



The present work was submitted to the Faculty of Engineering.

IMPROVEMENT OF FUEL CONSUMPTION FLOWMETER

Bachelor Thesis

by

Ariuntsetseg Uyanga

Mechanical Engineering

Supervisor 1 Odbileg Norovrinchen, Ph.D.
Associate Professor of Mechanical Engineering, Faculty of Engineering, GMIT

Supervisor 2 Sungchil Lee, Ph. D, P.E.
Associate Professor of Mechanical Engineering, Faculty of Engineering, GMIT

Ulaanbaatar/Nalaikh, 2023

Statutory Declaration

Uyanga, Ariuntsetseg

15348203233141

Last Name, First Name

Student ID Number

I hereby affirm in lieu of an oath that I provided the submitted bachelor thesis.

IMPROVEMENT OF FUEL CONSUMPTION FLOWMETER

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Executive summary

This thesis presents the development of a mass-based fuel consumption flowmeter for the GMIT staff bus Hyundai Starex. Mechanical engineering student, Dulamjargal of the previous year, researched this topic. The main task is to carry out further research and experiments using the flow meter she proposed. The flowmeter is based on the Coriolis flow measurement principle and is designed to be installed in the fuel line of industrial equipment.

This research begins with an overview of the existing knowledge regarding fuel flow meters and the various measurement principles used for measuring flow. The design of the flowmeter is presented, including the selection of the load cell sensors, HX711, and Arduino Uno board.

The flowmeter's performance is evaluated through experiments conducted on a test frame. The results show how accurately the flowmeter can measure the mass regardless of the fuel tank position.

Finally, the thesis ends with a discussion of the many methods of fuel consumption, including the effectiveness of the mass measurement method.

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1. Introduction

The fuel consumption flowmeter thesis aims to select the mass measurement method from the many instruments, equipment, and methods used to measure fuel consumption and to study its concept, techniques, and implementation. When fuel consumption is one of the most critical issues, it is essential to develop a way to measure it. GMIT also faced the same problem and raised the issue of reducing fuel consumption and saving.

This research paper covers the theory behind the flowmeter system, working principles, experimental results, and applications. It will also briefly present other flow measurement methods.

The main goal is to design a meter that accurately measures the mass of fuel at a given time of immobility, conduct experiments, make conclusions, and make suggestions for improvements. The measuring system will use advanced techniques such as load sensors, microcontroller boards, and load cell amplifiers.

Overall, this thesis focuses on the study, mass testing, and improvement of flowmeter technology. As a result, I plan to contribute to solving the problems faced by GMIT.

1.1 Background

Fuel consumption measurement is critical in various industries and sectors, including automotive, transportation, energy, and environmental monitoring. Accurate fuel consumption data is essential for optimizing operational efficiency, assessing environmental impact, managing costs, and making informed decisions regarding fuel usage. Over time, significant improvements have been made in developing ways to measure how much fuel vehicles use. It helps make cars more efficient and reduce pollution.

The traditional methods of estimating fuel consumption relied on manual calculations, often prone to errors and needing more precision. However, technological advancements have made the development of automated fuel consumption measurement systems possible. These systems utilize sensors, data acquisition systems, and advanced algorithms to provide accurate and real-time fuel consumption data.

Fuel consumption measurement systems employ different approaches based on the specific application requirements and desired accuracy. Direct measurement systems directly measure the flow or volume of fuel consumed. In contrast, indirect measurement systems estimate fuel consumption based on related parameters such as air intake, fuel

injection, or pressure. Hybrid measurement systems combine direct and indirect methods to improve accuracy and reliability.

The implementation of fuel consumption measurement systems offers several benefits. In the automotive industry, accurate fuel consumption data enables manufacturers to assess the efficiency of their vehicles, meet regulatory standards, and develop more fuel-efficient models. Fleet operators can use fuel consumption data to optimize route planning, monitor driver behavior, and reduce operational costs. In the energy sector, fuel consumption measurement systems help monitor energy usage, optimize fuel consumption in power generation, and identify areas for efficiency improvement.

Despite the progress made in fuel consumption measurement systems, ongoing challenges and opportunities for improvement exist. Ensuring high accuracy and precision, addressing the limitations of different measurement techniques, accounting for fuel variability, and accommodating real-world operating conditions are key focus areas. Additionally, cost-effectiveness, ease of installation, and compatibility with existing infrastructure are essential considerations in developing and adopting fuel consumption measurement systems.

This thesis aims to propose and evaluate a fuel consumption measurement system based on load cell technology. By utilizing load cells, which are commonly used in weight measurement applications, it is possible to indirectly estimate fuel consumption by measuring the change in weight of the fuel tank. This approach offers potential advantages in simplicity, cost-effectiveness, and compatibility with existing fuel storage systems. Furthermore, through experimental testing, data analysis, and system evaluation, this thesis aims to contribute to advancing fuel consumption measurement systems and provide insights into their practical application and limitations.

1.2 Problem Statement

Measuring fuel consumption can improve efficiency and reduce costs in many industries, such as transportation. There are many ways to measure fuel consumption by volume, pressure, and density. However, these are not the most sophisticated methods and have many shortcomings, such as direct dependence on temperature.

Therefore, there is a need to solve these problems, and the mass method was chosen to design a meter for accurate flow measurement. This method is not affected by temperature and can accurately measure fuel mass in time.

This thesis is already researched and aims to improve accuracy, reliability, and efficiency with further improvements. The research will investigate suitable technologies with vibration, simulate the error of load cells before and after long-term use, model flowmeter systems, conduct pilot tests, and analyze performance characteristics.

1.3 Objectives and Research Questions

The objectives of the study are to:

- Test the fuel consumption meter
- Debugging the program
- Study the structure of the fuel system of the experimental vehicle
- Design sub-frames for lifting fuel tanks
- Installation of a mass flow meter in the vehicle's fuel system
- Simulate the error of load cell before and after the long-term use
- Study of the suitable technologies with vibration

2. Literature Review

2.1 Overview of Flowmeter Technologies

A flow meter is a measurement device that measures how much liquid, gas, or vapor is moving through a pipe. It does this by measuring how fast, how much, or how many units of whatever flows through the pipe. Different types of flow meters operate through various means. In other words, a flow meter is a device used to facilitate flow measurement. These fluids include water, oil, natural gas, steam, and fuel. The two primary methods for flow measurement are volumetric and mass flow measurement.

2.1.1 Volumetric flow measurement

A volumetric flowmeter is an instrument used to measure the volumetric flow rate, also referred to as the actual flow rate, of fluid passing through it per unit of time. This measurement indicates the volume of fluid that passes through a given cross-section per unit of time and is typically expressed in units such as liters per minute (L/min), cubic meters per hour (m³/h), or gallons per minute (GPM). It is crucial to acknowledge that changes in fluid characteristics, such as temperature, pressure, and viscosity, can impact the precision of volumetric flowmeter measurements. Various standard volumetric flowmeters are available for use in different applications.

1. *Differential pressure flowmeters* (orifice plate, venturi tube, flow nozzle) measure flow by creating a pressure drop across a restriction. The flow rate is calculated using the pressure difference and fluid properties.
2. *Positive displacement flowmeters* (piston, gear, diaphragm meters) - Divides the fluid into fixed volumes and counts them as they pass through the meter. Common types include piston, gear, and diaphragm meters.
3. *Turbine Flowmeter* - Measures the velocity of a fluid using a turbine or vane placed in the stream. The rotation speed is proportional to the flow rate.
4. *Ultrasonic flowmeters* - Use ultrasonic sound waves to measure flow by sensing the time of flight difference or Doppler shift between upstream and downstream transducers.
5. *Variable area flowmeters* (rotameters) - Consists of a vertically oriented tapered tube with a float inside. The float rises as flow increases, indicating the flow rate on a calibrated scale along the tube.

6. *Electromagnetic flowmeters* - Apply a magnetic field perpendicular to fluid flow, with the induced voltage proportional to the flow rate.

2.1.2 Mass flow measurement

The mass flowmeter measures the mass flow rate. The mass flow rate measures the amount of mass moving through the instrument per unit of time. In other words, it determines the mass of a fluid flowing through a given cross-section per unit of time, typically expressed in kilograms per hour (kg/h) or pounds per minute (lb/min). Mass flowmeters provide direct mass flow measurement, making them less affected by changes in fluid properties. Common mass flowmeters are

1. *Coriolis mass flowmeter* - Work on the principle of Coriolis force, which is generated on a vibrating tube due to fluid flowing through it. The fluid's mass flow rate causes a change in the phase between the inlet and outlet sides of the sensor, and this phase difference is proportional to the mass flow rate. As a result, Coriolis flowmeters are highly accurate and can also measure fluid density.
2. *Thermal mass flowmeter* - Rely on the heat transfer principle. It usually has two temperature sensors, one heated and another unheated. As fluid flows past the heated sensor, it dissipates heat based on the flow rate. The cooling effect on the heated sensor and the difference in temperature between the two sensors are used to determine the mass flow rate.

Both types of mass flowmeters provide direct mass flow rate measurements independent of fluid properties, making them suitable for various applications.

2.2 Fuel consumption flowmeter

A *fuel consumption meter* is a device that measures the fuel consumption of an engine or system. Accurate measurement of fuel consumption is essential for applications ranging from monitoring vehicle fuel consumption to measuring fuel consumption in manufacturing. Additionally, it helps reduce costs and improve efficiency, an important area of research and development. Therefore, using these meters has many advantages for your vehicle or equipment.

