Development of Microcontroller Milligram Weighing System

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Abstract - *A microcontroller milligram weighing system was developed using re-cycled computer heatsink for fabrication of load cell The load cell was fabricated with Al sink of discard computer system board and re-mold to rectangular shape that was machined to slot type load cell frame. The 350 Ω strain gauge was mounted it. It was tested by connected it load cell to instrumentation amplifier, its response was very good. Also, it was standardized and performance evaluation was carryout under laboratory condition at post-Graduate research Laboratory, The Federal University of Technology, Akure, at normal temperature of 27.8ºC, relative humidity of 89% and atmospheric pressure of 988 mbar. It has the following characteristics: sensitivity is 13.952 mV/g when the load power with 5 V excitation voltage; range for accurate reading is 100 g; and error of 0.14 µg. The load cell instrumentation amplifier used is AMP04, has very good linear response from range of 1 to 1000 with less noise. The voltage gain is 120 with a very good filter to suppress noise from mains and radio interference. The examination carryout on the load cell instrumentation amplifier shows that it has very good linear response varying from tenth of micro-Volt to 200 mV. The ADC (ADS1220) 24-bit with varying power source from 2.7 V to 5.5 V. The system has minimum mass measurement of 0.001 g when place 1 mg standard mass on the scale pan. The system is fairly stable under laboratory test. Under proper examination the developed milligram weighing system (DMGWS) resolution of 0.001 g, the range is 100 g, the standard deviation is 0.0107, high precision instrument. It has 0.17 % error.*

Key Words: Re-cycled, load cell, milligram, 24-bit analog-to-digital converter, weighing-system, instrumentation-amplifier

1.INTRODUCTION

In chemical and physical processing of materials for both laboratory and industrial processes today are unthinkable without accurate weighing technology. Weighing technology is no longer confined to simple weighing on stand-alone instruments. Intelligent weighing systems in networks increasingly determine and influence drug and other allied processing to determine accurate quantity require for the production [1]. This effect also great when sold state physicist are preparing various type alloy for the production of new semiconductor materials in the laboratory, a milligram weighing system is important instrument.

In both laboratory and industrial scale, there two classification of weighing instruments there are non-automatic and automatic weighing instruments. While non-automatic weighing instruments require the intervention of an operator during weighing, automatic weighing instruments do not. They follow a predetermined program of characteristic automatic processes [2]. This paper is exclusively dealing with non-automatic low weighing instruments.

As other measuring instruments, also automatic and non-automatic weighing instruments have developed from purely mechanical stand-alone instruments to electromechanical and electronic instruments which are nowadays microprocessor or PC based or microcontroller, software controlled and capable of communicating with peripheral equipment via digital interfaces.

Already at the end of the 19th century the progressive industrialization called for a higher working speed than could be provided by non-automatic weighing instruments, especially for bulk products like raw material or grain that was used during the production of chemical and drug. [3,4].

Today there is a great variety of different kinds of automatic and non-automatic weighing instruments [3,5]: for the automatic it consists off belt weighers, catchweighers, weigh price labellers, checkweighers, mobile and in-motion vehicle weighing instruments and gravimetric filling instruments. Considering the market value of weighed products, belt weighers, totalizing hopper weighers and checkweighers are most important. And for and non-automatic weighing system comprise of rigid body, well fixed scale pan and display unit.

Many weighing instruments developed and published were for high capacity from tenth of kilogram to thousands of kilograms. But, for lower range the published paper for 1 µg to 100 grams were scares and the patient one developed instrumentation company found in international market were very expensive and highly customized if is malfunction it cannot repair. Therefore, there is need to developed a milligram weighing system compete with one in international market at reduce cost.

