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ELECTRONIC ENGINEERING

Design and Construction of Seismograph for Earthquake Measurement System

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Abstract— **The measurement of vibration of the earth by using the appropriate sensor is an essential part of the Meteorology and Hydrology. This research work aims to explore a seismic wave monitoring device which can record and monitor the ground motion with a low-cost PC based seismic data system. The constructed device can be used for the purpose of replacing conventional analog seismic recorders. The Seismograph for Earthquake Measurement System based on Microcontroller is designed and constructed. This system is divided into three main parts: (1) Movement Sensing Amplifier (2) Data logging circuit and (3) Interfacing circuit. Movement sensing amplifier consists of the Hall Effect sensor and signal conditioning circuit. To sense the ground vibrations, a magnet and magnetic field sensor is used. In order to measure ground motions, the seismograph must remain steady when the ground moves. To obtain this steady state, the pendulum assembly is used, in which a weight is suspended from a long wire secured to a suitable wall-mounted fixing point. Typically, a magnet is attached to the weighted end of the pendulum and a magnetic field sensor is fixed to a rigid base in close proximity to the magnet. The sensor reacts to change in the strength of the magnetic field in response to earth movement. These changes are detected by electronic circuitry and suitably processed for display or recording purposes. Data logging circuit requires data acquisition and storage. The analog output of the Hall Sensor, GH-700, is connected to a microcontroller, PIC16F877A, through an ADC for digital signal conversion and data logging. An LCD display is also connected to the microcontroller to display the current measurement value. The resulting digital value is then stored in the external EEPROM. The data can be transferred to a PC with RS-232 serial communication using software.**

Keywords— **Microcontroller, Sensor, LCD, EEPROM, serial communication**

I. Introduction

Earthquakes are one of the most powerful natural forces that can disturb our daily lives. An earthquake is the rapid vibration of the earth created by a sudden movement of large sections of rock. Earthquake generates seismic waves which can be detected with a sensitive instrument called a Seismograph. Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth. Although seismographs are widely used to monitor naturally occurring earthquakes, they can be used to monitor any shaking of the earth, including movement caused by man's activities.

II. Aims and Objectives

Most seismographs were analog type equipped with a moving pendulum to record earthquake motion on paper, but most of those now in use are digital type that converts earthquake motion to electrical output is then digitized by an ADC and record on an IC card etc. The objectives of this research are:

1. To measure the seismic waves from an earthquake
2. To study the vibration sensor
3. To study the PIC16F877A microcontroller, EEPROM, LCD, RS-232 serial communication
4. To design an advanced long-lasting, inexpensive and highly reliable devices
5. To construct and test Seismograph for earthquake measurement system using PIC16F877A microcontroller with cost effectiveness
6. To test the proposed seismograph system
7. To calibrate the proposed seismograph system

III. Methodology

The block diagram of earthquake measurement system is shown in Fig.1. This system is divided into three main parts. They are: Movement Sensing Amplifier Data logging circuit and Interfacing circuit.

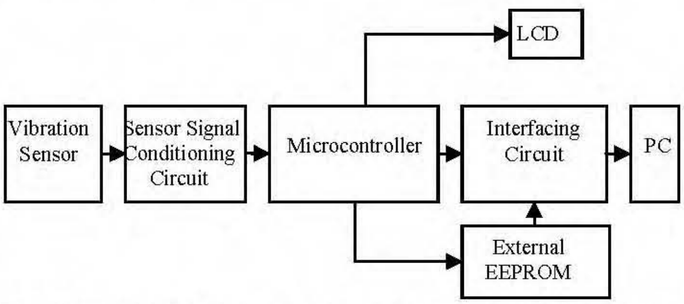

Fig. 1 Proposed Block Diagram of Seismograph for Earthquake Measurement System

Movement sensing amplifier consists of the Hall Effect sensor and signal conditioning circuit. Data logging circuit consists of the microcontroller, the external EEPROM and the LCD. The interfacing circuit facilitates the data transfer between the data logger and a PC. Reading the data, converting them into amplitude and displaying the results on the screen as a graph are required in the computer.

A. Movement Sensing Amplifier

A Hall Effect sensor is needed to measure the magnetic field. The sensor's signal conditioning circuit is required because the sensor's output signal is weak and noisy. The output voltage signal from the sensor is amplified and eliminated to remove the effects of external influence by ac mains currents which may be present near the sensor.

