# CSC Piggy Back Group
# MEE 487
# Final Report

Submitted to Professor Mick Peterson
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## I. Objective

The object of the Piggyback group is to continue to reverse engineer the existing stock engine control unit (ECU) on a 2003 Arctic Cat four stroke 660 cc snowmobile engine to improve upon last years results. This reverse engineering will allow improved control of emissions after the addition of a catalyst. Particularly, hydrocarbon (HC) and nitrogen oxides (NOx) emissions will be monitored for optimum performance in the SAE Clean Snowmobile Challenge (CSC). Since HC and $NO_x$ emissions are the most important to control in an engine, the CSC has based the emissions part of the competition on measurement of HC and $NO_x$ in each of teams' sleds. One of the goals in this project is to minimize the HC and $NO_x$ emissions for a total minimum percentage of emissions required for the greatest amount of design points. (CO emissions are also considered in the test, but are weighted less than the HC and $NO_x$ emissions levels). Table 1 lists the operating conditions of engine emissions testing, and scoring for the emissions event is listed in Equation 1 and Equation 2.

**Table 1: Operating Conditions for Emissions Testing**

| Mode | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Speed, % | 100 | 85 | 75 | 65 | Idle |
| Torque, % | 100 | 51 | 33 | 19 | 0 |
| Wt. Factor, % | 12 | 27 | 25 | 31 | 5 |

**Equation 1: Sled Emissions Number, must be greater then 100**

Sled Emission Number "E" =

$$\left[1-\frac{(HC+NO_x)-15}{150}\right]*100+\left[1-\frac{CO}{400}\right]*100\geq 100$$

Table 1 and Equation 1 courtesy of SAE CSC 2006Rules

**Equation 2: Scoring for CSC Emissions Test**

$$YourScore=100+200*\left\{\frac{\left[\frac{E_{\min}}{E_{your}}\right]^2-1}{\left[\frac{E_{\min}}{E_{\max}}\right]^2-1}\right\}$$

Last year's group used a "piggyback" or override for the existing ECU to control the emissions from the sled. The idea behind the piggyback is to allow a separate control unit or computer programmed microcontroller to bypass the existing engine control unit when certain operating conditions are met by the engine. This year we continued to work on the piggyback controller and have targeted improving on the sleds idle condition since this is where the team performed badly at competition last year. To fix this problem at idle we are going to add the throttle position as an input to the microcontroller. In order to do this an engine map will have to be created to understand what is happening in the engine.

## II. Engine Map

### 1. Overview

The purpose in doing an engine map is to have a better understanding of what is happening in the engine at all times. For our purposes the engine map must contain the throttle position, RPM, Speed, and AIT (air inlet temperature). This way we will know the AIT (variable we are trying to control) as a function of the RPM, and Speed. We will also use this map to find out how the throttle position very with theses same parameters. To aid us in creating an engine map an R-500 data logging unit was purchased from PLX devices. This unit can handle up to 6 analog inputs and also can display the air fuel ratio and the exhaust gas temperature (EGT).

### 2. Inputs

The R-500 unit has a direct set up for inputs. All that has to be done is to attach the wire you want to look at to the wire leading to the logger. This is possible because the logger has a built in ground wire so no input needs to be grounded. The logger can handle any 0-5 volt analog input and will reduce any input up to 25 volts to a 0-5 volt scale without damage to the unit. With this feature any sensor on the engine can be tapped into directly and all that has to be done is to use a volt meter to make sure the wire you are tapping into is not the ground or the supply, but the third variable wire. For the throttle position, the AIT, and the tachometer (RPM) the above process was all that had to be done to add the inputs to the data logger.

In order to get the input from the Speedometer into the data logger we needed to find a way to convert from a cable driven speedometer to one that would output a voltage signal. By looking on line we found a device to do just that. It will take the cable from one end and then attach directly to the speedometer.

**Figure 1: speedometer cable to voltage converter**

3. Problems with engine map

While trying to obtain an engine map for the end of this semester we ran into a few problems and that is why there are not graphs and charts of the engine map present in this section of the report. One problem we encountered was that the device we ordered to convert from the cable driven speedometer to a voltage signal, didn’t have the right connects to fit the sled. So to fix this problem we will have to fabricate our own connection. We also damaged the USB port on the data logger and had to send that back to PLX to get fixed so we could map the engine but we could not get the map off the logger and on to a computer.