1. *Fuel efficiency monitoring* - gives real-time data about fuel consumption, allowing you to track and optimize your vehicle's fuel efficiency based on its performance.

2. *Cost management* - by monitoring fuel consumption, you can better manage your expenses, allowing you to identify opportunities for cost savings and reducing fuel waste.
3. *Leak detection* - can help detect fuel leaks in the system, preventing potential hazards and minimizing environmental impact.
4. *Maintenance planning*- monitoring fuel consumption helps identify unusual patterns that might indicate a problem, allowing you to schedule maintenance and prevent unexpected breakdowns or failures.
5. *Emissions control* - understanding your fuel consumption can assist you in making adjustments to reduce harmful emissions and adhere to environmental regulations.

2.3 Load cell technology

A *load cell transducer* converts mechanical force, like pressure and weight, into an electrical output. Its widely used in weighing scales, industrial systems, and measuring equipment.

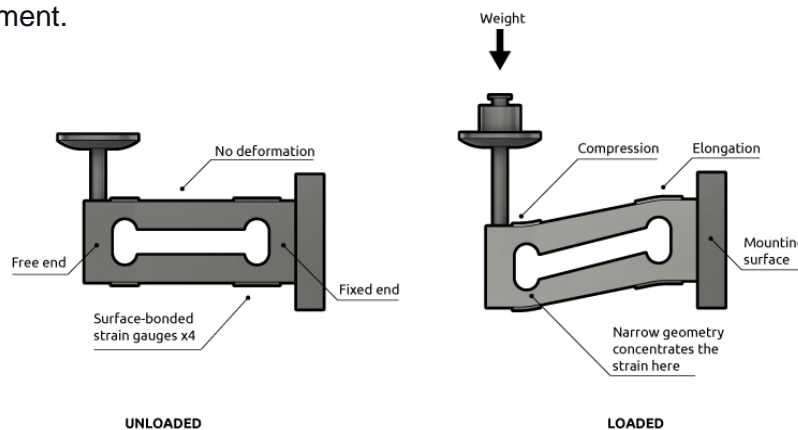


Figure 1. Working principle of load cell

Structurally, a force sensor comprises a metal body to which foil strain gauges are bonded. The main body bears the weight or force and accounts for most of the load cell's size. It is typically made from high-grade steel or aluminum, ensuring mechanical reliability and predictable and uniform strain distribution.

Strain gauges are electrical devices tightly attached to a thin film in a zigzag pattern. When the film is stretched, it and the conductors elongate. When it is compressed, it shortens. This shape change also causes resistance changes in the electrical conductors. The strain applied to the load cell can be determined based on this principle, as resistance increases with applied strain and decreases with compression.

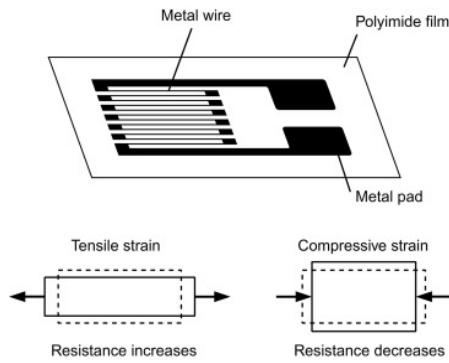


Figure 2. Metal Foil Strain Gauge

When force is applied (tension or compression), the metal deforms slightly and returns to its original shape when not overloaded. However, the strain gauge changes shape and resistance as it bends, creating a voltage difference through the Wheatstone Bridge circuit. Thus, the change in voltage is proportional to the applied force, calculated from the load cell's output voltage. Similarly, the strain gauge changes shape and resistance as the flexure deforms.

2.3.2 Types of load cell

A load cell converts mechanical force into electrical values the user can read and record. The inner working of a load cell differs based on the type of load cell. There are four main types of load cells.

1. Strain gauges load cells - are measured by the voltage fluctuation caused in the strain gauge when it undergoes deformation.
2. Capacitive load cells - use the capacitance change when pressure is exerted on the diaphragm.
3. Pneumatic load cells - measure pressure changes in an enclosed air chamber when force is applied.
4. Hydraulic load cells - are instruments that utilize force-balance principles to quantify weight by detecting changes in the fluid pressure within them.

2.3.3 Load cell application in flow measurement

Because flow meters measure the flow of a material as it passes through a specific point, they are generally better suited for continuous flow applications. While flow meters can tell you precisely how much liquid has traveled through a hose or pipe based on the flow rate, they cannot necessarily speak to the exact amount currently in a tank or vessel.

However, load cells can accurately tell you how much material has been added to the tank.

A load cell measures the tank's weight so delays are minimized. Load cells offer a particular benefit when dealing with products that do not usually work well with flow meters. For example, liquids with entrained air or bubbles may trouble meters, but they are no problem for load cells.

In addition to gaining accuracy from your load cell system, mass flow meters could be more cost-effective than other meters. On the other hand, load cells are a lower maintenance solution for flow measurement and can prove more accessible to manage and cost-effective over time.

One of the advantages of load cells, they can provide highly accurate and reliable force and weight measurements, even in challenging temperature conditions, because load cells are often made of carefully selected materials to minimize thermal expansion and contraction, which can lead to changes in the electrical resistance of the strain gauges. It allows the load cell to remain stable and accurate, even when exposed to temperature changes.

2.3.4 Existing Load Cell-based Fuel Consumption Meters

Here are a few examples of load cell-based fuel consumption meters that have been developed and used:

1. **Gravimetric Load Cell Meters:** Load cells are utilized by these meters to gauge the weight of the fuel supply tank both before and after a set period of fuel usage. The fuel consumption rate can be determined by computing the weight difference over time. This approach obviates the necessity for extra flow sensors and measures mass directly.
2. **Load Cell-based Fuel Flow Transducers:** These transducers incorporate load cells within the fuel flow path to measure the force the flowing fuel exerts. By converting this force into a corresponding mass flow rate, fuel consumption can be accurately calculated. Load cell-based transducers are designed to handle different flow rates and are suitable for various fuel types.
3. **Load Cell-integrated Fuel Injection Systems:** Some fuel injection systems use load cells to measure the force the fuel injector applies during a fuel delivery. By integrating load cells within the injection system, the fuel consumption can be determined based on the load cell readings and injection timings.

4. Load Cell-based Fuel Monitoring Systems involve load cells integrated into fuel storage tanks or transfer lines. The load cells measure the weight or force of the fuel, allowing for accurate fuel consumption monitoring. These systems can be used in various applications, including vehicles, industrial machinery, and stationary fuel storage facilities.
5. Load Cell-based Aircraft Fuel Consumption Meters: Load cells are used in aircraft fuel systems to measure fuel consumption accurately. These load cells are integrated into fuel lines or tanks and monitor real-time fuel usage. The data from load cells can be combined with other parameters, such as flight time and altitude, to calculate fuel efficiency and optimize aircraft performance.

These are examples of existing load cell-based fuel consumption meters, and specific technologies and implementations may vary.

2.3.5 Other typical applications of load cell

The most common application of a load cell is a scale. This is the most common example, but many other critical and widely used applications exist.

1. Construction

Load cells are commonly used in construction material dosing machines to accurately measure the amount of dispensed material. In these machines, load cells are typically installed underneath the hopper or container that holds the material. As the material is dispensed, the load cell detects the weight of the material and provides feedback to the control system, which adjusts the dispensing rate accordingly.

Load cells are essential to dispensing the correct amount of material, which is critical for achieving consistent and high-quality results in construction applications. For example, accurate dosing of cement, aggregates, and water materials in concrete production is crucial for achieving the desired strength, durability, and workability.



Figure 2. Construction material dosing machine

Overall, load cells are an essential technology for the construction industry, helping to ensure accurate and reliable measurement of materials and equipment in various applications.

2. Automotive

Load cells are used in several automotive applications to measure the forces and loads on the vehicle's components, ensuring they function correctly and safely. Some typical applications of load cells in automotive include

- **Suspension Testing:** Load cells measure the forces and loads on the vehicle's suspension system. This helps ensure the suspension functions correctly and can handle the vehicle's and passengers' weight.
- **Brake Testing:** Load cells are used in brake testing equipment to measure brake forces and loads. This helps to ensure that the brakes are functioning correctly and can safely stop the vehicle.
- **Seat Testing:** Load cells are used in seat testing equipment to measure seat forces and loads. This helps to ensure that the seats can safely handle the weight of the passengers and can provide the necessary support and comfort.
- **Crash Testing:** Load cells are used in crash testing equipment to measure the forces and loads during a crash. This helps to ensure that the vehicle's safety features, such as airbags and seat belts, are functioning correctly and can protect the passengers in the event of a crash.
- **Powertrain Testing:** Load cells are used in powertrain testing equipment to measure the forces and loads on the engine, transmission, and drivetrain components. This helps ensure that the components can handle the stresses of regular operation and provide the necessary power and torque to the wheels.

