GAUSS SENSOR FOR MAGNET ARRAY FILTER

Final Report

TEAM NUMBER : SDMAY 20-27

CLIENT : MAGNET ARRAY COMPANY

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Development Standards & Practices Used

- Circuits standards
    - Within safe power rating
    - IEEE 1522-2004 - IEEE Standard for Testability and Diagnosability Characteristics and Metrics
- Software Development Standards
    - Accuracy in taking measurements
    - Reliability in procuring data
    - Establishment of specific or custom software for designing,fabrication and installation

Summary of Requirements

Functional Requirements:

- Sensor able to detect magnetic particles up to 0.05 μm
- Able to detect iron particles
- Resistant to continuous vibration and temperature changes
- Able to withstand heat and vibration

Economic Requirements

- Able to detect when then buildups reach the threshold, indicating the time to change the filter, decreasing the amount of time and money used to gradually check and changing the filter.
- With the ability to know when the filter is full allows consumer to make sure metal is not going through system increasing life of engine.
- Minimal impact design standard

Applicable Courses from Iowa State University Curriculum

EE 201/230/285/311/332/330/333

CPR E 185/281/288

ENGL 314

New Skills/Knowledge acquired that was not taught in courses

- HTML Programming
- Usage of Gauss meter

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1. Introduction

1.1 Acknowledgement

We would like to acknowledge the help from the following people and organizations:

Magnet Array Company, Dennis O’neel, Dr. Mani Mina, Dr. Brian Stewart, Wei Shen Thea, Texas Instruments, Honeywell, Dr. Akilesh Tyagi, Dr. Joseph Zambreno

1.2 Problem and Project Statement

General Problem Statement:

A problem with closed systems is contaminants that can build within a mechanical system because with moving parts there will always be slight wear with the components that leads to particles traveling through the system. The filter for a vehicle helps to try and trap these particles but is not very effective for small contaminants. Thus the magnetic array filter acts as a second barrier in trapping these contaminants in the filter. Currently there is still no way of knowing when the filter has reached a certain threshold to where particles will not be caught. Our project is to design a sensor that is able to accurately determine when this threshold is reached and alert the user that it is time to change the filter.

General Solution Approach

To solve this problem, the team has to build a sensor array that works in conjunction with a microcontroller to alert the user when it is time to replace the filter. This will better protect their machinery and increase its lifetime.

1.3 Operational Environment

The magnetic field sensor created will have to withstand typical vibration found in combustion engines and hydraulic equipment. The sensor would also have to withstand wide temperature fluctuation existing in the combustion engine. The sensor would be used on a car engine, which is expected to be exposed to different weather conditions according to the season of the year. For example, the sensor would be expected to withstand extreme low temperature during winter, to withstand extremely high temperature during summer, to have water resistivity during rainy seasons, to withstand dusty sand from the road etc.

1.4 Requirements

For our project, the requirements intended include functional and economic regarding the sensor that is to be designed.

First of all, in the aspect of functional requirements, the sensor has to be able to detect magnetic particles down to 0.05 microns. Additionally, our sensor also has to be able to detect iron with high accuracy. Also, depending on time availability, a plausible additional functionality would include detecting brass and aluminum particles through the system. Our design also has to be resistant to continuous mechanical vibration and frequent temperature changes ranging from ambient to 200 F. The sensor has to detect the particle buildup and accurately depict when it reaches a certain threshold. It should also inform the user if there is a huge jump in particle buildup to indicate a pending catastrophic failure of the system.

In terms of economic requirements, the sensor should be able to detect iron, brass and aluminum particle buildup and inform the user of the current level. The idea of it is to indicate the predicted time to change the filter, thus decreasing the amount of time and money used to gradually check, change and replace the filter. It is important for consumers to make certain that no metals from the friction at sliding interfaces in combustion engines seep through the whole engine, which could damage the whole system.

Before, the user would have to frequently do an inspection manually on the filter and it took time on it. Not to mention, it is an inefficient way to make certain of the “exact” time to change the filter. Hence, with help from the sensor, it should have the ability to inform the user of the current buildup; and if the threshold is reached, the filter can be replaced at optimal periods, thus increasing the life expectancy of the machine and improving the efficiency of the overall maintenance process.

1.5 Intended Users and Uses

The intended users of our product are the drivers of motor vehicles, users of machineries and users of magnetic arrays. The sensor created would be expected to be able to monitor the change in magnetic field inside the machinery spin-ons filter, which is correlated to the iron particles accumulation in the filter. It is also expected that the sensor created should report the degree of iron particle accumulation to the microprocessors on the vehicle to help the car users to keep them updated about the situation of the car filter.

1.6 Assumptions and Limitations

Our board will have to withstand rapid temperature changes from ambient to 200 degrees Fahrenheit

This board will first be tested on the benches provided by Dr.Brian then we will look into implementations in machinary most likely as an LED indicator on the dashboard.

The board will have a voltage rating of 12-24V

Currently we will not be able to test the field with increasing temperatures accurately because we will not have direct access to a vehicle.

1.7 Expected End Product and Deliverables

1. **Sensor array for Magnetic Array Filter**

   The sensor array filter is designed specifically for the Magnetic Array Filter (MAF) that serves as a complement in utilizing the MAF to its full capacity on industrial and commercial usage. The sensor array functions in detecting the amount of particles built up in the magnetic filter. The sensor works with the hall effect sensor to monitor the changes in magnetic field on the filter that is mostly caused by the accumulation of metal particles -- mostly iron. With this, the sensor can detect the amount of metal amassing inside the filter.

   The data collected by the sensor will also be directed to the user for their information. With a set amount of threshold, they will have a clear indication on the level of the build up inside the filter, and depict the appropriate time to change them -- increasing the feasibility and efficiency of the MAF.

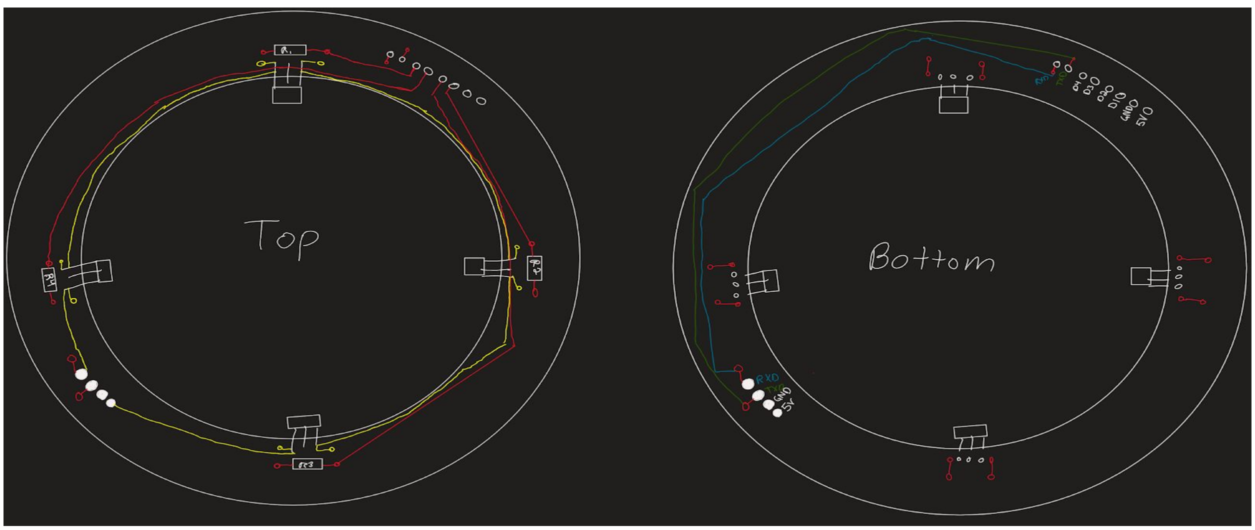
2. **User's Manual**

   The client will be provided with a clear and concise User's Manual of the completed sensor for the Magnetic Array Filter. The user's manual will serve as a guidebook on providing summary and overall information relating the presented product, detailed manual on steps of utilizing the sensor in the filter, and other miscellaneous related to the sensor

2. Specification and Analysis

2.1 Proposed Design

For our initial prototype we plan on designing a ring shaped PCB that will sit on top of the collar when it is connected to an oil filter. This will allow the hall effect sensors to lay off the inside of the ring and fit within the collar and oil filter. It will allow us to hopefully get more accurate changes with the magnetic field. We will also be using two different types of hall effect sensors to see which one will be more accurate for our purposes. The board will also have pin outs that can be directly connected to an arduino that will be used to collect the changes in field.