## III. Piggyback and Basic Stamp

1. Development

The original plan for the semester was to try and reuse last years piggyback. This ended up not being an option since the piggyback was potted making it impossible to add more inputs into it. So a very important part of this semesters work was learning what the inputs / outputs to the piggyback were and also learning how to properly wire the circuits.

**Figure 2: I / O Diagram for the piggyback digital potentiometer**

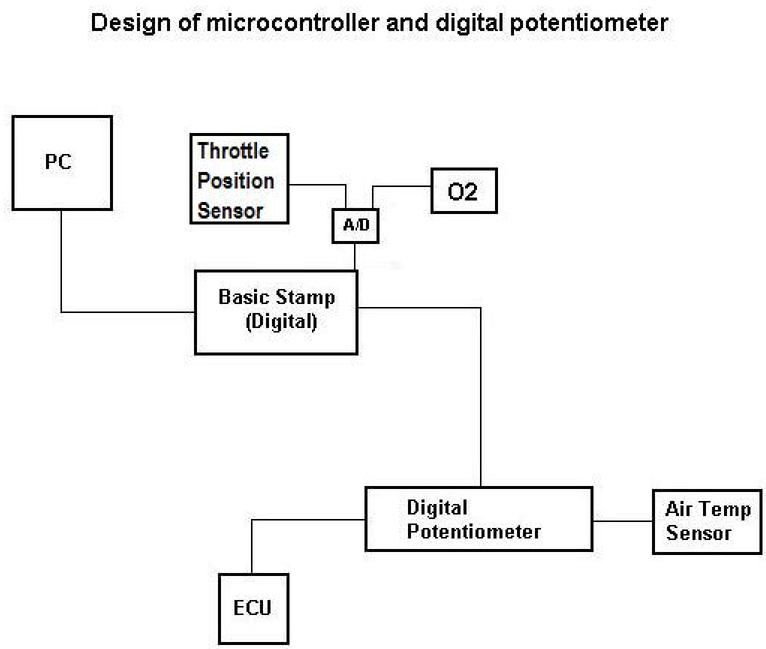



Figure 2 will allow us to change the A/F ratio on the snowmobile by using a microcontroller. The following is a description of the parts:

- PC – A computer used to program the basic stamp
- Basic Stamp – A microcontroller
- A/D – Analog to digital converter
- Digital Potentiometer – Changes the resistance
- ECU – Main computer which operates the snowmobile
- Air Temp Sensor – Measures inlet air temperature on the snowmobile
- $O_2$ Sensor – Measures the amount of oxygen in the exhaust system
- Throttle position sensor – measure the position of the throttle

2. Theory and Control of the Microcontroller

The basic stamp is a microcontroller developed by Parallax, model BS2P24IC. It can easily be programmed using a form of the BASIC programming language, called Stamp. After the program is written, the microcontroller connects to a computer through a serial cable, and the program downloads into the basic stamp's memory (EEPROM).

This year there will be two inputs to the microcontroller, a Bosch LSU4.2 wideband $O_2$ sensor, and an input from the throttle position sensor. The $O_2$ sensor will be mounted before the catalytic converter in the exhaust system to monitor the gas mixture. A program will be written and sent to the microcontroller based on the relationship between the $O_2$ sensor and the air inlet temperature sensor and the throttle position. Notice in

Figure 2, an analog to digital converter is used since the outputs of the $O_2$ sensor and throttle position sensor are analog and the microcontroller is digital.

A digital potentiometer will be wired in series between the ECU and air inlet temperature sensor. A catalytic converter was installed on the snowmobile, since the A/F ratio has been lean. Using a digital potentiometer to change the resistance of the air temperature sensor the A/F ratio can be changed. Changing the resistance tricks the ECU, and will allow the fuel mixture run a little richer. Since last years team had trouble with emissions at idle the throttle position sensor was added to be able to adjust the A/F ratio at this special condition.

## IV. Problems with Fall Emission Testing

1. Exhaust Gas Analyzer (EGA)

The EGA was used by last year's emission team to test the exhaust produced from the sled before they went to competition. Although the EGA is a very useful device that allows us to determine how accurate the piggyback is performing we had several problems getting the machine working properly. The first was the lab's supply of calibration gas. This had been exhausted from the previous year's crew. Without the proper gas to calibrate the O2 sensor in the EGA, the measurements taken would be inaccurate. This pushed back our initial goal of testing last years piggyback.