2   METHODOLOGY
2.1   Fabrication of Load Cell
a.   Collection and Sorting of Recycled Scraps

Aluminum coated scraps were salvaged from different computer repairer in computer village, Ikeja Lagos, Nigeria.

b.   Processing, Melting and Purification of The Scraps

The processing of the aluminum scrap was done using local techniques. Figure 1 shows a local furnace setup powered by a manually rotated bicycle wheel designed to supply air to the furnace needed for melting the aluminum through automobile air conditional fan. The aluminum to be melted was poured inside a bad compressor can that was also salvaged from a refrigerator repair workshop. The bad compressor can was used owing to its ability to withstand very high temperature even far above the melting point of aluminum. Palm kernel shafts were used as fueling agent because they burn steadily unlike coal or firewood. With continued manual rotation of the bicycle wheel shown in Figure 1(a) (used as an air-blower to the burner of Figure 1(b)), continuous heat was applied to the compressor can until all the aluminum had completely melted. Purification was done using a scoop; to remove contaminants and unwanted residues of other materials found in the melted aluminum ore as shown in Figure 2(a). More aluminum materials were added and further melted until all the scraps had completely melted as shown in Figure 2(b). The temperature of the locally designed oven rose up to 700°C which was burner point of aluminum.

c.   Molding of The Al block

Figure 3 shows a special type of Kaolin used in casting the molds of the load cell block. The mold for the block was placed on the Kaolin as shown in Figure 3(a) the mold was pressed against the Kaolin to leave an impression of its image on the Kaolin after which it was removed as shown in Figure 3(b). Figure 4 shows the completed mold of the block to which the melted aluminum ore was to be poured. Two molds were developed using the same technique described.

d.   Solidifying

Having completed the mold, Figure 5 shows the melted aluminum being poured inside the block mold by the help of a metallic tong. After the aluminum had solidified, the mold built from Kaolin particles was dismantled and Figure 6(a) reveals the developed block. Figure 6(b) shows the pairs of the developed blocks.

e.   Machining and Refinements

The aluminum bar produced was subjected to further engineering refinements by machining into the desired shape. The machined aluminum bar to the require shape is

shown in Figure 7 with mounted strain gauge and Figure 8 explain action that occur on strain gauge when load is applied.

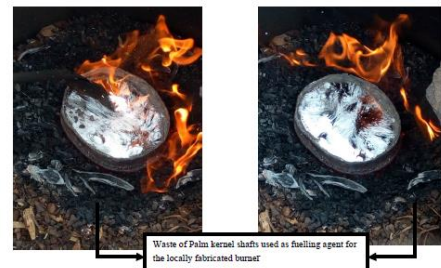Figure 1: A Local Furnace Constructed for Melting Aluminum Scraps

Figure 2: **(a) Contaminated and (b) Purified Aluminum Ore**

Figure 3: Fabrication Stages of The Mold.

Figure 4: The Completed Mold of The Heater Block.

Figure 5: Pouring the Melted Aluminum Inside the Molds

Figure 6: The Heater Blocks Aluminum Bar

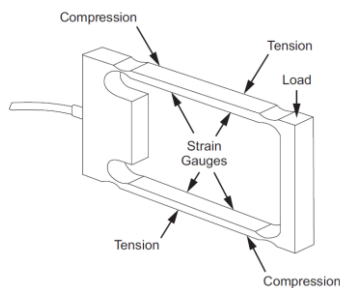**Figure 7: Shows Developed Load Cell**

Figure 8: Arrangement of Load Cell on Machined Al Block

2.1   Mounting the Single Point Load Cell

The sensing element was mechanically mounted in such a way that it is subjected to bending moment when loaded. In this position, it acts as a bending beam, which offers high sensitivity. The mount was shown in Figure 9.
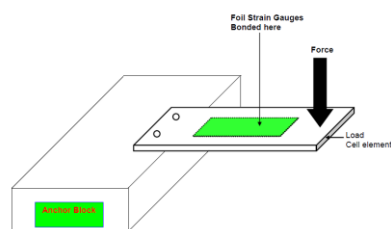