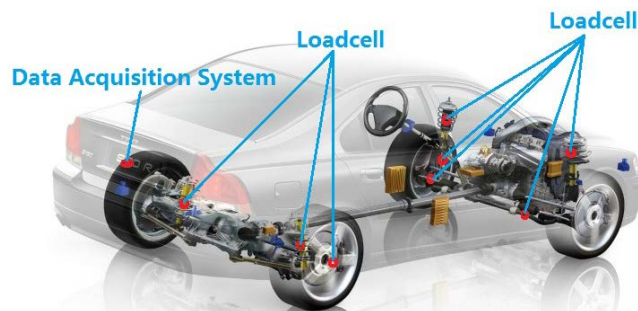


Figure 3. Load cells in automotive

Overall, load cells are critical in ensuring the safety and reliability of automotive components and systems. They help provide accurate and reliable measurements of forces and loads, essential for developing and testing new automotive technologies and ensuring that vehicles meet the necessary safety standards.

3. *Material Handling*

Load cells are widely used in material handling applications, providing accurate and reliable weight measurements. Some typical applications of load cells in material handling include

- **Cranes and Hoists:** Load cells are used in cranes and hoists to measure the weight of the lifted loads. This helps to ensure that the load is within the safe working load limit of the equipment and can also help prevent overloading.
- **Conveyor Belt Scales:** Load cells are used in conveyor belt scales, which are used to measure the weight of materials being transported on conveyor belts. This helps ensure the correct amount of material is transported and can also help optimize the conveyor system's efficiency.
- **Forklifts and Other Material Handling Equipment:** Load cells are used in forklifts and other material handling equipment to measure the weight of the transported loads. This helps to ensure that the load is within the safe working load limit of the equipment and can also help prevent overloading.
- **Pallet Jacks:** Load cells are used in pallet jacks to measure the weight of the transported loads. This helps to ensure that the load is within the weight limit of the pallet jack, and it can also help to prevent overloading.
- **Weigh Hoppers and Silos:** Load cells are used in weight hoppers and silos to accurately measure the weight of stored or dispensed materials. Accurately measuring the quantity of dispensed material helps guarantee that the correct amount is used. This can help prevent overloading or underloading by avoiding excess or insufficient material.

Overall, load cells are essential sensors in material handling applications, providing accurate and reliable weight measurements. They help ensure that the correct amount of material is transported, stored, or dispensed, essential for maintaining efficiency, safety, and quality in various industries.

2.4 Previous research on load cell-based flowmeters

2.4.1 Fuel flow selection

No	Types	Flowmeters	Suitability	Why
1	Differential pressure	Orifice plate	No	While fuel pumping, turbulent flow occurs there. It creates air bubbles that
		Flow nozzle		
		Venturi tube		
		Rotameters		
2	Velocity	Vortex	No	Creates vortexes in fluid flow.
		Electromagnetic	No	Low electrical conductivity.
		Turbine	No	Applicable in relatively big size of usage.
		Paddlewheel		
		Ultrasonic	Maybe	There is not enough research.
3	Positive Displacement	Piston	No	Low accuracy level. Mostly applicable in big sizes of usage.
		Gear		
		Helical		
4	Mass	Coriolis	Yes	Highly precise measurement. But expensive.
		Thermal	No	Diesel fuel is a flammable solution. Thermal expansion occurs.
		Impeller-turbine	No	Applicable in a relatively big size of usage.
		Gyroscopic	Yes	Highly precise measurement. But expensive.

Table 1. Fuel flowmeter selection. Source - Thesis of Dulamjargal Altankhuyg 2022

Based on the earlier factors, we conclude which types of fuel consumption meters are best for diesel engine fuel consumption. Depending on the operation principle, what selected the Coriolis mass flow measurement method from the two most suitable candidates, Coriolis and Gyroscope mass flow meters.

2.4.2 Flowmeter Placement

Comparing the advantages and disadvantages of each installation placement, the best option is a single chamber on the pressure side. It requires no external pump installation and has a relatively low measurement error compared to the differential chamber.

No	Chamber	Location	Advantages	Disadvantages
1	Single	On the suction side	<ul style="list-style-type: none"> - minimal interference into the fuel system - easy installation; - applicable to most engines 	<ul style="list-style-type: none"> - requires installation of an additional fine filter -additional load on the low-pressure fuel pump - fuel in the tank is not heated by a return flow line (a fuel heater is sometimes required)
2	Single	On pressure side	<ul style="list-style-type: none"> - locates after a regular fine filter - does not overload the low-pressure fuel pump; - fuel flows under pressure - return fuel can heat fuel in the tank 	<ul style="list-style-type: none"> - High-pressure fuel pump has slightly deteriorated - return flow fuel is lower than with a regular fuel system
3	Differential	On the suction side	<ul style="list-style-type: none"> - no changes in the fuel system - installation possible for the engine during the warranty period 	<ul style="list-style-type: none"> - higher costs - higher fuel consumption measurement error (up to 3%) - additional fine filter and meter increase load on the low-pressure fuel pump
4	Differential	On pressure side	<ul style="list-style-type: none"> - no changes in the fuel system - installation possible for the engine during the warranty period 	<ul style="list-style-type: none"> - higher costs (when compared with a single-chamber installation) - higher fuel consumption measurement error (up to 3%)

*Table 2. Coriolis Flowmeter installation locations: advantages and disadvantages.
Source - Thesis of Dulamjargal Altankhuyg 2022*

Comparing the advantages and disadvantages of each flowmeter installation placement, the best option is a single chamber on the pressure side. It requires no external pump installation and has a relatively low measurement error compared to the differential chamber.

A single chamber flow meter is installed according to the “On the suction side” scheme.

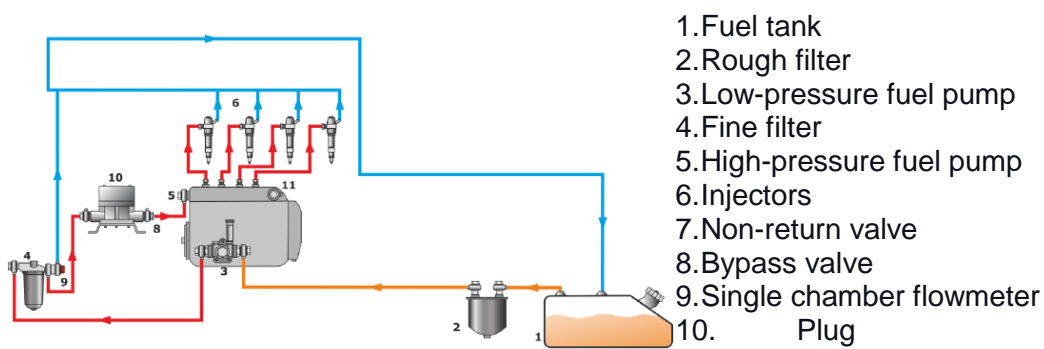


Figure 4. A single chamber flow meter is installed per the “On the suction side” scheme.
Source - Thesis of Dulamjargal Altankhuyg 2022

What will make the following changes to the standard fuel system:

- First, the return fuel line has to be modified. The fine filter output is equipped with a bypass valve and is then connected to the return line via a pipe. The excess fuel pumped by the low-pressure fuel pump will be dropped back into the fuel tank from the fine filter’s side. Hence, only the amount of fuel consumed by the engine will flow through the flowmeter.
- A bypass valve is removed from a high-pressure fuel pump output, and the appeared space has to be plugged in.

2.5 Modeling

2.5.1 Hyundai Grand Starex

This car is a GMIT staff bus that transports teachers and staff between Ulaanbaatar and Nalaikh. The Hyundai Grand Starex is a multi-purpose van manufactured by the South Korean automaker Hyundai. It was manufactured in 2013 and entered Mongolia in 2013. A 2.5-liter diesel engine powers it, and it has 12 passenger seats. According to the driver, this car consumes 15 liters of fuel per 100 km.



Figure 5. GMIT staff van, Hyundai Grand Starex

2.5.2 The fuel tank

The fuel tank design of the Hyundai Grand Starex 2013 is a standard fuel tank design that is commonly found in many vehicles. The fuel tank is made of high-quality materials designed to hold and store fuel for the engine. The fuel tank is located underneath the vehicle's rear, between the rear wheels.

The fuel tank capacity of the Grand Starex 2013 is 75 liters, which is a significant capacity and allows for long-distance travel without the need for frequent refueling. The fuel tank has a fuel level sensor that determines the fuel amount within the tank and transmits this data to the vehicle's fuel gauge.

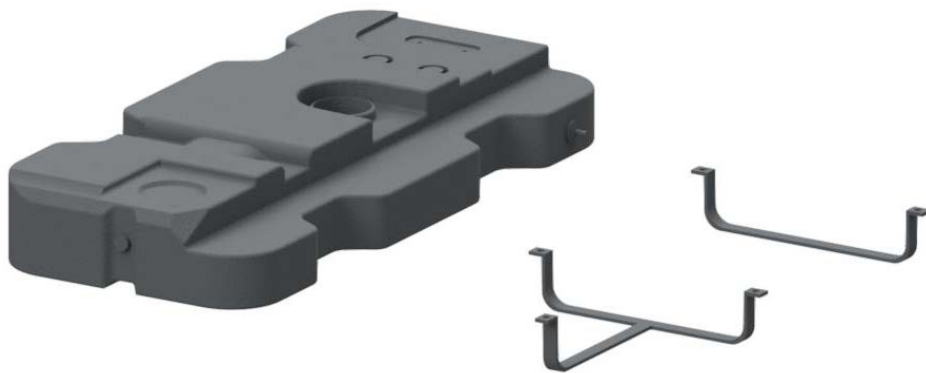


Figure 6. The fuel tank design of the Hyundai Grand Starex

3. Methodology

3.1 Overview of the proposed system

The study's main objectives are to simulate the long-term use error of the load cells by investigating how measurements are performed after long-term vibration. To simulate, adjust vibration with specific frequencies and amplitudes, and write a Matlab script showing how the external influence affected the measurement.