Once the proper gas, BAR 90, had been found and ordered through www.emissionsupply.net. We tried again to test the sleds emissions and compare these to what the team received last year. Again we had trouble getting the machine to calibrate. Either through the computer or manual controlling the EGA we were unable to capture a gas sample for calibration. After consulting with people from the help line, it was determined that the exterior filter was the likely cause. This would have to be changed out along with the interior filter for maintenance issues. The filters were ordered and should arrive sometime during break. Once they are installed the EGA unit should be able to be calibrated.

## V. Emissions Testing and Results

1. Testing Methods

The exhaust gas testing was conducted using a 5 gas analyzer, a DYNOjet dynamometer and the piggyback control unit. The sled was run for 30 seconds at idle, then held at speeds of 3000, 4000, 5000, and 6000 RPMs for 30 seconds each. The program used in the piggyback control unit was the same as last year's with the addition of an idle condition. This meant that alterations to the program were only done to improve idle conditions. Results were generated with many different versions of the control program and the best results can be seen in the below section.

After we arrived at competition we did find out that our power range for the sled was slightly incorrect. We assumed 65% throttle to be about 3000 RPM. It is actually closer to 4000 RPM. A corrected range that should be used for next years sled testing should be 4000, 5000, 6000 and 7000 RPM.

2. Results Presented in Competition Report

To determine the best potential areas to lower emissions with the 2006 piggyback unit the two previous years' methods for emissions reductions had to be tested in comparison. While the Five gas analyzer used gave us readings for several gases the only ones which concerned us were the HC, CO, and NOx emissions. These test results can be seen below in Figures 3.1, 3.2, and 3.3 for the full throttle range. The methods for taking this data can be found at the beginning of the Implementation section.

**Figure 3.1 Carbon Monoxide Emissions Data (CO)**

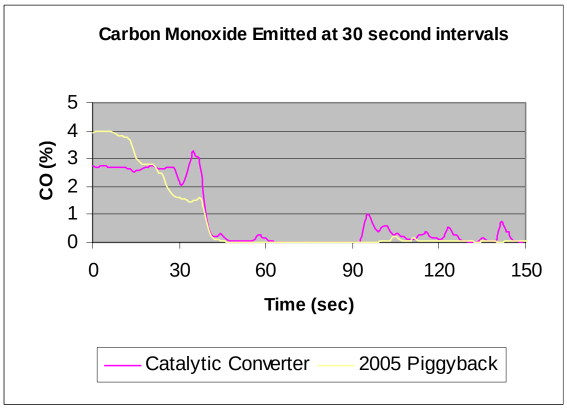



**Figure 3.2 Hydrocarbons Emission Data (HC)**

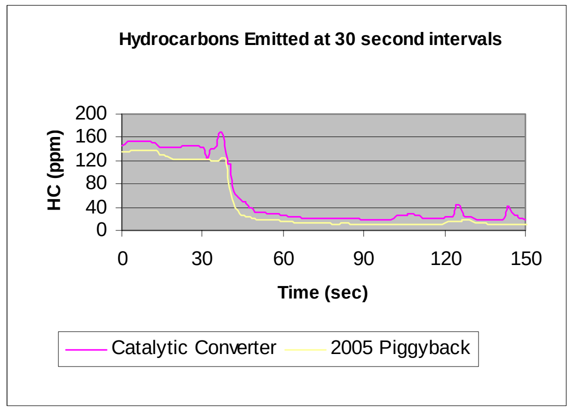
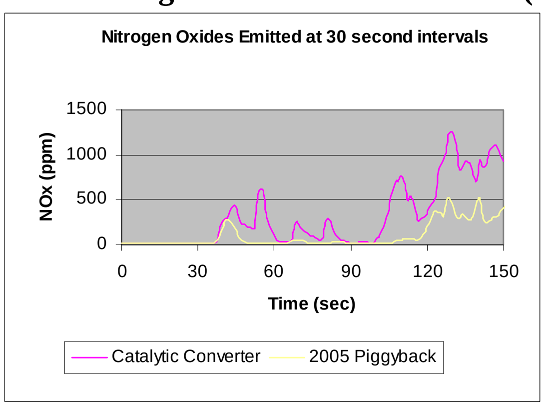