Figure 9: Principle used in mounting the Load Cell

2.2   Basic Design Principle of Milligram Weighing System

The Figure 10 shows the block diagram of the developed milligram weighing System. This consists of load cell, signal conditioning circuit (load cell amplifier), filter, analog-to digital converters (ADC), LCD display unit, scale selector, microcontroller and power supply unit.
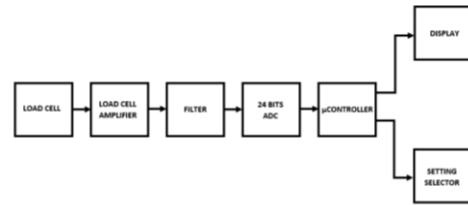

Figure 10: Basic Block Diagram of milligram Weighing System

2.3   Practical Bridge Circuit and its Operation

The load cell was arranged in bridge form as shown the Figure 11 of the load cell developed has alternate arrangement of compression and tension at the four arms. As weight is applied to the load cell, gauges C1 and C2 compress. The gauge wire becomes shorter and its diameter increases. This decreases the resistances of C1 and C2. Simultaneously, gauges T1 and T2 are stretched. This lengthens and decreases the diameter of T1 and T2, increasing their resistances. These changes in resistance cause more current to flow through C1 and C2 and less current to flow through T1 and T2. Now a potential difference is felt between the output or signal leads of the load cell.

The current flow through the load cell and amplifier as follows. Current is supplied by the power source through the -In lead. Current flows from -In through C1 and through -Out to the amplifier. From the amplifier current flows through the +Out lead, through C2 and back to the power source at +In. In order to have a complete circuit there is need to get current from the -In side of the power source to the +In side. Also, the current pass through the amplifier signal circuitry. These was accomplished by passing current from the -Out lead through the amplifier and back to the load cell through the +Out lead. Because of the high internal impedance (resistance) of the amplifier, very little current flows between -Out and +Out.

Since there is a potential difference between the -In and +In leads, there is still current flow from -In through T2 and C2 back to +In, and from -In through C1 and T1 back to +In. The majority of current flow in the circuit is through these parallel paths. Resistors are added in series with the input lines. These resistors compensate the load cell for temperature, correct zero and linearity.
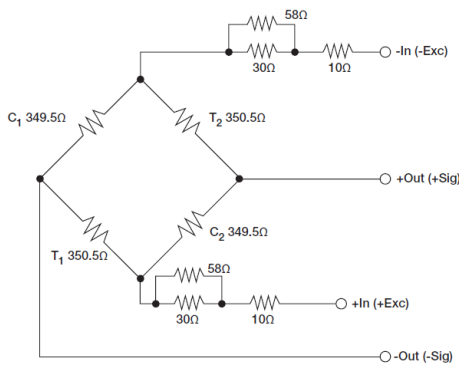
Figure 11: Practical Bridge Circuit with Compensated Resistor

2.4 Designing the Signal Conditioning Circuit

The AMP04 is a single-supply instrumentation amplifier designed to work over a +5 Volt to ±15 Volt supply range (see Figure 12). It offers an excellent combination of accuracy, low power consumption, wide input voltage range, and excellent gain performance.

Gain is set by a single external resistor and can be from 1 to 1000. Input common-mode voltage range allows the AMP04 to handle signals with full accuracy from ground to within 1 Volt of the positive supply. And the output can swing to within 1 volt of the positive supply. Gain bandwidth is over 700 kHz. In addition to being easy to use, the AMP04 draws only 700 µA of supply current.
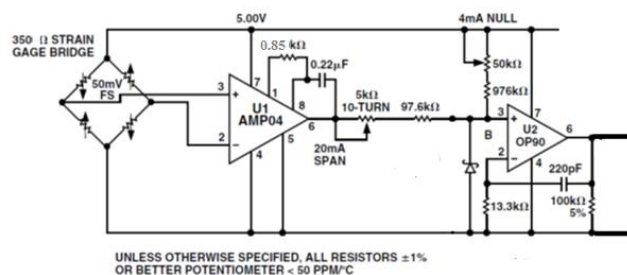