[1]Figure 1: Proposed Design

2.1.2 Finalized Design

For almost two semesters, the team had conducted multiple testings of the proposed design after fabricating it and undergone different alterations on the design of the PCB board and the collar itself. After each testing, the team would analyze every aspect of the data obtained, including any drawbacks potentially caused from the design of the board.

From the initial design of the board, some of the drawbacks are that it uses through-hole sensors on the board. A common difficulty that we went through when using through-hole sensors is their durability as it is easily damaged. Not to mention, another

[1] Figure 1: Proposed Design

important aspect regarding the hall effect sensors is their sensitivities towards the angle position of the sensors, and the initial design faces a huge problem as the PCB boards are rigid in position and are difficult to utilize during the calibration stage. Another drawback with the initial design is that the effective area of coverage by the hall sensor is insufficient in detecting the changes of the magnetic fields around the oil filter. This then affected the result from the testing and simulation to be inaccurate.

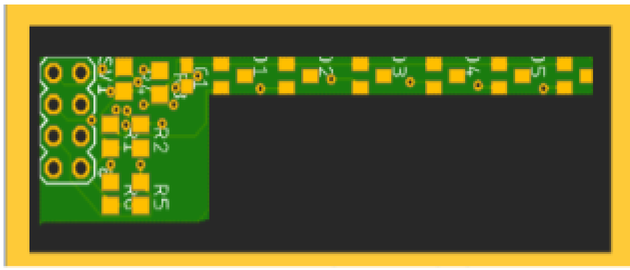


Figure 1.2: Final Design of PCB

After a few alterations on the design of the PCB and re-conduct of the testings, the team finally came up with an updated version and the finalized design of the PCB. Figure 1.2 above shows the final design of the PCB and Figure 1.3 below visualize the improved model of the collar with the PCB intact.

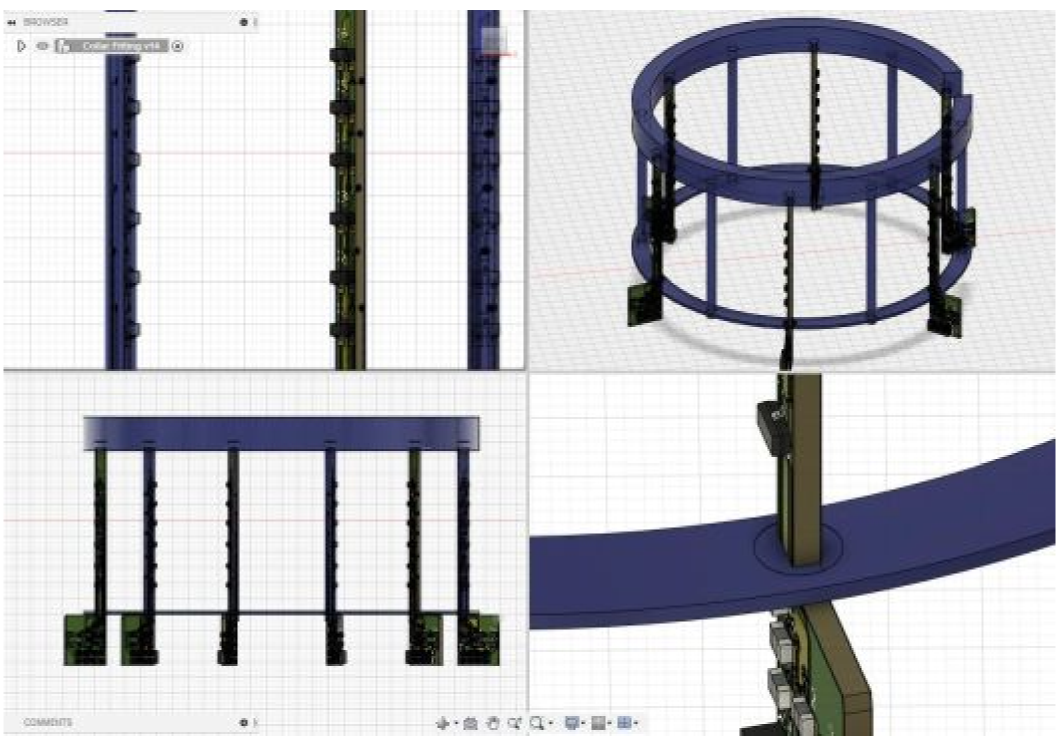


Figure 1.3: Overall Design of Collar and PCB

For the final design, a single board is attached with multiple sensors to increase the accuracy of the readings of the sensors. As we can observe from Figure 1.3, the six PCBs are aligned opposite to each other to allow better coverage around the oil filter. The collar is 3-D modelled with AutoCAD with the specifications and parameters of the design obtained by following the model specification of the oil filter provided by the client.

Also, the finalized version fully utilized surface-mounted Hall effect sensors instead of the regular through-hole sensors to mitigate the durability problem. Not to mention, another advantage of using surface-mounted sensors is their smaller size and allow better spacing management and sizing of the collar and the board overall. The sensor collar fitting also allows angle adjustment for the calibration of the sensors.

2.2 Design Analysis

Thus far, our team has drafted a design of a prototype and we are looking into possible parts as well as circuit designs that could be incorporated into the design. Currently, we are looking for possible hall effect sensors from Texas Instruments and Honeywell. We acquired some samples which included DRV5053, DRV5056, DRV5057 from Texas Instruments and SS49 and SS49ET from Honeywell.

Besides that, we have not done any testing yet as we are still in the process of ideating. However, after finishing our prototype, we should test it using a testbench that was constructed by Dr. Brian in his lab. The testbench consists of tubes and a filter where contaminated oil will run through the filter which is fitted with the magnetic array. After testing, we should have an idea on how to improve our design.

One of the advantages of our proposed design is it could be easily installed as it just needs to be placed on top of the magnet array. This makes our sensor easily accessible to the user which eases the user to abstract data/information from the sensor.

On the other hand, the placement of sensors is also important as it could affect the data received. Thus, one of the disadvantages of the system is if the sensor is not in the correct orientation and placement, the user will receive false information. Furthermore, the data received will also be affected if the sensor is not calibrated properly. The implemented code should tell the sensor to calibrate before taking any measurements.