1) Hall Effect Sensor

The purpose of the sensor is to convert a physical quantity into an electrical signal. A Hall sensor is a four-terminal, solid-state device capable of producing an output voltage V_H, proportional to the product of the input current, I_C, the magnetic flux density, B, and the sine of the angle between B and the plane of the Hall sensor.

$$V_H = K_{HOC}\, I_C\, B \sin \varnothing \qquad (1)$$

Many companies produce various kinds of vibration sensors. They are different from operating ranges, application areas, and sensitivity and so on. For movement sensing circuit, Hall Effect sensor is used. The output voltage of the sensor is linearly proportional to the magnetic field (in kG). The Hall Effect sensor has better temperature characteristics. It is also cheaper and high sensitivity. Table 4.1 shows the comparison of the Hall Effect sensors of GH-700 produced by Bell Technologies Inc. and SS495A produced by Honeywell Inc.

The sensitivity of GH-700 is higher than SS495A and the magnetic range of GH-700 is wide. In this project, the Hall sensor GH-700 is selected.

TABLE I

COMPARISON OF HALL EFFECT SENSOR SPECIFICATIONS

	GH-700 Bell Technologies Inc.	SS495A Honeywell Inc.
Magnetic sensitivity, V_H	50 to 140 mV/kG	3.125 ± 0.125 mV/Gauss
Max. resistive residual voltage, V_M @ B=0	±14 mV	2.5 ± 0.075V
Max. control current @ 25°C,	10 m A	8.7 mA
Nominal control current, I_{cn}	5 mA	1.5 mA
Magnetic Range	-10 kG to +10 kG	- 670 Gauss to + 670 Gauss
Operating temperature range	-55°C to +125°C	-40°C to +150°C
Size	Extremely small	Small

2) Design Calculation of Movement Sensing Amplifier

By amplifying the measuring voltage signal, the conditioned signal uses more of the effective range of the analog-to-digital converter and achieves better measurement accuracy.

$$A_v = 1 + \frac{R_4}{R_5} \qquad (2)$$

Assume the voltage gain of non-inverting amplifier A_v is 10.

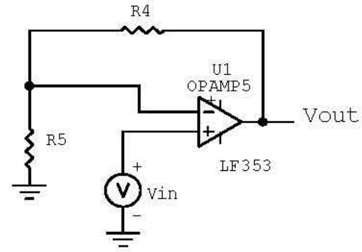

Fig. 2 Non-Inverting Amplifier Circuit

Choose R_5 = 10 kΩ

$$A_v = 1 + \frac{R_4}{10k}$$

$$= (10 - 1) \times 10\ k$$

$$R_4 = 90\ k\ \Omega$$

For this project, choose R_4 = 100 kΩ.

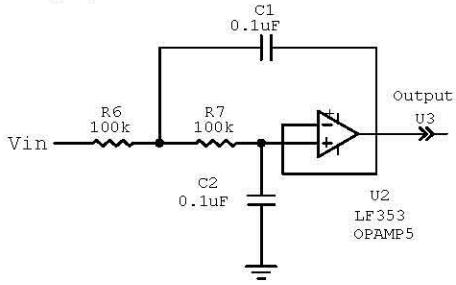

Fig. 3 Low Pass Filter Circuit

Fig. 3 shows the low pass filter circuit. In this project, the design of Chebyshev filter is chosen. This stage eliminates frequencies of about 50 Hz upwards, to remove the effects of external influence by AC main currents which may be present near the sensor. The natural frequency of low pass filter can be obtained,

$$f_c = \sqrt{\frac{1}{R_1 R_2 C_1 C_2}} \times \frac{1}{2\pi} \qquad (3)$$

Choose R = R_1 = R_2 = 100kΩ

Choose C = C_1 = C_2 = 0.1μF

$$f_c = \frac{1}{2\pi RC}$$

$$f_c = \frac{1}{2\pi \times 100k \times 0.1\mu}$$

$$= 15.9\ Hz$$

For this project, the natural frequency is 15.9 Hz.

B. Data Logging Circuit

The analogue output signal from the sensor is converted into digital signal by an ADC before being data-logging circuit which encompasses a microcontroller. The microcontroller not only controls the system but also synchronizes all the module operation. The resulting digital value is then stored in the external EEPROM and displayed on the LCD with the help of the microcontroller.

1) Choosing of Microcontroller

According to the requirement of the system, the microcontroller PIC16F877A is chosen in this project because PIC16F877A has 40 pins. There are five I/O ports. They are PORT A, PORT B, PORT C, PORT D and PORT E. Analog to digital converter (ADC) is also included in PORT A.

