“Design and Development of Automated Health Monitoring System (AHMS) for Track of Armoured Fighting Vehicle (AFV) based on Inductive Sensing”

A PROJECT REPORT

Submitted in partial fulfillment of the requirements for the award of degree of

MASTER OF TECHOLOGY

IN

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BY

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CONTROL AND INSTRUMENTATION

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Dedication

I dedicate this thesis to my wife Mrs. Vasudha Venkat, children Baby Puneeth Chandra and Baby Pushya Raghavi for their ever grateful cooperation, encouragement and continuous support provided during the project duration.

CERTIFICATE

This is to certify that the project thesis titled **"Design and Development of Automated Health Monitoring System (AHMS) of an Armoured Fighting Vehicle (AFV) based on Inductive Sensing"** being submitted to the Indian Institute of Technology Madras by **N Venkatramana (EE18M003),** in partial fulfillment of the requirements for the award of the degree of MASTER OF TECHNOLOGY IN ELECTRICAL ENGINEERING is a bonafide record of work carried out by him under my supervision.

The contents of this project thesis, in full or in parts, have not been submitted to any other institute or university for the award of any degree or diploma.

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Place: Madras
Date: 25th May 2020

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ABSTRACT

The role of an Armoured Fighting Vehicle (AFV) in the modern age of combat systems is redefined as the world witnessing technical advances at peak. Primarily, AFVs are used to destroy enemy battle tanks. AFVs play a crucial role not only in defending one's own territory, but is often used to contain enemy countries' captured territories. The major visible sub systems of an AFV are Turret, Main Gun, Hull and Track apart from the various other components viz. Engine, Power Transmission, electronic controls and hydraulic pipes which are placed inside of vehicle. The four important factors for any AFV in the battlefield are fire power, accuracy, mobility and protection.

The main function of track in an AFV is to provide the vehicle with mobility on all terrains and to help carry the turret load where the main gun is fitted. An AFV's Track consists of various components such as metallic links, rubber pads etc. As the vehicle maneuvers with different speeds, the track will experience the driving conditions viz. sudden turns, reverse movement, pivot, uphill and downhill drives, trench crossings, canal fording...etc. Due to these uneven movements and sudden jerks, track may undergo physical damage at any instant. The track of an AFV is one of the important sub system to achieve smooth maneuvers and desired speeds during war scenarios. Hence health monitoring of track for an AFV is essential as it runs in various types of hard environments.

The current manual inspection by an expert technician, is tedious, time consuming, requires skilled & experienced technicians and it is done at garage. This report presents an innovative mechanism using cost effective solution for meeting such critical application by employing Inductive sensing technology.

This report emphasizes the design and development of an automated health monitoring system (AHMS) for continuous health checkup of a roller metallic chain, a scale down model of an AFV track. The AHMS is designed using commercially off the shelf (COTS) components. The document also speaks on the way out to enhance the same for an AFV application. The key advantages are less human intervention, effective maintenance, enhanced safety & security, improved overall vehicle performance, also a provision for an automated system to monitor the condition of the track / chain continuously.

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INTRODUCTION

1.1. MOTIVATION

The track of an AFV plays an important role to achieve smooth maneuvers and desired speeds during was scenarios. Presently the track health is monitored by manual method employing physical inspection at garage once the vehicle comes back from defined operation. The inspection will be carried out by a trained technician who physically sees each part of the track and notifies for maintenance if any part goes damage or missing. This process is tedious, time consuming, requires skilled and experienced technicians and it is done at garage. Continuous monitoring the health of track is an important aspect to make the vehicle on road. An automated system for health monitoring of track will definitely helps the tank crew, for continuous checking of track and for the timely indications when track goes damage, may certainly impact on decision when the vehicle is in combat operation. An Indian origin Main Battle Tank has four member crew viz. Commander, Gunner, Driver and Loader.

1.2. PROBLEM STATEMENT

Design and development of an Automated Health Monitoring System (AHMS) for track of an AFV that could provide reliable information to the Vehicle Commander.

1.2.1 Objective

To be able to identify the damages occurred in the track parts and to decide on the level of repair and maintenance required to make the vehicle on road. To develop a lab model at scale down version depicting AFV track and to measure its health parameters.

1.2.2 Scope

AFV Track may get damages knowingly or unknowingly. When AHMS is interfaced with the AFV, it can serve as a check point to ensure proper condition of track when vehicle goes for initial test run. This thesis is an attempt to present the understandings of track formation, development of test setup and lab model at scale down. The method used could be extended for AFV application in future.

1.2.3 Principle

The project is about designing and developing AHMS for AFV applications. The magnetic profile of the track can be captured by using the proximity sensor which works on the principle of inductive sensing. By observing the nature of the track profile, the condition can be assessed and a decision on its state of health can be reached.

1.3. NEED OF SUCH SYSTEM

Presently the track health is monitored by manual method employing physical inspection at garage when the vehicle comes back from defined operation. The inspection will be carried out by a trained technician who physically sees each part of the track and notifies for maintenance if any part goes damage or missing.

This process is tedious, time consuming, requires skilled and experienced technicians and it is done at garage. Hence there is a need to develop an automated system which can monitor the track health continuously therefore avoiding human intervention for physical checks. This report presents an innovative mechanism using cost effective solution for meeting such critical applications. The development of AHMS also helps in effective maintenance of track, safety and security aspects of the crew as well as the vehicle.

1.4. CHALLENGES

The design and development of AHMS for AFV poses growing challenges and bottlenecks. One important problem is data scarcity. There are no useful reference test data available for developing the AHMS. One of the crucial tasks is to carefully select the appropriate sensor to meet this application, which is supposed to work in harsh environments.

CHAPTER 2
LITERATURE SURVEY

2.1. BACKGROUND

The major visible sub systems of an AFV are Turret, Main Gun, Hull and Track apart from the various other components viz. Engine, Power Transmission, electronic controls and hydraulic pipes which are placed inside of vehicle. In general the tank crew comprises of Commander, Gunner and Driver. Each crew will have defined job to perform. Track being the most visible component of AFV can be subject to immense pressure as the vehicle maneuvers day and night in all sorts of hard surfaces and rough terrains. One needs to understand the formation of track and its sub-components while designing a automated system for health monitoring.

2.1.1 Formation of Track

The components used majorly for track formation are listed below.

i) Rubber pads
ii) Metallic links
iii) Horns
iv) End Connector
v) Screws

The pictures of above track parts are shown under for better visualization.

Fig.1. Rubber pad

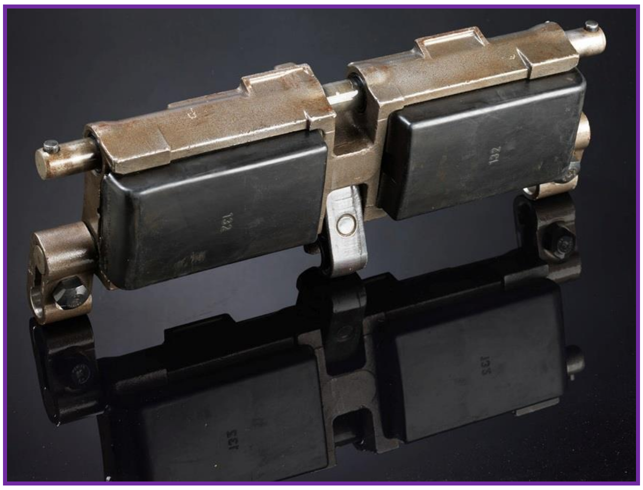

Fig.2.Individual Link

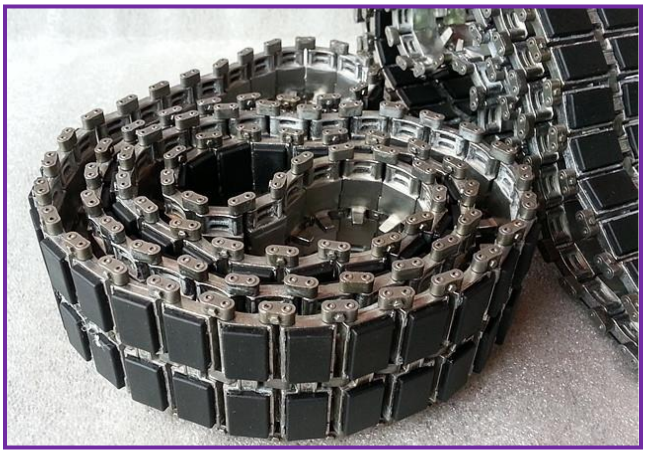

Fig.2.1. Metallic Links of a track

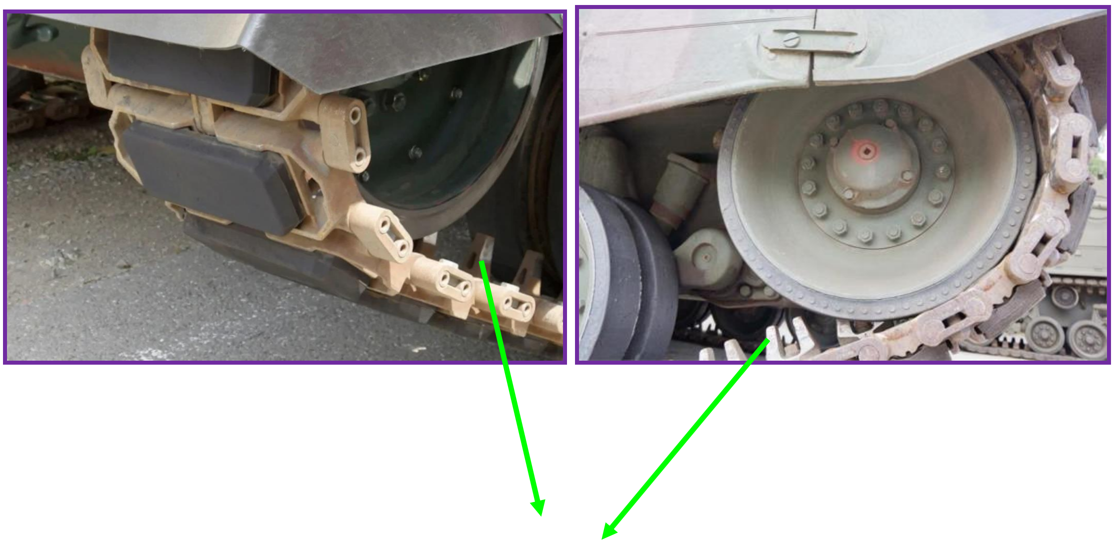

Fig.3. Horns

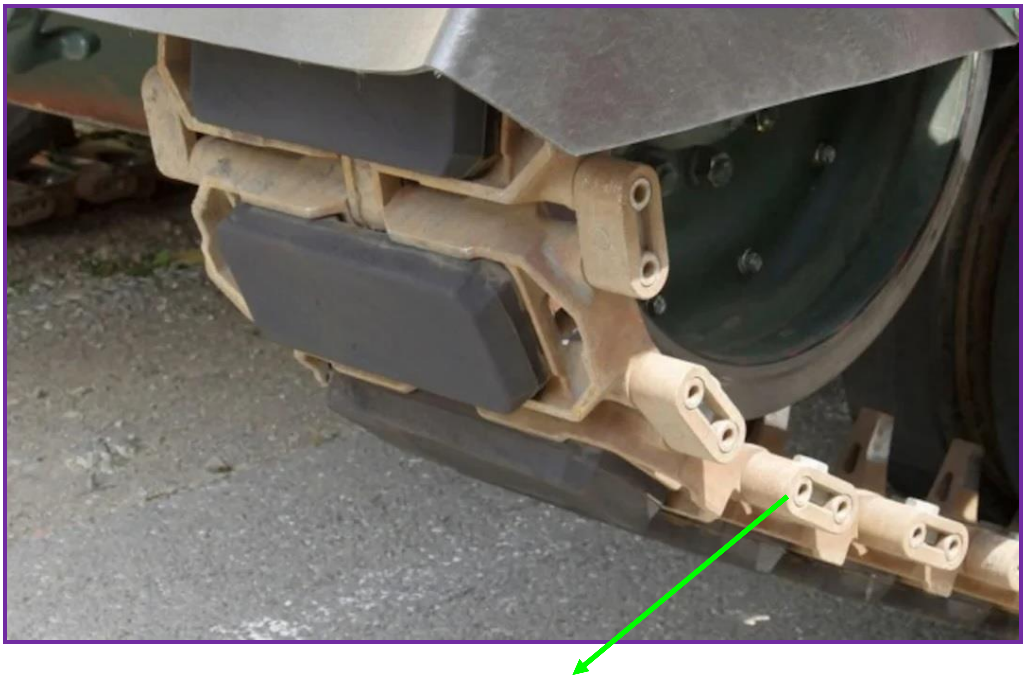

Fig.4. End Connector

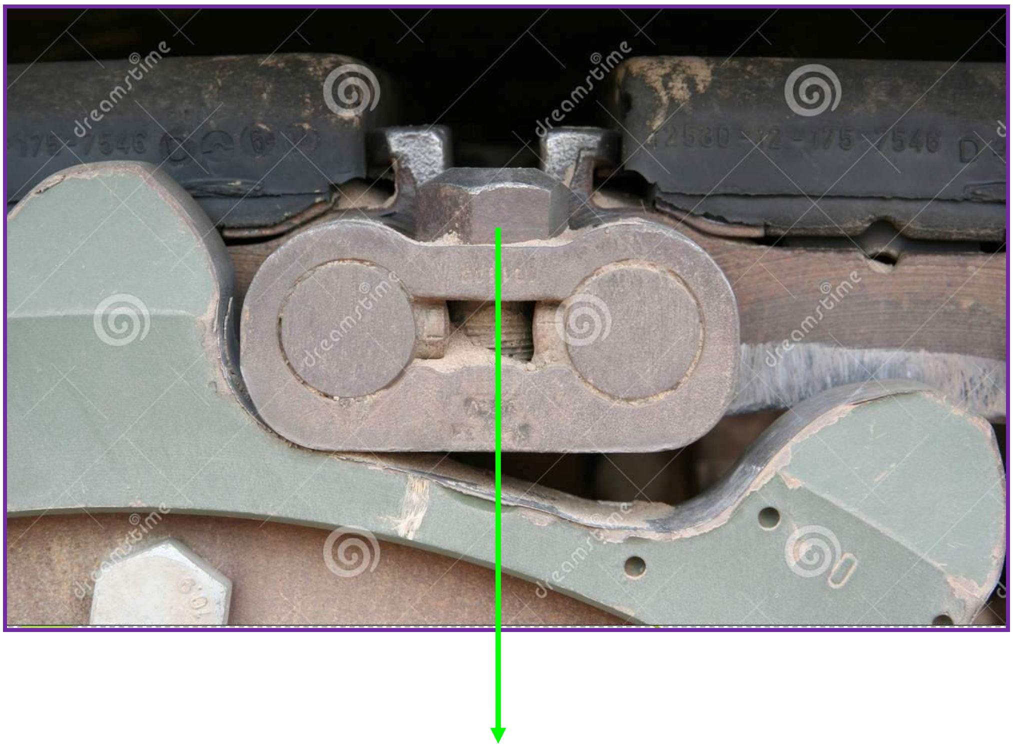

Fig.5. Screw

Fig.6. AFV Track and Road Wheels- Indian Origin

The track of an AFV consists of above mentioned sub components out of which the metallic links form as the basic component of track which is created with individual rubber pads pasting on to the metal caps. The end connector shown in fig.4., plays a significant role in maintaining track connectivity from link to link. The screw shown in fig.5., helps in tight fitment of end connector joining the individual links. The horns mentioned in fig.3., provides the balance required and support in positioning for road wheels shown on the track as mentioned in fig.6. Thus the AFV track is formed with multiple components.