**Figure 3.3 Nitrogen Oxides Emission Data (NOx)**

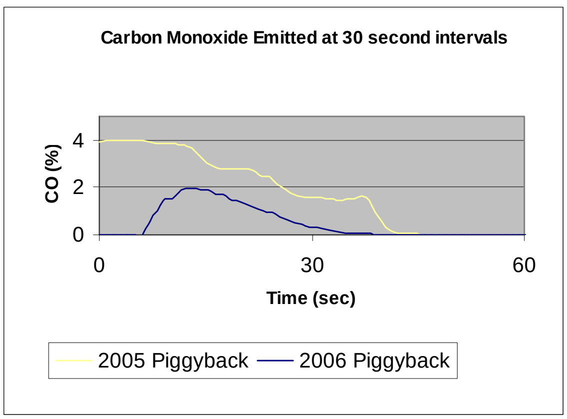



From these figures and running various tests through the full throttle range we were able to determine the best areas to improve emissions. The NOx emissions seemed to get larger between 5000 and 6000 RPMs. Other then this area these emissions were well maintained within the rest of the throttle rane. The CO and the HC emissions were exactly the opposite. These emissions seemed to get large at idle and low RPMs while they reduced the higher the throttle position was.

With additional tests it became clear that adjusting the NOx, HC and CO emissions at a higher throttle position such as 5000 or 6000 RPMs was possible but much harder to control. Taking this into consideration we decided controlling the idle conditions would be more beneficial to our team's emissions reductions.

A simple program was developed using the Basic Stamp programming language for our 2006 piggyback. This allowed the TPS to control the sled during certain voltage readings. Once the voltage readings exceeded a certain number we let the Wideband O2 sensor control the A/F ratio for the remainder of the throttle position. This provided the largest emissions changes from the idle range and the 30 second test range at 3000 RPM or 65% throttle position. These emission results can be seen in comparison on Figures 3.4, 3.5 and 3.6.

**Figure 3.4 2006 CO Emissions Data**



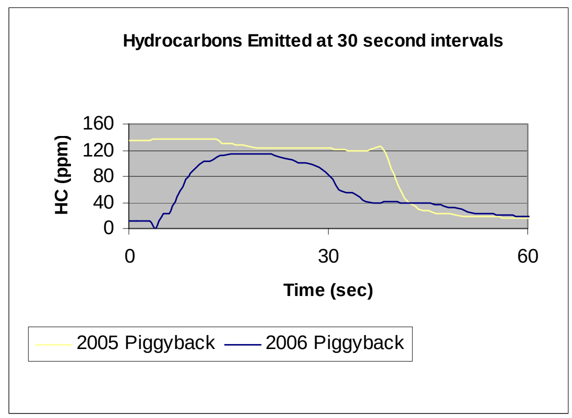
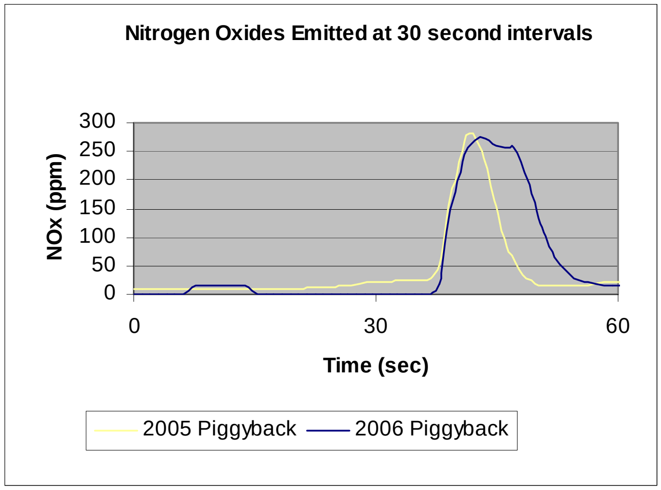