The resolution can be calculated.

$$\text{No of resolution} = 2^n = 2^8 = 256 \quad (4)$$

$$\text{Resolution} = \frac{\text{full scale range}}{\text{number of quantization levels}} \quad (5)$$

$$= \frac{5}{256} = 19.53 \text{ mV}$$

2) Choosing of Oscillator Types

The PIC16F877A can be operated in four different oscillator modes. The user can program two configuration bits (F_{OSC1} and F_{OSC2}) to select one of these four modes. The different oscillator modes are:

i. LP Low Power Crystal
ii. XT Crystal Resonator
iii. HS High Speed Crystal/Resonator
iv. RC Resistor/Capacitor

The oscillator using in this design is a ceramic resonator.

3) Choosing of LCD

Live data display is necessary if it need to view data as it is being acquired. More microcontroller devices are using ‘smart LCD’ displays to output visual information. LCD displays designed around Hitachi’s LCD HD44780 module, are expensive, easy to use, and it is even possible to produce a readout using the 8x80 pixels of the display. In this earthquake measurement system, the measured data is displayed into 16x2 lines LCD. The PIC and LCD can be interfaced by either parallel bus or serial bus. If the data is sent by serial, a shift register is needed. In this project, a parallel bus is used because a parallel bus is allowing simple and fast reading/writing of data to and from the LCD. For an LCD interface application, deciding how to send the data to the LCD is most critical decision to be made for an LCD interface application. Eight bit mode is best used on an application. But a 4-bit mode is used in this project so that the remaining 4 pins can be rationed for other function. For the four bit mode, two nibbles of data are sent to make up a full eight bit transfer.

4) Choosing of EEPROM

A non-volatile memory is essential to store onboard data. I^2C master mode can be used for communicating with other peripheral devices. For a seismograph, data from the sensor is needed to store for further manipulations and this requirement can be fulfilled by using a serial EEPROM.

In this project, the 24LC256 is chosen to store the converted value. It is a 32k x 8 (256k bit) serial EEPROM and low-power applications. This device also has a page write capability of up to 64 bytes of data. Data stored in the EEPROM can be accessed directly with a personal computer. The computer displays the data by using Real Terminal. Fig. 4 shows the test and result of the I^2C Sequential read test.

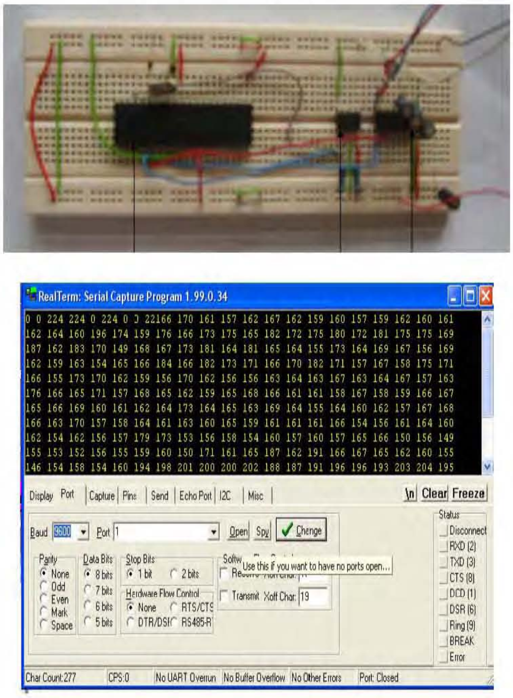

Fig. 4 Test and Result of I2C Page Write and Sequential Read

C. Pendulum Assembly

In order to measure ground motions, the seismograph must remain steady when the ground moves. Various types of pendulum have been used to obtain this steady state. The simplest pendulum assembly is a normal pendulum, in which a weight is suspended from a long wire secured to a suitable wall-mounted fixing point. Typically, a magnet is attached to the weighted end of the pendulum and a magnetic field sensor is fixed to a rigid base in close proximity to the magnet. The sensor reacts to change in the strength of the magnetic field in response to earth movement. These changes are detected by electronic circuitry and suitably processed for display or recording purposes. The period of a pendulum’s swing is directly related to the distance between its pivot point and the center of the pendulum’s mass. By changing the distance between the center of the mass and its suspension point, the pendulum can be tuned to different earth movement frequencies.

Essentially, the actual weight of the mass does not affect the swing rate. The mass is only to provide inertia for the moving half of the sensor. The pendulum mounting is 12cm wide and 56cm long. The oscillation period of a simple vertical pendulum can be calculated by the following equation.

$$T = 2\pi\sqrt{\frac{L}{g}} \tag{6}$$

where: L = length of the pendulum (from its pivot point to the center of its mass)
T = period of oscillation
g = acceleration due to free fall

The standard value of g is 9.80668 m/s^2.