2.1.2 Materials used in forming the track

Mainly Rubber composites, steel alloys and aluminum alloys are the materials used in the construction of the track.

2.2. UNDERSTANDING THE FUNCTIONING OF TRACK

The tracks (with links) of a tracked vehicle are subject to a tension control system which includes a movable idler wheel for applying force to each track, a hydraulic actuator for dynamically applying force to each track at zero spring rate, a pilot controlled check valve for selectively locking the actuator against tension relieving return movement, and a control sensitive to vehicle steering, direction of movement, acceleration and deceleration for deciding according to the requirement whether each actuator should be locked or free to move. An operator controlled switch modifies system hydraulic pressure to permit an optional low pressure operation. The various parts of hull of AFV are shown in fig.7., for better understanding.

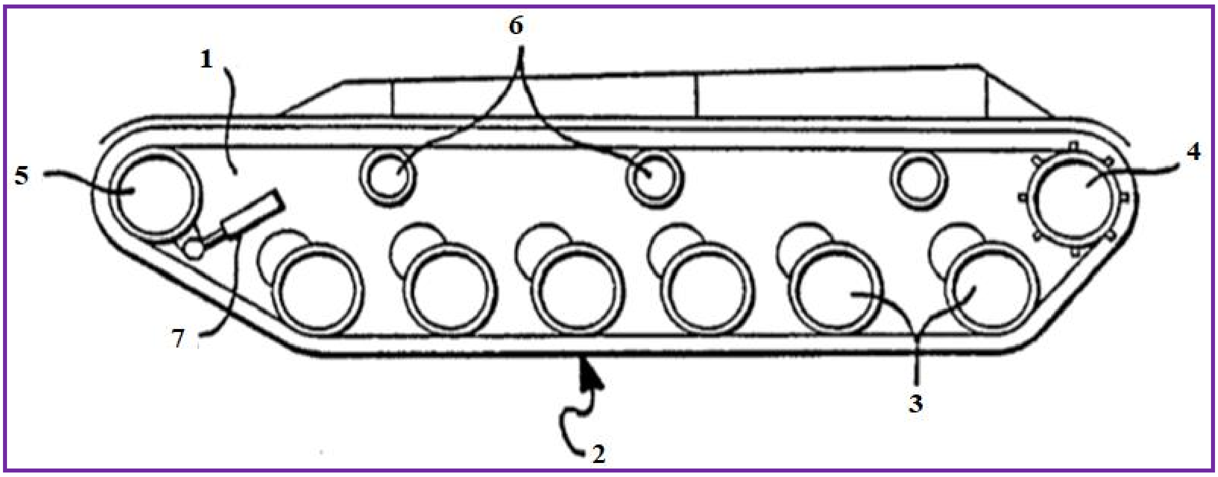

Fig.7.An elevation of tracked vehicle

1. Hull of tracked vehicle
2. Track
3. Road Wheels
4. Drive Sprocket
5. Movable Idler Wheel
6. Upper Idler Wheel
7. Hydraulic Actuator

In a tracked vehicle, especially a tank which is subject to rough terrain and severe operating conditions, the track and wheel dynamics cause widely fluctuating track tension. Typically an Idler wheel is provided to adjust tension but prior arrangements are limited in ability to control the tension. An ideal system would maintain, for all mobility scenarios, a track tension which is relatively uniform and of the lowest possible magnitude which provides proper guiding of the track throughout its entire path. Such an ideal system would maximize track and running gear life., aid in minimizing rolling resistance, which would improve drive train efficiency, assure a high level of mobility during aggressive and high speed maneuvering situations. In general a good dynamic system for track tensioning on tracked vehicles would enhance the combat readiness, reliability, and maintenance characteristics of the vehicle over its life cycle.

2.2.1 Track Tensioning System

Track tensioning systems could be grouped into two basic types based on the design: fixed idler systems and movable idler systems. In fixed idler systems, the idler wheel initially adjusted for desired static tension. The idler is then rigidly anchored to the hull. In movable idler systems track tensioning idler wheel connected to the forward road arm through a link whose length can be adjusted for a desired static tension.

2.2.2 Operating modes of Track

Track may operate in two modes: driving mode, braking mode. In driving mode the track is driven by the drive sprocket and applies a tractive effort to the ground which maintains or increases the track velocity.

In braking mode the opposite occurs to decrease the track velocity. The tension in a given section of track varies greatly as the track moves around the drive sprocket. The tension will be more on side of the sprocket nearest to the road wheels when in driving mode and less during braking mode. Reverse travel and turning changes the tension conditions on one or both tracks. The negotiation of an obstacle at high speed accentuates the difference in tensions. Thus the tension can vary widely and rapidly, if not controlled, and the wheels are affected as well.

When the vehicle is travelling forward with both tracks driving, the rear wheels tend to compress to a degree depending on the amount of tractive effort put. This reduces the total periphery of the track supporting members allowing the track to loosen and partially disengage from the tensioning idler. This condition can produce a thrown track if the vehicle should suddenly encounter an obstacle or attempt an abrupt steer maneuver.

2.2.3 Track tension and Terrain

The tension of track changes when vehicle maneuvers on different terrains. The track may get loosened or the track may become too tight based the nature of the terrain. The track components may get affected during these uneven terrain conditions when track stiffness gets changed. Different conditions of the track and the possible effects caused to the track are mentioned as under.

The findings from the literature survey are presented here:

Track - Too tight:

- machine components viz. Rollers, idler wheels, horns., will wear off faster
- Power & Productivity will consequently suffer
- Risk of tearing the track links if they are tuned too tight

Track – Too loose:

- Machines may suffer track link loss during turns or while travelling on uneven ground
- May puts operators & persons around in harming way

In general:

- Soft, muddy conditions demands slacker tracks
- Rocky, harder ground requires tighter tracks
- Maintaining track sag is harder since tension is constantly changing
- Cleanliness will affect the track tension

2.2.4 Problems and issues occur in AFV track

The major problems and potential issues occur in tracks which are attributed to the track parts viz., Cracks in End connector, Rifting of End connector, Tearing of end pins, Horn gets chopped off, Missing of Rubber pads, Track shedding..etc. The design and development of health monitoring system shall address the status of these issues., So that The track fitness can be retained while enhancing the track safety and overall vehicle performance.

2.3. ANALYTICAL TRACK MODELING FOR DYNAMIC SIMULATION

To understand the track dynamics and potential ride predictions and their connection with field test data, the results of literature survey on track models and ride dynamic track simulation are mentioned here. That helps to increase the vehicle's ride comfort.

Considering the tracked vehicle kinematics, track modeling is conceived while ignoring the vibrations of the track belt. The relative performance of these models is measured based on the accuracy of the response predictions and the computational time associated with them. The mobility performance of these off-road vehicles is often limited by the tolerance of their operators to the excessive low frequency ride vibrations induced by wheel track terrain interactions. In the presence of extremely irregular terrain surfaces, computer simulation of these off-rod vehicles often demands a high resolution non linear vehicle–terrain interaction model. In order to establish confidence in the use of computer simulated model, the Analytical predictions must be experimentally validated.

In the light of analytical modeling, a tracked vehicle represents a complete dynamical system mainly due to track presence. A tracked vehicle's ride dynamic model is built similar to wheeled vehicle despite some specific modifications to the track. For example, the enveloping characteristics of the track, wheel catching effects of the track, etc. contribute considerably to the vehicles ride dynamic behavior.

The track of high mobility tracked vehicle generally consists of:

- A number of inter connected metal track shoes with synthetic rubber pads on their inner and outer surfaces
- The adjacent track shoes are connected by a pin and rubber bushings are inserted between the pin hole walls of each shoe in order to avoid direct metal –to-metal contact between neighboring shoes

2.3.1 Strategies for track modeling

Various track modeling techniques for a clear understanding of ride dynamic simulation of tracked vehicles have been provided here.

a) Galaitsis model:

An accurate prediction of dynamic track loads would require a comprehensive model incorporating dynamics of each track shoe. However the equations of motion for track loop were developed for a tracked vehicle traversing over a flat surface by considering the inertia of shoes, stiffness and damping characteristics of the rubber bushings, and shoe-wheel interactions. But, such a track model in conjunction with rest of the vehicle yields a significantly large degrees-of-freedom dynamical system, which would be very ineffective for ride simulation purposes. Moreover the kinematic constraining effects of the track on the vehicle suspension system have more pronounced influence in ride dynamic studies than the track loop vibrations. Various modeling strategies from designers are represented as under for understanding the analytical modeling aspects of track.

a) *Eppinger's model:*

On the similar lines, Eppinger et al. developed a two degrees-of-freedom ride model, where the track was modeled as a continuous massless elastic band capable of transmitting tensile forces which are linearly proportional to the change total track length.

b) *Murphy's model:*

Murphy et al. developed a vehicle dynamics module (VEHDYN) to predict ride-shock-limiting speeds for off-road vehicles. Dynamic track loads were modeled by hypothetical vertical springs interconnecting adjacent wheels, which thus generate vertical track forces linearly proportional to the relative displacement between road wheels.

c) *Wheeler's model:*

Wheeler developed an in-plane model for the XM1 tank, where the vertical force due to the track restricting the downward motion of the wheel was considered to account for dynamic track load.

d) *Garnich model:*

Garnich et al. proposed an in-plane ride dynamic model for a M-60 battle tank crossing a discrete half round obstacle at constant forward speed. Dynamic track loads were modelled in view of four different track tensioning effects.viz. Global track tension, drive-sprocket induced track tension, track bridging effect, and tension due to track compensating linkage. The global track tension computed from change in the overall track-length was found to cause substantial change in the vehicle dynamics response.

e) *McCullough's model:*

Utilized the concept of super element representation to model a tracked vehicle, where the track tensioning effects were through catenary equations, track-wheel-ground forces, track connectivity and bridging.

f) *Bennette's model:*

The ride model developed by Bennette et al. considered the track as light string with exponential elastic characteristics measured from an initial track tension.

g) *Creighton's model:*

Creighton further enhanced the model developed by Murphy et al. to include the height of the vehicle and horizontal force effects (VEHDYN II). Where the interaction of the inclined track feelers with rigid terrain profile was also improved.

h) *Rakheja's model:*

Rakheja et al. studied the ride dynamics of an armoured personnel carrier, where the track was modelled using linear interconnecting springs as proposed by Murphy et al.

i) *Galway's model:*

Galway et al. proposed a ride simulation model for off-road vehicles traversing deterministic terrain profiles, where the track belt was assumed to be inelastic, and track tension was computed based on the pseudo-catenary approximations.

2.3.2 Track Sag

The track sag indicates the amount of slack found in the hanging track, and specifies the pre-tension of the track. A track suspended between two hull wheels can be treated as a cable hanging between two fixed supports under its own weight.

2.4. MEASUREMENT OF TRACK STIFFNESS

Measurement of track stiffness is useful for determining the condition of track. It is important to find out what causes problems with the sub-structure. Stiffness measurement of track potentially useful technique for system wide evaluation of track Safety & Performance.

After researching the track analytical models it is understood that the test data is essential to complete the dynamic simulation of the track from which the stiffness can also be known. It was therefore decided to design and develop a laboratory model, to depict the track and to try to measure health from the same.

2.5. STANDARDS, UNITS AND TOOLS

The present work focuses on Inductive proximity Sensors., The Sensor is of industrial grade.

2.5.1 UNITS

The shift in the Inductance is measured in terms of Micro Henries (µH).

2.5.2 SOFTWARE TOOLS

The software tools needed to be used are mentioned below.

(i) Sensing Solutions EVM GUI Tool V1.10.0 - for data capturing from Sensor

(ii) MATLAB 2019a – for plotting the sensor output and for analyzing the Profiles

CHAPTER 3
EXPERIMENTAL SETUP

DESGN AND DEVELOMENT OF LAB MODEL

3.1. SYSTEM ARCHITECTURE

The lab model system architecture is shown in Fig.8., which consists of Proximity Sensor, Personal Computer (PC), Metallic Roller Chain Assembly. In short, when operator operates the roller chain the sensor reads the data. Sensor output data will be displayed and stored in PC / Laptop. The sensor data are then analyzed using the MATLAB tool, and the data analysis be carefully understood by the operator. Now the operator will decide the health condition of roller chain and takes decision to run or stop the operation of roller chain based on the nature of the magnetic shift measured by the sensor continuously.

