechanical)

5 User Interface

The user interface of J2VK's Valvetronic Exhaust Control System is designed to be as simple as possible with minimal input from the driver. This allows the driver to focus on what's important to them, driving. The exhaust system utilizes two simple push buttons that will allow the driver to have full control over the noise of the exhaust.

In brief, the user interface contains only two push buttons. One button will be for completely opening or closing the exhaust valve and the other will be for turning on the "Automatic" mode of the exhaust system.

6 Test Plan

We have devised a test plan to ensure that the final product meets the requirements of our functional specifications. We will perform our test plan with various types of testing. Tests will be divided into different stages. First, we will conduct tests on each individual component of our product. Second, after assembly, we will perform post-integration testing on the final product.

6.1 Test Plan

6.1.1 Throttle-Position-Sensor

Throttle-Position-Sensor Testing Item: Accuracy and Detection Range

Testing Method:

Step on the pedal with TPS and get the full range of motion.

Expected Outcome:

Use Arduino Uno Microcontroller Board to read the output voltage from TPS.

6.1.2 Remote Control System

Remote Control System Testing Item: Functionality

Testing Method:

Connect the air control valve with a power generator (DC: 12V/5A). And use the two remote control buttons to test the open & close modes.

Expected Outcome:

When set in the open mode, the valve should be fully open.

When set in the close mode, the valve should be fully closed.

6.1.3 Micro-programming Board Control System

Micro-programming Board Control System Testing Item: Functionality

Testing Method:

Repeatedly step on the accelerator pedal.

Expected Outcome:

When set in “Automatic” mode, the valve should be controlled by the motion of range from the accelerator pedal.

6.1.4 Back Pressure Testing

Back Pressure Testing Item: Pressure

Testing Method:

Use pressure gauges with a scale that reads from 0 to 15 psi to record the back pressure from our exhaust system when the user steps on the accelerator pedal.

Expected Outcome:

Our system should induct our back pressure at low rpm by about 20%, when it is set in closed mode.

6.1.5 Torque Testing

Torque Testing Item: Torque

Testing Method:

Use a dynamometer to place a load on the engine and measure the amount of power that the engine can produce against the load when the user steps on the accelerator pedal.

Expected Outcome:

Our system should increase the torque at low rpm by about 20%, when it is set in closed mode.

6.1.6 Horsepower Testing

Horsepower Testing Item: Horsepower

Testing Method:

Use a dynamometer to place a load on the engine and measure the amount of power that the engine can produce against the load when the user steps on the accelerator pedal.

Expected Outcome:

Our system should increase the horsepower at high rpm by about 20%, when it is set in open mode.

7 Conclusion

All of J2VK's Valvetronic Exhaust Control System's design logic, specification and technical details have been discussed in this document. Requirements that must be met by the final product have also been discussed throughout this document. Test plans for ensuring that the final product works under different conditions have also been provided. As previously stated, this document will be used as a guideline to ensure that our exhaust system will function properly and safely. The team at J2VK is confident that the exhaust system will be ready by early April, 2016.

References

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