2.3 Development Process

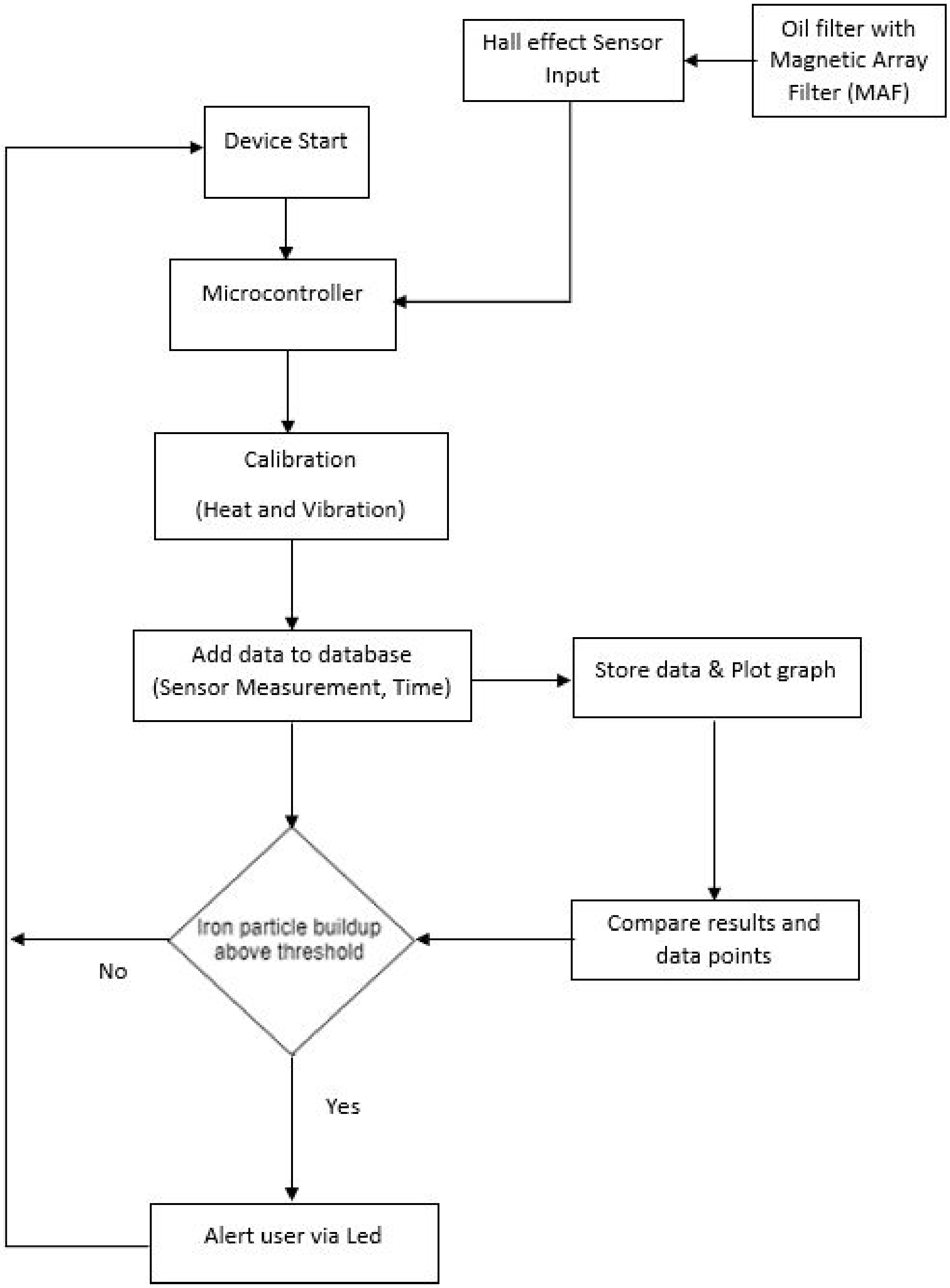
The development process used for this project is Agile. Our Agile process is as follows: Initiation of project followed by a team meeting. Then, it is followed by development of the sensor. We will then gather data based on our initial readings. It is then followed by internal evaluation. Then, we will go back to team meetings then development and evaluation. Then, we will have it evaluated by our client. In between all of these processes, reports are made and recorded.

One of the reasons why the team opted to use Agile is the process enables the team to deliver value faster and deliver a quality outcome. This is ensured as the item being worked on would not proceed to the next stage if it is not perfected.

2.4 Design Plan

First, we identify the problem to be solved, which is stated in our problem statement. Then, we gather the information from clients and end-users regarding the product limitations and requirements. Then, research is done by the team regarding issues that have to be solved and product end design is drafted. Then, possible solutions are thought about by the team members and discussed. The product feasibility is also discussed during this session. Then, a prototype design is selected and built. After that, testing is done and any problems that surface are discussed and the whole cycle restarts.

We will use three sensors in our initial testing that are not affected as much by temperature fluctuations and vibration which are Texas Instruments DRV5053, DRV5056, DRV5057. Then, we will design a circular PCB board that can be attached to the Magnet Array Filter. The PCB board is connected to a microcontroller that collects analog data from the sensor. The microcontroller will then decide whether the amount of particle buildup has reached the threshold. In the software design, we will take the input from the sensor and save it to a local database. The database data is tracked and if a sudden fluctuation is recorded, the alert will be sent to the user as well. Thus, there are 2 instances where the user will be alerted, which are when the threshold is reached, and if there is a sudden fluctuation in particle build up indicating a terminal failure. The microcontroller and sensor will use 12-24V inputs from the vehicle battery or the machinery that it is attached to. The microcontroller will be attached to a location away from the sensor via wires to avoid temperature changes and vibration to it. Nevertheless, the data will be calibrated with respect to changes in temperature fluctuations and vibrations if they do present. The following diagram is used in the microcontroller:



[2] Figure 2: Design Plan

[2] Figure 2: Design Plan

3. Statement of Work

3.1 Previous Work And Literature.

Background of project:

Fundamentally, as the mechanical system ages, the probability of failures increases. This is due to the primary drawback with closed systems as lubrication such as oil in a system engine breaks along with the moving parts of the engine. This allows components in the machine to wear, producing ferromagnetic debris particles in the circulating oil system. Hence, gradual monitoring of the system and preventative maintenance are to be conducted to prevent the machine from experiencing catastrophic failures that could break down the machine entirely.

Figure 3.1: Magnetic Array Filter (MAF)

Although nowadays consumers typically use oil filters to trap the wear debris particles, one of the limitations of the oil filter is that it is not as effective towards small particles. Standard oil filters are mostly effective for only particles approximately 20um and larger. This is concerning since many of the destructive ferrous wear particles are under the 20um limit (United States of America Patent No. US 7,662,282 B2, 2010). Hence, one solution for this dispute is the application of the Magnetic Array Filter (MAF)[3.1], designed and patented by our client, Dennis O'Neel from the Magnet Array Company. This magnet array filter acts as a secondary filter for the oil filtering system of the machine which helps in trapping these metal debris particles that are not removed by the conventional oil filter. The magnet array is designed as a collar and attached to an oil filter[3.2] of the machine.

Currently there is still no way of knowing when the filter has reached a certain threshold to where particles will not be caught. This is because as more of the wear debris metal particles are trapped by the magnetic array filter, the particle build ups causes a deterioration in the ability to attract any more of the wear particles inside the oil system.

Therefore, our project is to design a sensor that is able to accurately determine when this threshold is reached and alert the user that it is time to change the filter, to increase the lifespan of the machine. Our sensor designed for the filter utilizes the hall effect sensors which detects the changes in the magnetic field around the filter which indicates the changes in buildups of the metal particle debris on the filter. The information is then transferred into a software integrated in a microcontroller attached with the sensors, and displayed to inform the user. The software also provides a threshold for the user to compare with the current build up, indicating and alerting the user on the time to change the filter. This will then improve the feasibility of the magnet array filter as a preventative maintenance mechanism to help increase the lifespan of the machine or vehicles.

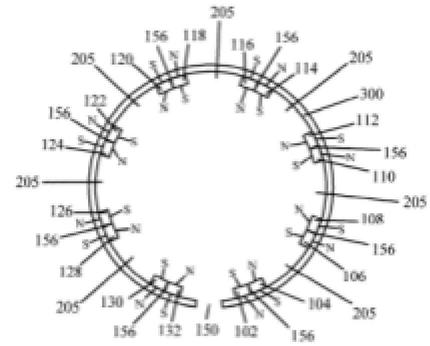


FIG. 3

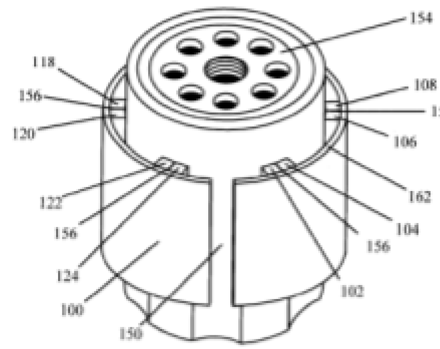


FIG. 4

Figure 3.2: MAF attached on Oil Filter

3.2 Technology Considerations

In consideration to our circuit design and implementation, since we are using sensors, one important aspect that is to be considered is the accuracy in measuring data. In addition to that, considering that the design is primarily used for an oil filter of a vehicle or an industrial machinery, we need to take into account the effect of temperature fluctuations and the effect of vibration towards the measurement of the sensor. The first solution that we came up with was to use the Hall effect sensors available from Texas Instrument. Specifically, for our testing we used the DRV5053, DRV5056, and DRV5057 Hall effect sensors from Texas Instruments. Also, other available sensors that we used for testing was the SS49 and SS49ET sensors from Honeywell. The reason these sensors were used are because they are not affected by temperature fluctuations and vibrations.

Also, the sensors will be connected to an Integrated Circuit, which for this part we will use an Arduino to connect the output. The necessity of Arduino is that is has an Analog-to-Digital-Converter (ADC) that helps in converting the analog signal inputs from the sensors to digital output, where it will be used in a user-interface software that we will develop alongside with the PCB. The software will take in the digital data and store the inputs into a local database and plot the changes in magnetic field that is then converted to the current level of the wear particle build ups inside the magnet array filter and the result displayed to the user. The software will also be provided with thresholds, where the software will alert the user if the current level reaches the threshold, pointing out that it is time to change the filter.