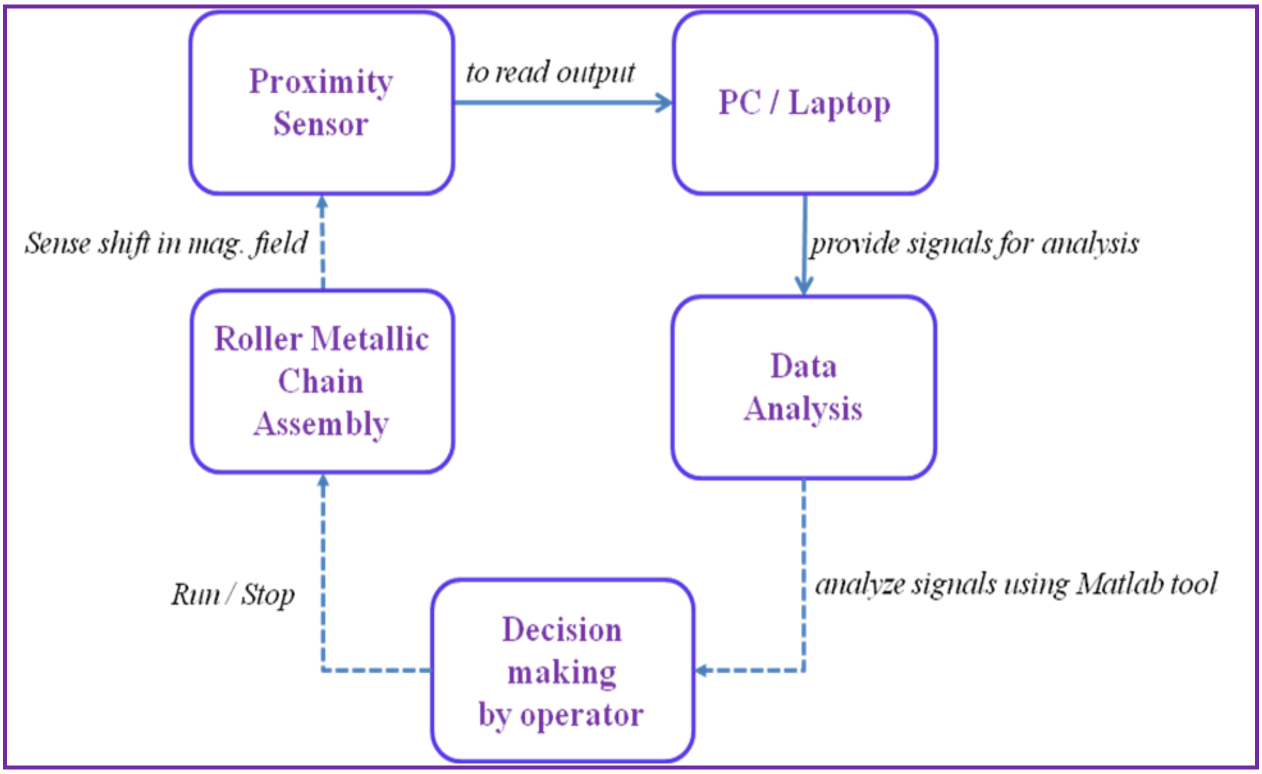

Fig.8. Laboratory model - System Architecture

3.2. HARDWARE DESIGN AND DEVELOPMENT

System design procedure: The following should be considered in order to design an AHMS for optimal performance.

1. *Mechanical system design:* The quantity, size, arrangement of mechanical components, as well as the optimal spacing between the target to sensor can influence the response of the system. The aspect of the system design is used to address the physical interface specifications. Considerations such as the no. of components viz. switches, mounting requirements, the size and shape of the mechanical components, materials used to fulfil the system requirements all need to be determined.
2. *Sensor Selection:* Sensor needs to be selected based on the system requirements of the resolution, accuracy and sensing environment. For the current project development, the LDC 1612 EVM is chosen to meet the lab model design requirement..
3. *Other considerations:* Power consumption, permanent mechanical changes, availability of components, cost implications, system portability and flexible operation need to be considered.

The system here refers the laboratory model, is developed with commercially available, low-cost components.

Components used for system development:

a. Proximity Sensor - LDC1612, Interface Cable (Part No. 3025010-03)
b. DC Motor Assembly
c. Starter Relay (UNO MINDA 850047 Starter Relay-12V/80 A- with wire coupler and C bracket)
d. Chargeable Battery (with lengthy leads)
e. Industrial switches for Motor and LED Light operation
f. Roller chain with metallic links
g. Sprockets (front & rare)-larger teeth
h. Sprocket (centre)-smaller teeth
i. Wheels with metal stud at centre

j. Flexible arm

k. Wood board & stand with dual safety

l. PC., and other necessary accessories

Fig. 8.1. Starter Relay

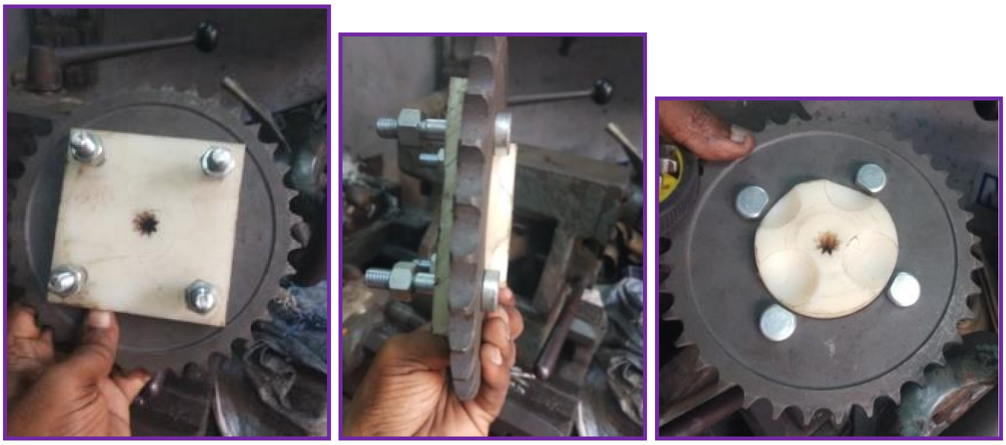

Fig.9. Sprockets (front & rare)-larger teeth

Fig.10. Sprockets (Centre)-Smaller teeth

Fig.11. Wheels with metal stud at centre

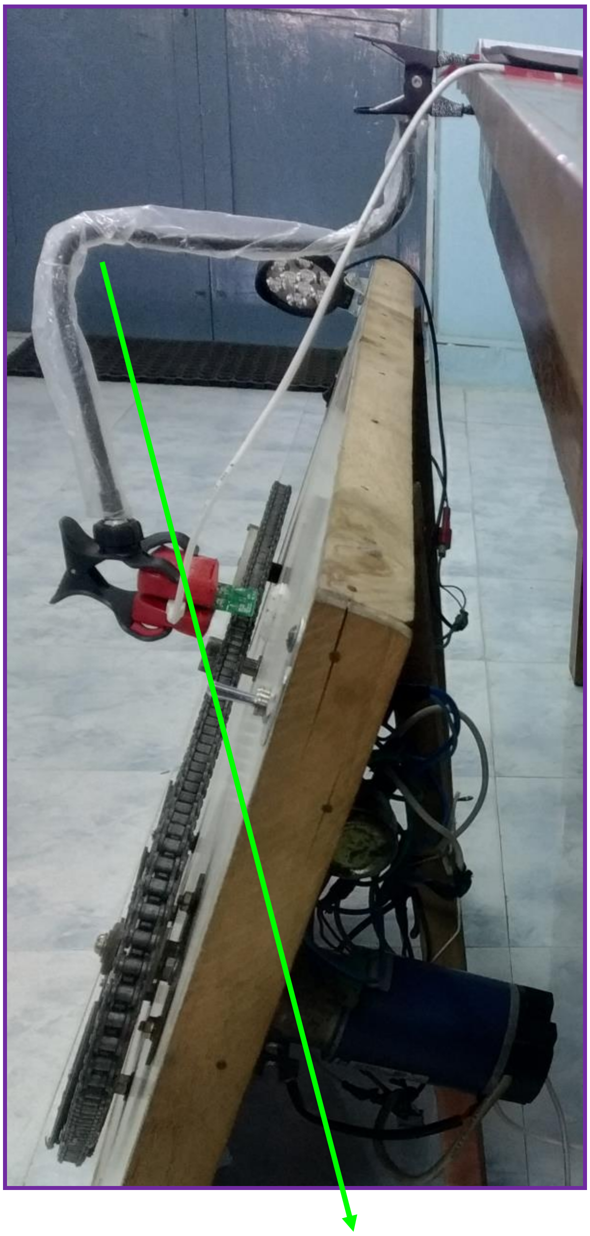

Fig.12. Flexible Arm

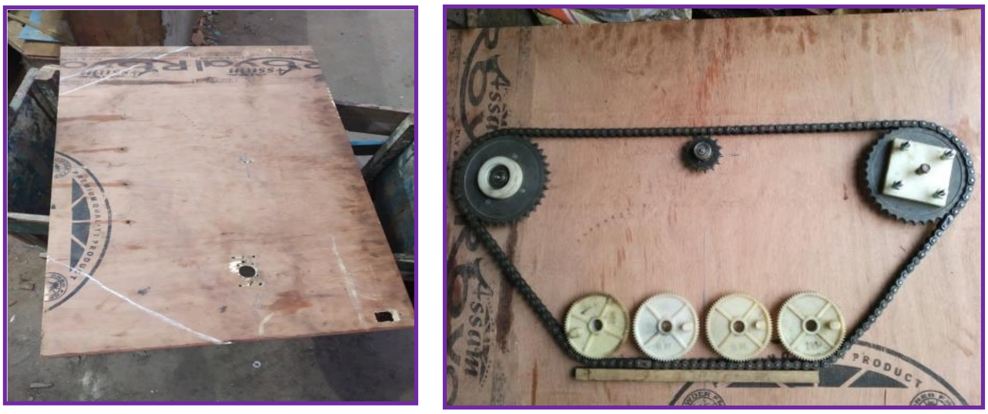

Fig.13.Wood board with Gears custom designed

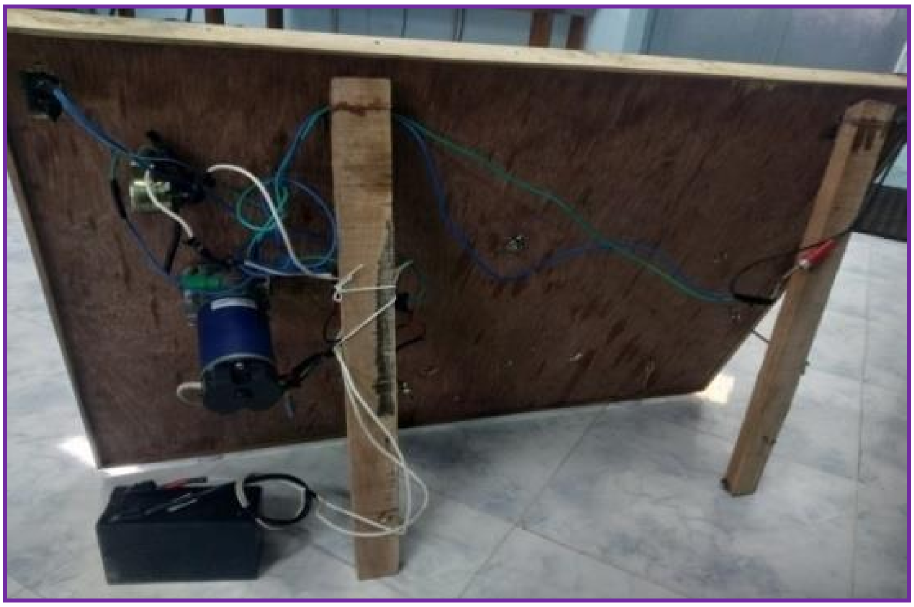

Fig.14. Wood Stand with dual safety

The lab model is developed with components mentioned above. The roller metallic chain of two Wheeler TVS SUPER XL, was used to make the trapezoidal structure identical to AFV Track. These chains generally consist of rollers and pins, and rollers are made with high carbon and hardened. The pins are made of hardened steel, too. The larger toothed Sprockets are used to replicate the Drive and idler at top corners of the structure. Smaller toothed sprocket is used as track adjuster placed exactly at the top centre of the structure. Toy wheels are used to depict the road wheels. All the three sprockets, 4 wheels are tightly fitted to the wooden board with custom made gears and metal studs anchored to the board.

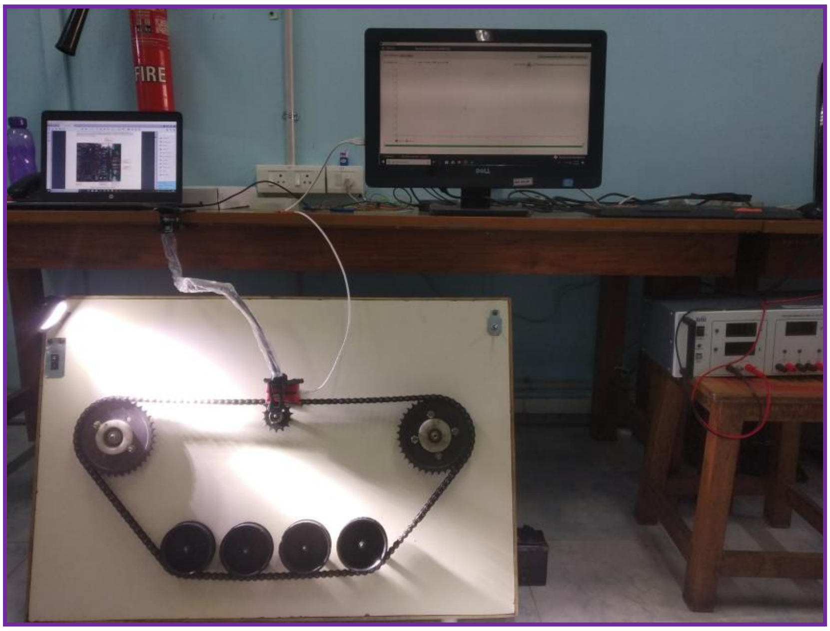

Fig.15. Mechanical design – depicting AFV track

The wooden board is custom designed to suite the track like set-up. DC Motor powered by traditional battery is used to power the Drive sprocket. Starter Relay is used for energizing the motor. Industrial switches are used for control of the Motor and LED light, placed at the top corner of the board. The firm stand with dual safety is made to position the set-up at a convenient angle for viewing and operating. Plastic Bushes have been provided at the bottom for providing balance to the board when it made stand at an angle. Flexible arm is used to position the sensor onto the board at various desired locations.