Figure 12: Functional Block Diagram of Instrumentation Amplifier with Noise Filter Capacitor

For high resolution data acquisition systems, laser trimming of low drift thin-film resistors limits the input offset voltage to under 150 µV, and allows the AMP04 to offer gain nonlinearity of 0.005% and a gain temperature coefficient of 30 ppm/°C. A proprietary input structure limits input offset currents to less than 5 nA with drift of only 8 pA/°C, allowing direct connection of the AMP04 to high impedance transducers and other signal sources.

The gain of the AMP04 is selected from a single external resistor R_{gain} that is given as:

$$\text{Gain} = 100 \text{ k}\Omega/R_{GAIN} \qquad (1)$$

The output voltage is then defined as the differential input voltage times the gain.

$$V_{OUT} = (V_{IN+} - V_{IN-}) \times \text{Gain} \qquad (2)$$

In single supply systems, offsetting the ground is often desired for several reasons. Ground may be offset from zero to provide a quieter signal reference point, or to offset "zero" to allow a unipolar signal range to represent both positive and negative values.

In this instrumentation amplifiers, the output stage's inverting input (Pin 8) is accessible by placing a capacitor across the AMP04's feedback path (Figure 13, Pins 6 and 8) a single-pole low-pass filter is produced. The cutoff frequency (f_{LP}) follows the relationship:

$$f_{LP} = \frac{1}{2\pi(100k\Omega C_{EXT})} \qquad (3)$$

2.5 Designing the signal conditioning circuit for Load Cell

The equation 1 given gain of instrumentation amplifier and the gain of the load cell instrumentation amplifier (AMP04) was designed to be 120, the require resistor that was obtained is 833.33 Ω (equivalent value is 850 Ω). To reduce noise a low pass filter with cutoff frequency of 10 Hz that will be reduced by a factor 4. The capacitor used is 0.22 µF. The load cell developed is shown in Figure 13.
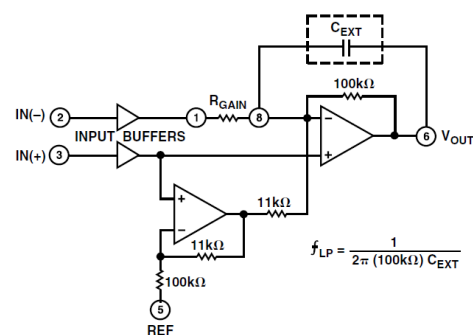

Figure 13: Load Cell Amplifier

2.6 Analog-to-Digital Converter

a. Analog-to-Digital Converter (ADS1220)

The ADS1220 is a small, low-power, 24-bit, ΔΣ ADC that offers many integrated features to reduce system cost and component count in applications measuring small sensor signals. In addition to the ΔΣ ADC core and single-cycle settling digital filter, the device offers a low-noise, high input impedance, programmable gain amplifier (PGA), an internal voltage reference, and a clock oscillator. The device also integrates a highly linear and accurate temperature sensor as well as two matched programmable current sources (IDACs) for sensor excitation. All of these features are intended to reduce the required external circuitry in typical sensor applications and improve overall system

performance. An additional low-side power switch eases the design of low-power bridge sensor applications. The device is fully configured through four registers and controlled by six commands through a mode 1 SPI-compatible interface. The Functional Block Diagram shows in Figure 14 the device internal circuitry and Schematic Circuit. [7,8]
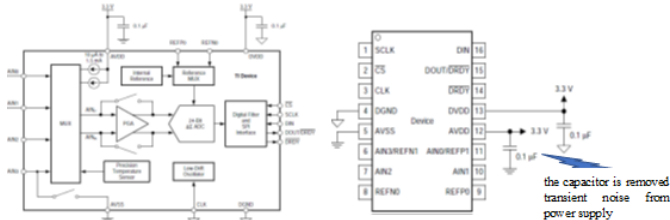