Moreover, the database data is tracked and if a sudden fluctuation is recorded, an alert will be sent to the user as well. Thus, there are 2 instances where the user will be alerted, which are when the threshold is reached, and if there is a sudden fluctuation in particle build up indicating a terminal failure.

One advantage in our design is that the sensors can be used while the machine or vehicle is online, meaning that we can get a live data of the reading without having the necessity of shutting down the machine or vehicle first. With this, it allows the user to obtain a real-life data and an immediate notification regarding sudden changes on the machine or vehicle. It also prevents additional cost or the necessity to shut-down the machine and examine the magnet array filter that is attached to the oil filter.

Design alternatives:

For our initial prototype design, we plan on designing a ring-shaped PCB[3.3] that will sit on top of the collar when it is connected to an oil filter. The ring-shaped PCB also has a mounting compartment available for the sensors that allow the hall effect sensors to lay off the inside of the ring and fit within the collar and oil filter. This is done to ensure that the sensors are mounted into place, ensuring that the sensors are not affected by the vibration from the engines, allowing us to hopefully get more accurate changes with the magnetic field. The board will also have pin outs that can be directly connected to the arduino which is located differently from the PCB, far from the oil filters

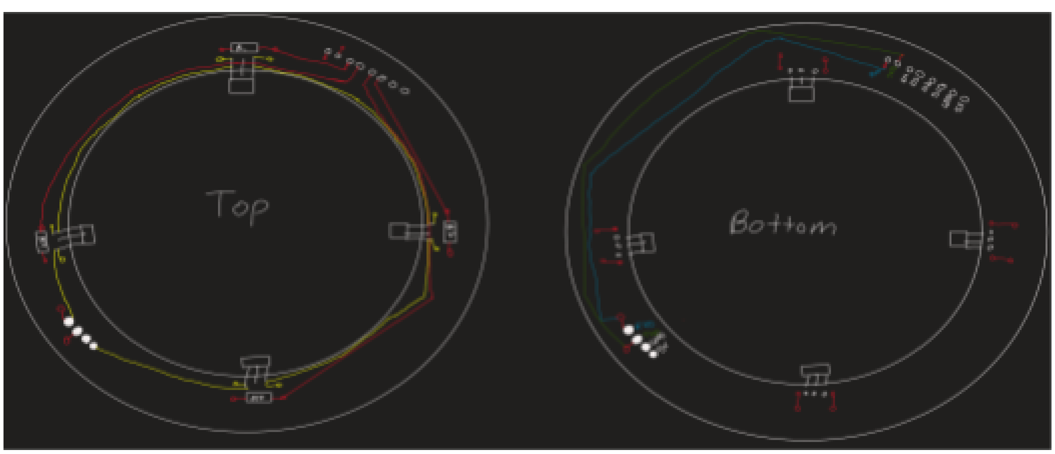


Figure 3.3: Initial Design (Ring-Shaped PCB)

by long connecting wires. This is to prevent the Arduino from being affected by the heat produced from the engine of the machines.

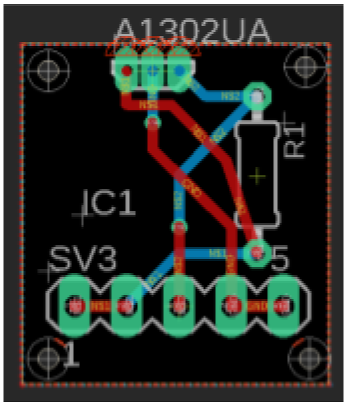


Figure 3.4: Square PCB

After going through some testing and discussion with the team, we decided to change the design of the PCB from the ring-shaped approach to a square PCB[3.4]. This allows a simplification in modelling the PCB and easier in terms of wire connection. The PCB will also be mounted on a circular silicon or plastic ring that will sit on top of the magnet filter instead of having the whole ring as PCB. As before, this will allow the hall effect sensors to lay off the inside of the ring and fit within the collar and oil filter. The collar is also designed for both top and bottom of the oil filter, having a total of 8 sensors for both PCBs to ensure that the sensor covers the whole perimeter of the Magnet Array Filter.

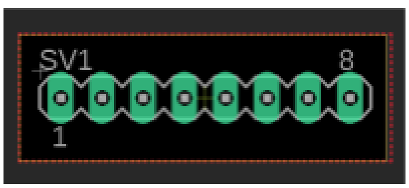


Figure 3.5: Output Pins

[3.5]Figure 3.5 shows the 8 output pins for the sensors that are to be connected and mounted on the plastic ring mount as with the four square PCBs[3.6]. The necessity of using a plastic or silicon ring mount is the characteristic of both materials that are a good heat insulator, preventing the PCB mounted to conduct excessive heat.

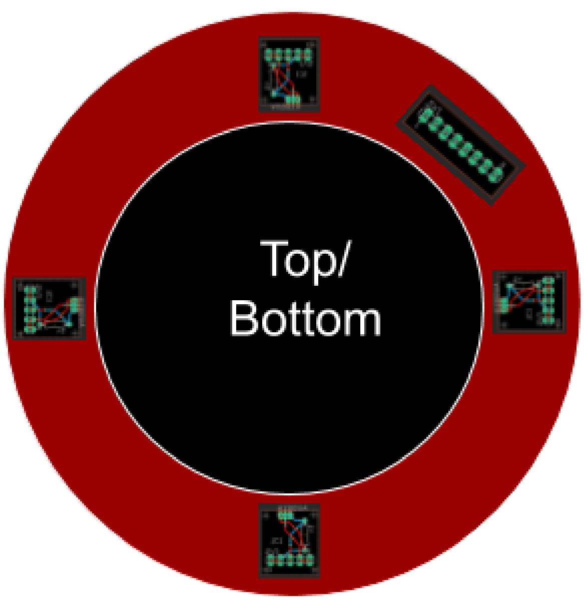


Figure 3.6: Square PCB and Output Pins on Plastic Ring Mount

3.3 Task Decomposition

Tasks for our project can be broken down into the following parts:

1. Hardware Development
    a. Choose a sensor that is sensitive enough to detect the change.
    b. The sensor should be able to withstand heat.
    c. The sensors are soldered onto a pcb and mounted to a PVC board which is placed on top of the collar.

2. Data management
    a. The data received from the sensors is processed by a microprocessor (Arduino Uno).
    b. The data should also be stored for the users reference.

3. Software development
    a. Before taking data, the code should instruct the sensors to be calibrated first.
    b. The code should be able to read the incoming data and store it at the same time plotting a graph.
    c. If a certain threshold value is reached, the user should be alerted.

4. Testing
    a. Taking data when the temperature of the oil is increased.
    b. Taking data with different configuration of sensor placement.

5. Refining the system (software and hardware)
    a. Changing the code based on the findings of the testing.
    b. Changing the configuration of sensors based on the testing.
    c. Testing the system again before approving the change.

3.4 Possible Risks and Risk Management

There are several risks that the team has to prepare for. These risks are as follows:

1. Accuracy

    · This project's largest risk is accuracy of the sensors. The sensors will be placed in areas where there will be a large fluctuation in temperature and also repetitive mechanical vibration. These two conditions will cause our measurements to be less accurate.

    · Another accuracy related risk is movement of collected particle. Since the magnet only has a certain potential energy, once it reaches the maximum, or is hit by oil fluids or other particles, it may shift. Since we are only taking a reading at a specific point along the filter, the particles that are magnetized may shift and cause incorrect future measurements.

2. Equipment

    · A risk in terms of equipment is using the hydraulic test bench. We will have to use it extensively to collect datasets to ensure that our data is accurate. Even though our team members are trained on how to use the equipment, the risk of oil spills, high temperature oil leaks are still a risk in this project.

3. Knowledge of Area

    · The main risk in terms of knowledge is with Hall Effect sensors. We are taught how they work but do not have in depth hands-on experience with them. This can cause some delays in reaching milestones for the project.

3.5 Project Proposed Milestones and Evaluation Criteria

There are several milestones in the project. These will be listed below:

- Initial Contact With Client
- Problem Statement
- Research
- Prototyping I
- Data collection
- Prototyping II
- Refinement of Final Product
- Delivery to Client

The key milestones would be Prototyping I, Data Collection and Prototyping II. They're the key milestones because they prove our proof of concept. After these milestones, little work is left and our work pace can be hastened.