3.2.1 Functioning of System

The system functioning is defined in two ways viz. clock wise (CW) operation and Counter clock wise (CCW) operation. First the metallic roller chain is made to rotate in clockwise direction by the operation of DC motor. The sensor output i.e., the magnetic field profile of chain has been recorded in the PC by placing the sensor at desired location using flexible arm. It will be done for full rotation cycle, and the same will be repeated for the number of cycles necessary.

The sensor output is measured for various speeds. This is achieved by changing the DC motor speed. The motor can operate at the supply voltage up to 36 V. Hence by increasing the battery voltage to the motor in steps viz. 6V, 12V, 18V, 24V, 30V..etc the magnetic profiles will be captured for analysis. The sensor output for counter clock wise (CCW) rotation of the roller metallic chain is measured by reversing the DC motor rotation by changing the polarity of battery power leads, and repeating the above mentioned procedure.

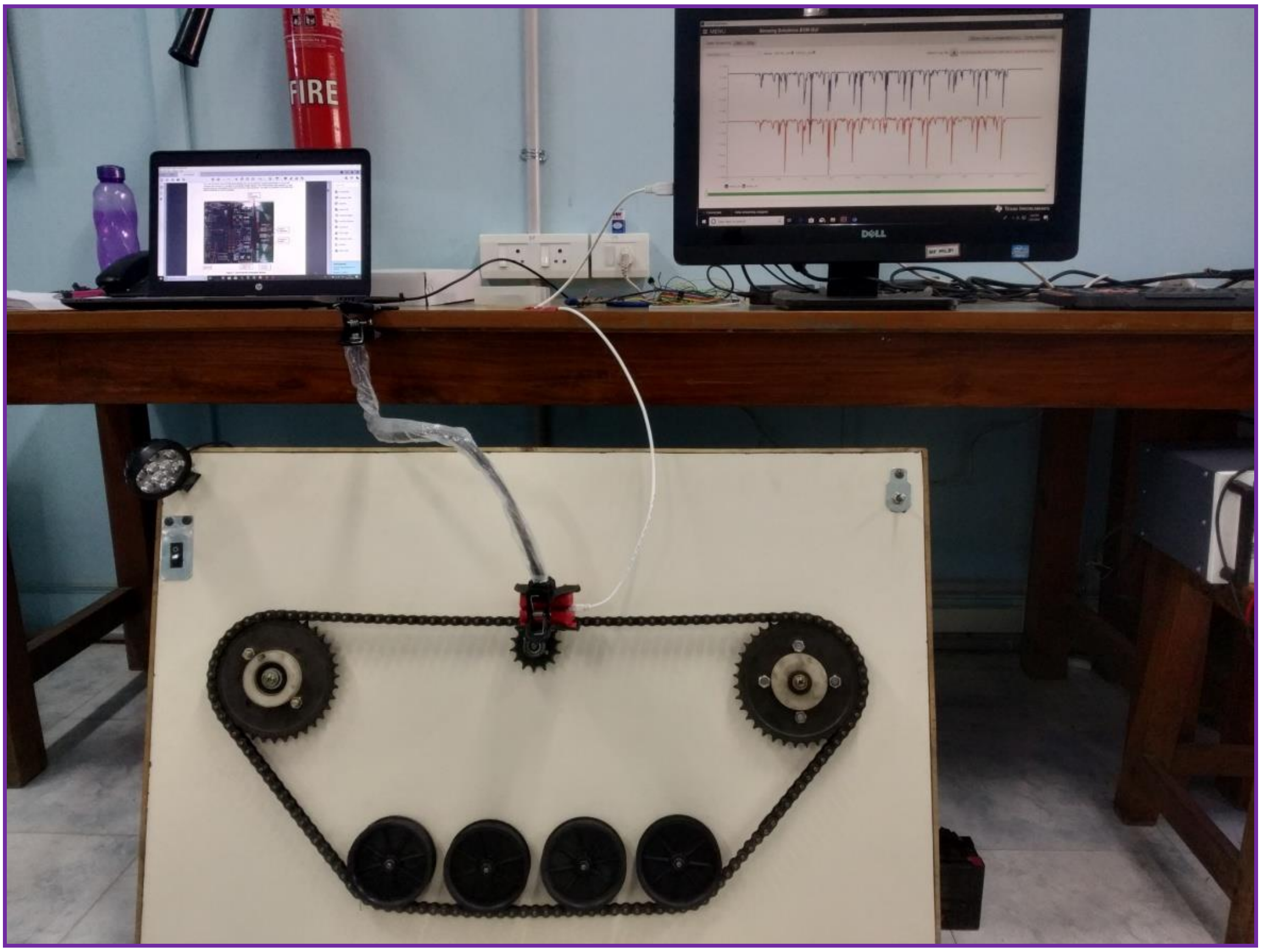

Fig.15.1. System operation when sensor placed at the centre

3.3. SENSOR MODULE

A proximity sensor is a sensor that can sense the presence of nearby objects without any physical contact. The proximity sensor usually emits an electromagnetic field or a beam of electromagnetic radiation (infrared, for instance), and looks for changes in the field or return signal.

The object being sensed is often referred to as the sensor's target. Different targets for the proximity sensor require different sensors. For example, a capacitive proximity sensor or photoelectric sensor may be ideal for a plastic target; a metal target often needs an inductive proximity sensor. The goal is the metallic roller chain, and the inductive sensor is the right option. The same will also be suitable for AFV application.

3.3.1 Inductive Sensing

Inductive sensing works on the principle of electromagnetic coupling between a sensor coil and the metal target to be detected. When the metal target enters the EM field induced by a sensor coil, some of the EM energy is transferred into the metal target as shown in Fig.16. Transferred energy causes a circulating electrical current called an eddy current. The eddy current flowing in metal target induces reverse EM field on the sensor coil, which results in a reduction of effective inductance of sensor coil. This shift in the inductance will be measured using sensor.

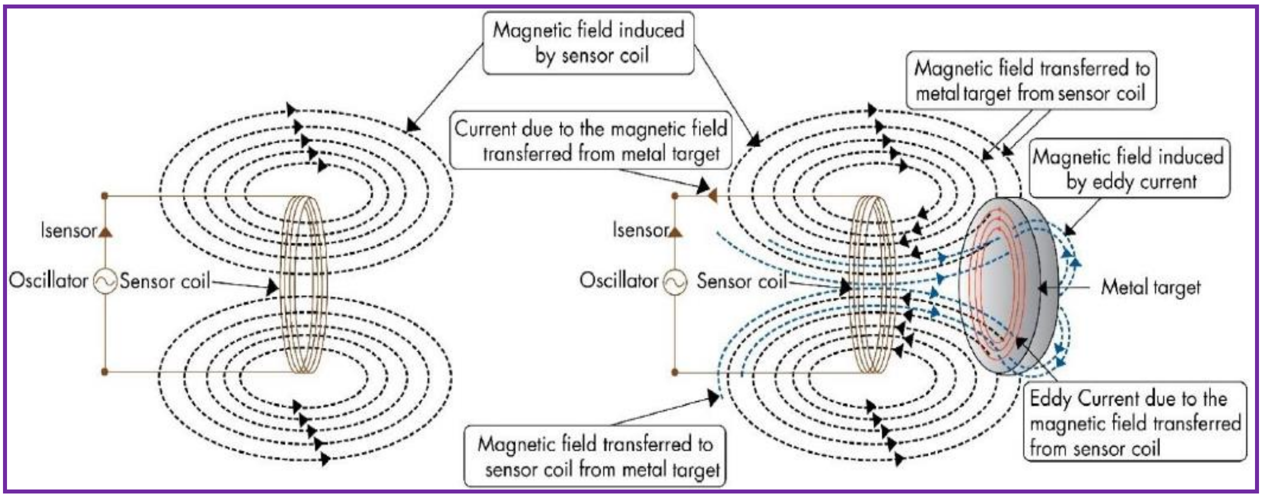

Fig.16. Field coupling between sensor and metal target

An inductive sensor is a device that uses the principle of electromagnetic induction to detect or measure the metallic objects. As discussed, an inductor develops a magnetic field when a current flows through it; alternatively, a current will flow through a circuit containing an inductor when the magnetic field through it changes. This effect can be used to detect metallic objects that interact with a magnetic field. Non-metallic substances such as liquids or some kinds of dirt do not interact with the magnetic field, so an inductive sensor can operate in wet or dirty conditions.

3.3.2 Advantages of Inductive Sensing

- Reliable of being contactless, Does not require magnets
- Insensitive to environmental Contaminants (dust, dirt..etc)
- Sub micron Resolution, Low cost
- Electronics can be located remotely from the sensor

3.3.3 Sensing Range

The sensing range of an inductive Sensor or switch is dependent on the type of metal being detected. Ferrous metals, such as iron and steel, allow for a longer sensing range, while nonferrous metals, such as aluminum and copper, may reduce the sensing range by up to 60 percent. Since the output of an inductive sensor has two possible states, an inductive sensor is sometimes referred to as an inductive proximity switch. The LDC 1612 has sensing range up to 28mm with high accuracy.

3.3.4 LDC 1612 EVM Sensor features

The LDC 1612 EVM includes two PCB sensors which are PCB inductors with 330 Pf 1% COG/NP0 capacitors connected in parallel to form an LC tank. PCB perforations allow removal of the sensor coils or the micro controller, so that custom sensors or a different micro controller can be connected. The sensing solutions EVM GUI provides direct device register access, user friendly configuration, and data streaming.

System requirements for GUI installation:

The host machine is required for device configuration and data streaming. The following steps are necessary to prepare the EVM for the GUI:

- The GUI and EVM drive must be installed on a host computer
- The EVM must be connected to a full speed USB port(USB 1.0 or above)

The Sensing Solutions EVM GUI supports the operating systems (both 32-bit and 64-bit):

- Windows XP, Windows 7, Windows 8 & 8.1 and Windows 10

Connecting and configuring the EVM:

1. Attach the EVM to the computer through USB.
2. The GUI always shows the connection status on the bottom left corner of the GUI.

Configuring the EVM Using the Register Page:

The register page allows users to control the device directly with the register values. The user may also use this page to read the current register values on the device. User may choose to auto read the register values, manually update of registers.