This flow meter is unsuitable for measuring during machine operation, and vibration directly affects the measurement. Therefore, additional tasks are to investigate techniques to measure mass during vibration.

It is necessary to continue the previous year's research and make a test frame, test the flowmeter, and then study the data and compare the measurement method by mass and other methods related to improvement.

3.2 Description of Load Cell-based Fuel Consumption Meter

A load cell-based fuel consumption meter is a device that utilizes load cells as the primary sensing element to measure fuel consumption accurately. The meter is designed to provide direct and precise measurements of the mass flow rate or weight of fuel consumed over a specific period. Below is an overview of the fundamental elements and capabilities of a fuel consumption meter that utilizes a load cell:

1. **Load Cells:** Load cells are the fundamental sensing elements of the fuel consumption meter. These specialized transducers are designed to convert mechanical force or weight into electrical signals. Load cells are typically integrated into the fuel flow path or storage system to measure the force or weight exerted by the flowing or stored fuel.
2. **Mounting and Integration:** Load cells are intentionally installed and incorporated into the fuel system to measure the forces or weights related to fuel flow. Their placement may vary depending on the application and design specifications, and they can be found in fuel tanks, fuel supply lines, or fuel transfer systems. Installing and accurately calibrating the load cells securely is essential to guarantee precise and dependable measurements.
3. **Signal Conditioning:** The electrical signals generated by the load cells are typically weak and require signal conditioning to amplify and process them

effectively. Signal conditioning circuits convert the load cell signals into usable data, such as voltage, current, or digital signals, that can be further analyzed and processed.

4. **Data Acquisition and Processing:** The load cell-based fuel consumption meter incorporates data acquisition and processing capabilities to collect, analyze, and calculate fuel consumption data. This involves capturing the load cell signals, applying calibration factors, and performing mathematical calculations to determine the mass flow rate or weight of fuel consumed. The processed data can be displayed in real-time on a digital display or logged for further analysis.
5. **Calibration and Accuracy:** Load cell-based fuel consumption meters require calibration to ensure accurate measurements. Calibration involves comparing the load cell readings against known standards or reference measurements. In addition, factors such as temperature compensation, linearity correction, and calibration drift should also be considered to maintain accuracy over time.
6. **Integration with Fuel Management Systems:** Load cell-based fuel consumption meters can be integrated with fuel management systems, vehicle telematics, or industrial control systems to provide comprehensive fuel consumption monitoring and management. This integration enables real-time data transmission, remote monitoring, and automated control of fuel consumption.

Overall, a load cell-based fuel consumption meter combines the sensing capabilities of load cells with signal conditioning, data acquisition, and processing to provide accurate and reliable fuel consumption measurements. In addition, it offers a direct measure of fuel mass or weight, eliminating the need for calculations based on density and volume, thereby improving accuracy and reducing measurement uncertainties.

3.3 Test Procedure

3.3.1 Vibration damping simulation

1. **Define vibration characteristics:** Define the vibration characteristics you want to simulate, such as vibration frequency, amplitude, duration, etc. These parameters will affect the performance of the load cell.
2. **Specify the duration of the Simulation:** Specify the period of the Simulation, in this case, 90 days and 180 days for testing.

3. Create a Time Vector: Defines a time vector covering all simulation periods. Choose an appropriate time step based on the vibration frequency and the desired accuracy of the Simulation.
4. Generate Vibrate Alerts: Generates an alert based on the specified properties. This signal can be a sine wave or a more complex one depending on the specific vibration profile you want to simulate. It can use the sin function in MATLAB to generate a sine wave.
5. Simulate load cell failure before vibration: Simulate load cell failure due to factors other than vibration before the vibration period begins. This can be affected by drift, noise, and nonlinearity. Calculate the load cell readings during the Simulation without adding the vibration signal.
6. Simulating Load Cell Errors During Vibration: Add vibration signals to the load cell readings to simulate additional errors caused by vibration during vibration. The vibration signal calculates the load cell reading during the vibration period.
7. Plot and analyze the results: Plot the simulated load cell readings. Analyze the simulated data to observe the vibration effects and assess the degradation of the load cell's performance

3.3.2 Experiment with the flowmeter

1. Equipment Setup:
 - a. Gather the required equipment, including load cells, HX711 amplifier module, Arduino board, breadboard, jumper wires, power supply, and a container for the liquid.
 - b. Following the manufacturer's instructions, connect the load cells to the HX711 amplifier module. Ensure proper wiring and connections.
 - c. Connect the HX711 module to the Arduino board using jumper wires. Refer to the HX711 and Arduino pinout diagrams for the correct connections.
 - d. Connect the Arduino to a computer or a power supply for power.
2. Calibration:
 - a. Write and upload a calibration code to the Arduino board. This code will allow you to calibrate the load cells and establish a reference point for accurate measurements.

- b. Place an empty container on the load cells and tare the system. This step sets the zero point or the initial reference measurement.
 - c. Record the tared value as the initial calibration factor.
- 3. Liquid Measurement Setup:
 - a. Fill the container with the liquid to be measured, ensuring that it covers the load cells evenly and does not exceed their specified capacity.
 - b. Ensure the container is stable and not subject to external forces or vibrations during the measurement.
- 4. Data Acquisition:
 - a. Write a data acquisition code for the Arduino board that reads the load cell values from the HX711 module.
 - b. Adjust the code to convert the raw load cell readings into meaningful units based on the calibration factor obtained earlier.
 - c. Set the sampling rate and duration of data acquisition according to the requirements of your Experiment or application.
- 5. Data Recording and Analysis:
 - a. Run the data acquisition code on the Arduino board to start recording load cell measurements for the liquid.
 - b. Collect a sufficient amount of data to ensure statistical significance and accuracy.
 - c. Store the acquired data on the Arduino board or transfer it to a computer for further analysis.
 - d. Analyze the data using appropriate software tools or programming languages. Calculate statistical parameters such as mean, standard deviation, or relevant metrics.
- 6. Validation and Accuracy Assessment:
 - a. Compare the measured liquid weight or mass obtained from the load cells with a reference measurement method, such as a weighing scale or laboratory-grade measuring equipment.
 - b. Calculate the measurement error between the load cells and the reference method to assess the accuracy of the load cell setup.

- c. Perform statistical analysis to evaluate the precision and consistency of the load cell measurements.
7. Iterative Calibration (if required):
- a. Consider performing iterative Calibration to refine the load cell setup if there are significant measurement errors or inconsistencies.
 - b. Repeat steps 2 and 3 to establish new calibration factors and validate the updated measurements.
8. Documentation and Reporting:
- a. Document the entire test procedure, including the equipment setup, calibration process, data acquisition parameters, and analysis methods.
 - b. Record the results, including measured liquid weights or masses, measurement errors, and other relevant observations or findings.
 - c. Present the findings clearly and concisely, supporting them with appropriate tables, graphs, or visual representations.

By following this test procedure, it can evaluate the performance of load cells, HX711 amplifier module, and Arduino board for liquid measurements. The Calibration, data acquisition, and analysis steps will help ensure accurate and reliable results, enabling you to assess the suitability of this setup for your specific liquid measurement requirements.

3.4 Simulation Modelling

This analysis can provide insights into the load cell's performance, its resilience to vibration, and any potential degradation or changes in its characteristics.

A MATLAB script will be developed to execute the Simulation, accurately modeling the influence of external factors on load cell measurements during long-term use. In addition, the script will consider the effect of vibrations on the measurement output and provide a visual representation of the measured data.

3.4.1 Matlab script

```
% Simulation parameters
vibrationStartDay = 30;      % Day when vibration starts
vibrationEndDay = 150;     % Day when vibration ends
vibrationFrequency = 10;   % Vibration frequency in Hz
vibrationAmplitude = 0.02; % Vibration amplitude
```

```

duration = 180;           % Duration in days
timeStep = 1;           % Time step in days

% Time vector
time = 0:timeStep:duration; % Time vector in days

% Generate vibration signal
vibrationSignal = zeros(size(time));
vibrationStartIndex = vibrationStartDay / timeStep + 1; % Index when
vibration starts
vibrationEndIndex = vibrationEndDay / timeStep + 1; % Index when
vibration ends
vibrationSignal(vibrationStartIndex:vibrationEndIndex) = vibrationAmplitude
* sin(2 * pi * vibrationFrequency *
time(vibrationStartIndex:vibrationEndIndex));

% Simulate load cell error before vibration
loadCellReadingsBeforeVibration = zeros(size(time));
initialReading = 0; % Initial load cell reading

for i = 2:vibrationStartIndex
    % Calculate load cell reading at each time point before vibration
    loadCellReadingsBeforeVibration(i) = initialReading + randn; % Add
random noise component

    % Update initial reading for the next time step
    initialReading = loadCellReadingsBeforeVibration(i);
end

% Simulate load cell error during vibration
loadCellReadingsDuringVibration = loadCellReadingsBeforeVibration; %

Initialize load cell readings during vibration
loadCellReadingsDuringVibration(vibrationStartIndex:vibrationEndIndex) =
loadCellReadingsBeforeVibration(vibrationStartIndex:vibrationEndIndex) +
vibrationSignal(vibrationStartIndex:vibrationEndIndex);

% Simulate load cell error after vibration
loadCellReadingsAfterVibration = loadCellReadingsDuringVibration; %

Initialize load cell readings after vibration
for i = (vibrationEndIndex + 1):numel(time)
    % Calculate load cell reading at each time point after vibration
    loadCellReadingsAfterVibration(i) = initialReading + randn; % Add random
noise component

```

```

% Apply additional error components (e.g., drift, non-linearity)
% based on the specific characteristics of the load cell

% Update initial reading for the next time step
initialReading = loadCellReadingsAfterVibration(i);
end

% Plot results
hold on;

plot(time, loadCellReadingsBeforeVibration, 'b', 'LineWidth', 2);
plot(time, loadCellReadingsDuringVibration, 'r', 'LineWidth', 1.5);
plot(time, loadCellReadingsAfterVibration, 'g', 'LineWidth', 1);
xlabel('Time (days)');
ylabel('Load Cell Reading');
title('Simulated Load Cell Error before, during, and after Vibration');
legend('Before Vibration', 'During Vibration', 'After Vibration');

hold off;

```

This Simulation shows a test run for 180 days. For the first 30 days, measurements will be taken in a simple, quiet environment without any vibrations. After that, for 120 days or four months, it is estimated that there will be constant vibrations with a frequency of 10Hz and an amplitude of 0.02. It simulates the vibrations that occur during the operation of the vehicle. Finally, after 120 days of operation, it will be measured again for 30 days in a quiet environment without vibration.