There are several tests that the group will conduct to ensure it works. First, we will run a demo test with two purposes, to find out which sensor is the best sensor and also prove our concept. Then, we will run sensor data sampling for different amounts of particle contaminants and record the data. This will also be conducted with different temperatures of oil. In this test, we will use our sensor assembly, an Arduino and also a computer. All the data collected by the sensors will be saved for analysis in the future. Then, we will further refine the product in terms of accuracy and looks.

3.6 Project Tracking Procedures

The team uses GitLab to track progress throughout the whole project. The team also uses Google Drive to track documents, CAD files, and also reports.

3.7 Expected Results and Validation

The desired outcome of our project is a sensor array that will accurately depict when a certain change in magnetic field has been achieved by a vehicle or systems oil filters. This would mean that the filter is full of particulates that would otherwise travel through the system. The array will then tell the user when it is necessary to change the filter out

We will confirm or work by running many tests on different types of oils at different stages in their life, use change in temperature of the oil in order to understand how that affects the magnetic field, and run specific amounts of 10 micron particulates to understand how each particulate affects the field. We will be conforming to the IEEE 1413-2010 - IEEE Standard Framework for Reliability Prediction of Hardware and IEEE 1641-2010 - IEEE Standard for Signal and Test Definition. These standards will help to ensure that we are creating an accurate and effective final product.

4. Project Timeline, Estimated Resources, and Challenges

4.1 Project Timeline

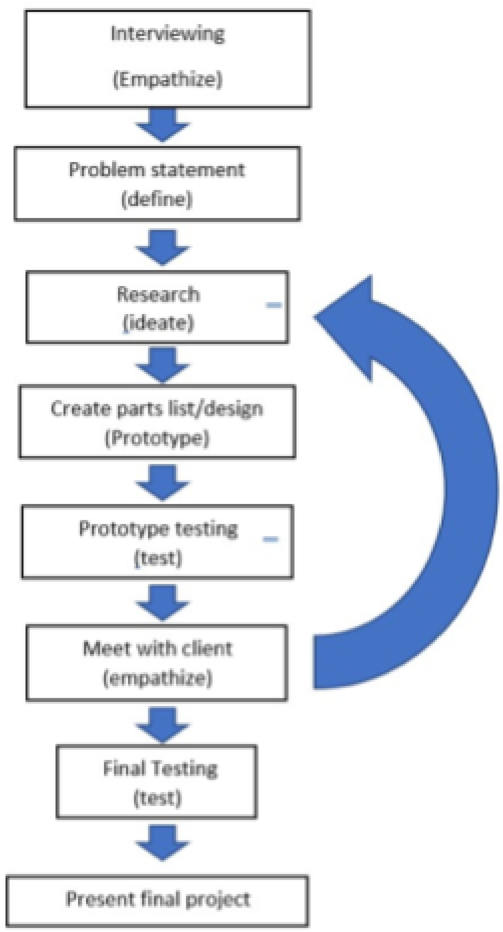


Figure 3.7 : Project Plan

1. The first part of the project is to gain information from the client which is apart from the empathizing stage. This step is done in order to really know the problem the client is facing and discussing the expected outcomes.

2. The second step is defining the problem statement. After receiving the information from the client, the team should formulate a thorough problem statement which would represent the problem the client is trying to solve and the expected outcome.

3. The third step is to ideate which is where the team does research and collect data that could help in solving the problem. This step is where the team brainstorm ideas and connect them all together.

4. The fourth step is where the team collects the required parts in order to build a prototype based on the ideas generated earlier.

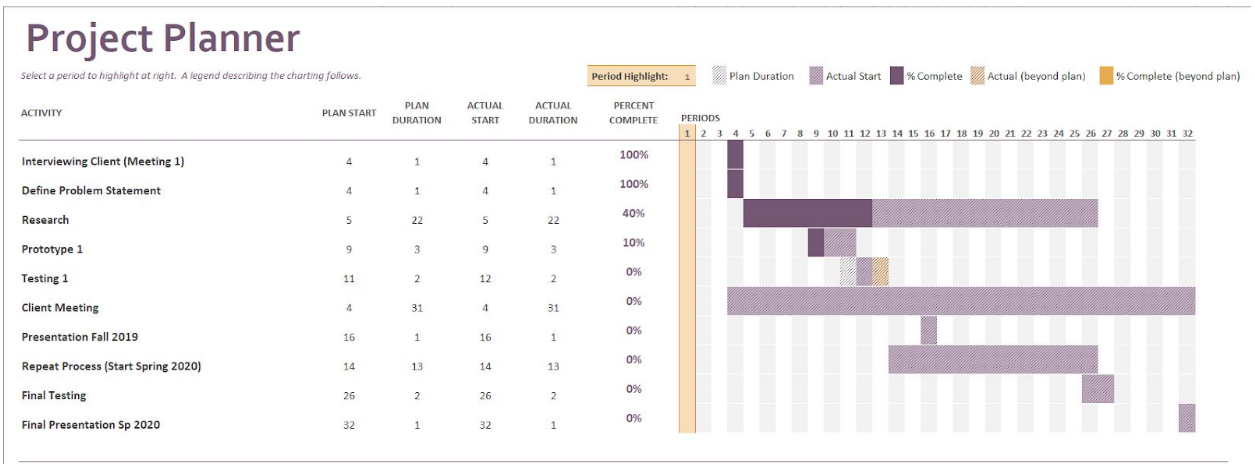
5. The fifth step is where the team conducts rigorous testing on the prototype and prove that the solution works.

6. After requiring a possible solution, the team should present it to the client and receive feedback. If the requirements are not met, the team should go back to the ideate stage and formulate a new plan to tackle the problem.

7. If the client is satisfied with the outcome, the team should conduct a final testing on the final product to endure the quality of the product.

8. After the final testing, the team should present the product to the client and public. At this step, the team should be confident that a quality final product is made.

Figure 4 is the Gantt Chart derived from the tasks that was specified in Section 3.3. This Chart specifies the timeline that our group planned in order to complete the project in the given time.



[3] Figure 4: Gantt Chart

The first step that the group took was to gain information about the project. After we were assigned to this project, we initiated contact with our client and set up an initial meeting to kick off the project. The first meeting is crucial as we would negotiate about the expectations of the project and what the client wants the group to achieve by the end of the semester. This was done around the 4th week. After that, we would have to define our problem statement which is the problem that we are going to solve and it dictates the direction that the team would be taking for the rest of the semester. This step was completed the same week as that we met with our client. On the other hand, research is a step that is done throughout the semester as the team would be searching for ideas to improve our proposed solution. That is why this step is scheduled until the team conducts the final testing whereby we achieved a satisfying final product.

The next step is a repetitive process that is done according to the improvements that the team applies to the prototype. This step involves building the prototype, testing,

[3] Figure 4: Gantt Chart

client meeting and back to the research step. The first prototype started in week 9 whereby the team designs the circuit and builds the PCB. After that, we proposed to start the first testing in week 11 but changes were done to the circuit design which caused the first testing to be scheduled in week 12. After testing, we would have to schedule a meeting with our client to report our progress as well as our findings. The feedback that the team receives will be used to improve our design and the cycle repeats. We scheduled the client meeting as a process that is also done throughout the semester. At the moment, the team meets with the client once every 2 weeks.

The final testing is tentatively scheduled for a month before the final presentation in week 32. This step is not yet to be determined as it depends on the challenges that the team faces over the semester. Finishing a few weeks before the final presentation would give the team time to organize the material gained from the project and successfully complete any remaining requirements.

4.2 Feasibility Assessment

A series of collected data for reference and proposals of some suggested methods to detect the change in magnetic field in oil filters due to brass and aluminium will be provided at the end of this project. Realistically, a prototype of a magnetic array sensor might be created but the prototype might be flawed due to time constraint. The calibration of the sensor array requires a large amount of time which might cause the outcome of the project to be very limited.

<u>Foreseen challenges:</u>

1. Time consumption
    - This project relies heavily on the sample data collected as we are using those data to calibrate the gauss meter and the magnetic array filter created by the team. For instance, we need the magnetic field reading of the filter at 1000 miles, 10000 miles, 20000 miles etc. Hence, a large amount of time is actually needed to obtain sample data.

2. Accuracy of data collected
    - The sensitivity of the hall effect sensor can greatly impact the accuracy of the data collected as we are dealing with a very small change in magnetic field. The sensitivity of the hall effect sensor varies among different brands and models. Hence, it will be a challenge for us to decide which brand and model of hall effect sensor to use.