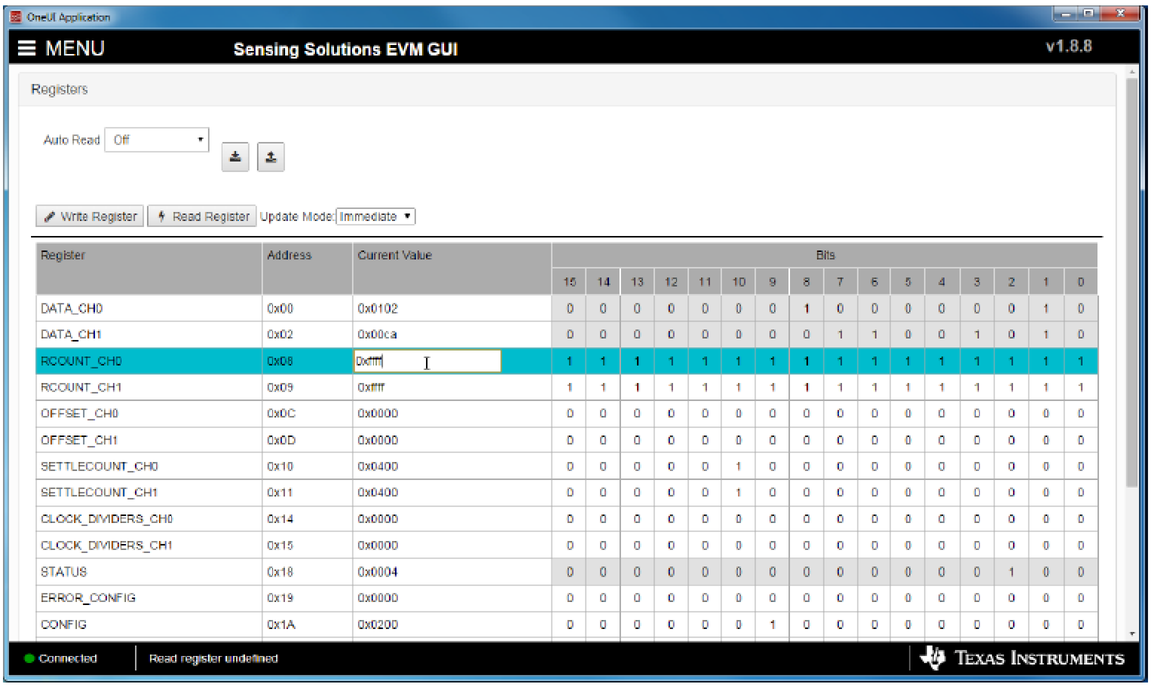

Fig.16.1. Selecting a Register's Current Value for Editing on Register page

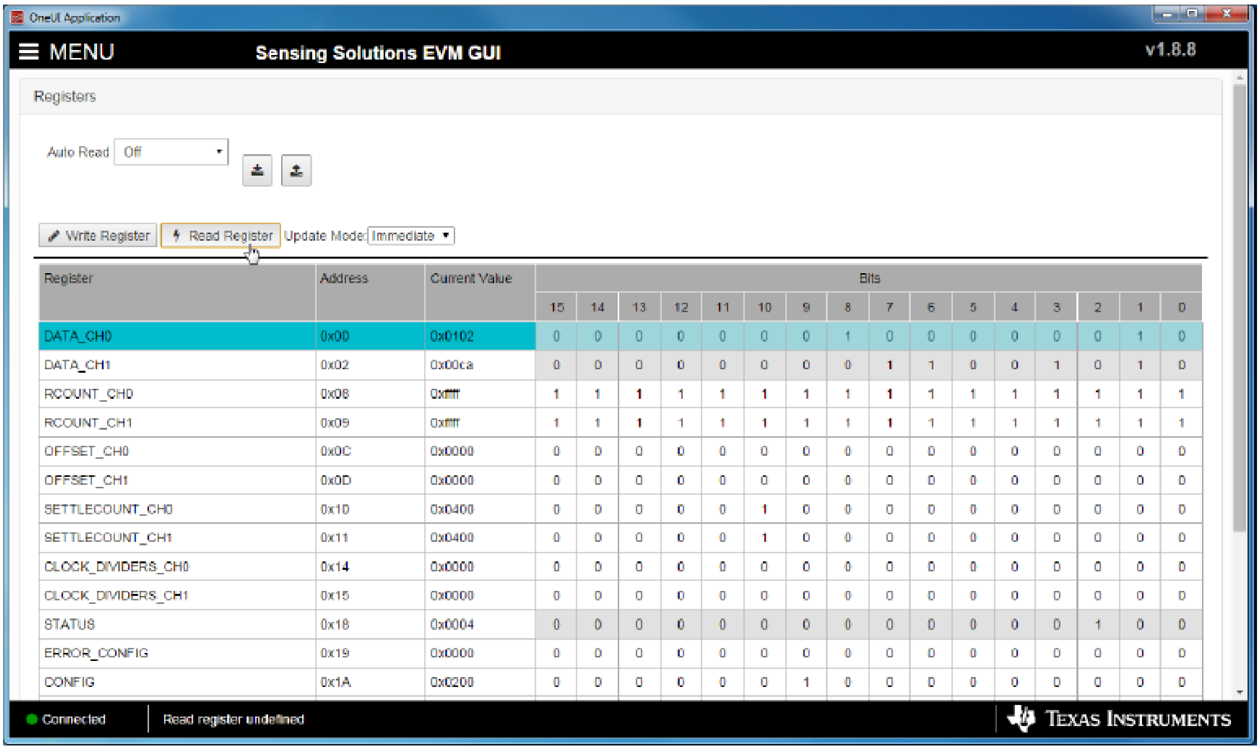

Fig.16.2. Reading the current device Register value on a register page

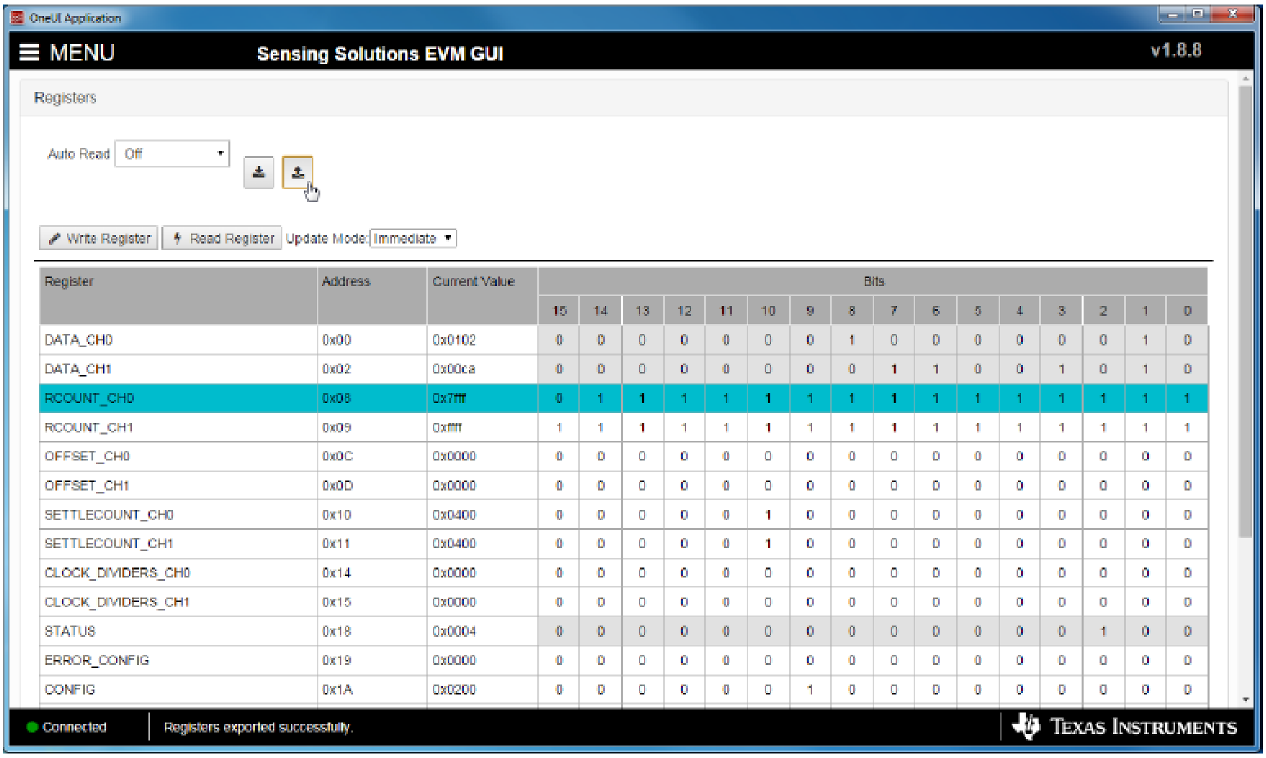

Fig.16.3.Loading previously saved Register values from file on register page

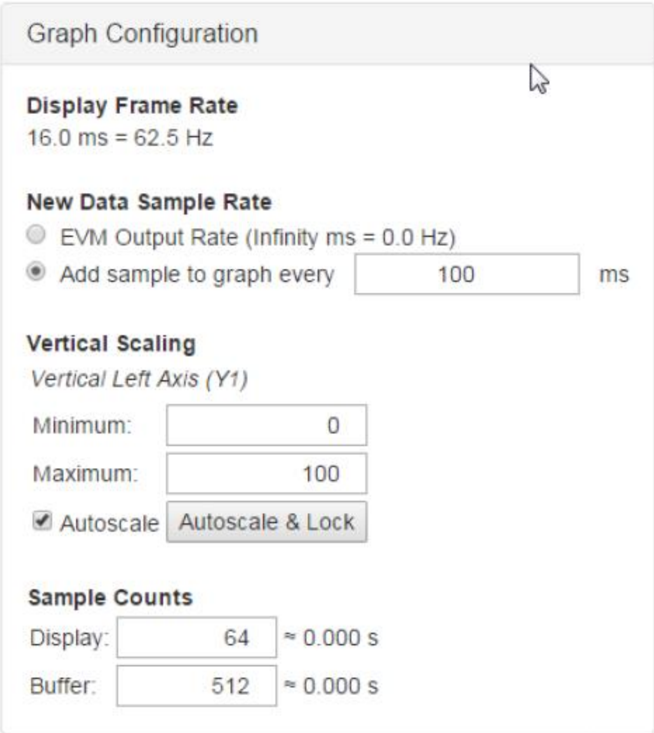

Fig.16.4. Graph configuration on data streaming page.

The user may enable or disable channels measurements, can use different sensor, can do streaming of measurement data, loading data to a file. Also the user can start and stop streaming of data. User can see the data statistics, may configure the graph.

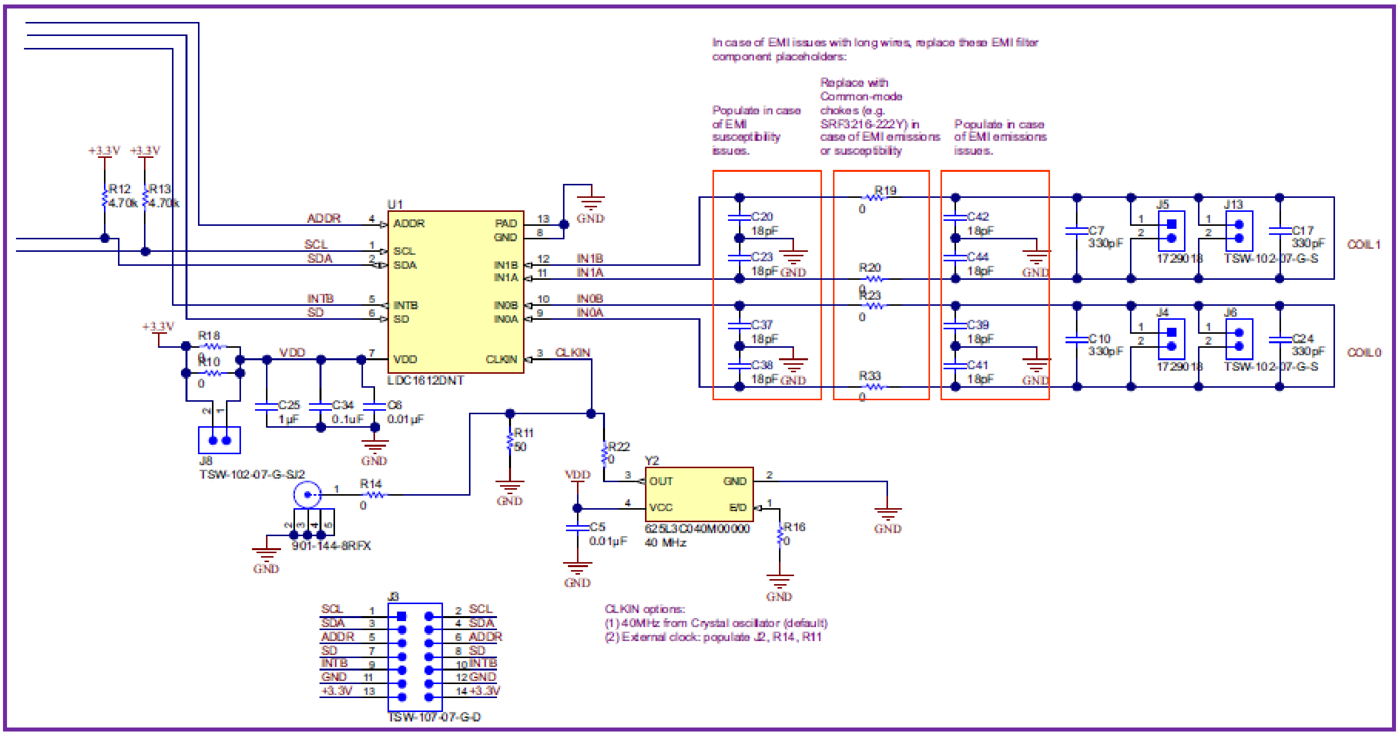

Fig.16.5.LDC 1612 Circuit diagram

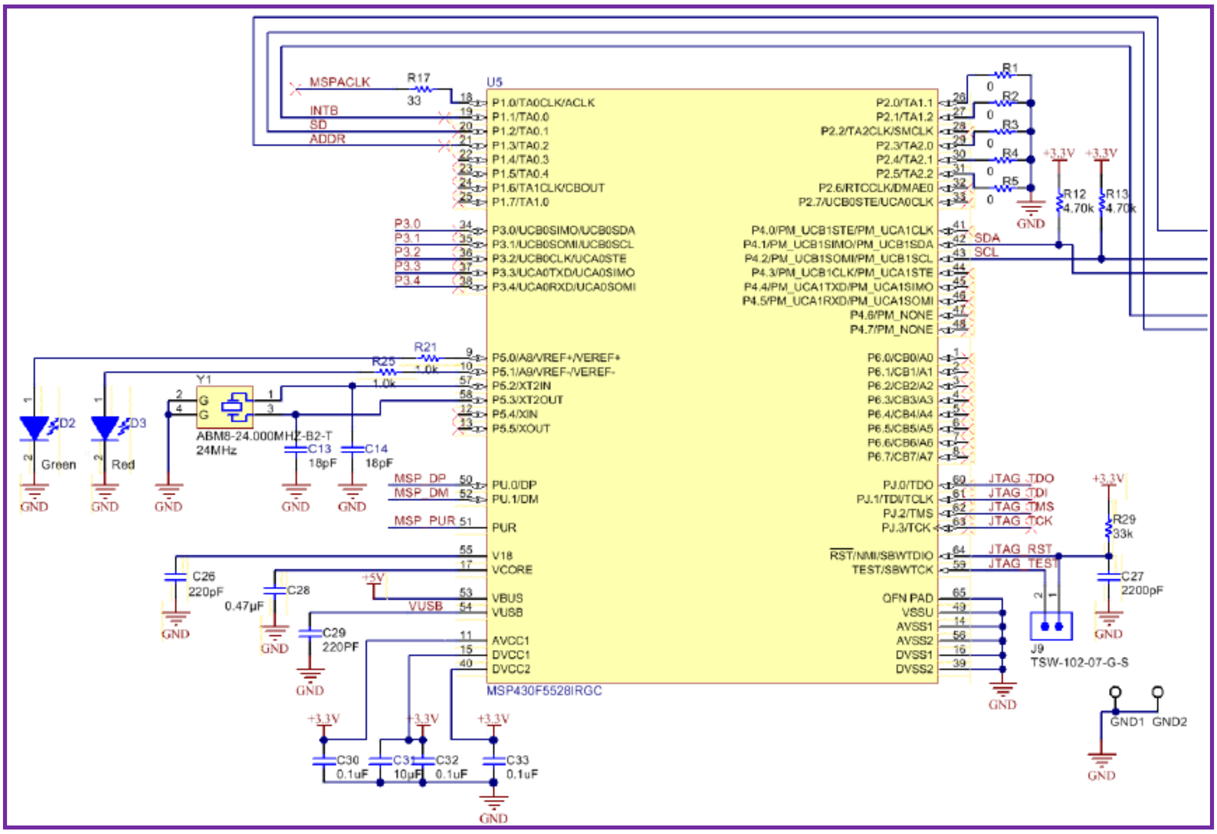

Fig.16.6.LDC 1612 MSP430 Schematic Connections

Key features of LDC:

- Inductive Sensing Technology, Non-Contact Detection and Measurement
- Increased Flexibility and Performance without requiring Analog Trimming Techniques
- Remote Sensor Placement
- Insensitive to Environmental Contaminations
- More Reliable Operation, Sensor Self Diagnostic
- High Resolution and Accurate
- Replaces Legacy Analog only solutions
- Low Power, Low Cost, and Low footprint solution

