DIGITIZATION OF VIBRATING WIRE TYPE LOAD CELL FOR MINE SUPPORT SYSTEMS

THE THESIS SUBMITTED TO IN PARTIAL FULFILMENT OF THE REQUIRMENTS FOR THE DEGREE OF

MASTER OF TECHNOLOGY
IN
MINING ENGINEERING

BY

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Under the Guidance of

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Dedicated to my dear Maa

Department of Mining Engineering

National Institute of Technology, Rourkela

CERTIFICATE

This is to certify that the thesis entitled “**DIGITIZATION OF VIBRATING WIRE TYPE LOAD CELL FOR MINE SUPPORT SYSTEMS**” submitted by **Ms. Saswati Biswas**, for the partial fulfilment of the requirements for the degree of M.Tech, embodies the bonafide work done by her in the final year of her degree under my supervision. The thesis or any part of it has not been submitted earlier anywhere for any degree or diploma or any other qualification.

Date: 03/06/2014

Place: Rourkela

Prof. Singam Jayanthu
(Supervisor)

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Last but not the least I acknowledge my parents and my sisters Didibhai and Payel for being with me throughout my life. I could not have done it without them.

Date: 03/06/2014 **Saswati Biswas**

Place: Rourkela

ABSTRACT

Vibrating wire type load cells are extensively used in mining applications now-a-days. These cells are very unlikely to be affected by temperature or gravitational effects. Thus they are preferred over strain gauge type load cells. The reading of these cells is extracted by connecting a readout unit with it. It gives a low amplitude pulse signal which excites the coil inside the instrument and selects the frequency corresponding to peak voltage generated on it being the resonant frequency of the highly tensioned wire fixed in the vicinity of the coil. There are three coils and each of the coils is connected at a time with the read out unit to extract reading. It takes time as well as calculations to be done afterwards. Vibrating Wire type load cells of 20 to 50 T capacities are generally used in underground coal mines for measurement of load on supports and for evaluation of behaviour of the supports. Setting load is invariably kept at about 2 to 5 tons and maximum load in typical mines may be about 20 T for which the support system is considered as adequate with safety factor exceeding 2.

In this study an attempt is made to digitise the output of load cells using electronic circuitry and microcontrollers and its loading profile has been made. The circuit used to excite internal coils of load cell is Wien Bridge Oscillator. The frequency range of each coil was determined for which optimum output is produced from the load cell. The overall frequency range observed during experiment is 60 to 160 kHz. Wien Bridge Oscillator circuit was developed which gives a frequency range of 78 to 143 kHz. Wien Bridge oscillator was interfaced with the instrument and it was loaded from 0 to 25 T using Compression Testing Machine (CTM) and changing the input frequency for a certain load within its range i.e. 78 to 143 kHz. The output rms voltage changed from 1.15 to 0.195 V for red coil, 1.17 to 0.18 V for yellow coil and 1.18 to 0.172 V for green coil. Finally the microcontroller was introduced at the output end for display of digitised load reading from the VW type load cell. The load display in microcontroller display was showing fluctuations. The experimental setup can be further improved by introducing a rectifier along with a suitable filter which would convert the AC output signal to DC. This will minimise the fluctuations of the microcontroller display. It can also be proposed to further extend the work for continuous monitoring using a wireless sensor network.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ABBREVIATION	DEFINITION
AC	Alternating current
ADC	Analog to digital converter
CISC	Complex instruction set computing
CMOS	Complementary metal oxide semiconductor
CRO	Cathode ray oscilloscope
CTM	Compression Testing Machine
DC	Direct current
GND	Ground
JTAG	Joint test action group
LSB	Least significant bit
MIPS	Million instructions per second
RC	Resistance Capacitance
RISC	Reduced instruction set computing
RMS	Root mean square
SRAM	Static random access memory
VCC	Common collector voltage
VW	Vibrating Wire

Chapter 1

INTRODUCTION

Underground excavation of minerals causes disturbance in earth surface. Therefore mine strata needs to be supported by means of artificial support systems. These support systems are of two types, Active and Passive. Active support system consists of props, chocks, roof bolts etc whereas Passive support systems include mesh, straps, shotcrete, and steel sets etc. The active supports i.e. props, chock, roof bolt need continuous monitoring as these are of certain capacity. If the pressure coming upon the roof supports exceeds its capacity, it can cause failure of roof supports and this can lead to disturbance of roof which may also lead to roof fall. To avoid these accidents, condition of the roof supports should be monitored time to time with reference to the variation of load on the support at different stages of extraction of mineral. For this purpose, load monitoring of roof support systems is necessary.

There are different types of Props, such as Hydraulic, Friction, and Wooden. Props are also classified as Open circuit and Close circuit Props. The images of various support systems are shown in Fig 1.1 and 1.2.

Fig 1.1 Support systems of an underground coal mine[1]

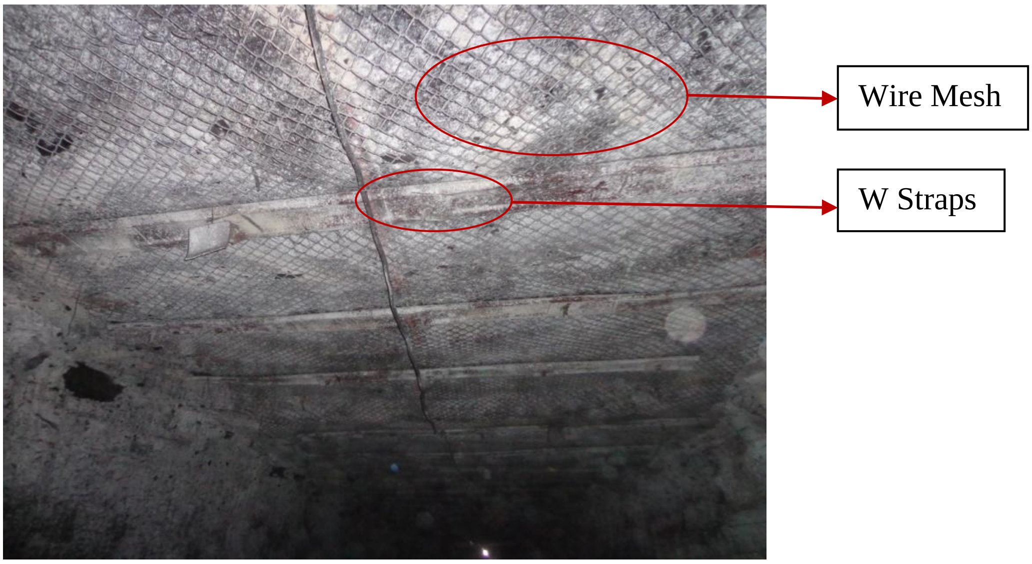

Fig 1.2 Wire mesh supports with w straps in an underground mine[1]

In long wall mining method, close circuit supports are used, these are of hydraulic in nature. These supports have in-built load measurement arrangement. Fig 1.3 shows a typical hydraulic chock shield with inbuilt pressure gauge.

Fig 1.3 Hydraulic chock shield with inbuilt pressure gauge[2]

Open circuit props are monitored using load measuring gauges. These are known as load cells. In earlier days there was no technology to monitor load on supports. It was done manually by observing visible changes such as crack on wooden props, subsidence of roof etc. It was an unhealthy practice as it could not predict the failure of the support system within a safe time period. Thus there was a need for monitoring of load coming upon the support. This is why load cells were introduced into underground mine support system. There are different types of load cells, such as Hydraulic, Mechanical, Strain gauge, Vibrating wire type.

Hydraulic Load Cells- These consists of fluid filled deformable chambers, which are connected to either a pressure gauge or an electric pressure transducer. The load is transferred to the fluid by means of a piston or in case of a flat jack, deformation of the fluid confinement. Though most hydraulic load cell are of rugged construction, they have become obsolete, due to physical size, temperature sensitivity and poor load resolution.

Mechanical Load Cells- These consists of an elastic disk element, which is sandwiched between two plates. When load comes upon the instrument, the disk deflects changing the distance between the plates. The deflection is measured using dial gauge or any suitable electronic transducer. Though these types of load cells are not very costly, these are used quite rarely, because its calibration curve is non linear. Proving ring is a commonly used Mechanical load cell.

Strain Gauge Load Cells- These types of load cells are most commonly used in Industries. Strain gauge load cells consist of a resistive element, which undergoes change in resistance when it is subjected to axial strain. These gauges are generally fixed with the load cell’s cylindrical casing and connected with each other to form a Wheatstone bridge. Whenever there is an imbalance in resistance, deflection can be observed in Galvanometer. The main disadvantage of this instrument is poor temperature compensation.

Vibrating wire type load cells- These are popularly used in mining applications due to many of its advantages. Firstly the readings can be taken from distance as it takes on account the vibrating frequency of the wire rather than any electrical signal. Thus signal loss due to long length of wire is remarkably less. Secondly these cells have long term reliability i.e. very little drift in readings at no load or zero displacement over time. Some of its disadvantages are their physical size, cost, complicated readout and poor temperature compensation. Readings are extracted from these cells using a readout box. There are three wires which are connected with the readout unit one by one to get the load readings and these readings are averaged to get the exact load. The whole process takes a lot of time as well as skilled person to operate the readout unit. On the other hand continuous monitoring of the load is very much required for underground mine roof support system. Fig 1.4 gives an overview of load monitoring on underground roof supports using vibrating wire type load cell.

Fig 1.4 VW type load cell installed above a hydraulic prop[3]

Load readings are taken every one or two days. Carrying the readout unit which is of approx 1.5 kg to every load cell and taking reading out of it is a tough job. It takes lot of time as well as requires a skilled person who can operate the readout unit. If the load cells can be digitised, monitoring of the load can be much easier. Continuous load monitoring is also possible. Thus this study on digitisation of vibrating wire type load cell for mine support systems is conducted.

1.1 Objective

The main objective of this study is to digitise vibrating wire type load cell and display load reading using electronics components. Another objective is to study vibrating wire type load cell readings with varying load and input frequency.

1.2 Methodology

To achieve the objective of the study, various experiments were performed on the instrument. At first, it is required to design an oscillator circuit which would excite the internal electromagnetic coil of the load cell. Designing of an oscillator circuit needs some specific details like the frequency range within which the instrument gives optimum output i.e. the working frequency range of the load cell and the amplitude of voltage signal. These factors were determined beforehand. After that the circuit was interfaced with the instrument and finally the microcontroller i.e. ATmega32 was connected with the output end. The steps are elaborately discussed in different sections of this thesis.