As a result, it graphically shows how the load cell was deformed and worn out after four months of continuous operation and whether it affected the measurement. Also, as a result of this Simulation, it is possible to analyze whether this load cell is a suitable device and technology for vehicles, especially for liquid measurement.

3.5 Test Flowmeter

3.5.1 Material Selections for Test

Load cell - custom-designed metallic components affixed with strain gages. These strain gages are resistors that change resistance when they are subjected to bending. The load cell undergoes a transformation in resistance when it bends, which is detected and precisely measured by the HX711.

The HX711 microchip amplifier - on a breakout board specifically amplifies signals from load cells and transmits them to another microcontroller. The load cells are connected to this board, relaying the measurements to the Arduino.

Microcontroller - Arduino UNO - can interpret and translate various inputs into corresponding outputs.



Figure 7. Load cell



Figure 8. HX711 amplifier



Figure 9. Arduino Uno Microcontroller

Display - TFT LCD 2.4 inch touchscreen display

Others - Breadboard 2.4 mm Pitch - for building temporary circuits

Dupont - Hookup wire - Male to male



Figure 10. 2.4 inch TFT LCD touchscreen display

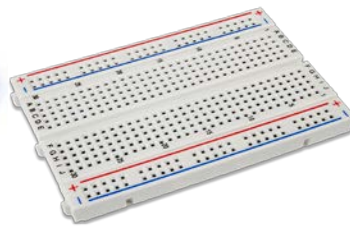


Figure 11. Breadboard and its jumper

3.5.2 Setup for test

To test, the load cell needs to be mounted. The mounting process will be unique for each individual. Still, specific guidelines must be followed:

1. The aluminum load cell should have four tapped holes and a label indicating the direction of a force. Mount the side without the label to the fixed surface and the side with the label to the moving surface. The arrow on the labeled side should point downwards in the direction the platform will move when a load is applied.
2. The mounting and moving plates should be as rigid as possible.



Figure 12. Design of frame to test

3. Clear between the mounting plates and the load cell is essential. Spacers or washers can separate them. These spacers aim to ensure that the force acting on the moving plate causes the load cell to bend and twist. Without spacers, the load will be transferred directly from the moving plate to the fixed plate without affecting the load cell.

4. See the wiring diagram to properly connect the load cells, HX711, and Arduino. Aluminum load cells have multiple strain gages that are pre-wired together to form a Wheatstone bridge. Therefore, to ensure the wires are connected to the HX711 board in the appropriate orientation.

- RED Wire is connected to E+
- BLACK Wire is connected to E-
- WHITE Wire is connected to A-
- GREEN Wire is connected to A+

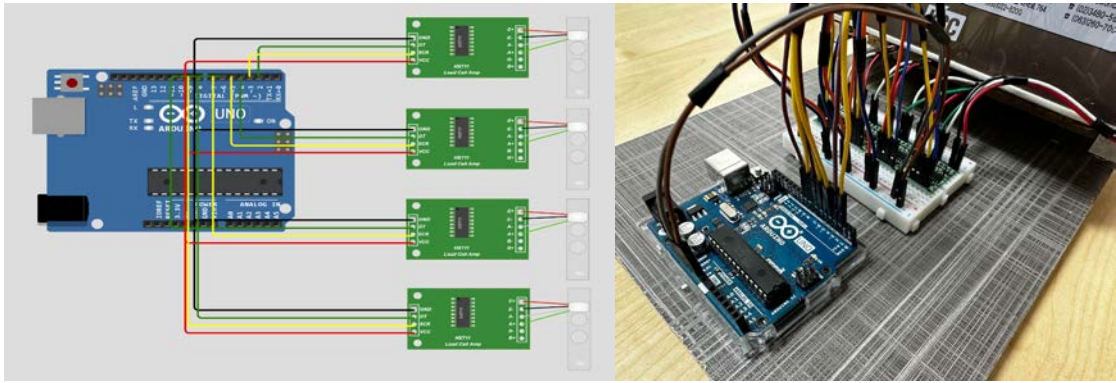


Figure 13. Connection of Arduino Uno, load sensors, and its amplifiers

5. Write and upload a calibration code to the Arduino board. To calibrate each load cell one by one.
6. After the calibration, put the code in an Appendices on the Arduino Programm window. If it works, it is possible to connect your LCD screen.



Figure 15. Frame-mounted screen

Figure 14. The test view

3.6 Measurement with Vibrations

Our design can measure the fuel mass before and after the vehicle operation or while the vehicle is stationary. Because while the car is moving, the fuel tank's orientation loses its axis. However, it needs to meet the requirements of excellent and accurate measurement. Therefore, we must explore the technology of load cells that can be measured even when the vehicle moves.

3.6.1 KIS load cell

The KIS load cell has a circular and symmetrical measuring element and a sleeve that fits concentrically over the component. This design allows loads to be applied in line with the strain gages, resulting in proportional deformation of the measuring part and leaving the strain gages unaffected by bending movement errors.

The load cell's beam also behaves similarly when subjected to side loads, enabling the transducer to reject errors caused by thermal or structural movement. Transverse side loads resulting from agitation, wind, or structural deflections are similarly dismissed. Under 100% side load conditions, the measuring element maintains its symmetrical form, ensuring accurate and stable weight measurement.

The KIS load cell boasts several features that set it apart from other load cells, including ease of installation and high accuracy even under severe environmental conditions and disturbing forces such as thermal expansion, structural movement, vibration, or twisting.

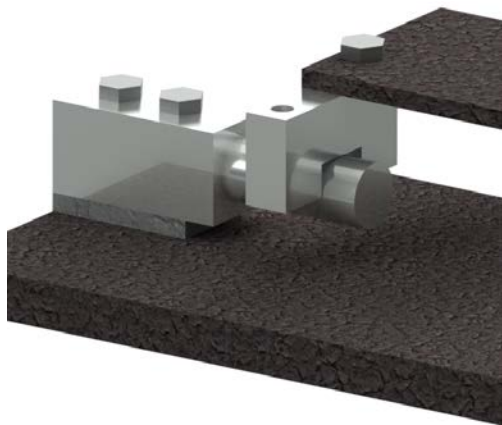


Figure 16. KIS load cell



Figure 17. Shear force load cell

Source - KIS Landing Page | BLH Nobel [Internet]. Blhnobel.com. 2023 [cited 2023 May 15].

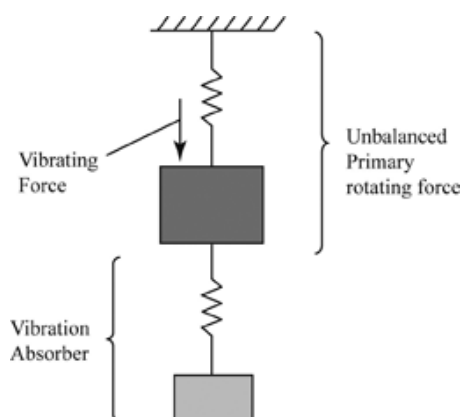
Available from: <https://blhnobel.com/products/kis-series-load-cells>

3.6.2 Waversaver

In other words, waversaver is a vibration eliminator. The working principle of a vibration eliminator, such as a vibration isolator or an anti-vibration mount, is to absorb or dampen the vibrations generated by a vibrating source and prevent them from propagating to other parts of the system or structure. The main goal is to minimize the adverse effects of vibrations, such as noise, mechanical wear, or structural damage.

The following are the general steps involved in the working principle of a vibration eliminator:

1. **Mounting:** The vibration eliminator is installed between the vibrating source and the supporting structure. It acts as a flexible connection or interface that separates the vibrating equipment from the surrounding environment.
2. **Absorption and Isolation:** When the equipment generates vibrations, they are transmitted through the structure. Depending on its design and properties, the vibration eliminator absorbs and isolates these vibrations.
3. **Energy Dissipation:** The vibration eliminator is designed to dissipate or dampen the energy of the vibrations. This can be achieved through various mechanisms, such as the deformation of rubber or elastomeric materials, the movement of fluid within dampers, or the active control systems that generate counteractive forces.
4. **Resilience and Restoring Force:** After absorbing the vibrations, the vibration eliminator may have a resilient property that allows it to return to its original position. This property enables the vibration eliminator to absorb and isolate vibrations effectively over time.