Featured Application:

- Factory Automation and Process control
- Sensors and Field Transmitters
- Building Automation and Portable Instruments

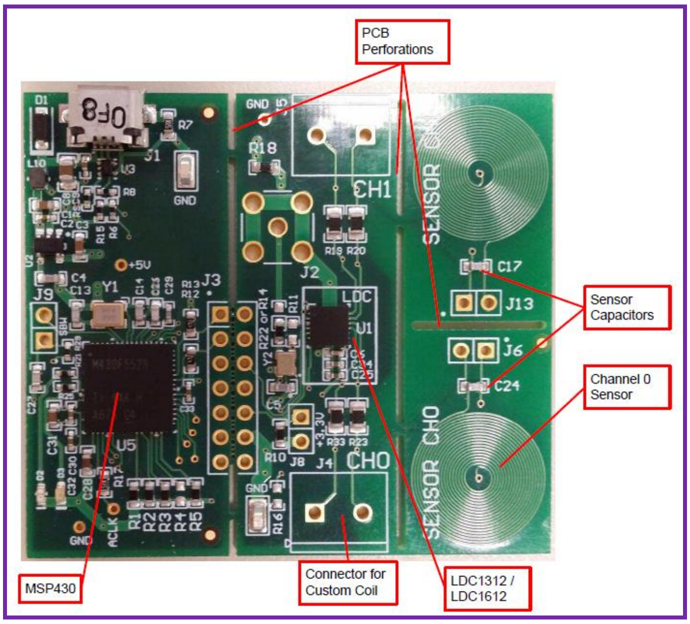

Fig.18. LDC 1612 Sensor PCB Fig.17. LDC 1612 EVM Sensor module

Working Principle of LDC:

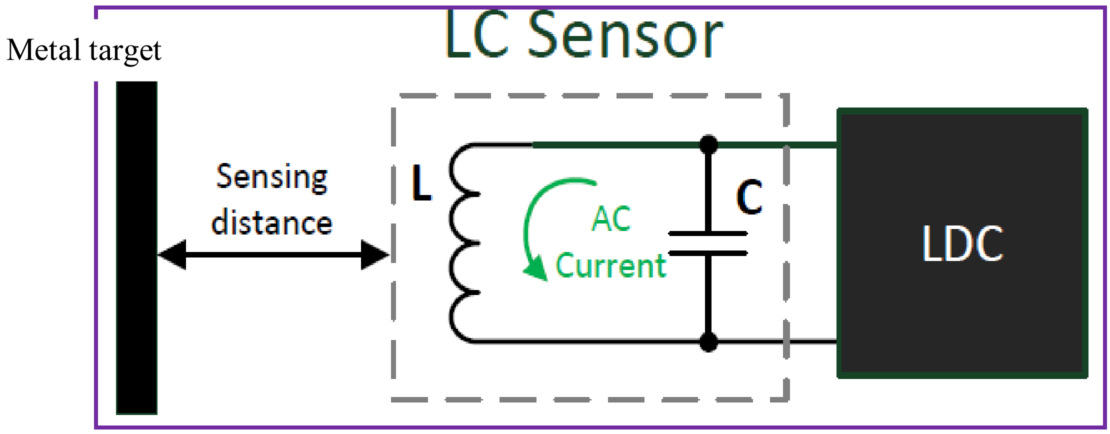

Fig.18.1. LC Sensor Components

An Inductive-to-digital converter (LDC) senses the change in inductance caused by the movement of the conductive target through the sensors AC magnetic field. The target movement with respect to sensor may be either axial or lateral with respect to the plane of the sensor. The LDC generates an AC magnetic field by supplying an AC current into the parallel LC resonant circuit as shown above in fig.18.1.

If a conductive target is brought into the vicinity of the inductors AC magnetic field, small circulating current known as eddy currents will be induced by the magnetic field onto the surface of the conductor shown in fig.18.2.

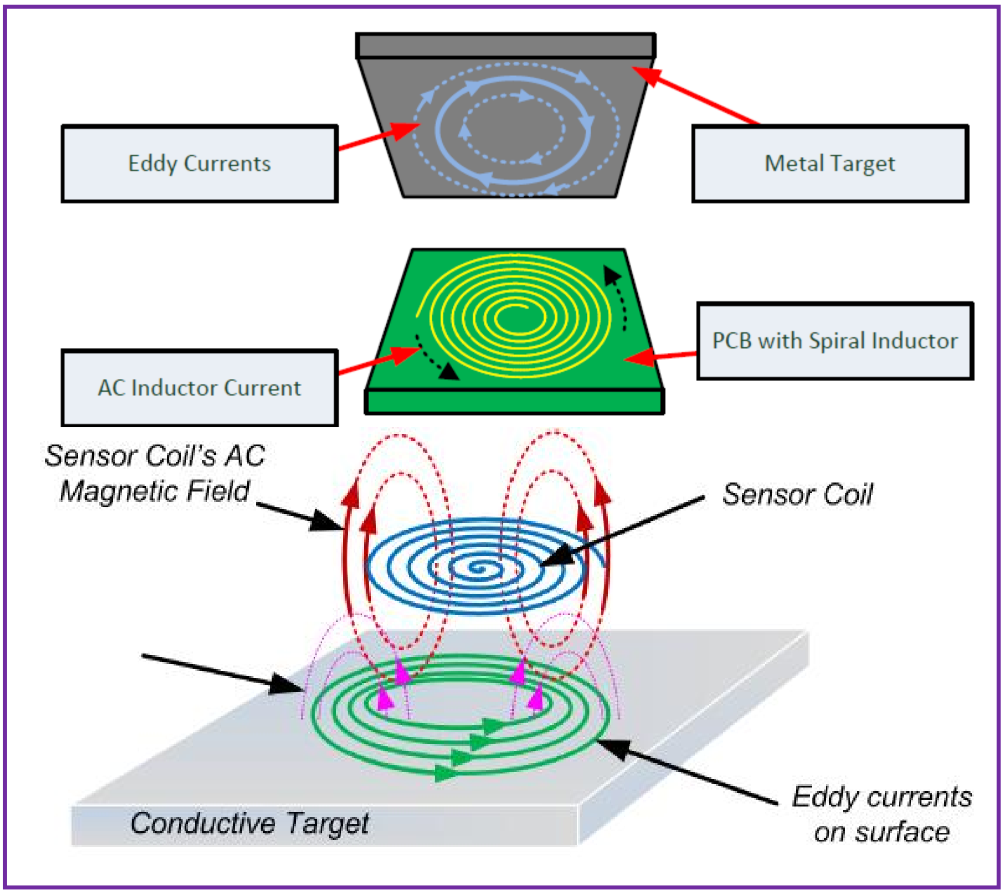

Fig.18.2. AC magnetic field Interaction with conductor

Lenz's law states that induced current will flow in a manner to oppose the magnetic field, which weakens the original magnetic field in a measurable way. LDC device use an inductor in a resonant circuit to generate an AC magnetic field as shown in fig.18.2. Any generated eddy currents will weaken the inductors magnetic field which effectively reduces the inductance of the resonant circuit, which is typically detectable by the LDC. Depending upon the device, the LDC will measure either the shift in the resonance and/or the energy losses in the resonant circuit and in the target (due to the eddy currents).

$$f_{SENSOR} = \frac{1}{2\pi \times \sqrt{LC}} \quad (1)$$

The combination of Inductance and Sensor Capacitance, determines the sensor frequency(f_s) of LC Tank as shown in equation(1). The optimal choice of f_s depends on the selection of metal materials and thickness. LDC1612 has maximum fs of 10MHz. but to allow manufacturing tolerance, a value of 100PF is chosen to achieve f_s of 9.1MHz.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. SENSOR OUTPUT

The sensor output readings were recorded and Inductance values measured, initially tested on bench for various targets viz. Open Air, metal Stud, metal Coin,.etc.

4.1.1 Profile for different metal targets

The magnetic profiles for various metal targets were captured on bench for testing the sensor functioning before interfacing to the system.

Fig.19. Metal stud, outer dia:10mm, inner dia:5mm

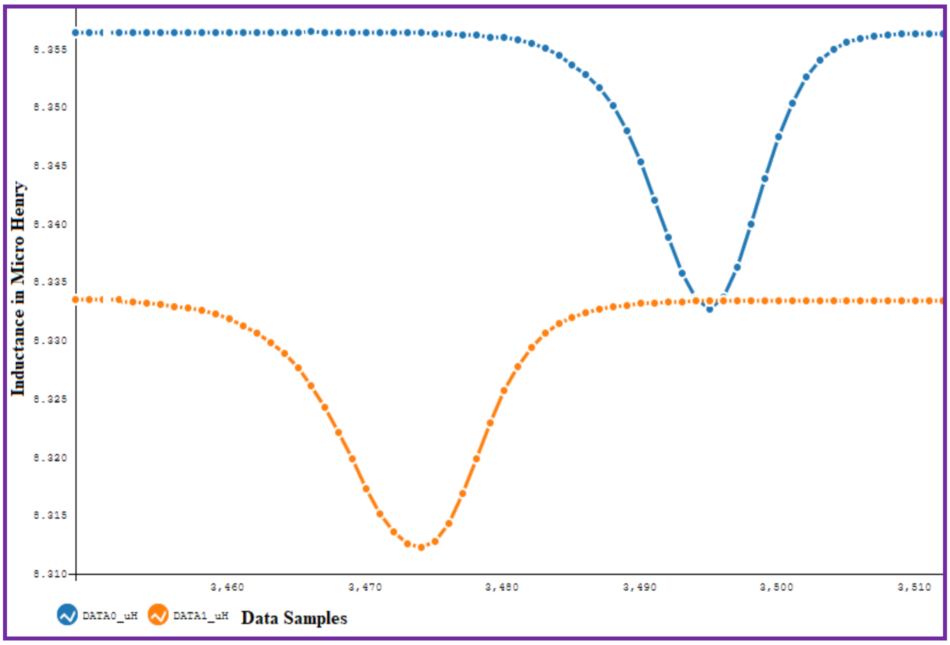

Fig.19.1. Sensor response for metal stud

In the above figure fig.19.1., the blue and orange graphs corresponds to channel '0' and channel '1', Where LDC 1612 has two channels. The target is allowed first to go through channel '0' followed by channel '1'. Hence we can observe the slight delay in between these two signals. However one can clearly observe the nature of target profile is same from both channels.

When a Five Rupee Coin is placed under the sensor, the output of the sensor can be seen in the following figure.

Fig.19.2. Five Rupee metal Coin

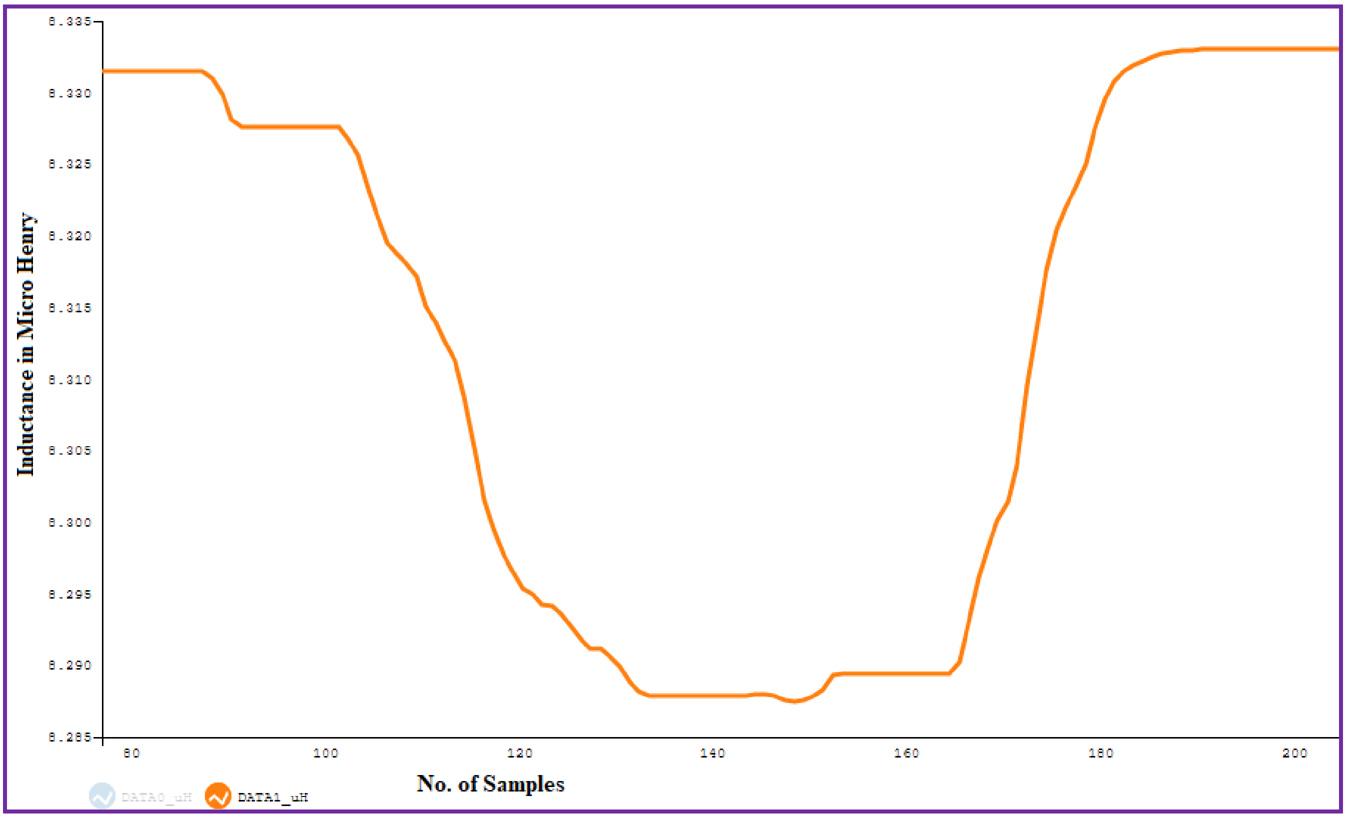

Fig.19.3. Sensor response for metal Coin, dia: 22mm

Here only one channel is being used i.e. channel '1' to measure the shift in the magnetic field when the coin comes into close contact of the sensor coil.