1.3 Organization of Thesis

Chapter 1 includes an introduction on mine support systems and load cells. An overview has been given on various type of support systems used in underground mines. The different kind of load cells and their limitations are also discussed. Finally the objective of the thesis and an outline is being presented.

Chapter 2 presents literature review on the work done so far on vibrating wire transducers and an overview of the devices and instruments used for the study. It also gives a clear view of support systems and load monitoring of supports including a table of readings from a load cell installed above a hydraulic prop.

Chapter 3 describes the experimental investigations carried out during the study. The step by step procedure for achieving the objective is discussed. The experiment procedure is described in detail.

Chapter 4 contains results of the experiments and analysis of the results. The loading profile of the three coils and their relation with output frequency and rms voltage is provided. **Chapter 5** gives conclusion and suggests scope for future work.

Chapter 2

LITERATURE REVIEW

Vibrating wire technique is being used from a very long time in various instruments for different applications for both industry and laboratory use. In the year 1979, Ivor Hawkes first invented an instrument named vibrating wire stress meter which as the name reflects is a stress measuring instrument [18]. It is rugged in construction and has very less influence of temperature. Thus it was ideal to measure stress inside a borehole as its construction allows it to provide readings from a safe distance. This instrument was further modified to find its application in various mining applications, laboratory experiments and for monitoring structural health. In underground mines, support systems are designed according to the stress of the strata.

2.1 Application of Load Cell in Mines

Many investigators used vibrating wire load cells for monitoring the behaviour of supports in underground mines with various methods of extraction of coal and metal deposits. In coal mines, recently load on supports was measured on hydraulic props in Longwall mining, Bord and Pillar mining, Blasting Gallery methods of extraction[1-3] . For better understanding of location of load cells in mine workings, a typical mine plan and support system during extraction is presented in Fig 2.1 to 2.3.

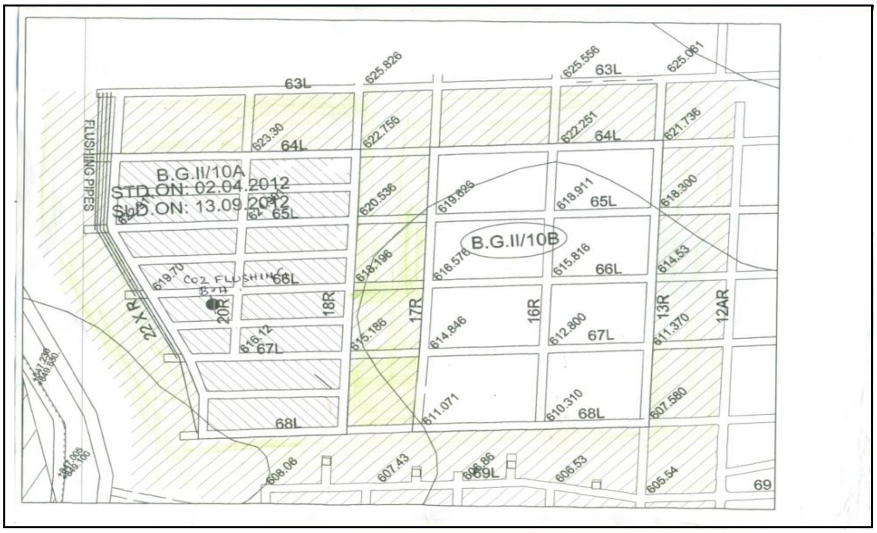

Fig 2.1 Working plan of a typical Blasting Gallery panel of an underground mine[1]

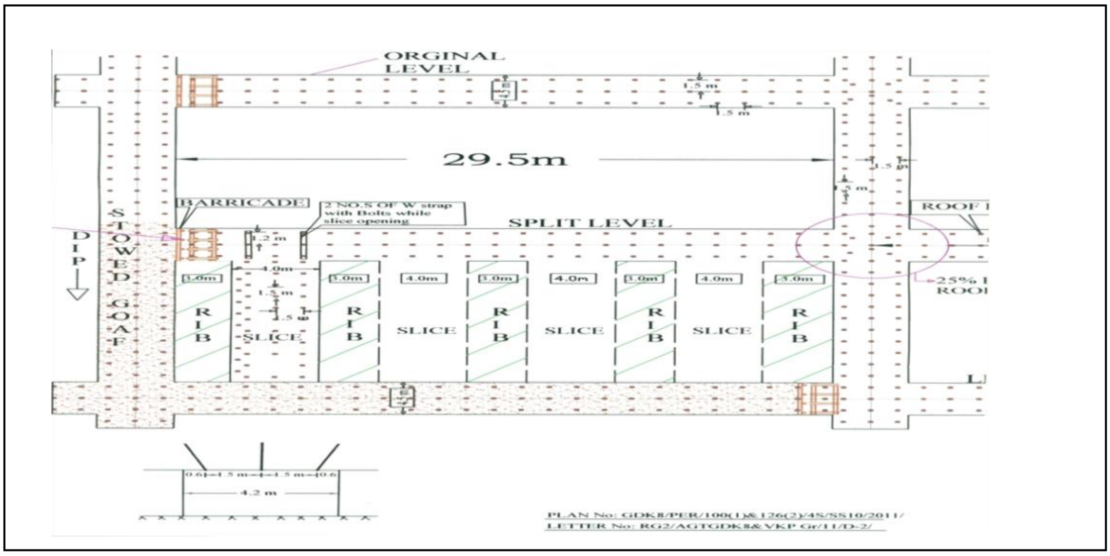

Fig 2.2 Support systems for the working Blasting gallery panel[1]

Fig 2.2 shows a typical support system for an underground Blasting gallery panel. Additional supports are provided at the junctions using bolts and W straps. Various instruments are installed in these support systems for strata monitoring. An instrumentation plan is shown in Fig 2.3 for better understanding.

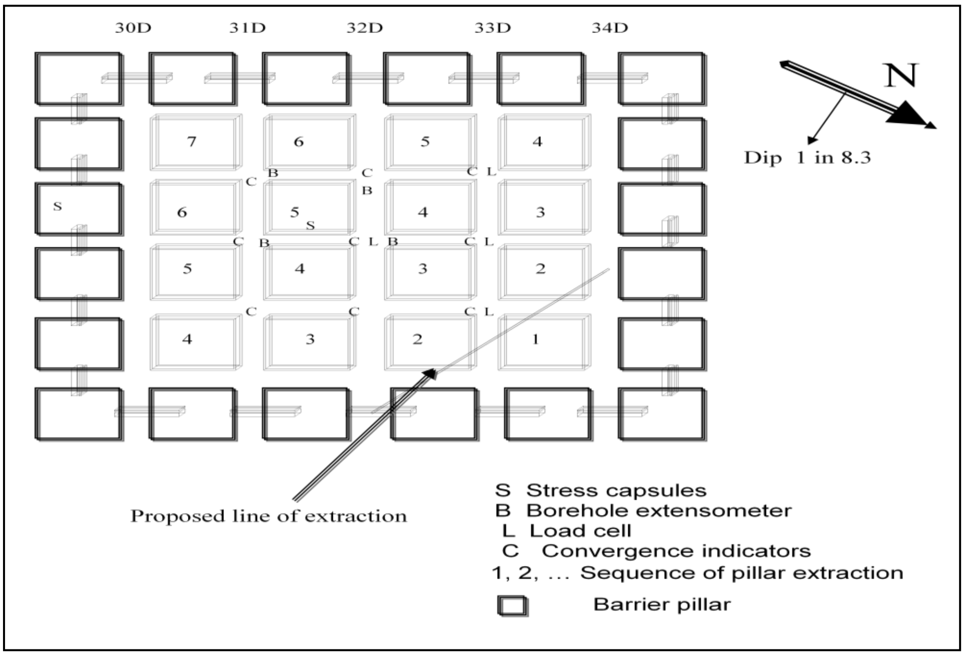

Fig 2.3 Instrumentation plan for a BG panel of a typical underground mine[1]

From Fig 2.3 we can clearly visualise the positions of load cells. Load cells were installed in the supports at a distance of 10 m along the level [12]. These are monitored in every 2-3 days and the readings are maintained in a table format. Table 2.1 shows readings of one of the load cells installed above a hydraulic prop of capacity of 40 T for a certain time period. The observations are recorded date wise.

Table 2.1 Load cell observation for a certain time period in a typical underground mine [1]

DATE	GED (M)	RED LOAD (T)	BROWN LOAD (T)	BLUE LOAD (T)	LOAD AVG (T)	DAILY LOAD (T)	CUM. LOAD (T)
28-05-2012	22.5	6.4	2.8	2.4	3.87	IR	0
29-05-2012	22.5	6.8	3	2.5	4.1	0.23	0.23
30-05-2012	19.5	5.5	2.3	1.7	3.17	-0.93	-0.7
31-05-2012	19.5	4.8	1.9	1.4	2.7	-0.47	-1.17
02-06-2012	19.5	4	1.7	2.1	2.6	-0.1	-1.27
05-06-2012	19.5	6.2	1.9	2.2	3.43	0.83	-0.44
06-06-2012	19.5	6.5	2	2.3	3.6	0.17	-0.27
07-06-2012	19.5	6.9	2.2	2.7	3.93	0.33	0.06
08-06-2012	19.5	7.4	2.4	3	4.27	0.34	0.28
09-06-2012	19.5	7.6	2.3	3.1	4.3	0.06	0.34
10-06-2012	19.5	7.6	2.3	3.1	4.3	0	0.34
11-06-2012	19.5	8.2	2.7	3.6	4.83	0.53	0.87
12-06-2012	17.5	9.3	3.6	4.3	5.73	0.9	1.77
13-06-2012	15.5	10.3	4.1	5	6.5	0.84	2.61
14-06-2012	15.5	10.6	4.3	5.2	6.7	0.2	2.81
15-06-2012	15.5	11.4	4.7	5.7	7.3	0.6	3.41
16-06-2012	15.5	14	7	7	9.3	2.03	5.44
17-06-2012	11.5	16.2	7.8	7.9	10.6	1.3	6.77
18-06-2012	11.5	16.2	7.8	7.9	10.6	0	6.77
19-06-2012	9.5	18.3	8.8	8.9	12	2.6	9.37
20-06-2012	8.5	19.8	12.1	15.6	15.8	3.83	13.2
22-06-2012	5.5	19.8	12.1	15.6	15.8	0	13.2
			GOAF				

In the table 2.1 GED is the Goaf edge distance in metres. Goaf is the part of mine from where the mineral has been extracted. Red, Brown and blue represents three coils which are positioned inside the load cell 120° apart. Readings are taken from three coils and the average of three readings is recorded as the final reading. Reason of that is because of inhomogeneous geomining conditions the supports cannot be installed in exact vertical position. Thus there is always a possibility of eccentric loading. Positioning three coils 120° apart instead of one coil at the centre is gives more accuracy as it eliminates the errors due to eccentric loading. . Fig 2.4 shows the positions of three coils inside a load cell.