By absorbing, isolating, and dissipating the vibrations, the vibration eliminator reduces the transmission of these vibrations to other parts of the system or structure, thus minimizing the adverse effects of vibrations.

Figure 18. Working principle of vibration eliminator

4. Results and Discussion

4.1 Overview of Results

The simulation code generates load cell readings before, during, and after a specified vibration period for 180 days and 365 days.

- **Load Cell Readings Before Vibration:** The load cell readings before the vibration period will show the initial reading with random noise components. The magnitude of the noise will depend on the rand function, which generates random numbers following a standard normal distribution.
- **Load Cell Readings During Vibration:** The vibration signal will influence the load cell readings during the specified vibration period. The vibration signal is a sinusoidal waveform with a fixed frequency and amplitude. Therefore, the load cell readings will show fluctuations corresponding to the vibration signal and the random noise.
- **Load Cell Readings After Vibration:** After the vibration period ends, the load cell readings will continue to show random fluctuations due to noise components. The specific characteristics of the load cell, such as drift and nonlinearity, can also be included in the Simulation to affect the readings further.

The plot generated by the code will display the load cell readings over time, with different colors representing the periods before, during, and after the vibration. The y-axis represents the load cell reading values, while the x-axis represents the time in days.

4.3 Analysis of Results

4.3.1 Simulation of load cell before and after vibrating

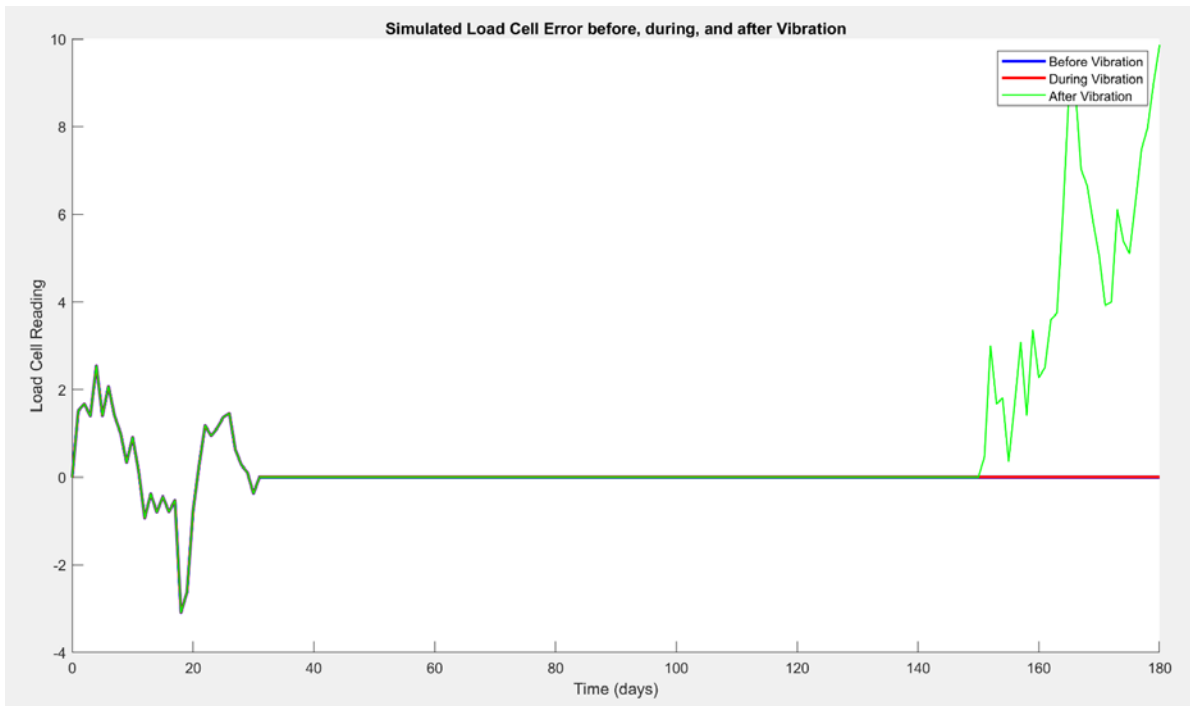


Figure 19. Result of Simulation for 180 Days

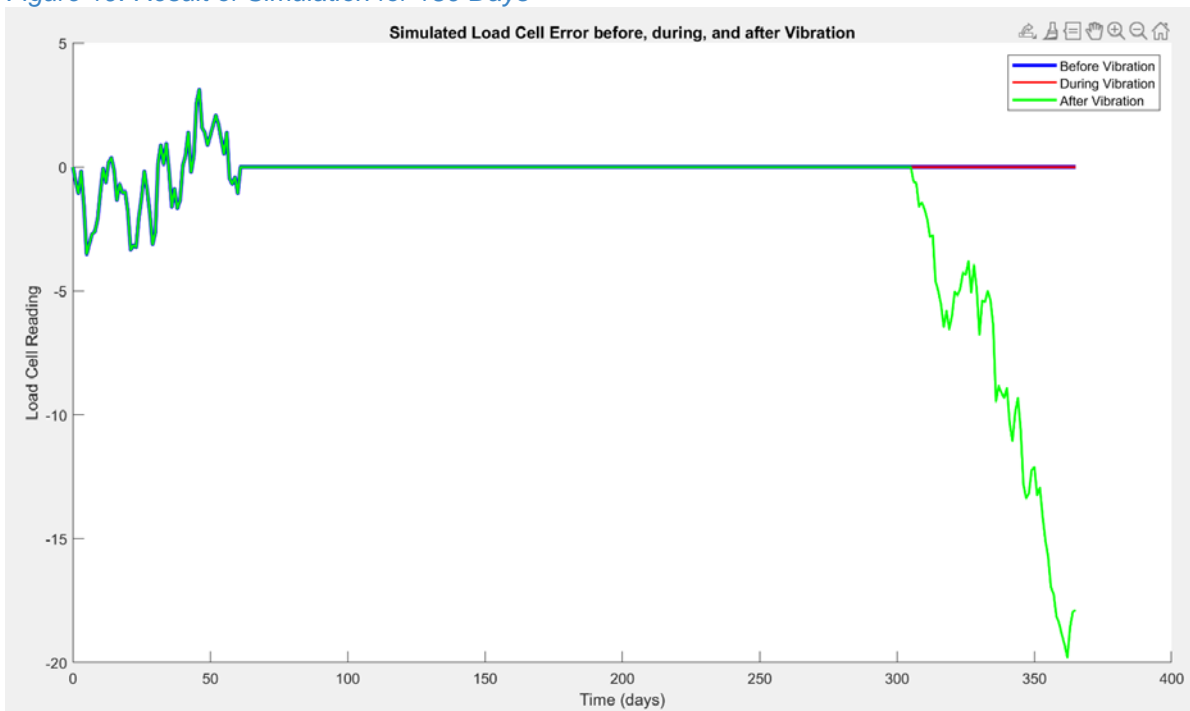


Figure 20. Result of Simulation for 365 Days

Load Cell Readings Before Vibration:

- The load cell readings before the vibration period exhibit random fluctuations due to the noise component added to the initial reading.
- The magnitude of the fluctuations depends on the characteristics of the noise, which follows a standard normal distribution.
- The load cell readings may also be affected by other error components, such as drift and nonlinearity, which can be included in the Simulation based on the specific load cell characteristics.

Load Cell Readings After Vibration:

- After the vibration period ends, the load cell readings show random fluctuations due to the noise component.
- The load cell readings may still be influenced by other error components, such as drift and nonlinearity, which can contribute to further variations.
- The magnitude and pattern of the fluctuations after vibration can differ from those observed before and during vibration, depending on the load cell's behavior and the specific error components included in the Simulation.

4.3.3 Fuel consumption meter test failed

As for the test, this needs to be improved and more effective. I checked my connection and app code several times, but it did not work because of some error. It did not work because of some error; I could not do the success test on time because I could not find the error.

There are several reasons why the test procedure outlined may not work as expected:

- **Incorrect Wiring or Connections:** If the load cells, HX711 amplifier module, and Arduino board need to be wired correctly, or the connections need to be fixed, it can lead to unreliable or inconsistent measurements. Double-check the wiring and connections to ensure they are properly established according to the manufacturer's instructions.
- **Inadequate Calibration:** Calibration is essential for accurate measurements. If the calibration process is not performed correctly or the calibration factors are not accurate, it can result in measurement errors. Ensure that the calibration process

is followed accurately and that the calibration factors are appropriately determined.