Similarly when LDC Sensor is used to measure the magnetic profile of open air, the output is a straight line where there is no shift in magnetic field observed recalling the principle of operation of inductive sensor.

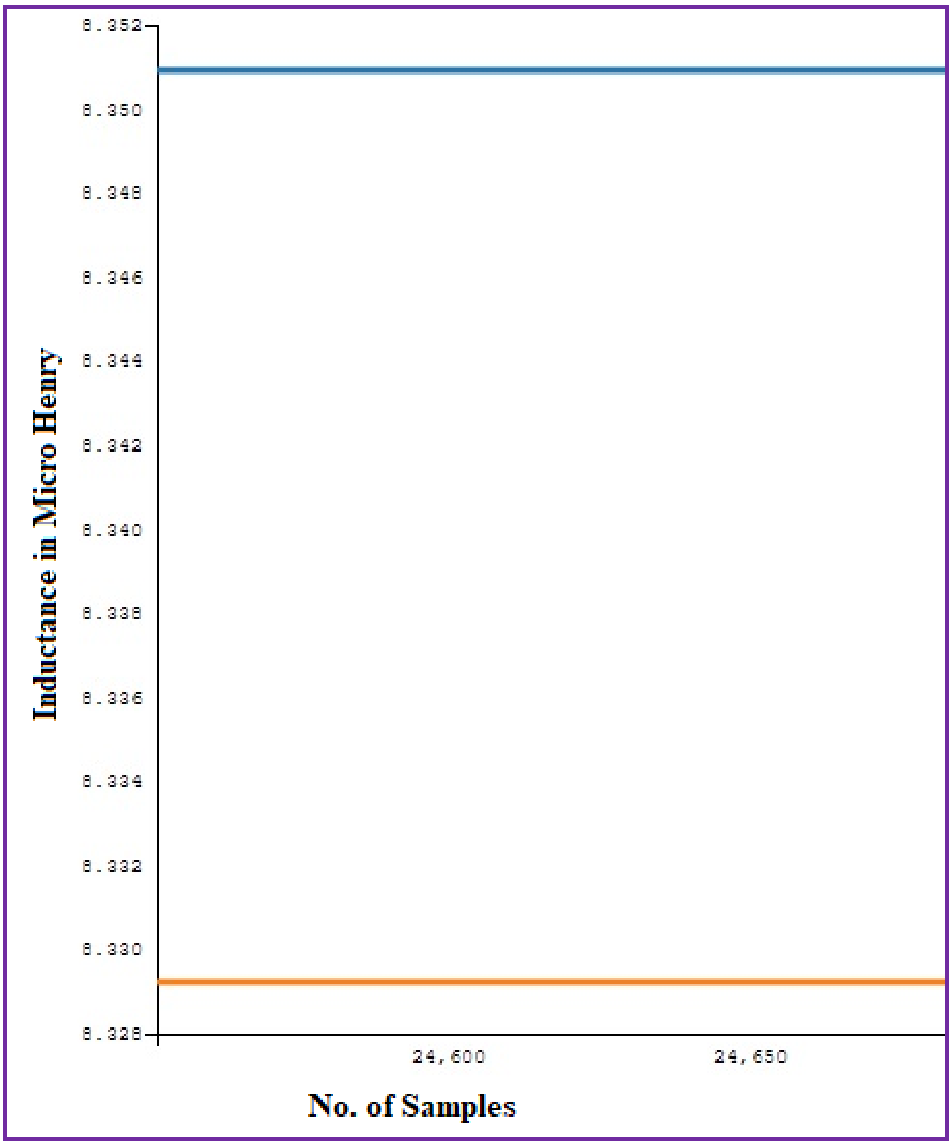

Fig.19.4. Sensor output for Open Air as target

4.1.2 Independent metallic link

The roller chain is made up of number of links. Among these links, one link can be separated from the chain and the response of the independent link can be studied by subjecting the link to the sensor.

Individual link has curved shape with the measurements mentioned below in Fig. 19.5. One Link has two metallic hallow tubes with inner dia: 5mm, Link Length: 24mm.

Fig.19.5. Roller metallic chain links

One individual link subjected to take its magnetic profile and it was shown here under:

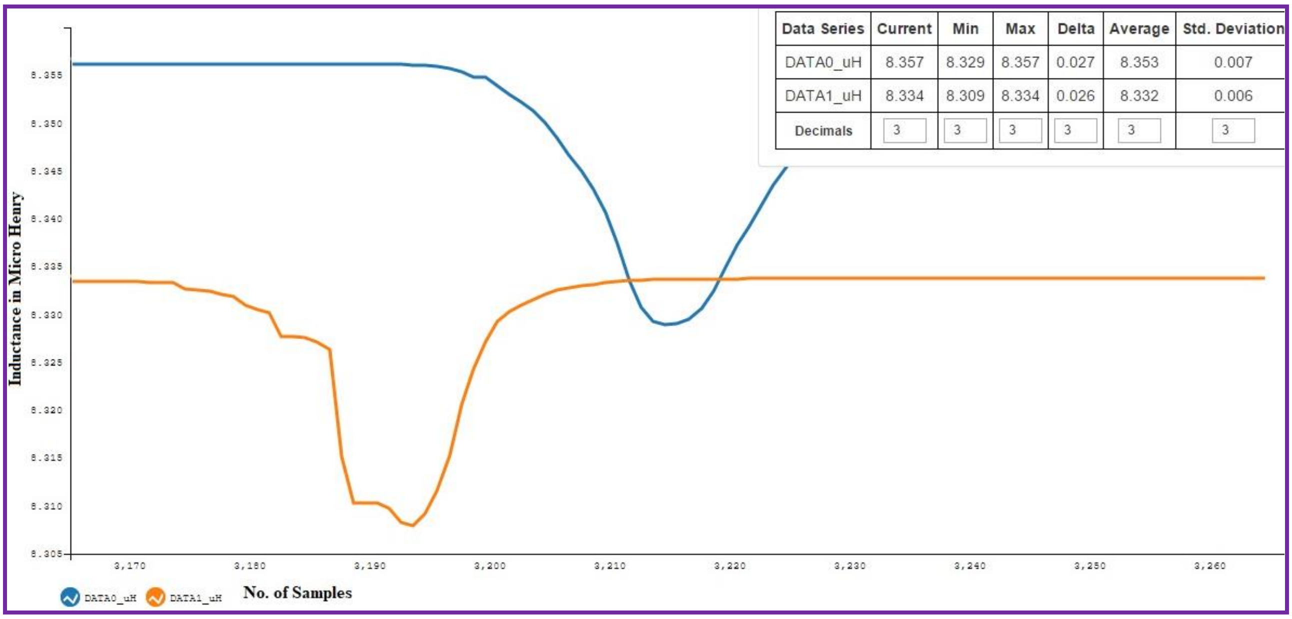

Fig.19.6. Sensor Response – Individual metallic link

4.1.3 Sensor output - CCW Rotation

The sensor output recorded when the system rotates in CCW direction is shown here in below figure. The profile was captured in both channels where the uniformity can be clearly seen from output of channel ‘0’ and channel ‘1’. This is done for minimal speed of operation by keeping the sensor at the top centre just above the center sprocket.

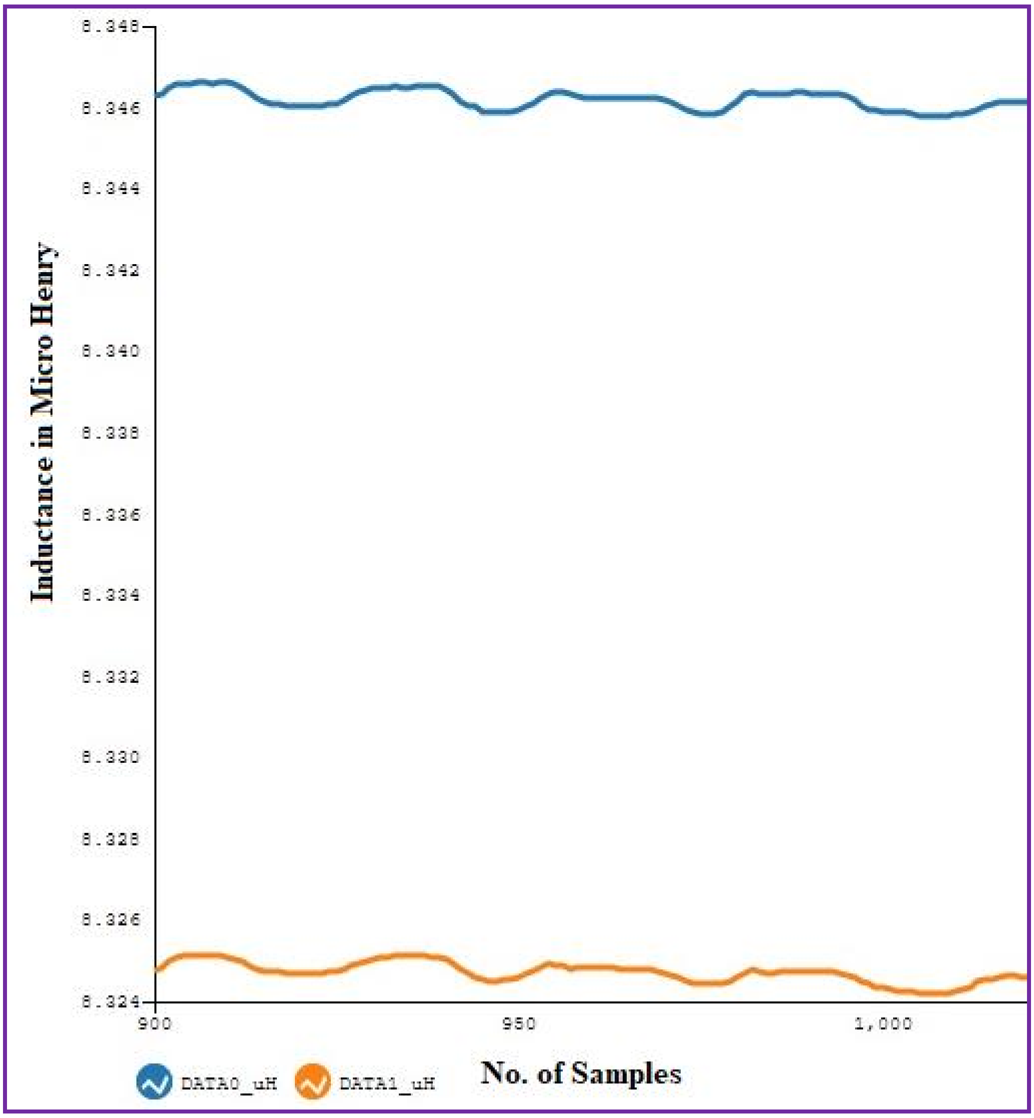

Fig.19.7. Sensor response recorded for CCW rotation

Similarly the sensor response was captured when chain is moved in CW direction and CCW direction. This was repeated for multiple times for varied speeds and for further analysis.

4.2. INTRODUCTION OF MALFUNCTIONS

In order to verify the magnetic profiles of a good metallic roller chain with that of damaged or partly damaged chain, one of the metallic link was detached from the chain and subjected to introduce the malfunctions.

The individual link has got two hollow parts which are connected by a metal connector. V – shaped cuts have been made in multiple numbers. The damaged link is subjected for testing where the magnetic profile was recorded for analysis.

Fig.20. Multiple cuts

Fig.20.1.V-Cut

Fig.20.2.Deep Cut

Fig.20.3. Large multiple cuts

Each of the above damaged links are subjected for testing, the profiles have been taken and compared with good ones. One can easily observe and identify the difference in wave form profile of good link and damaged link. As a noticeable remark, even one can assess by observing the change in the inductance value, whether the damage is small or larger.

4.3. ANALYSIS AND INFERENCES

The magnetic profiles for each case viz. individual link, multiple links, CW rotation, CCW rotation with varied speeds, were taken and analyzed for making the meaningful conclusions.

The sensor was placed firmly on a bench as shown in figure below, and Sensor is interfaced to PC using USB cable. Half link was taken and subjected for testing with LDC Sensor. The response of the sensor was captured in PC through TI software, manually on a bench. The half link was placed under the sensor in close proximity and moved gradually in step distance to pass all parts of the half link under the sensor coil.

The shift in Inductance was noted for each instance and tabulated in excel sheet. On the other hand, an half link was taken and machined the cuts. The damaged half link is now subjected for testing in the similar fashion, the inductance values were noted for each instance.