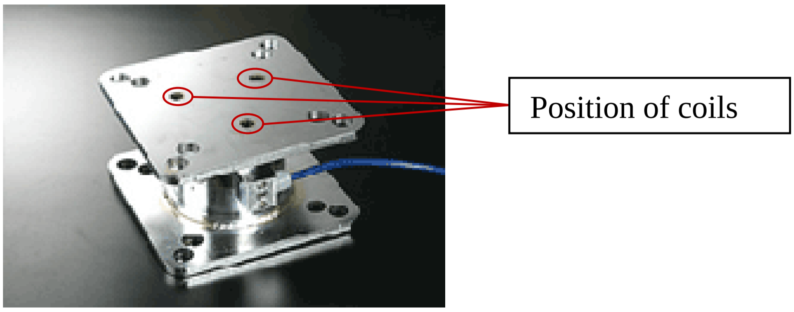

Fig 2.4 Position of coils inside a VW type load cell

As seen in table 2.1 the initial load or the set load at the day of installation o the load cell is 3.87 T at a distance of 22.5 m from the goaf. As the goaf edge distance decreases i.e. goaf approaches near the supports, load on the supports increases. The plot between date and corresponding cumulative load is shown in Fig 2.5.

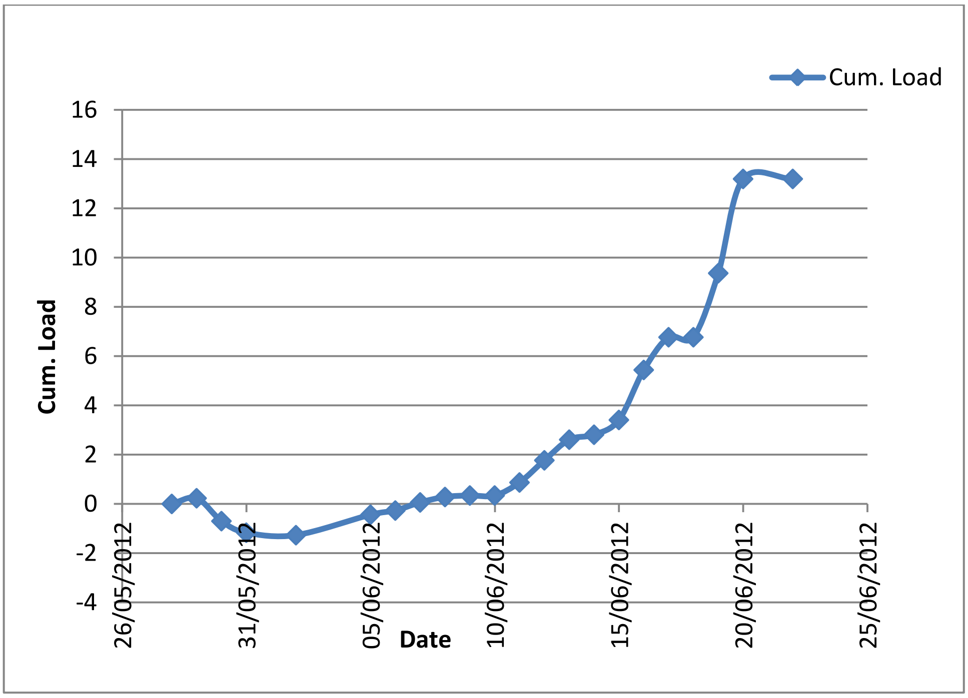

Fig 2.5 Cumulative Load variations on supports in a typical mine

There are some negative load readings starting from May 30 2012 to June 5 2012. This is observed due to some disturbance. After June 6th cumulative load increased day by day and it reached up to a maximum of 13.2 T at a distance of 5.5 m from goaf edge. Then the support was removed. Table 2.1 shows load profile from a single load cell. Readings of all the load cells of a panel are kept in record likewise and finally these are analysed as shown in Table 2.2.

Table 2.2 Summary of load cell observations of a typical Blasting Gallery panel[1]

Location	**Date of Installation with GED**	**Max. day load with GED**	**Final Cum load (T)**
68L-(5)	07-11-2012 at 16.5m GED	1.7 at 5.5m GED on 23-11-2012	4.5T, GED 2.5m on 27-11-2012
67L-(5)	26-12-2012 at 17.5m GED	3.1 at 4.5m GED on 02-01-2013	10.2 T, GED 4.5m on 06-01-2013
67AL-(8)	07-01-2013 at 14.5m GED	2 at 8.5m GED on 17-01-2013	14.2 T, GED 8.5m on 17-01-2013
66L-(3)	07-01-2013 at 18.5m GED	5.5 at 13.5m GED on 15-01-2013	19 at 4.5m GED on 24-01-2013
66AL-(4)	17-12-2012 at 25.5m GED	3.4 at 8.5m GED on 13-01-2013	19.7 T, GED 8.5m on 16-01-2013
65L-(1)	20-12-2012 at 14.5m GED	7.8 at 11.5m GED on 04-01-2013	11.1 T, GED 3.5m on 16-01-2013
65AL-(1)	20-12-2012 at 14.5m GED	2.2 at 3.5m GED on 15-01-2013	10.5 T, GED 3.5m on 16-01-2013

The left most column shows the locations where the load cells are installed. The locations are mentioned as the number of level and dip in an underground coal mine such as at 68 L, load cell was installed on 07-11-2012 at 16.5 m from Goaf Edge. Maximum load on th support was 1.7 T per day when the lao9d cell was at 5.5 m from the goaf edge on 23-11-2012. Total load on the support was 4.5 T, at a distance of 2.5 m on 27-11-2012. Similarly other load cells were also used and monitored at other typical location in the GDK – 8 Inline mine while extraction of pillars by Blasting Gallery Method, long wall method [1-3].

2.2 Previous Research on VW type Load Cell

There is various works done by different investigators on Vibrating wire type load cells for various applications. Some of the important findings by various investigators related to application of load cells are presented in Table 2.2.

Table 2.3 Important findings on Vibrating wire type load cell

Year	**Author**	**Important findings**	**Conclusion**
1994	K.Balasubramanian, K. Güven and Ziya Gokalp Altun	This paper presents Microprocessor based technique for measuring pneumatic pressure which uses optocoupler controlled vibrating wire transducer[4]. In this instrument a diaphragm is exposed	As the frequency of vibration is more sensitive to changes in the pressure extended on the diaphragm, the proposed pressure

		to bear pneumatic pressure and inside a hollow cylinder the string is fixed. The electromagnet is excited by using a microprocessor. This electromagnet in turn plucks the string periodically to vibrate it in its resonant frequency. An optocoupler is fixed near the string which senses the vibrating frequency of the string. This is how the instrument works to measure pneumatic pressure.	measuring device has more sensitivity compared to other conventional devices[4].
1999	P. Choquet & F. Juneau et.al	The authors have worked on performance and long time reliability of Vibrating wire transducers. Due to popularity of data acquisition systems reliable instruments are needed to monitor real time behavior of structures. The paper describes some experiences about long-term stability and reliability of different kinds of vibrating wire instruments such as pressure sensor, strain gage and displacement transducer[5]. The accuracy over time and gage performance is also provided as case histories.	Many tests in laboratory, including long-term tests, have been conducted to evaluate the gage performance. Long-term tests of piezometers, strainmeters and displacement transducers over a period varying between 600 and 1400 days have presented good stability of readings[5].
2000	Mark K. Larson, Douglas R. Tesarik, J. Brad Seymour, and Richard L. Rains	Instruments for monitoring stability of underground openings.	An overview of sensor technologies has been presented. The authors have summarized the use of several instruments and

			offered tips to help the user obtain better measurements. Also, the experiences of co-workers are cited[9].
2009	Vlad Bande, Septimiu Pop, Liviu Viman, and Dan Pitica	In this paper they have proposed a complex measuring procedure which includes both data acquisition and MATLAB application. Calculation of transducer impedance is also possible with this method. Using different range of frequencies (high to low), the real and Imaginary parts of the impedance can be correctly evaluated. They have used a 1.5 V AC source to excite the transducer, a three channel oscilloscope to monitor readings. Readings were extracted by using a flash drive and then these are simulated in MATLAB environment. The vibrating wire transducer’s frequency analysis is a fast algorithm for calculation of impedance over a frequency domain. A MATLAB dedicated program helps acquire data in real time and let us calculate the real and imaginary parts of the impedance. The transducer was compared with a four pole circuit	Taking into consideration those results, it is possible to make a more accurate analogy between the mechanical behavior and electrical behavior of a vibrating wire transducer[6].