Figure 14: The Functional Block Diagram of ADS1220 and Schematic Circuit of ADS1220

b.   Basic Feature of ADS1220 and Schematic Circuit

The ADS1220 is a precision, 24-bit, analog-to-digital converter (ADC)

Programmable Gain: 1 V/V to 128 V/V at step 2^n

Wide Supply Range: 2.3 V to 5.5 V

The ADC used Serial Peripheral interface (SPI) communication with microcontroller

The device has two available conversion modes: single-shot and continuous conversion mode. In single-shot mode, the ADC performs one conversion of the input signal upon request and stores the value in an internal data buffer. The device then enters a low-power state to save power. Single-shot mode is intended to provide significant power savings in systems that require only periodic conversions, or when there are long idle periods between conversions. In continuous conversion mode, the ADC automatically begins a conversion of the input signal as soon as the previous conversion is completed. New data are available at the programmed data rate. Data can be read at any time without concern of data corruption and always reflect the most recently completed. The device features a low-noise, low-drift, high input impedance, programmable gain amplifier (PGA). The PGA can be set to gains of 1, 2, 4, 8, 16, 32, 64, or 128. Three bits (gain 2) in the configuration register are used to configure the gain. The PGA consists of two chopper stabilized amplifiers (A1 and A2) and a resistor feedback network that sets the PGA gain. The PGA input is equipped with an electromagnetic interference (EMI) filter. [7,8]

2.7   Complete Circuit Description of the DMGWS

The developed MGWS system consists of main microcontroller, Arduino Mega 2560 that controls all the activities within the system. The complete circuit of the MGWS system is shown in the Arduino Figure 15. The load

cell was connected to load cell amplifier and this load cell amplifier was link to an analog-to digital-converter, ADS1220 which is then linked to Arduino Mega 2560 via an SPI communication link. The SPI pot is pins PD50, PD51, PD52 for master input serial output (MISO), master output serial input and serial clock respectively, and used pin PD6 and PD7 for chip select and enable respectively. LCD display is driven using serial communication link to the microcontroller using data pins of PD13, PD12, PD11, PD10, PD9, PD8 on Arduino Mega 2560 were link last four digital pins and E and R/W of data input of LCD pins. The remaining four digital pin were connected to ground.

The complete weighing system is in Figure 16. It the gravity adjuster was attached at base with plumb beside the housing. Also, a transparent enclosure was provided over the scale pan reduced the effect of air current on weighing system. About two-kilogram weight was attached at the base of the casing to reduce vibration effect on the milligram weighing system developed.
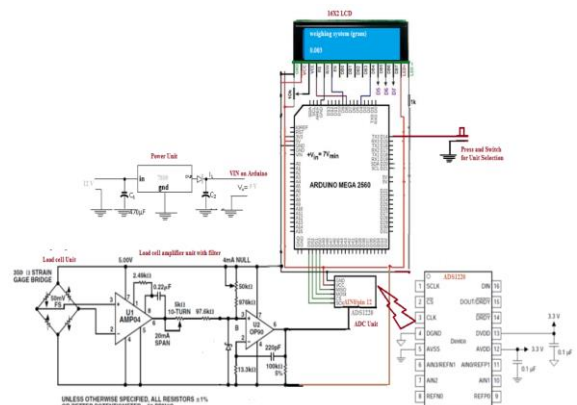

Figure 15: Complete Schematic Circuit Diagram of milligram Weighing System

Figure 16: Complete Setup

3.   Testing and Calibration of the Milligram Weighing System

3.1   Testing

Testing is necessary after the completion of any developed equipment to confirm if the attached sensors are responding and at the same time giving proper signals at the output when it subjected to appropriate external force.