Fig.20.4. Half link

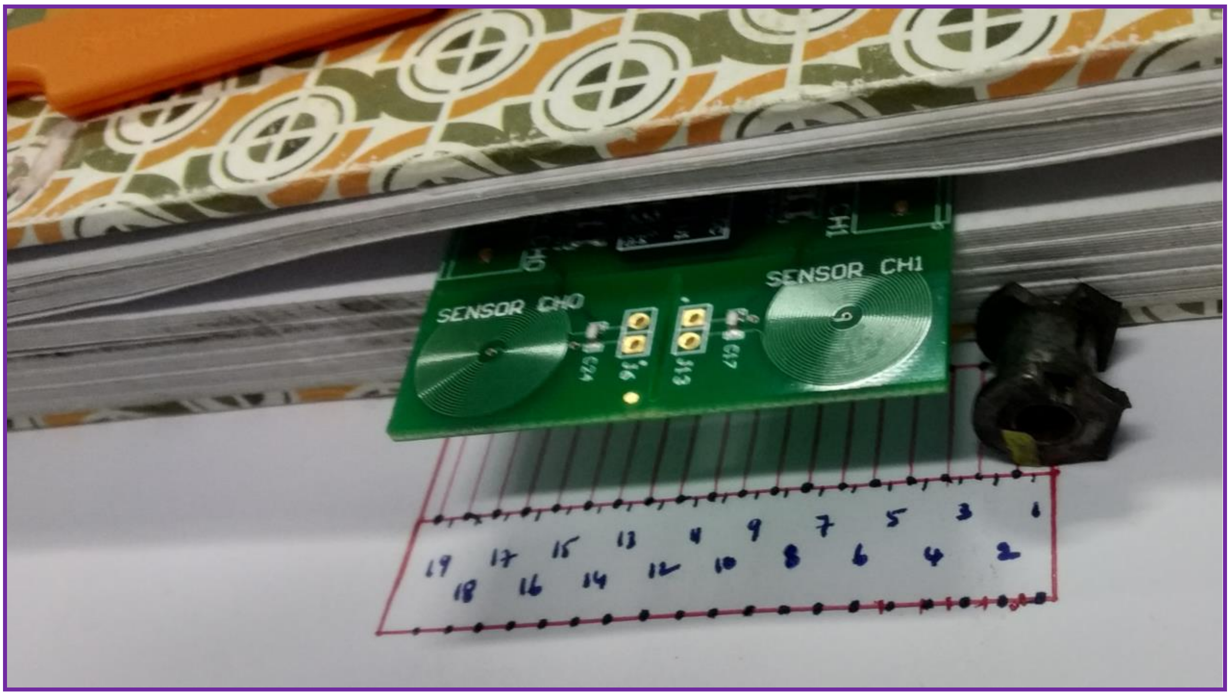

Fig.20.5. Damaged half link – subjected for test on bench

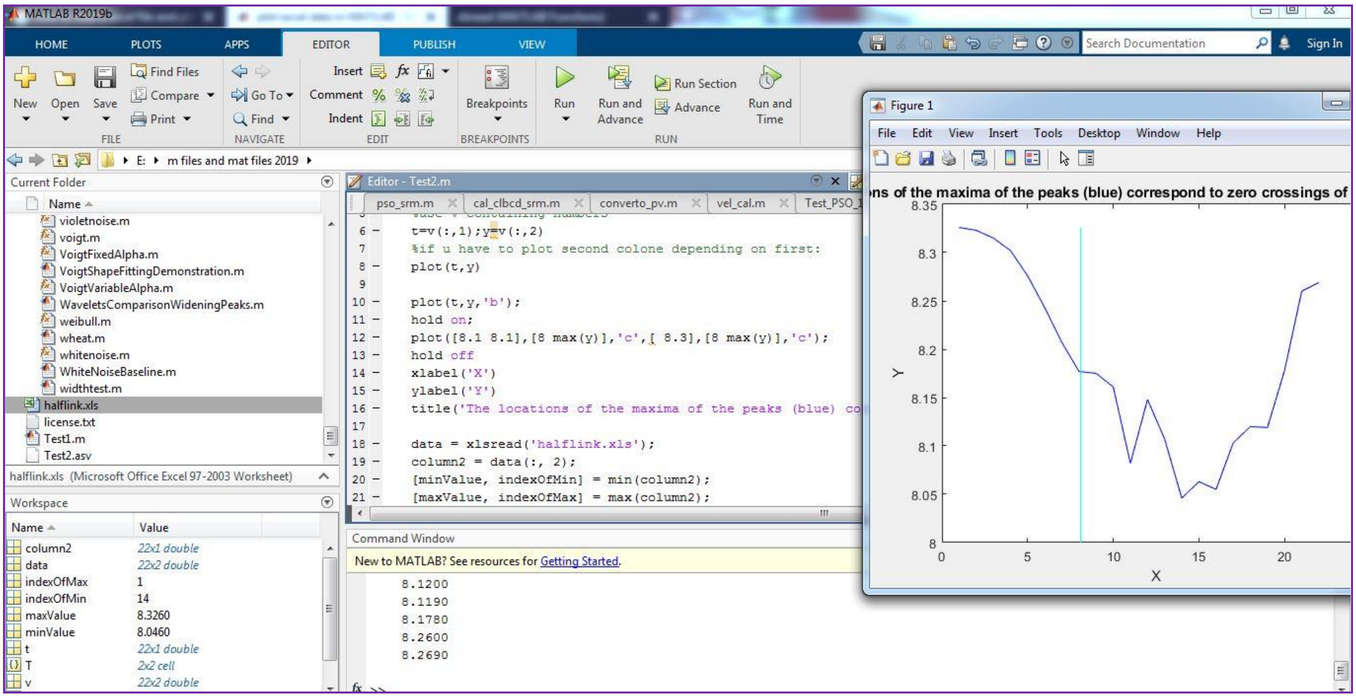

Fig.20.6. Magnetic profile plot of damaged Half link using Matlab

Similarly the magnetic profile was plotted using matlab for good half link, shown below.

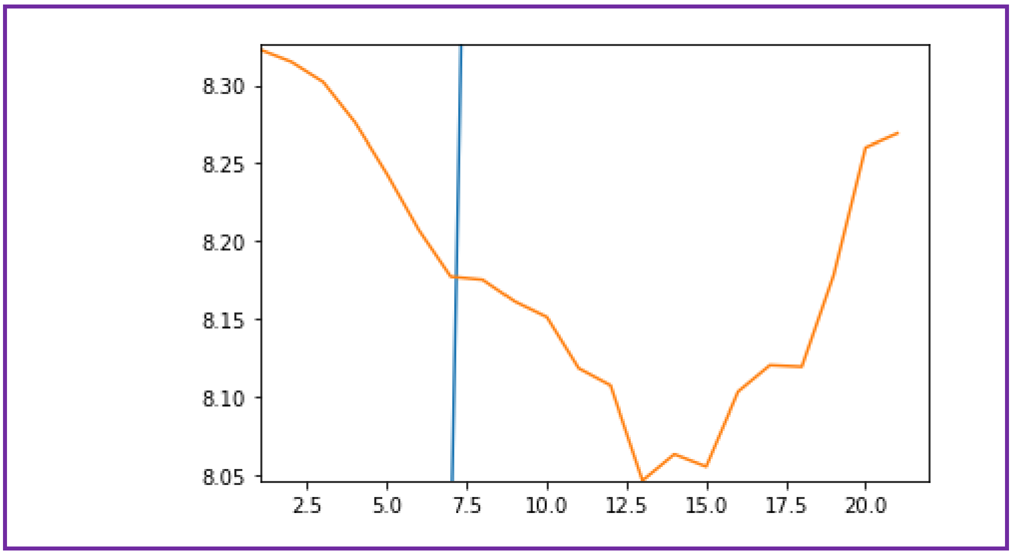

Fig.20.7. Magnetic profile plot of Half link

The profiles of damaged half link and the good half link were analized and it is evident that a sharp peak occurred in profile of damaged half link between tha samples 10 and 15. This sharp peak corresponds to the presence of physical damage such as cut or crack. This occurred when there is a change in the proximity of target to the sensor coil.

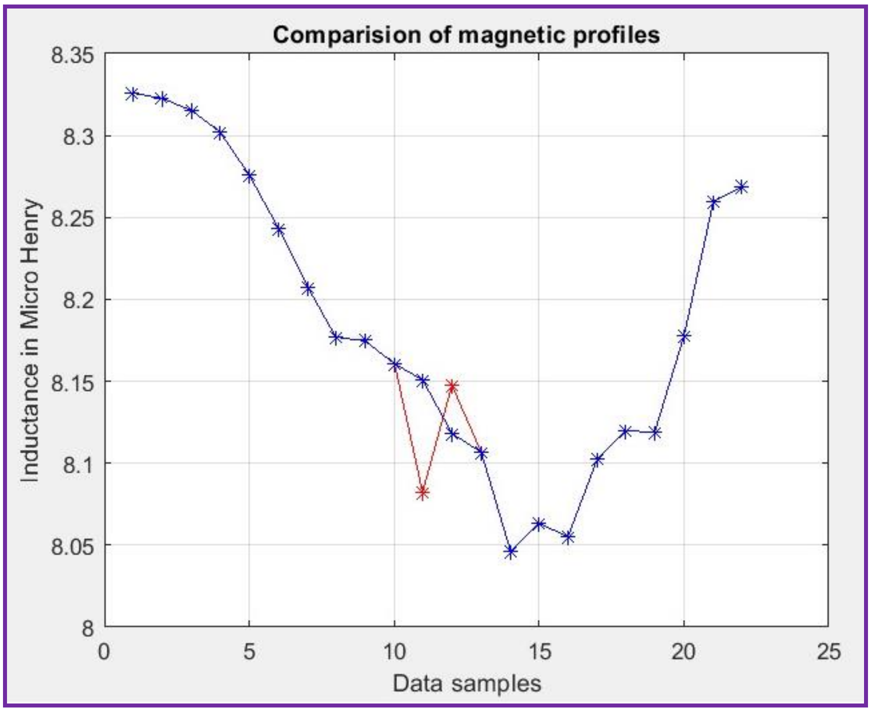

Fig.20.8. Comparision of sensor outputs

Hence by comparing the current profile of a target with a reference profile, it is easier to determine the changes in the inductance shift by carefully observing the nature of profile.

It is therefore infered that the natural or man made damages to the chain or track can easily be identified by employing this innovative mechanism. If the damage is small, can be repaired on the spot using the available spares and tool set. In case of heavy damages, the vehicle may be referred for repair works at Regimental repair workshop. The concerned Operator / inchare of the vehicle may decide on changing the complete track which happens at zonal workshop. Hence the nature of damage and the level of repair and maintenance may also be kown using AHMS.

CHAPTER 5
SUMMARY AND FUTURE WORK

This chapter prescribes the compilation of the gist of the understandings developed based on the results and discussions carried out in the present work.

5.1. SUMMARY

The health monitoring system is designed and developed for roller metallic chain by employing innovative mechanism of Inductive sensing. The health of the system is monitored by analyzing the magnetic profile and comparing the same with reference profile. A lab model is designed and developed using low cost, commercially available components depicting AFV track. By using this lab model, different metal targets were tested, their magnetic profiles were taken and analyzed successfully at various speeds of rotation in CW and CCW directions.

Also various malfunctions viz. V – Shaped cuts, cracks, deep cuts etc. were made on the roller metallic chain parts. Each of these targets were subjected for bench test, the shift in the inductance was measured and recorded. The magnetic profile of damaged target was compared with good target. The analysis was carried out using MATLAB tool, remarkable outcomes and inferences were brought out.

It is evident that the sharp peaks in the magnetic profile corresponds to the physical damages occurred on the target. Hence the health of the roller metallic chain was assessed successfully by careful observation and analysis of sensor output. The mechanism used in making the lab model may be enhanced to the actual AFV track where multiple number of sensors may be used at various locations to get the track profile. By careful observation of track profile one can definitely assess the current health status. The development of AHMS also helps in effective maintenance of track, safety and security aspects of the crew as well as the vehicle.

5.2. RECOMMENDATIONS FOR THE FUTURE WORK

The innovative mechanism which involves the measurement of shift in inductance based on the proximity of metal target with sensor coil, is used in design and development of the lab model. The state of art Inductance to digital converter's (LDC's) are best employed for their high accuracy and best resolution in making lab model. I recommend the concept of

Inductive sensing and the LDC's for AFV application. The AHMS for an AFV could be well designed, developed and interfaced to AFV.

Using these proximity sensors at multiple locations on the AFV track, the condition of track would be well conceived. This will enhances the mobility and overall performance of Battle tank. Considering the fast developments of Network Centric Warfare (NCW) Scenario, the concept of Internet Of Things (IoT) based online health monitoring for AFV's may plays an important role in the Warfield. There is a good scope for the concept of the thesis, which may be used to implement automated health monitoring system for all the available tracked vehicles viz. Main Battle tanks (MBT's), Infantry Combat Vehicles(ICV's), Bridge Layer Tanks(BLT's), Amphibious Vehicles, Unmanned Ground Vehicles(UGV's)..etc.

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[11].(*online*) http://www.ti.com/lit/an/snoa957a/snoa957a.pdf?ts=1590789138076

APPENDIX

Matlab Code for analysis and comparison of sensor output:

```
%The generated inductance data need to be uploaded to the MATLAB .m file
%using the bellow commands
dataset= xlsread('halflin_kwith_V_cut','Sheet1','B3:C24');
dataset2= xlsread('halflink_with Vcut_and Nocut','Sheet1','F28:G49');

%Asseiging variables to the datasets
x=dataset(:,1);
y=dataset(:,2);
z=dataset2(:,2);

%plotting the First curve and assigning title, lables.. etc
plot(x,y, 'r*-')
title('Comparision of magnetic profiles');
xlabel('Data samples');
ylabel('Inductance in Micro Henry');

%Command for merging the plots
hold on

%Plotting the seccond plot
plot(x,z, 'b*-')
grid;
%fplot('8.1')
```

STANDARD OPERATING PROCEDURE (SOP) FOR AHMS LAB MODEL

a) Check the Battery Connections and Voltage. Charge the Battery if the voltage level measured is lower than the rated voltage.

b) Check the electrical connections of Motor, Starter Relay, Battery, Light and Switches, do the repair if any of these connections are not proper.

c) Check the condition of Metallic Roller Chain., adjust the same if any mis-alignments., Apply grease to the chain for smooth operation periodically.

d) Check the wheel alignment; tighten the metal stud at the centre of wheel to align the four wheels horizontally.

e) Check the tightness of Sprockets (Drive, Idler and Adjuster), gears, motor shaft assembly, do the repairs if needed.

f) Check the position of Sensor; adjust the flexible arm as required.

g) Check the Sensor Interfacing to PC and update the GUI for data streaming as and when used.

h) Ensure the EVM GUI Register settings as required.

i) Switch on the Motor; observe the rotation of metallic roller chain. Do the data streaming of target profile in PC through EVM GUI.

j) Interchange battery polarity and repeat Step No. (i) to do the CW/CCW rotation of chain.

k) Increase the voltage applied to the motor in steps viz.9V, 12V, 15V, 18V, 21V, 24V, 28V and 32V to check the system operation for varied speeds, Repeat Step No. (i) and (j).

l) Save the target profiles in PC from EVM GUI for further analysis with appropriate file name.

m) Switch off the motor switch, disconnect the battery leads once the work completed.

n) Ensure the safety; avoid keeping hands on the chain, Sensor when it is under operation.

o) Ensure the tool set: Digital Multi Meter (DMM), Electrical Tester, Screw driver set and Spanner set.

p) Ensure the dual lock safety of the wood stand is working in good condition.

q) Ensure the availability of First aid kit in case of any risk