2010	Fernando M. Janeiro, Pedro M. Ramos et. al	In this paper they have proposed to use impedance spectroscopy of a vibrating wire cell for measurement of viscosity. One of the ultimate aims of this work is to improve the portability of the instrumentation and reduce its investment costs. Two different liquids are used in this study: diisodecyl phthalate (DIDP), which is non-conductive, and an ionic liquid, which is conductive[7]. The movement of the vibrating wire depends on its radius, density and internal damping, as well as on the liquid density and viscosity. it is possible to extract the viscosity of the liquid sample From the resonance characteristics of the measured impedance if its density and the cell parameters are known. A four wire impedance measurement system was used to measure the resonance characteristics of the sensor. Two different liquid is considered in this study one is DIDP which is non conductive and another conductive liquid.	The viscosity of the liquid is obtained from the resonance characteristics of the vibrating wire cell. An equivalent impedance model is fitted to the measured impedance to extract the resonance parameters[7]. The main improvement on this measurement procedure is inclusion of both magnitude and phase value in the impedance model. The second improvement is the increase of the portability of the newly developed measurement equipment, when compared to previous experimental setups.
2010	Liviu Viman and Serban Lungu	They have proposed an electrical model for two coils vibrating wire transducers without mutual coupling. The electrical models of vibrating wire transducers are important to determine oscillating circuit	The impulse train excitation represents a method that can use one coil for both excitation and measuring. Compared

		performance. It also helps in dictating the excitation method to use as well as to establish the best criteria to reveal the main transducer parameters. Experiments were performed on two VW deformation transducers (F1 model produced by Telemac and TDUE1 produced by Icemenerg) to determine the passing band at 3 dB damping (B 3 dB), the quality factor (Q). To excite the transducer, a signal generator was used which generates 1.6 V_{v-v} sine wave. The excitation signal was applied in both maintenance and listening coils and the data was put into graph. Simulation was made by giving sinusoidal permanent regime and impulse train excitation.	to voltage pulse excitation has the advantages as- non-aggressive, the damping response in frequency is slower and is easy to implement by using microcontroller. Using the electrical model without mutual coupling allows to obtain immediately results that could be very difficult to acquire on the analytical way[8].
2010	Liviu Viman and Serban Lungu	This study was made on the same topic but on electrically coupled model. Comparisons were made between mechanical vibrating wire transducer and electrical mutually coupled model. After solving equations and frequency analysis and finally validating the model in MATLAB the experimental and theoretical results are confirmed. The obtained electrical model has an ultra selective behaviour and a very good quality factor.	A 3% difference was computed between the quality factors of the model and of the experimentally tested transducers and a 3.5% difference was computed between the 3dB attenuation band of the model and of the experimentally tested transducers. The electrical model resonance frequency f_0

			is approximately equal to the vibrating wire equivalent circuit resonance frequency f_{0c}. The difference between the obtained values is 0.25Hz (0.04%)[9].
2011	Pasquale Arpaia, Marco Buzio, Juan Jose Garcia Perez, Giancarlo Golluccio, Carlo Petrone, Louis Walckiers	Vibrating wire method is also used for magnetic field measurement on small magnets. The magnet multipoles are assessed by positioning the wire in different point on a circle inside the magnet aperture and measuring the amplitude of wire vibration. An optical sensor is used to acquire the oscillation parameters. The physical principle is mainly based on Lorentz law: when an AC current flows through a wire, a force proportional to the magnitude of the local transverse field component is exerted. Simulations are carried out in MATLAB software. A model relating the Fourier analysis of the signal acquired by displacing the wire over positions distributed along a circle in the magnet to the field multipoles is derived.	It gives satisfying results in comparison to a reference rotating coil system. Future work includes Thermal variation, influence of the perpendicularity between the optical sensors and linearity response of the sensors[10].
2012	Kovacs Istvan, Mircea Maria, Gyurka Bela-Zoltan	They have proposed a measurement method by stimulation with steps of variable frequency sinusoidal pulse	As the stimulation frequency is very close to the vibrating wire

	and Balogh Szabolcs	trains. In some cases, “pluck-read” (single coil) measurement mode of the resonant frequency of vibrating wire sensors does not lead to result. For these cases, the authors of this article have developed a new stimulation method with step of variable frequency sinusoidal pulse trains[11]. As a result the output signal duration of the sensor will be longer. This method consists in applying on the VW coil short (10 ms) steps of constant frequency sinusoidal pulse trains. Each of the pulse trains (step) has a frequency of 10 Hz higher than the previous one.	resonance frequency, for the entire duration of the pulse train, the amount of energy transmitted to the sensor is higher. Thus the output signal duration will be longer than other stimulation methods used currently. The drawback of this method is the total time duration for frequency measurement is much longer[11].
2012	Andrea Simonetti	The author has proposed a strain measurement technique of vibrating wire transducers based on RMS (root mean square) value of the harmonic response. The main target was to demonstrate that these sensors can be driven with low energy pulses as a consequence of the fundamental property of the harmonic system. Only at the resonant frequency the response reaches its maximum amplitude. Two coil vibrating wire gauges were used. The sensor is excited by a square wave whose period (the duty cycle is exactly 0.5). In the reading	An accurate measurement technique based on the RMS value of the waveform response has been presented and discussed in this paper. An experimental testbed with a dedicate circuit and six professional sensors demonstrates the feasibility of this technique. The proposed algorithm is particularly suitable for

		phase, the RMS value of the sampled waveform is calculated and stored in s FIFO array. Vibrating wire transducers are difficult to adapt to low power applications.	the wireless sensor networks powered by energy harvesting solutions[12].
2013	A. Cellatoglu and K. Balasubramanian	In this paper a dual diaphragm based vibrating wire type transducer for sensing pneumatic pressure is proposed. A dual diaphragm structure holding a tightly stretched wire at the vertices of the diaphragms as to increase the sensitivity of the pressure transducer. An optocoupler is installed to measure the frequency of vibration of the wire. Three tests such as static test, measuring time constant and dynamic test were performed on single diaphragm vibrating wire, double diaphragm vibrating wire and single diaphragm strain gauge. Both static and dynamic tests show better performance of dual diaphragm pressure sensor.	The improved performance of the dual diaphragm based vibrating wire pressure cell in its sensitivity encourages us to replace the single diaphragm vibrating wire pressure transducers used in practice[13]. The cost involved in it is also very less. The deflection characteristics of the diaphragm depend on the elastic properties of the material used for wire and for diaphragms and on the physical dimensions of the materials employed. For measurement of extremely high pressures, the thickness need be relatively larger as to withstand

			the pressure and offer reasonable durability[13].

2.3 Sensor and Transducer

Sensor or sensing element is the primary element of the measuring system which senses the physical quantity being measured and converts it to a more suitable form. The block diagram in Fig 2.4 would illustrate the difference between sensor and transducer.

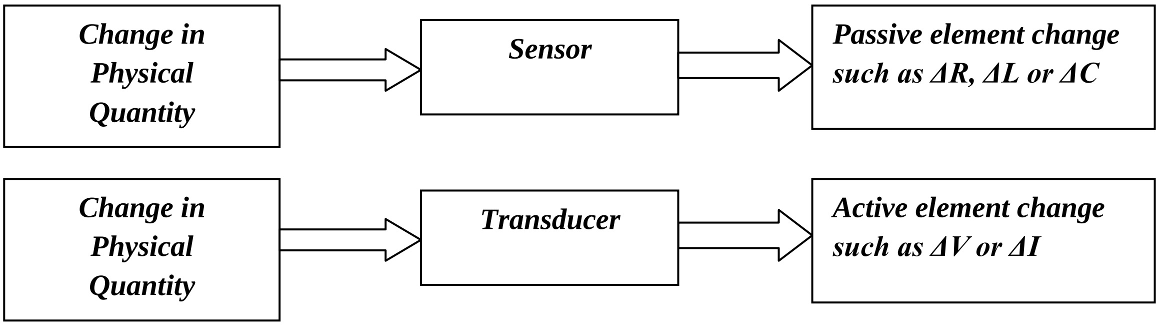

Fig 2.6 Block diagram showing difference between sensor and transducer

Thus sensor can be defined as the primary measuring element. A simple mercury thermometer is also a sensor which senses temperature. It can be embedded in a transducer to perform further functions [14]. That means transducer can be defined as a combination of a primary element (i.e. sensor) and a secondary element (i.e. signal conditioning circuit) that transforms small passive changes to active signal changes such as voltage or current which can be easily detectable and measurable.

Vibrating wire type load cells are sensors. It senses change in load and when it is connected to any reading extracting instrument such as a read out unit or data logger then the combination is said to be a transducer.

2.4 Vibrating Wire Transducer

Vibrating-wire transducers are used in many instruments, including load cells, deformation gauges, surface and embedment strain gauges, earth pressure cells, pressure sensors for piezometers, and liquid level settlement gauges[15]. The schematic diagram of a vibrating wire sensor is shown in Fig 2.5.

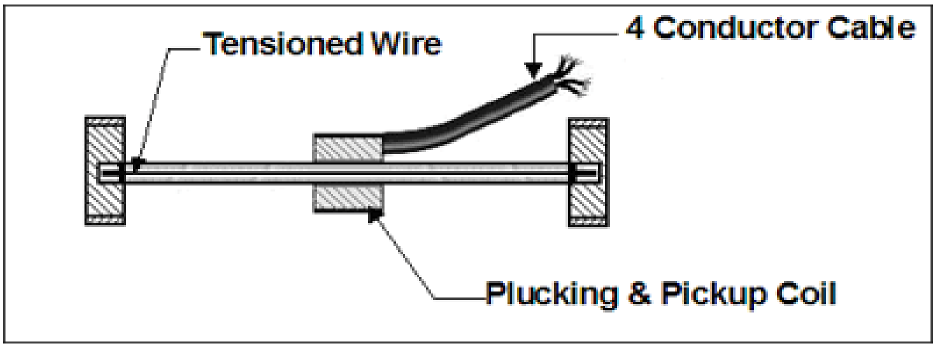

Fig 2.7 Schematic diagram of vibrating wire transducer

2.4.1 Working principle

The working principle of Vibrating wire load cells is well known. A highly tensioned wire is fixed between two flanges inside the hollow casing across the length. A coil is positioned almost near the middle of the wire. When this coil is energised by using some external source, the magnetic field generated plucks the wire and lets it vibrate in its resonant frequency reflective of the external force. These vibrations cause voltage fluctuations in the coil that corresponds to the vibrations. When stress or pressure comes upon the load cell, the tension on the wire changes as the two flanges are physically moved towards each other and this in turn causes small decrease in the effective length and tension of the wire. Thus the vibration frequency of the wire also changes. A vibrating wire type load cell is shown in Fig 2.6.

Fig 2.8 Vibrating wire type load cell (SME 2240)

A read out unit is used to extract readings from the load cell. It provides a low voltage pulse signal to the magnetic coil which in turn causes the wire to vibrate at its natural frequency. The read out unit selects the frequency corresponding to peak voltage generated in coil being the resonant frequency. If continuous read out is needed then two coil vibrating wire transducers are used. One coil electronically plucks the wire and senses the vibration caused voltage fluctuations. This frequency is calculated. The second coil vibrates the wire at the same frequency. As frequency changes, so does the plucking frequency of the second coil.