**Figure 3.5 2006 HC Emissions Data**

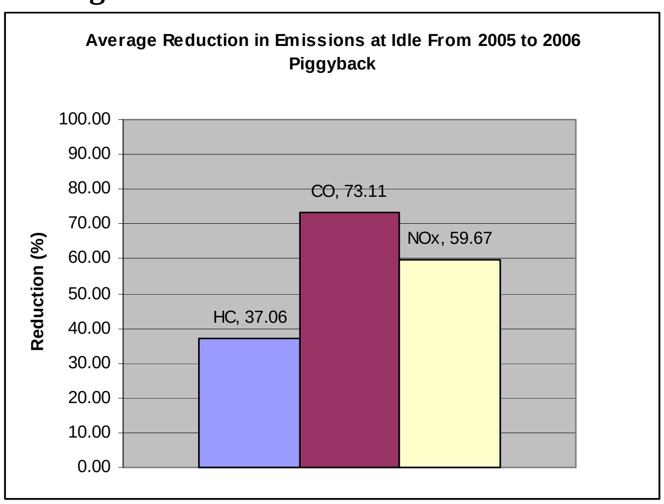
The emissions results for the HC and CO have been greatly reduced at idle conditions. The NOx did have a slight spike in them but on average they were also lower at idle conditions. Once the sled moved past its idle condition into 3000 RPM some fluctuations happened on the HC and NOx emissions. This is attributed to the program switching from using the TPS input to the Wideband O2 input. The program seems to give the best results when it takes a reading and adjusts every 3 seconds. If the program samples faster then this there tends to be more spermatic behavior, because the ECU chooses to adjust what it sees more frequently. This can lead to higher emissions and lower fuel economy.

**Figure 3.6 2006 NOx Emissions Data**



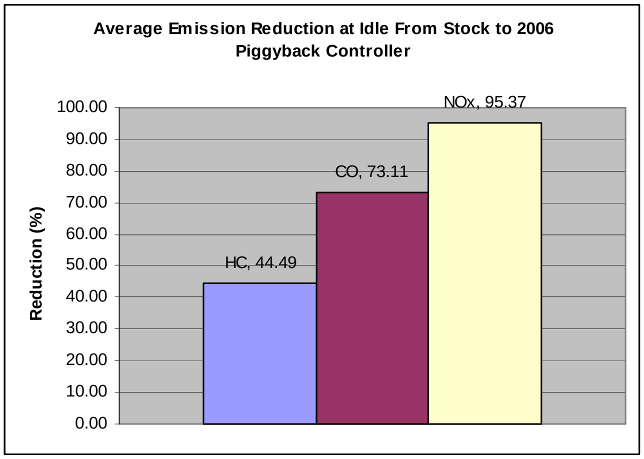

The easiest way to show the overall emission reductions from the 2005 to the 2006 piggyback would be to observe Figure 3.7 below. This shows that we were very success in our goal to reduce the emissions at idle.

**Figure 3.7 Percent Emission Reductions**




The HC were reduced by 37.06% the CO by 73.11% and the NOx by 59.67%. With the 2006 piggyback all emissions at the idle position run under the 2012 emission standards. The emissions are even higher when in comparison to the stock sled, which can be seen in Figure 3.8.

**Figure 3.8 Percent Emission Reductions from Stock Sled**




3. Competition Testing Procedures

At competition the testing procedures for the emissions of the sled are as follows. The representative from LandSea Dynojet will give the sled a horse power pull test to determine the throttle percentage and range before the test begins. The sled is connected to the coolant system, which are two 55 gallons drums of coolant. Once they are ready to begin the test there is a 5 minute warm up to the sled, which you are allowed to do anything to the sled in order to prepare it for the test. The first test is at 100% throttle and is held there for one minute. There is a 2 minute idle time. Then the other throttle tests continue decreasing from 85%, 75% to 65% and each last 2 minutes with a 2 minute idle period between tests.

VI. For your Information

1. Problems with this years testing

This year not as much testing was done do to continual failures of equipment and difficulties making the piggyback unit work effectively. All year long the exhaust gas analyzer would not work. Filters were replaced, different calibration gas ordered, and the entire unit was sent out for repairs; this lead to an inability to test the piggyback unit until a few weeks from competition. Once all the equipment needed for testing was fixed problems with the actual piggyback unit emerged. Manly when the program is running it causes a "hiccup" in the sled. The "hiccup" is when the sled no longer has the ability to rev above 2500 RPM. This could be happening for a number of reasons, one the AD converters on the piggyback unit are not getting an accurate signal and so the ECU on the sled is getting confused, or two there could be something wrong with the power supply to the stamp or the sled. In order to see if the problem is with the AD converters a second piggyback unit was built with a two AD converter set up.

## 2. Future Work

The second piggyback unit has not been programmed or tested. This should be one of the first things done next year. This testing will help to solve the “hiccup” issue on the sled. If the new piggyback still encounters the same problems as the old then some other solutions will have to be sought. Also both units need more testing to fine tune the programs and further reduce emissions (for more information see the piggyback manual on the website). If there is time after the “hiccup” problem has been solved and both units programmed for optimal efficiency an additional logical statement can be added to help control the emissions at the wide open throttle range.