D. Implementation of Overall System

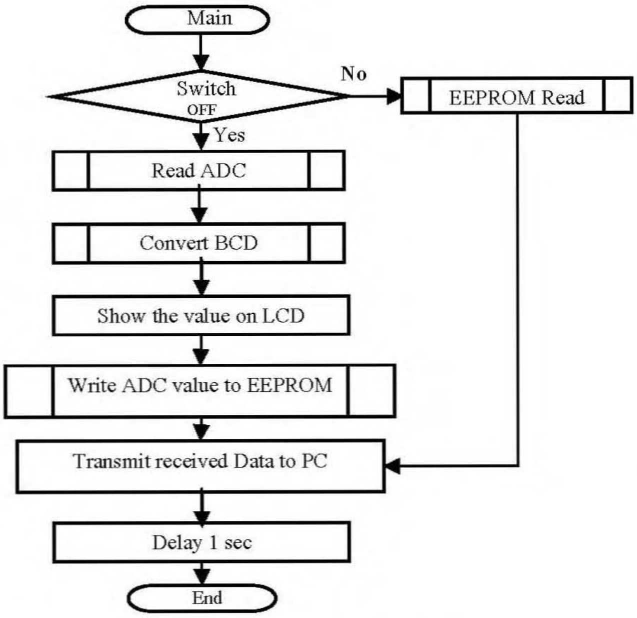

Fig. 5 Overall Flow Chart of Proposed System

E. Experimental Results

In the main program, manual switch is used to change the external EEPROM for reading or writing data. When the switch is ON, read the data from EEPROM and display at PC. When the switch is OFF, storing the data from the microcontroller to EEPROM, displaying the current measurement value at a time on line 2 of LCD and also display at PC after 1 second. Fig. 5 shows the overall flow chart main program.