The vibrating wire theory thus can be expressed as follows:

$$\frac{}{} \qquad \frac{}{} \qquad\qquad [5]$$

Where,

f= resonant frequency of wire vibration

ΔL= change in length of vibrating wire

L= initial length of vibrating wire

E= Young’s modulus of the steel wire

ρ= volumetric weight of wire

2.4.2 Reading extraction

There are three coils placed inside the load cell 120° apart. The reason behind this is when load comes upon the upper platen; it is not uniform throughout the surface. Thus reading should be taken from various parts of the surface and then averaged o get the accurate reading. For this study I have used the load cell model of SME 2240. It has four different colour wires (red, yellow, green and black) coming out of it for measurement purpose. Red, yellow and green wires represent the positive end of the wires inside and the black one is the negative end. While taking readings every coil is connected to the read out unit one by one i.e. red-black, yellow-black and green black. Then the readings are noted down. If it comes in frequency or time period then it is multiplied by a constant named gauge factor to obtain the load reading and finally these three readings are averaged to obtain the final reading. Now-a-days there are read out units available which gives load reading instead of frequency or time period. Fig 2.7 shows the readings being taken from a load cell installed on a hydraulic prop.

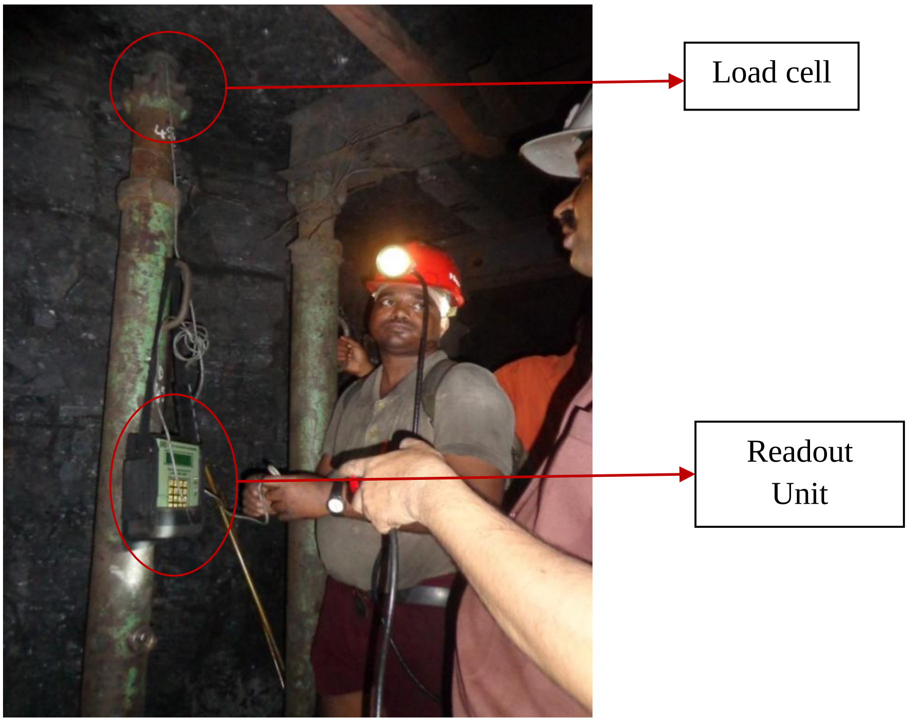

Fig 2.9 Load cell installed on hydraulic prop in a typical Underground coal mine[3]

2.6 Readout Unit

The read out unit used these days are microprocessor based. These are programmed to display the reading in frequency or time period or directly in engineering unit like Ton or kg/cm^2. It has a double line alphanumeric LCD, internal real time clock and battery backed 64 KB memory. It has two different ports for charging and interfacing with the sensor. Its weight is 1.5 kg approx. the readout unit sends a low voltage pulse signal to the magnetic coil which in turns makes the wire to vibrate at its natural frequency. The readout unit selects the frequency corresponding to peak voltage generated in coil being the resonant frequency.

2.7 Compression Testing Machine (CTM)

Compression testing machine has two platens such as top and bottom platen. The bottom platen is fixed whereas the top platen is adjustable. The sample is placed in between these platens and load is manually given using a hydraulic lever. The machine has a maximum capacity of 500 kN. It is manufactured by Soillab. In our study, we have used this CTM to give load to the vibrating wire type load cell. Load was increased step by step up to 250 kN with an interval of 10 kN.

2.8 Wien Bridge Oscillator

The Wien Bridge Oscillator is a two stage RC coupled amplifier circuit. It has good stability at its resonant frequency and is used in audio and sub audio frequency ranges (20-20kHz). The circuit design of this oscillator is very simple and its size is also compact. It uses a feedback circuit consisting of series RC circuit connected with a parallel RC of the same component values producing a phase delay advance circuit depending upon the frequency. At the resonant frequency f_r the phase shift is 0° [16]. The RC network consists of a series RC connected to a parallel RC forming basically a High pass filter connected to a Low pass filter producing a very selective second order frequency dependant Band pass filter with a high Q factor at the selected frequency f_r [16].

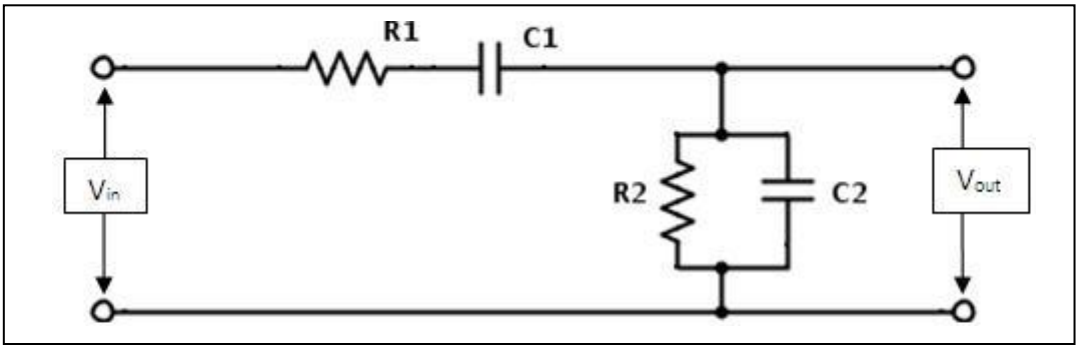

Fig 2.10 RC coupled amplifier circuit

At low frequencies the reactance of capacitor C1 is very high so it acts as an open circuit. Thus it blocks all input signal. At very high frequencies, the reactance of capacitor C2 is very low. Thus it acts as short circuit. In that case also there is no output signal, whereas between these two extremities there a frequency exists where the output voltage reaches a maximum value. This particular frequency is known as resonant frequency (f_r).

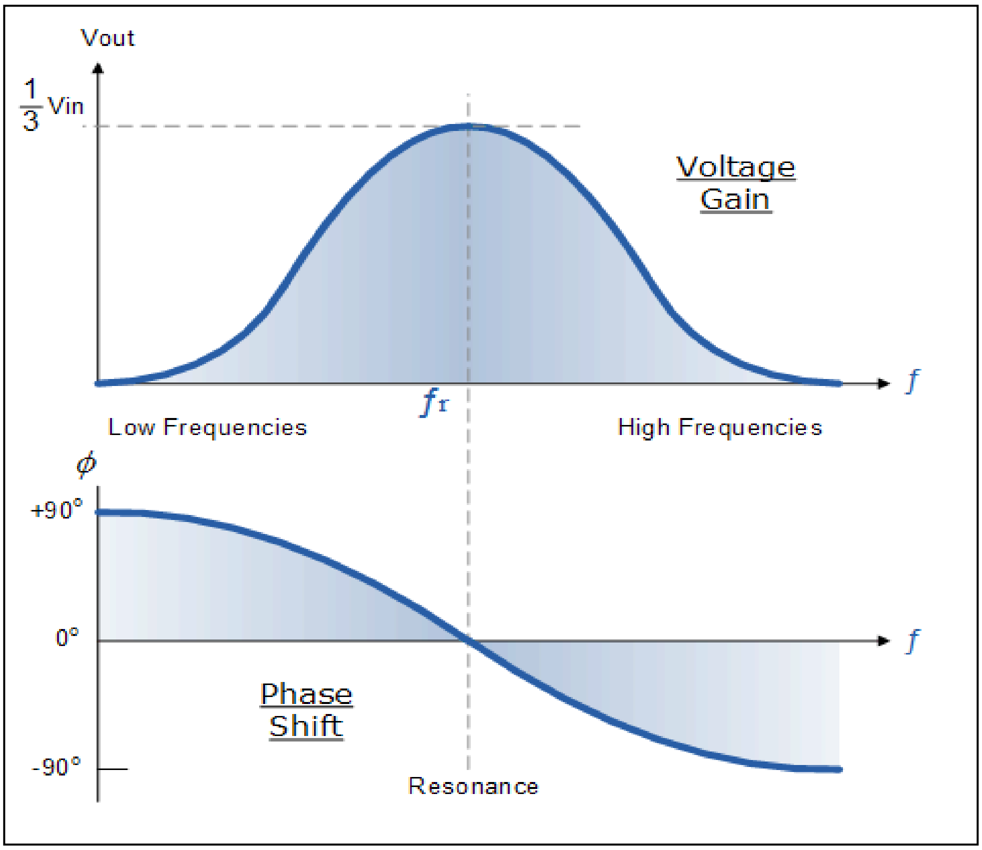

Fig 2.11 Voltage and Phase diagram of RC coupled circuit[16]

At this resonant frequency the circuit reactance equals to its resistance i.e. X_c=R. so the phase shift between input and output becomes zero degrees. The magnitude of the output voltage is maximum and equals to one third of the input voltage. At very low frequencies the phase angle between input and output signals is ‘positive’ (i.e. phase advanced), whereas at very high frequencies the phase angle becomes ‘negative’ (i.e. phase delay). Therefore the Wien Bridge Oscillator frequency can be expressed as,

—— [16]

Where,

f_r is the resonant frequency in Hz

R is the resistance in Ohms

C is the capacitance in Farads

This frequency selective RC network forms the basis of Wien Bridge Oscillator circuit. If this circuit is placed across a non-inverting amplifier with a gain of $(1+R_3/R_4)$ then the total oscillator circuit is produced which is shown in Fig 2.10.