4.3 Personnel Effort Requirements

Task	**Projected Effort**
Identifying problem statement	● Initiate contact with client ● Identify the needs of client
Identifying the outcomes of the project	● Research on magnetic array sensors ● Propose ideas to team advisor ● Determine if the need of client is achievable ● Determine the outcome of the project we can provide to the client
Searching for alternative options	● Research on the possibility of using the physics of eddy current to detect the change in magnetic field caused by brass and aluminium ● Determine the possibility to use the physics of eddy current towards our goal
Obtaining required tools and equipment	● Creating a list of the tools needed ● Request lab and equipment access from ETG(Electronics Technology Group) of Iowa State University
Obtaining sample data for setting the threshold	● Initiate contact with CyRide to request for used oil filters ● Research on the effect of sensitivity of sensor on the accuracy of data
Creating prototype	● Creating board designs ● Running test on the created prototype to minimize errors ● Improvements of prototype
Presenting the outcome of project to clients	● Display and explain the results and effectiveness of the prototype <u>In cases where the prototype does not meet the requirements</u> - Research on the possible improvements of the prototype - Creating a better prototype

Table 4.3: Personnel Effort Requirement

4.4 Other Resource Requirements

Part Name	Part Number	Part Price	Quantity	Total Price
Linear Hall-effect sensor (honeywell)	SS39ET	$0.85	3	$2.55
Linear Hall-effect sensor (TI)	DRV5053-Q1	$0.74	3	$2.22
PCB			6	$26
Arduino Uno		$18.41	1	$18.41
Total				$49.18

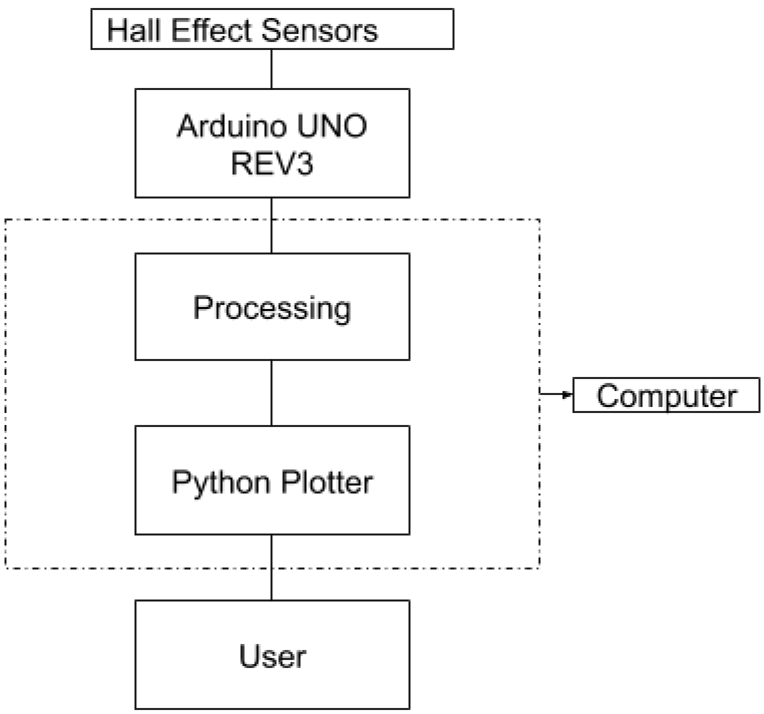
4.5 Financial Requirements

At the moment, the team only requires some financial help in terms of getting a microcontroller(Arduino), hall effect sensors, and also PCB. However, we are considering getting an accurate Analog-to-Digital-Converters in the future.

5. Testing and Implementation

5.1 Interface Specifications

In this project, there will be several layers of interface from the sensors to the user. The interfaces are laid out as follows:



The raw data will be transmitted from the Hall Effect Sensor to the Arduino via Serial I/O pins. Then, the Arduino UNO will send the data to a computer via a USB cable. The computer and Arduino can be replaced with a Raspberry Pi in the future if needed. Then, the raw data is processed by Processing, saved into a Comma-Separated-Value(.csv) file. This includes timestamps, sensor ID, and also temperature. Then, these values will be used to determine any errors in sensor data by either eliminating the outlier in average measurement, or median calculation. Then, it is saved. Every data is appended to a single .csv file, and is then plotted by the Python Plotter. The user will only require to interface with the plotter User Interface.

5.2 Hardware and Software

For hardware, we are using the following:

- Arduino UNO REV3
- Standard Computer
- DRV5053, DRV5056, DRV5057 Hall Effect Sensor
- Magnet Array Filter

For software, we are using the following:

- Arduino Programming Tool
- Processing
- PyCharm
- AutoCAD
- Autodesk Eagle
- GitLab

5.3 Functional Testing

For functional testing, the most important aspect to be examined is on the functional requirements that are defined in the sections above.

One of the functional testing to be conducted is to test the reliability and performance of the system. Since, the magnetic collar will be installed on different types of vehicles and machineries, the collar will be exposed to heat. Heat will definitely affect the magnetic field of the collar. Thus, it would affect the reliability of the entire system. To address this problem, the team will be testing the system with hydraulic fluid with a higher temperature. From this test, the team is hoping to gain more insight regarding the behavior of the magnetic array collar under heat variations, and be able to construct a calibration according to the heat fluctuations.

Furthermore, the designed prototype will also be tested on its resistance towards vibration. Since the designed MAF sensor is to be implemented on various industrial machineries and vehicles, the sensor should be able to withstand continuous vibration and produce accurate readings.

Furthermore, the designed sensor will be tested on the hydraulic test bench to test on the ability to detect changes in particle build ups on the MAF. The test bench is set up in a closed environment to clarify the proof of concept of our project statement, which is to design a gauss sensor that is capable of determining when the threshold is reached and alert the user that it is time to change the filter. The designed sensor will be tested with 0.05 μm iron particles.

5.4 Non-Functional Testing

Non-functional testing is done in order to check the non-functional aspects of the system which are not covered during functional testing, where the aspect that are to be tested are used to consider the operation of the system.

One of the non-functional testing that is to be tested is on the compatibility of the product. This testing is important to ensure the implemented software is compatible and able to be integrated into a different software.

For performance aspect of the designed prototype, a test will be conducted on the usage of different Hall effect sensors. The logical aspect behind the testing is to determine the sensitivity and accuracy of the output of each sensor in deciding for the best sensor to use for the project design. As of now, the Hall effect sensors that will be tested are DRV5053, DRV5056, DRV5057 from Texas Instruments and SS49 and SS49ET from Honeywell.

5.5 Process

We will begin testing by using the testbench that Dr. Brian Steward has granted us access to. We will start by running the bench with a new filter and new hydraulic oil in order to get our baselines of how the magnetic field changes as the runs through the system. After that we will introduce a small amount of iron particles in order to see how the field changes and be able to predict how more particles will affect the field. After getting the baselines we will later determine a threshold that will be used to tell the user that it is time to change the filter.

Figure 5: Testbench

6. Closing Material

6.1 Conclusion

Our goal with this project was to create a sensor array that works in conjunction with a microcontroller to alert the user when it is time to replace the filter as this will better protect their machinery and increase its lifetime. The sensor is going to be able to detect magnetic particles up to 0.05 micrometer. It will detect iron particles which are considered as contaminants in a closed engine system. The sensor will be able to adapt to continuous vibration of the engine and it can adapt easily to temperature changes. Hall effect sensors DRV5053, DRV5056, and DRV5057 from Texas Instruments will be used in our testing. These models of Hall effect sensors are used because their properties are only slightly affected by temperature fluctuations and vibrations. We have decided the suitable models of sensor to be used and we have determined the position of sensor in the filter. We have also established a connection with Cyride to obtain used dirty oil that is to be used in the testing. We have successfully and progressively determined the equipment and devices to use and will be able to start our testing. To achieve our goal to create a sensor array that works as we expected, we would first need testing to obtain thresholds to be set on the sensor arrays. Hall effect sensors are used as compared to other methods such as the utilisation of eddy current because eddy current can only be used to detect magnetic fields when the system is at stationary. We would like to create a sensor that is able to give threshold readings while the vehicle is moving. Hence, the usage of Hall effect sensors outweigh the rest of the possible solutions tested.