Different mass with designing range were place on the scale pan and value was display according to the mass. The implication is that sensing device is responding accordingly.

3.2 Determination of Load Cell Amplifier (LCA) Amplification Response

The load cell amplifier was examined for each correct amplification to the design for the voltage gain of 120. This was done by generated a low voltage by using a resistance network in Pi arrangement as is shown in Figure 17. The pin 2 of the amplifier is grounded and small value of voltage generated was feed into pin 3 the instrumentation amplifier. The theoretical value obtained for input voltage and output voltage amplification is shown in Table 1. The graph of the result in Table 1 is shown in Chart 1. The voltage of amplifier obtained was 120.7 practically. It closed to theoretical value calculated for with 0.7 discrepancy.

3.3 Standardisation of Developed Load Cell (DLC)

The milligram weighing system was assembly and after ensure adjust gravity effect making sure the plumb is set appropriately. Various know standard load was placed on the scale pan the corresponding output voltage was recorded as shown on Table 2 and Chart 2 shows graphical scatter plot representation of developed load cell standardization.
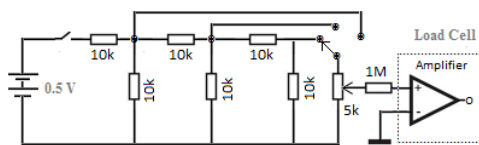
Chart 2: Standardisation of DLC

Table 1: LCA Amplification Output

Input(uV)	Output Amplifier(mV)
0.0021	0.343
0.0032	0.537
0.0043	0.585
0.0045	0.634
0.0049	0.670
0.0053	0.731
0.0057	0.803
0.0083	1.094
0.0096	1.251
0.0156	1.977
0.0206	2.582
0.0243	3.030
0.0271	3.127
0.0285	3.539
0.0592	6.528
0.0671	8.210
0.0782	9.574
0.0952	11.611
0.1045	12.937

Figure 17: DC Voltage Attenuation with Load Amplifier

Chart 1: Examination of Load Cell Amplifier Amplification Response

Table 2: Standardisation of DLC
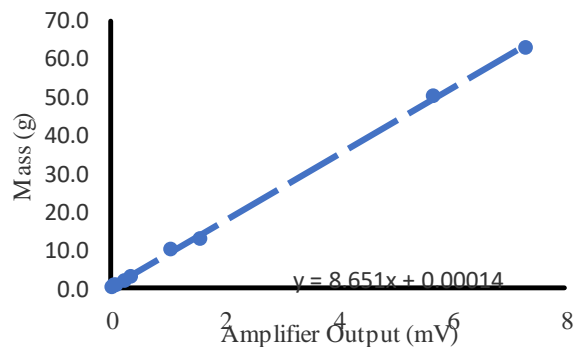
Load (g)	Amplifier Output(mV)
0.2	0.023
0.5	0.059
0.7	0.084
2.0	0.238
2.7	0.335
10.0	1.055
12.7	1.565
50.0	5.675
62.7	7.321

std Mass	Standard Mass
MAIHC	Measurement after Initial Hardware Calibration

The result shows a good linear response with about 90% points falls on the linear graph line. The line is almost start from origin with, Know mass = (8.651*Output Voltage) + 0.00014. The sensitivity of the load cell 13.952 mV/g. It was obtained from the slope of Figure 19 and gain of the instrumentation amplifier. The load cell sensitivity (γ) is given as

$$\gamma = \frac{instrumentation\ amplifier\ gain}{slope\ of\ DLC} \left(\frac{mV}{g}\right) \quad\quad 4$$