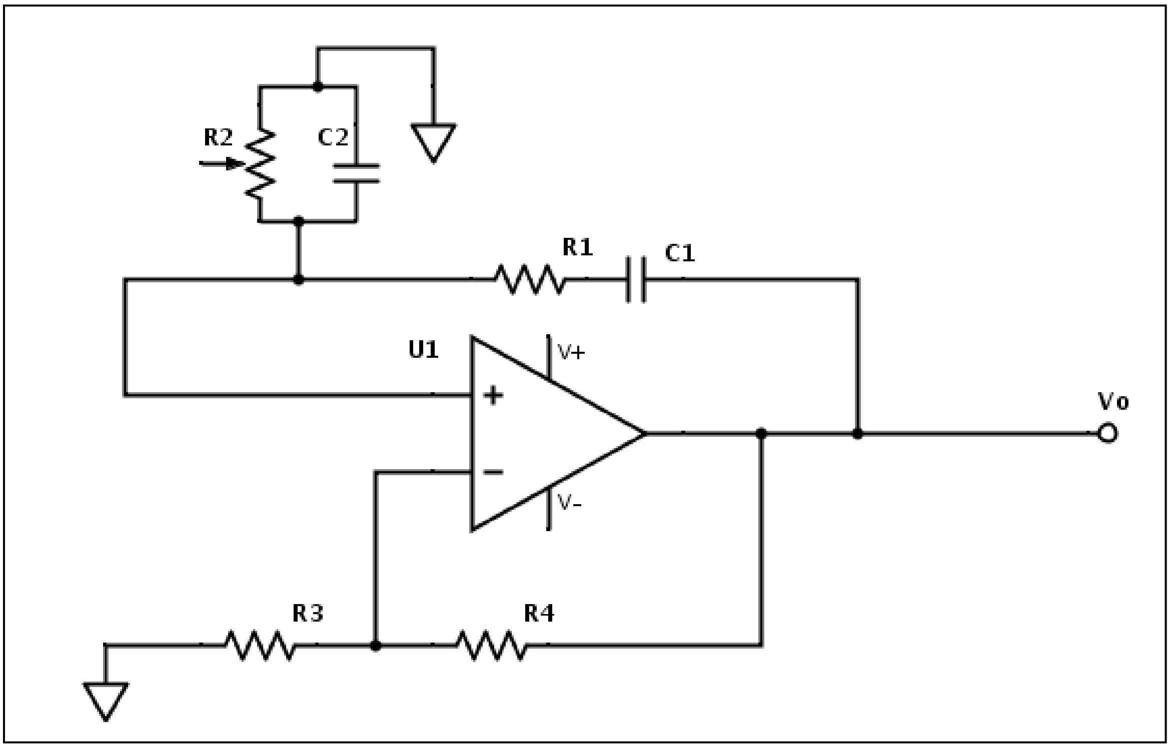

Fig 2.12 Wien Bridge Oscillator circuit diagram

The output of the op amp is fed back to both the inverting and non inverting inputs of the amplifier. One part of the feedback is connected to the inverting input terminal (negative feedback) through resistor divider network of R3 and R4 and the other part of feedback is connected to the non inverting end (positive feedback) through Wien Bridge network.

2.6 ATmega32

The Atmel AVR ATmega32 is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture[17]. By executing powerful instructions in a single clock cycle, the ATmega32 achieves throughputs approaching 1 MIPS per MHz allowing the system designed to optimize power consumption versus processing speed[17]. The Atmel AVR AVR core combines a rich instruction set with 32 general purpose working registers. All the 32 registers are directly connected to the Arithmetic Logic Unit (ALU), allowing two independent registers to be accessed in one single instruction executed in one clock cycle.

The resulting architecture is more code efficient while achieving throughputs up to ten times faster than conventional CISC microcontrollers[17]. There are various pins in the ATmega32 microcontroller. These are described as follows-

VCC- Digital supply voltage.

GND- Ground.

Port A (PA7 to PA0) - Port A serves as the analog inputs to the A/D Converter. Port A also serves as an 8-bit bi-directional I/O port, if the A/D Converter is not used. Port pins can provide internal pull-up resistors (selected for each bit)[17].

Port B (PB7 to PB0) - Port B is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit)[17].

Port C (PC7 to PC0) - Port C is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit). Port C also serves the functions of the JTAG interface and other special features of the ATmega32[17].

Port D (PD7 to PD0) - Port D is an 8-bit bi-directional I/O port with internal pull-up resistors (selected for each bit)[17].

RESET- Reset Input. A low level on this pin for longer than the minimum pulse length will generate a reset, even if the clock is not running[17].

XTAL1 - Input to the inverting Oscillator amplifier and input to the internal clock operating circuit.

XTAL2 - Output from the inverting Oscillator amplifier.

AVCC - AVCC is the supply voltage pin for Port A and the A/D Converter. It should be externally connected to VCC, even if the ADC is not used. If the ADC is used, it should be connected to VCC through a low-pass filter[17].

AREF - AREF is the analog reference pin for the A/D Converter[17].

The main features of ATmega32 are, 32 Kbytes of In-system programmable Flash program memory with read-while-write capabilities, 1024 bytes EEPROM, 2Kbytes SRAM, 32 general purpose I/O lines, 32 general purpose working registers, a JTAG interface for boundary scan, On-chip Debugging support and programming, three flexible timer/counters with compare modes, internal and external Interrupts, a serial programmable USART, a byte oriented two wire serial interface etc.

The ATmega32 contains a 10 bit successive approximation ADC. The ADC is connected to an 8 channel Analog Multiplexer which allows 8 single-ended voltage input constructed from the pins of Port A. the single ended voltage refers to 0V (GND). The ADC contains a Sample and Hold circuit[17]. This ensures the input voltage is kept constant during conversion. The ADC converts an analog input voltage to 10 bit digital value through successive approximation. The minimum value represents GND and maximum represents the voltage on AREF pin minus 1 LSB[17].

Chapter 3

EXPERIMENTAL INVESTIGATIONS

This section gives a detailed description of the experiments performed during this study on vibrating wire type load cell to achieve the objective. The experiments were performed step by step to starting from determination of frequency range for optimum output to finally interfacing of microcontroller with the load cell analog output. The experiments were performed on the instrument at unloaded condition and also loading it from 0 to 25 T. The load cell used for the study is SME 2240 and its capacity is 50 T.

3.1 Determination of Optimum Frequency Range

The load cell input was given by a function generator and the output was connected to a CRO (Cathode ray oscilloscope). A 1 kΩ resistance was connected in series with the load cell coil. An input voltage of 2 V_{pp} was given and the input frequency was varied from 1 Hz to 1 MHz. The results thus came out were kept in record. These were the range of frequency within which the load cell coils give optimum output of $1.8V_{pp}$. This experiment was performed in no load condition. According to the results the oscillator circuit was made. The experimental set up is shown in Fig 3.1.

Fig 3.1 Experimental setup for determination of the optimum output frequency range

3.2 Circuit Development

Wien Bridge oscillator is the most commonly used oscillator circuit which gives voltage output of certain frequency range. For my study I have chosen it because it has a very simple circuit. The component values are so chosen that it covers a range of frequencies from 78 to 143 kHz. The different component values are R1 and R2- 50 Ω, R3- 12kΩ, R4- 47kΩ, C1 and C2- 0.01μF. A potentiometer is fixed at resistance R2. The circuit is shown in Fig 3.2.

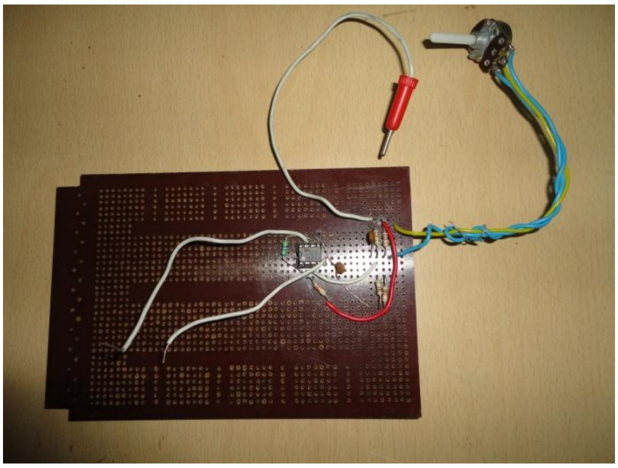

Fig 3.2 Wien Bridge oscillator circuit

3.3 Interfacing with Wien Bridge Oscillator

The oscillator circuit used for this purpose is Wien Bridge oscillator. A potentiometer was connected at one of the feedback resistances at the non inverting input terminal. This potentiometer is used to vary frequency within its optimum output range. The components values for the circuit were so chosen to get the desired output. The oscillator circuit was connected to input of load cell and output was monitored in a CRO. The instrument was loaded from 0 T to 25 T at an interval of 1 T. At a certain load the frequency was so varied to have the maximum output voltage. The frequency is manually changed to obtain the maximum output voltage as it corresponds to the resonant frequency of the vibrating wire. The results were recorded in tabular form of output rms voltage with varying load and frequency. The experimental set up is shown in Fig 3.3.

Fig 3.3 Experimental setup for interfacing with Wien Bridge Oscillator

3.4 Interfacing with Microcontroller

As discussed in the previous chapter, Atmega32 microcontroller has an inbuilt ADC i.e. analog to digital converter. The output from load cell was directly fed to Port A of ATmega32 and it was programmed according to the output voltage readings. As the input to the microcontroller was sine wave i.e. AC thus the output being displayed was showing fluctuations. To minimise the fluctuations a rectifier is needed which would convert the AC voltage signal to DC or discrete signal. Thus this problem can be resolved. The microcontroller was programmed to display the load reading. The program code is given below. This code was written for the red coil readings.

```
void p(long w)
void p(long w)
{
        int n =0,r=0;
        lcd_cursor(1,10);lcd_string("    ");

        n=0;
        if (w < 14)
        {
                w = 28 - 16.31*(w*0.019);
        }
        else
        {
                w = 61 - (51.58*(w*0.019));
        }

        r = w;
```

```
		while(r>0)
		{
			n++;
			r=r/10;
		}

		lcd_print(1,10,w,n);
	}

		else
		{
			w = 61 - (51.58*(w*0.019));
		}

		r = w;

		while(r>0)
		{
			n++;
			r=r/10;
		}

		lcd_print(1,10,w,n);
	}
```

Chapter 4

RESULTS AND DISCUSSION

At first the frequency range for optimum output was determined. Then the Wien Bridge oscillator circuit was developed corresponding to the output values from the previous experiment. Finally it was interfaced with the instrument i.e. load cell and the response was recorded. The results are discussed in this section accordingly.

4.1 Results

The frequency range within which optimum output comes out is shown in the Table 4.1. The table shows that the frequency range to be covered is 60 to 160 kHz i.e. the oscillator circuit should provide those frequencies. The Wien Bridge oscillator circuit was developed. It gives the output voltage of 3.56 V and a frequency range of 78 to 143 kHz. Results of interfacing the Wien Bridge oscillator circuit with the three coils are shown in the Tables 4.2 to 4.4.