6.2 References

C. .Chaiyachit, “Hall Effect Sensor for Measuring Metal Particles in Lubricant,” Proceedings of the International MultiConference of Engineers and Computer Scientists 2012 Vol II, IMECS 2012, Mar. 2012.

I. Fox, “Numerical evaluation of the potential for fuel economy improvement due to boundary friction reduction within heavy-duty diesel engines,”Tribology International, 2005.

lin Zheng, H. Zhang, and Q. Wang, “Monitoring of Non-Ferrous Wear Debris in Hydraulic Oil by Detecting the Equivalent Resistance of Inductive Sensors,” Mar. 2018.

Lee, S.-J., & O'Neel, D. (2010, February 10). *United States of America Patent No. US 7,662,282 B2.*

6.3 Appendices

Appendix 6.3.1 PCB Board Design (Eagle) -

https://drive.google.com/file/d/11jvsrUetxSJWxbLceeqGk2guPWvlMQw3/view?usp=sharing

Appendix 6.3.2 Texas Instrument DRV5053 Data Sheet -

https://drive.google.com/file/d/1sWPdXHhu2pDTDvNUVKWnu4zhFFgIIEOG/view?usp=sharing

Appendix 6.3.2 Texas Instrument DRV5055 Data Sheet -

https://drive.google.com/file/d/1CoqqEd9e5VtvxIQD8j1BHpi9crrUfqEQ/view?usp=sharing

Appendix 6.3.3 Texas Instrument DRV5055 Data Sheet -

https://drive.google.com/open?id=1r25ZZWQoHh15J9KvE6RmzD-Vxal9P7zx

Appendix 1 : Operation Manual

DISCLAIMER

This manual is intended for the functioning of the testbench which works for both the previous and also current version of the prototype. The only difference is the prototype that is used on the filter.

All the necessary precautions should be taken when handling the testbench. Every student should abide by the lab rules when inside the lab such as wearing appropriate attire as well as all the recommended safety equipment. High pressure hydraulic fluid is dangerous as it could harm the personnel handling the equipment.

DISCUSSION

In order to operate the testbench, the following steps should be taken.

1. Ensure all the connections are secured and also ensure that all the valves are open according to the flow that we would want the fluid to flow. Below is the circuit that is used for this testbench (Figure 1). Also, make sure that the filter is securely fitted onto the filter head.

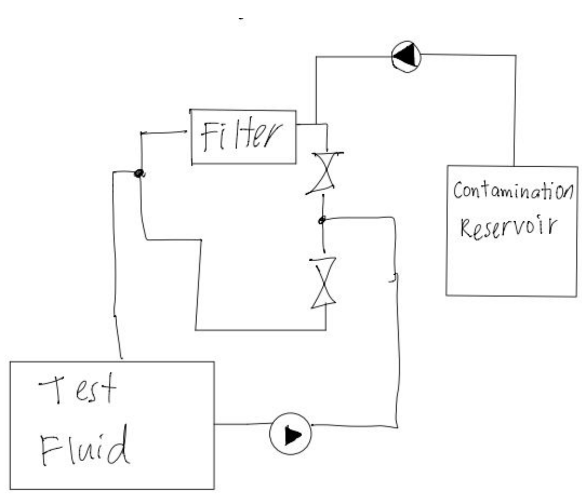


Figure 1

2. Weigh the desired amount of iron filling that would be injected into the system. The iron fillings will be mixed with the hydraulic fluid in the contamination reservoir which should be swirled to ensure that it mixes well with the fluid.

3. Set the pump to the highest setting which is 2600 ml/s. Below is the type of pump used for this testbench (Figure 2).

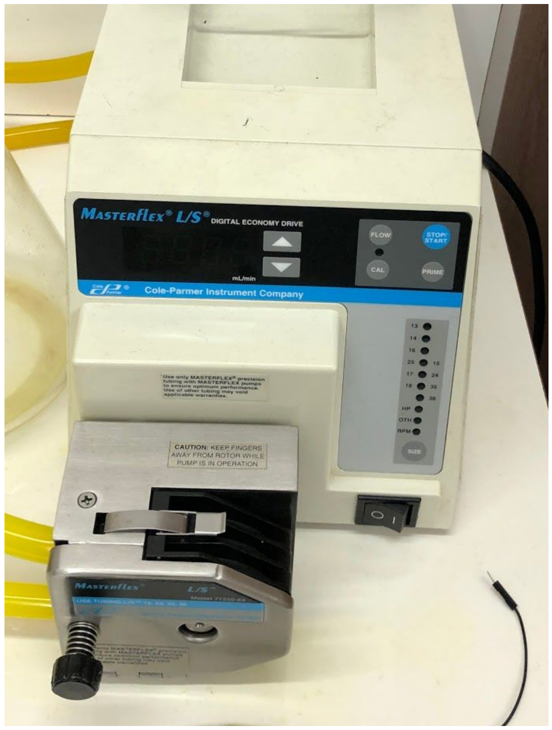


Figure 2

4. After starting the pump, let the fluid flow through the system for 5 minutes before recording any measurements.

5. In order to start recording data, the user should access two sets of programs which include Arduino and Processing. The user should upload and compile the code onto the Arduino. After that, Processing is used to get the data from the sensors and send them to the Arduino. (Port Number on Arduino and Processing has to be changed by user depending on the machine)

6. In order to inject particles into the system, the user should open the valve that connects the contamination reservoir to the filter. The contaminated fluid should be injected gradually into the system. This is done as we would want to replicate the actual scenario of the gradual tear of a machine.

7. Run the program for 30mins and the used should expect to see a plateau in the readings.

Appendix 2: Alternative version of the design

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1. **Initial/Proposed Version:**

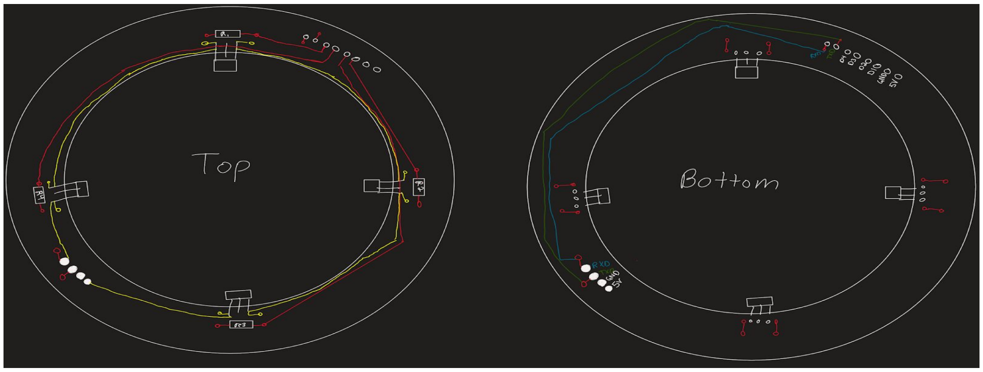
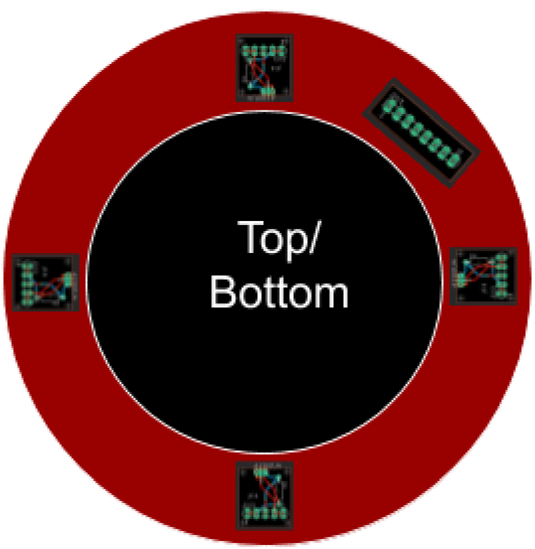


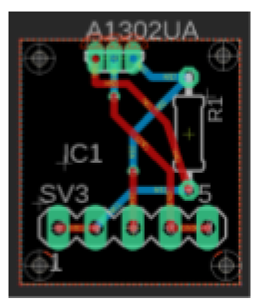
Figure 1

This is the initial design of the sensor board, shaped as a ring. From the design, the PCB is shaped fully as a ring to allow easy installment of the PCB by simply placing the board on top of the oil filter collar.