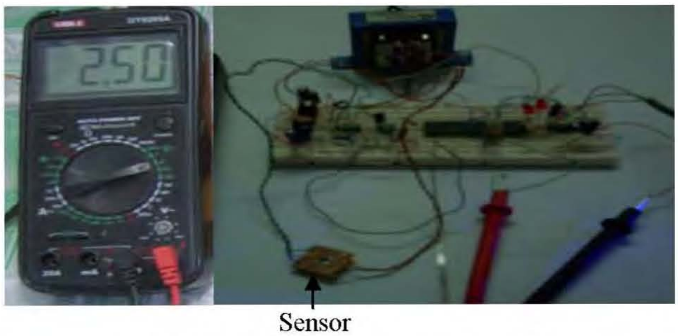

Fig. 6 Tests and Result of Movement Sensing Amplifier

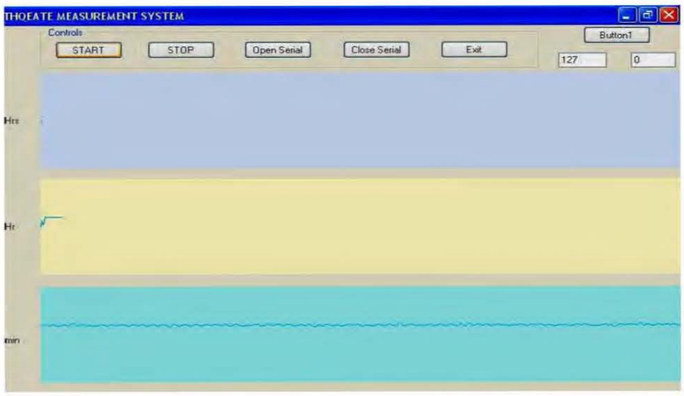

Fig. 7 Test Result of the Measurement Value without Magnet

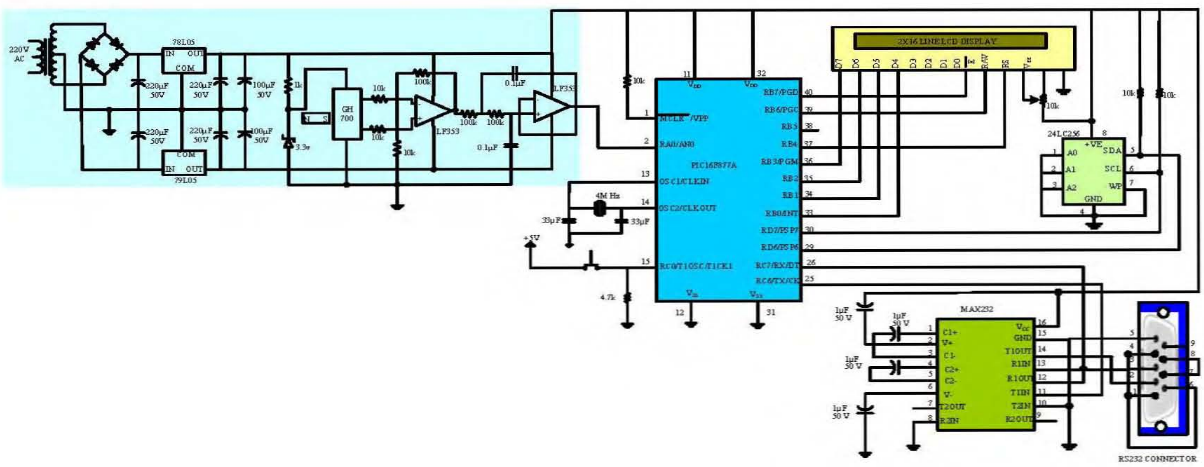

Fig. 8 Schematic Diagram for Overall Circuit

Testing is implemented in order to know whether the sensor, the signal conditioning circuit and all the required features of the PIC are functioned well or not. The data transmitted from the PIC is the value of voltage that is equivalent to the value of the vibration measurement. A computer program is necessary to convert this data to display as a graph. The main purpose of this test is to determine whether the result of the computer program is correct or not while the data are inputted. The completed circuit board assemblies can be tested without the pendulum mechanics. To check the sensor, a digital meter is used. Firstly, adjust preset resistor until the output of the movement sensing amplifier is at exactly 2.5V. In the absence of the magnet, the voltage is displayed at 2.5V as shown in Fig. 6 and Fig. 7.

Fig. 8 shows the overall circuit diagram of the earthquake measurement system. Fig. 9 shows the photo for completed circuit board assemblies with the pendulum mechanics.

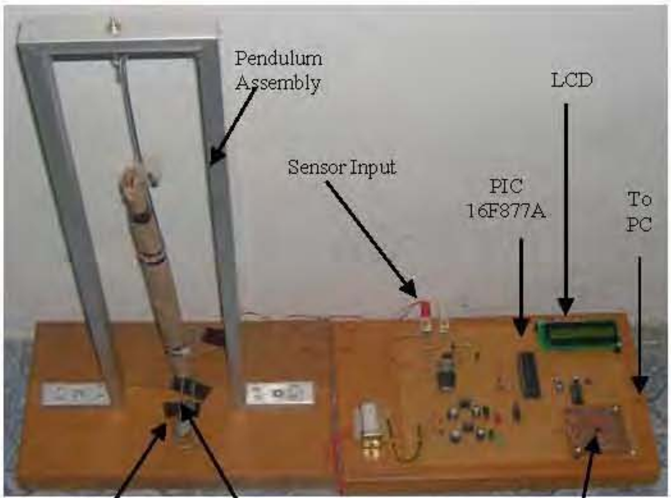

Fig. 9 Constructed Circuit Board Assemblies with the Pendulum Mechanics

IV. Discussion and Conclusion

The conventional seismological instruments deployed for vibration measuring and data recording system use lever arrangements connected to the pendulum to record seismic activity on paper using an inking pen. The speed of rotation of the drum, on which paper is attached, should be uniform. So based on traditional seismic detection techniques, the seismograph for earthquake measurement system with personal computer is constructed to overcome this drawback for monitoring and recording. The sensor output voltage is proportional to the magnetic field. The Hall voltage contacts are placed on the semiconductor plate as accurately as possible so that very little output voltage will exist when there is no magnetic field present. For applications, this resistive null voltage is low enough to be neglected, but for low field applications, it may be appreciable compared to the Hall output voltage V_H. Calibration of the sensor signal is required for greater accuracy. To get the best condition, it is necessary to make many experiments. In other words, it is largely depended on the user experience. For real-time display of graph, it is impossible or very difficult to do accurate value.

V. Limitations

The sensitivity of the sensor will depend on the magnet strength and the alignment position. A distance of about 0.5 inches was used with the test pendulum and the magnet specified. Many types of seismograph are usually installed both on the ground surface and at the bottom of the observation boreholes. This system uses a 32 k bytes external EEPROM. Although this amount is sufficient to record data for four hours time, more storage size is required for real application.

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