Table 4.1. Frequency range for optimum output of load cell

Coil name	Frequency range (in kHz)	Output voltage (peak to peak)
Red	100-160	1.8V
Green	70-120	1.8V
Yellow	60-100	1.8V

Table 4.2 Output from the red coil with varying load and frequency

Load (in Tonnes)	Frequency (in kHz)	o/p rms voltage (in volts)
0	80.6	1.15
1	81.3	1.14
2	82.6	1.13
3	83.3	1.11
4	83.3	1.1
5	84.7	1.07
6	86.2	1.05
7	87.8	1.03
8	87.7	1
9	89.3	0.996
10	90.9	0.974

12	92.6	0.957
13	94.3	0.92
14	98	0.888
15	100	0.808
16	111	0.674
18	114	0.62
19	116	0.57
20	120	0.49
21	125	0.42
22	135	0.3
23	137	0.23
24	143	0.23
25	143	0.195

Table 4.3 Output from the yellow coil with varying load and frequency

Load (in Tonnes)	Frequency (in kHz)	o/p rms voltage (in volts)
0	80.6	1.17
1	82	1.14
2	82.6	1.12
3	83.3	1.09
4	84.7	1.08
5	85.5	1.06
6	86.2	1.03
7	87.7	1.01
8	90.9	0.978
9	92.6	0.963
10	94.3	0.936
11	96.2	0.902
12	98	0.86
13	100	0.844
14	102	0.81
15	106	0.728
16	111	0.655
17	119	0.523
18	122	0.485
19	125	0.426
20	132	0.317
21	135	0.244
22	139	0.218
23	141	0.197
24	143	0.185
25	143	0.18

Table 4.4 Output from the green coil with varying load and frequency

Load (in Tonnes)	Frequency (in kHz)	o/p rms voltage (in volts)
0	79.4	1.18
1	80.6	1.16
2	82	1.15
3	83.3	1.11
4	84	1.09
5	84.7	1.06
6	86.2	1.05
7	87	1.03
8	87.7	1.01
9	90.1	0.985
10	92.6	0.964
11	94.3	0.928
12	98	0.867
13	100	0.818
14	102	0.81
15	104	0.766
16	106	0.708
17	111	0.658
18	116	0.56
19	122	0.471
20	127	0.395
21	135	0.291
22	139	0.232
23	139	0.185
24	143	0.178
25	143	0.172

4.2 Analysis

The Table 4.2 to 4.4 shows change in output rms voltage while there is a certain load and the input frequency is being changed from 78 to 143 kHz. There are different output voltages in the three coils. It is due to difference in their impedance.

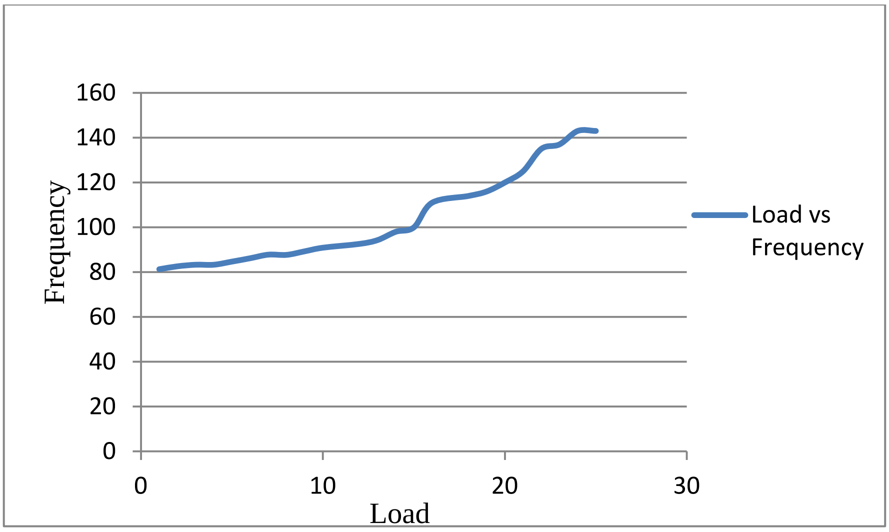

Fig 4.1 Load vs. Frequency graph for red coil

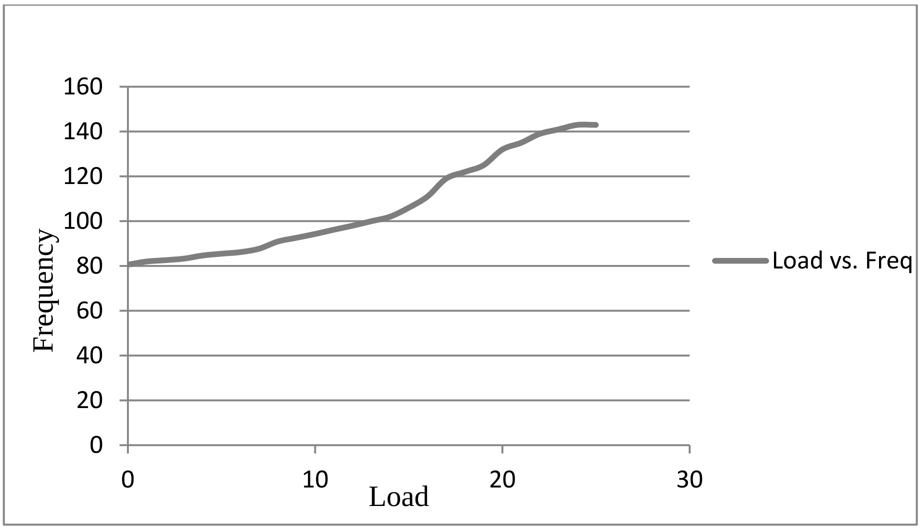

Fig 4.2 Load vs. Frequency graph for yellow coil

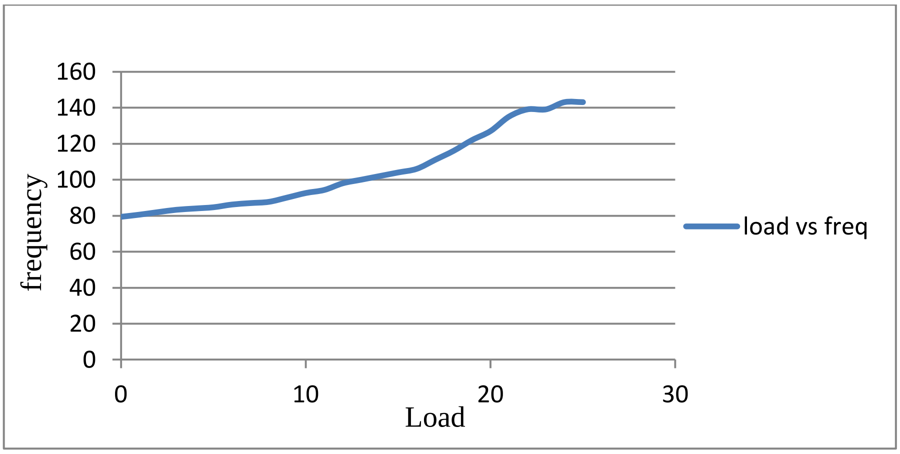

Fig 4.3 Load vs. Frequency graph for green coil

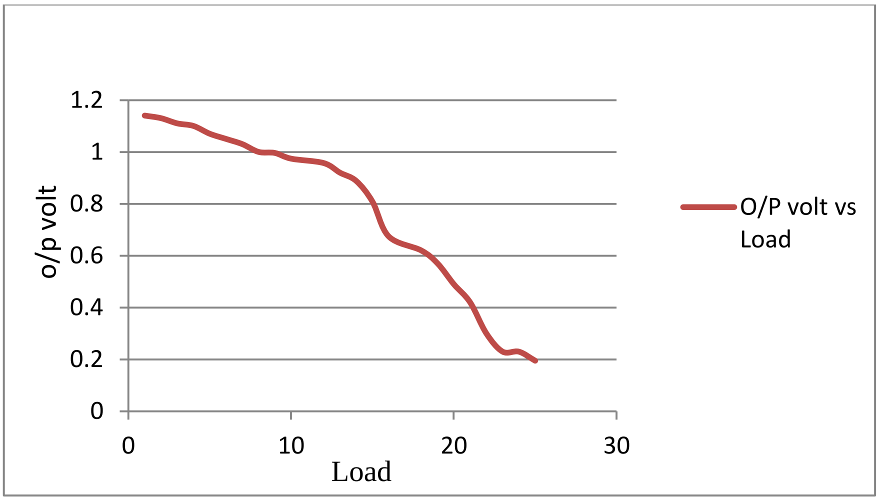

Fig 4.4 Load vs. o/p volt graph for red coil

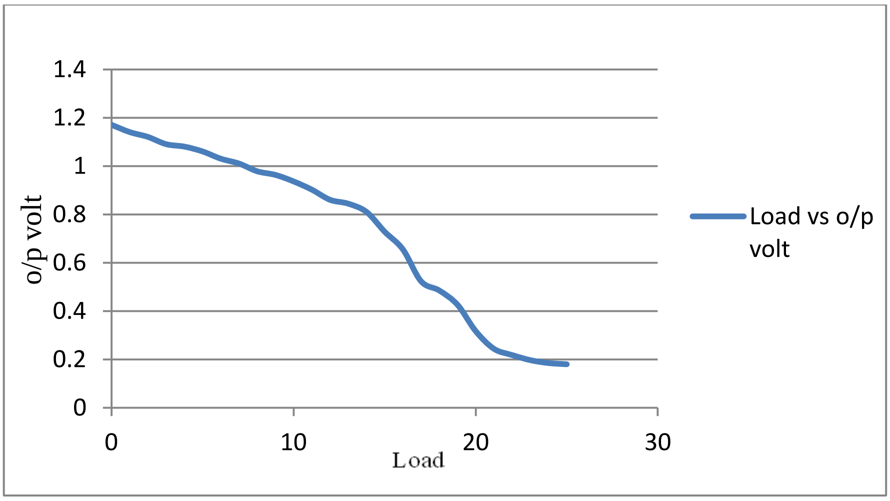

Fig 4.5 Load vs. o/p volt graph for yellow coil

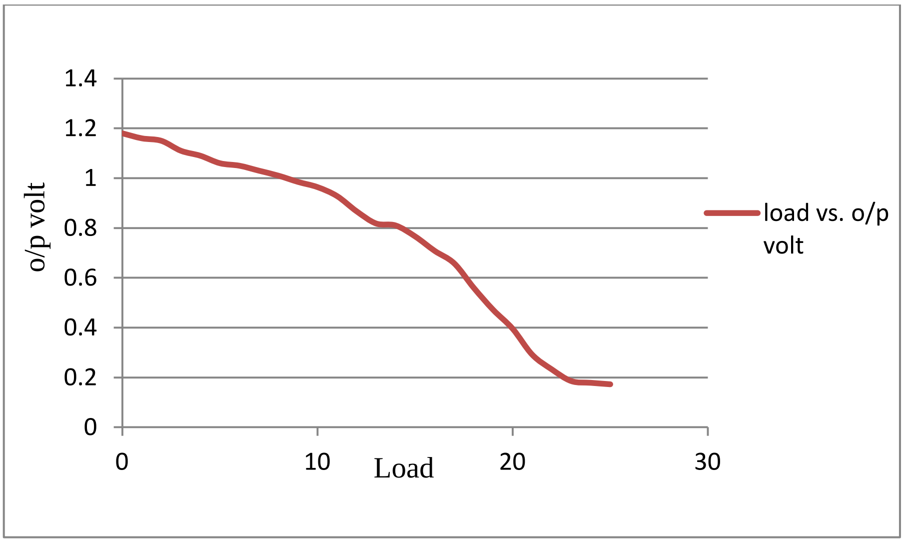

Fig 4.6 Load vs. o/p volt graph for green coil

From the graphs we can see that load vs. frequency graph has a rising trend i.e. frequency is rising with load whereas output voltage is decreasing with increasing load upon the instrument.