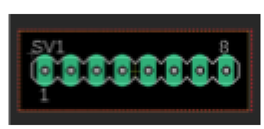
This version is disregarded since it is inefficient to build a fully ring-shaped PCB due to the designing process and the tendency for the PCB to conduct heat as it has few insulators around it.

2. **Early Development Version:**





PCB Board

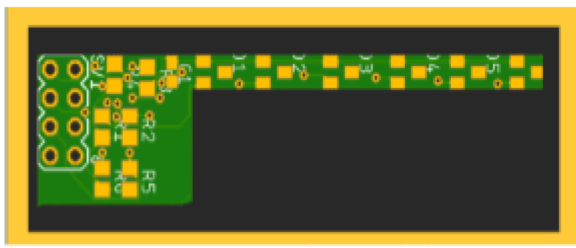


Output pins

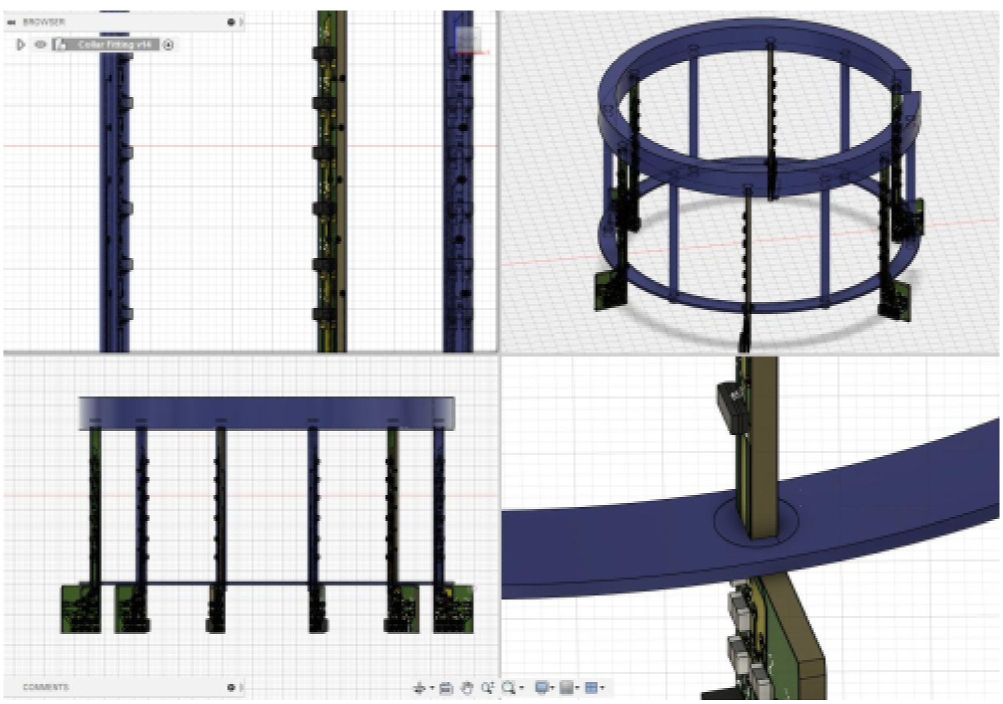
For this version of the sensor board and collar, the PCB is designed to be square in shape for simplicity and it is then attached on top of a silicon/PVC collar. Similar to the initial version, the collar is also designed for both top and bottom of the oil filter, having a total of 8 sensors for both PCBs to ensure that the sensor covers the whole perimeter of the MAF.

Nevertheless, this version is disregarded after observations on the data obtained during simulation and testing. This is due to the reason for the sensors being rigid in position, imposing difficulties in calibrating the sensors and causing the results to be inconclusive. Also, another reason is because this version uses through-hole sensors, which are low in durability and easily damaged during installing the collar and soldering it onto the board.

3. **Finalized Version:**



Final Board Design



Overall Design of Collar and PCB

For the finalized version, a single board is attached with multiple sensors that increases the accuracy of the readings of the sensors. The six PCBs are aligned opposite to each other to allow better coverage around the oil filter. The collar is 3-D modelled with AutoCAD with the specifications and parameters of the design obtained by following the model specification of the oil filter provided by the client.

Also, the finalized version fully utilized surface-mounted Hall effect sensors instead of the regular through-hole sensors to mitigate the durability problem. Not to mention, another advantage of using surface-mounted sensors is their smaller size and allow better spacing management and sizing of the collar and the board overall. The sensor collar fitting also allows angle adjustment for the calibration of the sensors.

Appendix 4: Code

---

1. Arduino Input

```
int sensorPinA = 13;  //drv5057
  int sensorPinB = 12;  //drv5056
  int sensorPinC = A0;  //drv5053
  int sensorPinD = A1;
  int sensorPinE = A2;
  int sensorPinF = A3;
  String command = "";
  float highValue[] = {0,0,0,0,0,0};
  float lowValue[] = {0,0,0,0,0,0};
  float serialValue[] = {0,0,0,0,0,0};
  float  cycleValue;
void setup() {
  // put your setup code here, to run once:
  Serial.begin(9600);
  pinMode(sensorPinA, INPUT);
  pinMode(sensorPinB, INPUT);
}

void loop() {
  if(Serial.available() > 0){
      command = Serial.readStringUntil('\n');
      if(command.equals("CLEARFUNC")){
        }
    }
  String sendViaSerial = "";
  /*
  To read digital Hall Effect Sensor
  highValue[0] = pulseIn(sensorPinA, HIGH);
  lowValue[0] = pulseIn(sensorPinA, LOW);
  This returns time in microseconds for PWM HIGH and LOW
  Then calculate DutyCycle:
  float cycleValue = highValue[o] + lowValue[o];
  dutyValue[o] = highValue[o]/cycleValue;
  */
  highValue[0] = pulseIn(sensorPinA, HIGH);
```

```
lowValue[0] = pulseIn(sensorPinA, LOW);
highValue[1] = pulseIn(sensorPinB, HIGH);
lowValue[1] = pulseIn(sensorPinB, LOW);
serialValue[2] = analogRead(sensorPinC);
serialValue[3] = analogRead(sensorPinD);
serialValue[4] = analogRead(sensorPinE);
serialValue[5] = analogRead(sensorPinF);

cycleValue = highValue[0] + lowValue[0];
serialValue[0] = highValue[0]/cycleValue;

cycleValue = highValue[1] + lowValue[1];
serialValue[1] = highValue[1]/cycleValue;


int i = 0;
for(i = 0; i < 6; i++){
  Serial.print(serialValue[i], 7);
  Serial.print(", ");
  }
  Serial.print('\n');
  Serial.flush();
  delay(1000);   //1 second delay

}
```

2. **Processing input**

```
import processing.serial.*;
import java.io.FileNotFoundException;
Serial port;
Table hallData = new Table();
int writeInterval = 500;
int counter = 1;
File chkFile;
String filePath = "/Users/aimnzulkefli/Desktop/HallData/";
//change this path to where you want to save it
String outputFile = "hallEffectData";
PrintWriter outputWriter;
void setup(){
  try{
    int checkFile = 0; //<>//
    String toCheck = filePath + outputFile + str(checkFile)+
".csv";
    //System.out.println(toCheck);
    chkFile = new File(toCheck);
    while(chkFile.exists()){
      checkFile++;
      toCheck = filePath + outputFile + str(checkFile)+ ".csv";
      chkFile = new File(toCheck);
    }
  }
  catch(NullPointerException e){
    e.printStackTrace();
  }
  outputWriter = createWriter(chkFile); //<>//



  port = new Serial(this, Serial.list()[3], 9600); //set to
portnumber of arduino
  String initialOut = "Count, Sensor 1, Sensor 2, Sensor 3,
Sensor 4, Sensor 5, Sensor 6, Time";
```

```
  outputWriter.println(initialOut);
  outputWriter.flush();
}

void draw(){
  if(port.available() > 0){
    String value = port.readStringUntil('\n');
    String counterStr = str(counter) + ", ";

    if(value != null){
     System.out.println(value);
     value = value.replace("\n", "");
     outputWriter.print(counterStr);
     outputWriter.print(value);
     outputWriter.println(System.currentTimeMillis());
     outputWriter.flush();
     //System.out.println(System.currentTimeMillis());
     counter++;
     port.clear();
    }
  }
}

void stop(){
  outputWriter.flush();
  outputWriter.close();
  port.stop();
  port.write("CLEARFUNC");

  port.write('\n');
  exit();
}
```