3.4 Calibration of Developed milligram Weighing System (DMGWS)

The DMGWS initial calibrated by enter DLC characteristic amplifier equation from Chart 2, y = 8.651x + 0.00014, in the embedded Arduino Program. The output response is shown in Table 3. when various standard weight was placed on the scale pan. From the graph the scatter plot with between the standard weight and measured weight almost correlation closed to unity but when linear regression was computed with Excel the P-Value ($5.66*10^{-16}$) obtained is less than 0.05. That means the value are in strong agreement but deviation value from standard value is about ±0.5 g is high. Due to this, the system was re-calibrated. The Secondary calibration was done by enter DMGWS characteristic amplifier equation obtained from Chart 3, y = 0.9708x - 0.0083, for further process initial calibration in the embedded Arduino Program. The output response is shown in Table 4. It has little or no discrepancy from the standard weight which about ±0.9 μg. Also, level of precision was examined by placing 500 mg on it. The value was on display LCD, recorded every 2 minutes, shown on the Table 4. The standard deviation obtained was less 1.0(0.0105). That means that only one read is better at any time of usage due to its high repeatability.

Table 3: Validation and Recalibration Data DMGWS

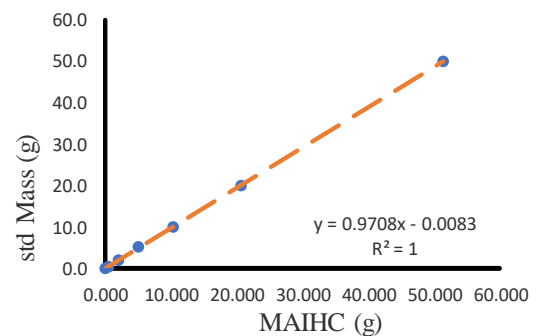| std Mass	MAIHC_1	MAIHC_2	MAIHC
0.0	0.035	0.039	0.037
0.5	0.530	0.555	0.543
2.0	2.027	2.043	2.035
5.0	5.184	5.115	5.150
10.0	10.333	10.263	10.298
20.0	20.650	20.575	20.613
50.0	51.561	51.465	51.513

y = 0.9708x - 0.0083
R² = 1

Chart 3: Further (Secondary) Calibration of DMGWS

Table 4: Standard Deviation of DMGWS

Mass(M)(0.5 g)	Deviation (M- 0.5) g
0.502	0.002
0.506	0.006
0.503	0.003
0.504	0.004
0.495	-0.005
0.502	0.002
0.500	0.000
0.495	-0.005
0.507	0.007
0.505	0.005
0.501	0.001
0.507	0.007
0.507	0.007
0.508	0.008
Mean	0.500857
Deviation	0.000857
Standard Dev.	0.0105

4 CONCLUSIONS

The load cell was fabricated with Al sink of discard computer system board and re-mold to rectangular shape that was machined to slot type load cell frame. The 350 Ω strain gauge was mounted it. It was tested by connected it load cell to instrumentation amplifier, its response was very good. Also,

it was standardized and performance evaluation was carryout under laboratory condition at post-Graduate research Laboratory, The Federal University of Technology, Akure, at normal temperature of 27.8^{o}C, relative humidity of 89% and atmospheric pressure of 988 mbar. It has the following characteristics:

  i.   sensitivity is 13.952 mV/g when the load power with 5 V excitation voltage;
  ii. range for accurate reading is 100 g; and
  iii. error of 0.14 μg.

The load cell instrumentation amplifier used is AMP04, has very good linear response from range of 1 to 1000 with less noise. In this work set voltage gain is 120 with a very good filter to suppress noise from mains and radio interference. The examination carryout on the load cell instrumentation amplifier shows that it has very good linear response varying from tenth of micro-Volt to 200 mV. The ADC (ADS1220) 24-bit with varying power source from 2.7 V to 5.5 V. The system has minimum mass measurement of 0.001 g when place 1 mg standard mass on the scale pan.   This makes detection ability of the system very high and with 0.001g resolution. The system is fairly stable under laboratory test. Under proper examination DMGWS resolution of 0.001 g, the range is 100 g, the standard deviation is 0.0107, high precision instrument. It has 0.17 % error. The cost reduction compared with equivalent in the international market is about 69 %.

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