- **Unsuitable Load Cells:** The chosen load cells may not be suitable for the intended liquid measurement application. Load cells have specific characteristics and capacities that need to match the requirements of the liquid being measured. Ensure the selected load cells suit the expected load range and environmental conditions.
- **External Interference:** External factors such as vibrations, electromagnetic interference, or temperature fluctuations can affect the performance of load cells and the accuracy of measurements. Ensure the test setup is located in an environment where such interferences are minimized or controlled.
- **Limitations of the HX711 Amplifier and Arduino Board:** The HX711 amplifier module and Arduino board have limitations regarding resolution, sampling rate, and noise filtering capabilities. If these limitations are not considered, it can impact the accuracy and reliability of the measurements. Therefore, please review the specifications of the HX711 module and Arduino board to ensure they meet the requirements of the liquid measurement application.
- **Non-linear Load Cell Behavior:** Load cells may exhibit non-linear behavior, especially at the extreme ends of their measuring range. If this nonlinearity is not accounted for during Calibration or data analysis, it can introduce significant measurement errors. Therefore, consider performing additional tests or using appropriate correction algorithms to compensate for nonlinearity.
- **Liquid Characteristics:** The liquid's properties, such as viscosity or density variations, can introduce measurement challenges. If the fluid being tested deviates significantly from the assumptions made during calibration or model development, it can affect the accuracy of the measurements. Ensure the liquid properties align with the assumptions made during the test procedure.
- **Insufficient Sampling Rate or Duration:** If the sampling rate or duration of data acquisition needs to be increased, it may result in inadequate data resolution or the inability to capture transient behavior accurately. Make sure the sampling rate and duration are appropriate for the dynamics of the liquid being measured.
- **Measurement Range Exceedance:** If the load cells or the measurement setup is subjected to loads that exceed their specified capacity, it can lead to inaccurate

measurements or even damage to the equipment. Ensure the load cells and measurement setup are appropriately sized and rated for the expected loads.

- **Software or Programming Errors:** Mistakes in the code implementation or data analysis algorithms can lead to incorrect results. Double-check the code for errors, validate the data processing steps, and verify the accuracy of the software implementation.

It is essential to thoroughly review and troubleshoot each potential issue to ensure the test procedure's success. Adjustments or modifications may be necessary based on the specific circumstances and requirements of the liquid measurement application.

4.4 Discussion of Results

4.4.1 Discussion of the Simulation

The results of the 180-day Simulation show that the load cell readings after the vibration have increased significantly compared to those before the vibration. However, for the load cell that operated for 365 days, after one year, the load cell reading differs from the original, and the load cell reading has decreased. Long-term vibrations cause the error. In other words, the load cell under the vehicle's fuel tank keeps losing its axis when it moves and any potential degradation or changes in its characteristics over time. It can also be called wear.

In conclusion, the Strain gauge load cell is a simple and accurate load cell that is easy to use but unsuitable for this fuel measurement case. Since the machine constantly moves and vibrates, choosing a load cell that measures three axes instead of 1 axis is possible. Another way is to extend the life of the load cell by using vibration absorbers, as mentioned above.

5. Conclusion

The main task of this thesis study is to develop a method for measuring fuel consumption that can be used for Hyundai Grand Starex with a diesel engine.

First, flowmeters are mentioned, and information about fuel consumption flowmeters is also studied. In contrast to previous studies, more information was collected on load cells than flowmeter studies. Next, a comprehensive literature review was conducted to understand load cell technology and its applications in fuel flow measurement. Finally, the methodology section detailed the load cell-based fuel consumption meter's design, simulation, and experimental setup.

In conclusion, the load cell-based fuel consumption meter presented in this thesis is another alternative for fuel consumption measurement. Using load cells as the main element of the sensor provides real-time and accurate information without relying on density or volume calculations. The direct measurement of fuel mass or weight offered by load cell-based meters contributes to optimizing fuel efficiency, reducing costs, and reducing environmental impact.

Nevertheless, the thesis identified some limitations and challenges associated with load cell technology, such as the effects of vibration. The simulation results showed that our chosen load cell is unsuitable for a vibrating environment and will wear quickly, affecting the measurements.

However, several techniques can be used to overcome the shortcomings. For example, a KIS load cell measuring three axes can be used, and vibration absorbers can be used.

Although the test experiment was unsuccessful, it is possible to conclude because most of the primary research work has been completed. Therefore, it was concluded that this flowmeter is unsuitable for vehicle fuel consumption.

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Appendices

Calibration code

```
/*-----  
-----  
  HX711_ADC  
  Arduino Library for HX711 24-Bit Analog-to-Digital Converter for  
Weight Scales  
  Olav Kallhovd sept2017  -----  
-----*/  
  
/*This example file shows how to calibrate the load cell and  
optionally store the calibration  
value in EEPROM, and also how to change the value manually.  
The result value can then later be included in your project  
sketch or fetched from EEPROM.  
  
To implement calibration in your project sketch the simplified  
procedure is as follow:  
  LoadCell.tare();  
  //place known mass  
  LoadCell.refreshDataSet();  
  float newCalibrationValue =  
LoadCell.getNewCalibration(known_mass);*/  
  
#include <HX711_ADC.h>  
#if defined(ESP8266) || defined(ESP32) || defined(AVR)  
#include <EEPROM.h>  
#endif  
  
//pins:  
const int HX711_dout = 4; //mcu > HX711 dout pin  
const int HX711_sck = 5; //mcu > HX711 sck pin  
  
//HX711 constructor:  
HX711_ADC LoadCell(HX711_dout, HX711_sck);  
  
const int calVal_eeepromAdress = 0;  
unsigned long t = 0;  
  
void setup() {  
  Serial.begin(57600); delay(10);  
  Serial.println();  
  Serial.println("Starting...");  
}
```

```

LoadCell.begin();
//LoadCell.setReverseOutput(); //uncomment to turn a negative
output value to positive
  unsigned long stabilizingtime = 2000; // preciscion right after
power-up can be improved by adding a few seconds of stabilizing time
  boolean _tare = true; //set this to false if you don't want tare
to be performed in the next step
  LoadCell.start(stabilizingtime, _tare);
  if (LoadCell.getTareTimeoutFlag() ||
LoadCell.getSignalTimeoutFlag()) {
    Serial.println("Timeout, check MCU>HX711 wiring and pin
designations");
    while (1);
  }
  else {
    LoadCell.setCalFactor(1.0); // user set calibration value
(float), initial value 1.0 may be used for this sketch
    Serial.println("Startup is complete");
  }
  while (!LoadCell.update());
  calibrate(); //start calibration procedure
}

void loop() {
  static boolean newDataReady = 0;
  const int serialPrintInterval = 0; //increase value to slow down
serial print activity

  // check for new data/start next conversion:
  if (LoadCell.update()) newDataReady = true;

  // get smoothed value from the dataset:
  if (newDataReady) {
    if (millis() > t + serialPrintInterval) {
      float i = LoadCell.getData();
      Serial.print("Load_cell output val: ");
      Serial.println(i);
      newDataReady = 0;
      t = millis();
    }
  }
}

// receive command from serial terminal
if (Serial.available() > 0) {
  char inByte = Serial.read();
}

```

```

    if (inByte == 't') LoadCell.tareNoDelay(); //tare
    else if (inByte == 'r') calibrate(); //calibrate
    else if (inByte == 'c') changeSavedCalFactor(); //edit
    calibration value manually
}

// check if last tare operation is complete
if (LoadCell.getTareStatus() == true) {
    Serial.println("Tare complete");
}
}

void calibrate() {
    Serial.println("***");
    Serial.println("Start calibration:");
    Serial.println("Place the load cell on a level stable surface.");
    Serial.println("Remove any load applied to the load cell.");
    Serial.println("Send 't' from serial monitor to set the tare
offset.");

    boolean _resume = false;
    while (_resume == false) {
        LoadCell.update();
        if (Serial.available() > 0) {
            if (Serial.available() > 0) {
                char inByte = Serial.read();
                if (inByte == 't') LoadCell.tareNoDelay();
            }
        }
        if (LoadCell.getTareStatus() == true) {
            Serial.println("Tare complete");
            _resume = true;
        }
    }

    Serial.println("Now, place your known mass on the loadcell.");
    Serial.println("Then send the weight of this mass (i.e. 100.0)
from serial monitor.");

    float known_mass = 0;
    _resume = false;
    while (_resume == false) {
        LoadCell.update();
        if (Serial.available() > 0) {
            known_mass = Serial.parseFloat();

```

```

    if (known_mass != 0) {
        Serial.print("Known mass is: ");
        Serial.println(known_mass);
        _resume = true;
    }
}
}

LoadCell.refreshDataSet(); //refresh the dataset to be sure that
the known mass is measured correct
float newCalibrationValue =
LoadCell.getNewCalibration(known_mass); //get the new calibration
value

Serial.print("New calibration value has been set to: ");
Serial.print(newCalibrationValue);
Serial.println(", use this as calibration value (calFactor) in
your project sketch.");
Serial.print("Save this value to EEPROM adress ");
Serial.print(calVal_eepromAdress);
Serial.println("? y/n");

_resume = false;
while (_resume == false) {
    if (Serial.available() > 0) {
        char inByte = Serial.read();
        if (inByte == 'y') {
#if defined(ESP8266) || defined(ESP32)
            EEPROM.begin(512);
#endif
            EEPROM.put(calVal_eepromAdress, newCalibrationValue);
#if defined(ESP8266) || defined(ESP32)
            EEPROM.commit();
#endif
            EEPROM.get(calVal_eepromAdress, newCalibrationValue);
            Serial.print("Value ");
            Serial.print(newCalibrationValue);
            Serial.print(" saved to EEPROM address: ");
            Serial.println(calVal_eepromAdress);
            _resume = true;
        }
        else if (inByte == 'n') {
            Serial.println("Value not saved to EEPROM");
            _resume = true;
        }
    }
}
}