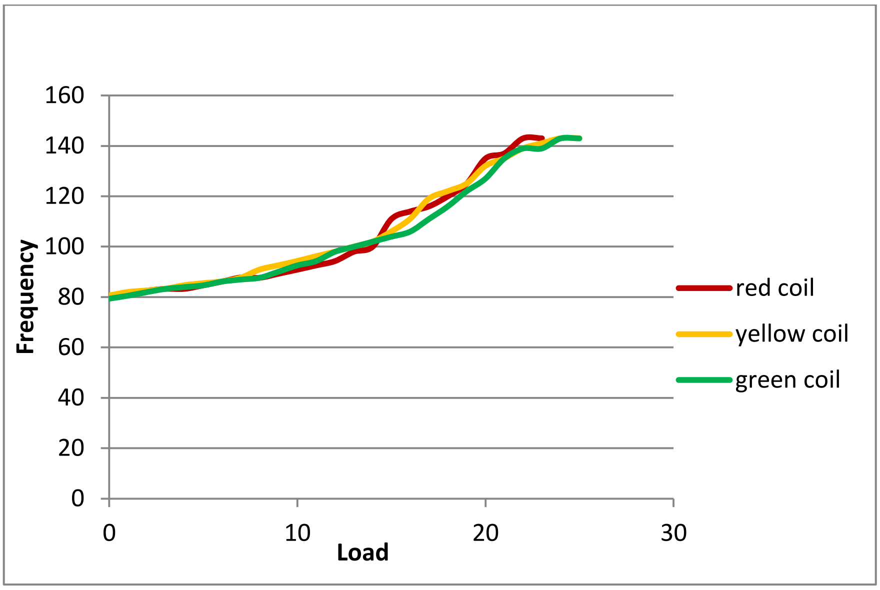

Fig 4.7 Load vs. Frequency graph of three coils

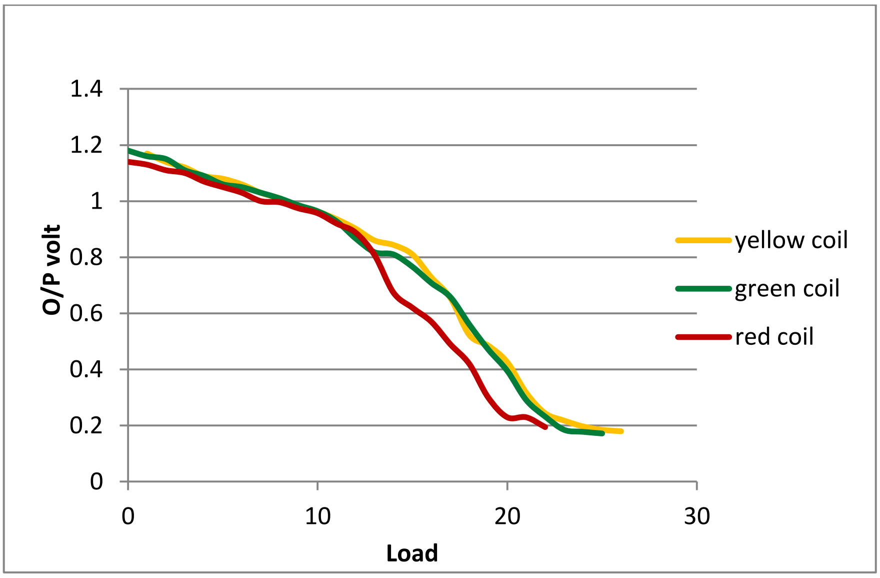

Fig 4.8 Load vs. o/p volt graph of three coils

These two plots of Fig 4.7 and 4.8 show that three coils are showing almost same profile with increasing load. That explains the continuity of the experiments performed and also the accuracy of the devices used for these experiments.

From the above experimental investigations, it was observed that applied load on the cell can be digitised with some more modifications in the developed circuit as described below

1. A rectifier along with a suitable filter which gives exact output DC voltage may be introduced. It will minimise the fluctuations in microcontroller display.
2. Increase in voltage gain of Wien Bridge Oscillator can give better results. In effect of it, the output voltage level will also raise.

Chapter 5

CONCLUSION AND SCOPE FOR FUTURE WORK

5.1 Conclusion

Based on critical review of application of load cells in underground mines and the experiments conducted on Vibrating wire type load cell using Wien bridge oscillator as an input to the instrument and loading it from 0 to 25 T, the following conclusions are drawn.

1. Vibrating Wire type load cells of 20 to 50 T capacities are generally used in underground coal mines for measurement of load on supports and for evaluation of behaviour of the supports. Setting load is invariably kept at about 2 to 5 tons and maximum load in typical mines may be about 20 T for which the support system is considered as adequate with safety factor exceeding 2.
2. In the experimental investigations on load cell, the change in Load from 0 to 25 T has no influence in output voltage. If load is given with fixed input frequency then there is no change in output voltage of load cell. This may be attributed to failure of detection of voltage fluctuations caused by the wire vibrations with fixed input frequency.
3. Change in input frequency for a certain load causes change in output voltage from 1.18 V to 172 mV. At resonant frequency of the wire, peak voltage is generated across the coils. The frequency is changed manually using potentiometer fixed in the Wien Bridge oscillator circuit.
4. Load reading in microcontroller display experienced fluctuations due to sine wave input into it. As microcontroller works on either discrete or DC signals, it fails to display a fixed reading.

5.1 Scope for Future Work

The objective of this project was to digitise vibrating wire type load cell using basic electronic circuitry and microcontroller. The experimental setup can be further improved by introducing a rectifier along with a suitable filter which would convert the AC output signal to DC. This will minimise the fluctuations of the microcontroller display. It can also be proposed to further extend the work for continuous monitoring using a wireless sensor network.

REFERENCES

1. Jayanthu, D.S., Scientific Study in BG-II/10 sub-panel A and sub-panel B panel and 4 seam sand stowing SS-10 of GDK NO.8 INC. RG-II area-SCCL 2012, National Institute Of Technology Rourkela-769008, ODISHA. p. 51.
2. Jayanthu, S., Strata Monitoring Report Of Longwall Panel No.3d1 & 3d2 Of Gdk.10a, Apa, Sccl.2013 p. 48.
3. Jayanthu, S., Strata Monitoring In Blasting Gallery Panel # BG3E OF Queen Seam of 21 incline, Yellandu Area, SCCL. 2013. p. 70.
4. Balasubramanian, K., K. Guven, and Z. Altun. Microprocessor based new technique for measuring pneumatic pressure using optocoupler controlled vibrating wire transducer. in Instrumentation and Measurement Technology Conference, 1994. IMC/94. Conference Proceedings. 10th Anniversary. Advanced Technologies in I & M., 1994 IEEE. 1994: IEEE.
5. Choquet, P., et al. Reliability, long-term stability and gage performance of vibrating wire sensors with reference to case histories. in Proceedings of the fifth international symposium field measurements in geomechanics. Rotterdam: Balkema. 1999.
6. Bande, V., et al. Behavioral model and a MatLAB simulation interface of vibrating wire transducers. in Electronics Technology, 2009. ISSE 2009. 32nd International Spring Seminar on. 2009: IEEE.
7. Janeiro, F.M., et al. Impedance spectroscopy of a vibrating wire for viscosity measurements. in Instrumentation and Measurement Technology Conference (I2MC), 2010 IEEE. 2010: IEEE.
8. Viman, L. and S. Lungu. Electrical model for two coils vibrating wire transducers without mutual couplings. in Design and Technology in Electronic Packaging (SIITME), 2010 IEEE 16th International Symposium for. 2010: IEEE.
9. Viman, L. and S. Lungu. Electrical coupled model for two coils vibrating wire transducer. in Electronics Technology (ISSE), 2010 33rd International Spring Seminar on. 2010: IEEE.
10. Arpaia, P., et al. Magnetic field measurements on small magnets by vibrating wire systems. in Instrumentation and Measurement Technology Conference (I2MC), 2011 IEEE. 2011: IEEE.

11. Istvan, K., et al. Vibrating wire sensor measurement method by stimulation with steps of variable frequency sinusoidal pulse trains. in Automation Quality and Testing Robotics (AQTR), 2012 IEEE International Conference on. 2012: IEEE.
12. Simonetti, A. A measurement technique for the vibrating wire sensors. in NORCHIP, 2012. 2012: IEEE.
13. Cellatoglu, A. and K. Balasubramanian, Increasing the Sensitivity of Vibrating Wire Pressure Sensor.2013
14. Sensor and Transducer. 35 anonymous.
15. Larson, M., et al., Instruments for monitoring stability of underground openings. Proceedings: New Technology for Coal Mine Roof Support, 2000. 9453: p. 259-269.
16. http://www.electronics-tutorials.ws/oscillator/wien_bridge.html
17. Datasheet, A.A., Atmel Corporation. Technical Support, 2009.
18. Ivor Hawkes 1979, Vibrating wire stress meter, Pat no. US 4159641 A