```

```

    }
}

Serial.println("End calibration");
Serial.println("***");
Serial.println("To re-calibrate, send 'r' from serial monitor.");
Serial.println("For manual edit of the calibration value, send 'c'
from serial monitor.");
Serial.println("***");
}

void changeSavedCalFactor() {
    float oldCalibrationValue = LoadCell.getCalFactor();
    boolean _resume = false;
    Serial.println("***");
    Serial.print("Current value is: ");
    Serial.println(oldCalibrationValue);
    Serial.println("Now, send the new value from serial monitor, i.e.
696.0");
    float newCalibrationValue;
    while (_resume == false) {
        if (Serial.available() > 0) {
            newCalibrationValue = Serial.parseFloat();
            if (newCalibrationValue != 0) {
                Serial.print("New calibration value is: ");
                Serial.println(newCalibrationValue);
                LoadCell.setCalFactor(newCalibrationValue);
                _resume = true;
            }
        }
    }
    _resume = false;
    Serial.print("Save this value to EEPROM adress ");
    Serial.print(calVal_eeepromAdress);
    Serial.println("? y/n");
    while (_resume == false) {
        if (Serial.available() > 0) {
            char inByte = Serial.read();
            if (inByte == 'y') {
#if defined(ESP8266)|| defined(ESP32)
                EEPROM.begin(512);
#endif
                EEPROM.put(calVal_eeepromAdress, newCalibrationValue);
#if defined(ESP8266)|| defined(ESP32)
                EEPROM.commit();
#endif
            }
        }
    }
}

```

```

EEPROM.get(calVal_eepromAddress, newCalibrationValue);
Serial.print("Value ");
Serial.print(newCalibrationValue);
Serial.print(" saved to EEPROM address: ");
Serial.println(calVal_eepromAddress);
_resume = true;
}
else if (inByte == 'n') {
Serial.println("Value not saved to EEPROM");
_resume = true;
}
}
}
Serial.println("End change calibration value");
Serial.println("***");
}

```

Source - [GitHub - olka1/HX711_ADC: Arduino library for the HX711 24-bit ADC for weight scales \[Internet\]. GitHub. Available from: https://github.com/olka1/HX711_ADC](https://github.com/olka1/HX711_ADC)

Software code

```

//-----
-----
// This is an example sketch on how to use this Library for two or
more HX711 modules
// Settling time (number of samples) and data filtering can be
adjusted in the config.h file

#include <HX711_ADC.h>
#if defined(ESP8266) || defined(ESP32) || defined(AVR)
#include <EEPROM.h>
#endif

//pins:
const int HX711_dout_1 = 8; //mcu > HX711 no 1 dout pin
const int HX711_sck_1 = 9; //mcu > HX711 no 1 sck pin
const int HX711_dout_2 = 6; //mcu > HX711 no 2 dout pin
const int HX711_sck_2 = 7; //mcu > HX711 no 2 sck pin
const int HX711_dout_3 = 4; //mcu > HX711 no 3 dout pin
const int HX711_sck_3 = 5; //mcu > HX711 no 3 sck pin
const int HX711_dout_4 = 2; //mcu > HX711 no 4 dout pin
const int HX711_sck_4 = 3; //mcu > HX711 no 4 sck pin

//HX711 constructor (dout pin, sck pin)
HX711_ADC LoadCell_1(HX711_dout_1, HX711_sck_1); //HX711 1

```

```

HX711_ADC LoadCell_2(HX711_dout_2, HX711_sck_2); //HX711 2
HX711_ADC LoadCell_3(HX711_dout_3, HX711_sck_3); //HX711 3
HX711_ADC LoadCell_4(HX711_dout_4, HX711_sck_4); //HX711 4

const int calVal_eepromAddress_1 = 0; // eeprom adress for
calibration value load cell 1 (4 bytes)
const int calVal_eepromAddress_2 = 4; // eeprom adress for
calibration value load cell 2 (4 bytes)
const int calVal_eepromAddress_3 = 8; // eeprom adress for
calibration value load cell 1 (4 bytes)
const int calVal_eepromAddress_4 = 12; // eeprom adress for
calibration value load cell 2 (4 bytes)
unsigned long t = 0;

void setup() {
  Serial.begin(57600); delay(10);
  Serial.println();
  Serial.println("Starting...");

  float calibrationValue_1; // calibration value load cell 1
  float calibrationValue_2; // calibration value load cell 2
  float calibrationValue_3; // calibration value load cell 3
  float calibrationValue_4; // calibration value load cell 4

  calibrationValue_1 = 696.0; // uncomment this if you want to set
this value in the sketch
  calibrationValue_2 = 733.0; // uncomment this if you want to set
this value in the sketch
  calibrationValue_3 = 696.0;
  calibrationValue_4 = 733.0;
#ifdef ESP8266 || defined(ESP32)
  //EEPROM.begin(512); // uncomment this if you use ESP8266 and want
to fetch the value from eeprom
#endif
  //EEPROM.get(calVal_eepromAddress_1, calibrationValue_1); //
uncomment this if you want to fetch the value from eeprom
  //EEPROM.get(calVal_eepromAddress_2, calibrationValue_2); //
uncomment this if you want to fetch the value from eeprom
  //EEPROM.get(calVal_eepromAddress_3, calibrationValue_3); //
uncomment this if you want to fetch the value from eeprom
  //EEPROM.get(calVal_eepromAddress_4, calibrationValue_4); //
uncomment this if you want to fetch the value from eeprom

  LoadCell_1.begin();
  LoadCell_2.begin();
  LoadCell_3.begin();

```

```

LoadCell_4.begin();
//LoadCell_1.setReverseOutput();
//LoadCell_2.setReverseOutput();
//LoadCell_3.setReverseOutput();
//LoadCell_4.setReverseOutput();
unsigned long stabilizingtime = 2000; // tare preciscion can be
improved by adding a few seconds of stabilizing time
boolean _tare = true; //set this to false if you don't want tare
to be performed in the next step
byte loadcell_1_rdy = 0;
byte loadcell_2_rdy = 0;
byte loadcell_3_rdy = 0;
byte loadcell_4_rdy = 0;
while ((loadcell_1_rdy + loadcell_2_rdy + loadcell_3_rdy +
loadcell_4_rdy) < 2) { //run startup, stabilization and tare, both
modules simultaniously
    if (!loadcell_1_rdy) loadcell_1_rdy =
LoadCell_1.startMultiple(stabilizingtime, _tare);
    if (!loadcell_2_rdy) loadcell_2_rdy =
LoadCell_2.startMultiple(stabilizingtime, _tare);
    if (!loadcell_3_rdy) loadcell_3_rdy =
LoadCell_3.startMultiple(stabilizingtime, _tare);
    if (!loadcell_4_rdy) loadcell_4_rdy =
LoadCell_4.startMultiple(stabilizingtime, _tare);
}
if (LoadCell_1.getTareTimeoutFlag()) {
    Serial.println("Timeout, check MCU>HX711 no.1 wiring and pin
designations");
}
if (LoadCell_2.getTareTimeoutFlag()) {
    Serial.println("Timeout, check MCU>HX711 no.2 wiring and pin
designations");
}
if (LoadCell_3.getTareTimeoutFlag()) {
    Serial.println("Timeout, check MCU>HX711 no.3 wiring and pin
designations");
}
if (LoadCell_4.getTareTimeoutFlag()) {
    Serial.println("Timeout, check MCU>HX711 no.4 wiring and pin
designations");
}
LoadCell_1.setCalFactor(calibrationValue_1); // user set
calibration value (float)
LoadCell_2.setCalFactor(calibrationValue_2); // user set
calibration value (float)
LoadCell_3.setCalFactor(calibrationValue_3); // user set

```

```

calibration value (float)
  LoadCell_4.setCalFactor(calibrationValue_4); // user set
calibration value (float)
  Serial.println("Startup is complete");
}
void loop() {
  static boolean newDataReady = 0;
  const int serialPrintInterval = 0; //increase value to slow down
serial print activity

  // check for new data/start next conversion:
  if (LoadCell_1.update()) newDataReady = true;
  LoadCell_2.update();
  LoadCell_3.update();
  LoadCell_4.update();

  //get smoothed value from data set
  if ((newDataReady)) {
    if (millis() > t + serialPrintInterval) {
      float a = LoadCell_1.getData();
      float b = LoadCell_2.getData();
      float c = LoadCell_3.getData();
      float d = LoadCell_4.getData();
      Serial.print("Load_cell 1 output val: ");
      Serial.print(a);
      Serial.print("    Load_cell 2 output val: ");
      Serial.println(b);
      Serial.print("Load_cell 3 output val: ");
      Serial.print(c);
      Serial.print("    Load_cell 4 output val: ");
      Serial.println(d);
      newDataReady = 0;
      t = millis();
    }
  }
  // receive command from serial terminal, send 't' to initiate tare
operation:
  if (Serial.available() > 0) {
    char inByte = Serial.read();
    if (inByte == 't') {
      LoadCell_1.tareNoDelay();
      LoadCell_2.tareNoDelay();
      LoadCell_3.tareNoDelay();
      LoadCell_4.tareNoDelay();
    }
  }
}

```

```
//check if last tare operation is complete
if (LoadCell_1.getTareStatus() == true) {
    Serial.println("Tare load cell 1 complete");
}
if (LoadCell_2.getTareStatus() == true) {
    Serial.println("Tare load cell 2 complete");
}
if (LoadCell_3.getTareStatus() == true) {
    Serial.println("Tare load cell 3 complete");
}
if (LoadCell_4.getTareStatus() == true) {
    Serial.println("Tare load cell 4 complete");
}
}
```