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Design and Development of an Embedded System for Testing the Potentiometer Linearity

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Abstract: Component testing is one of the most important tasks before it is put to use in any application. In this direction linearity of potentiometer plays an important role, especially the multi turn rotary potentiometers. This is because; such potentiometers are used in vital applications such as in aircrafts for the maintenance of certain pressure systems and as rotary position sensors. Testing for linearity is an important task in such a scenario. Testing of components calls for an analog to digital converter for converting analog information into digital domain. The main aim of the present work is to design and develop an embedded system to test the linearity of such a potentiometer. Such a system is portable. The hardware makes use of a stepper motor, a Darlington driver IC ULN 2003 and a small jig to attach the potentiometer to a stepping motor. Philips ARM LPC 2103-mixed signal controller controls the entire assembly. Software is developed to acquire data from potentiometer, to store the data on the on-chip memory, to display it on LCD, and to send the same to PC on serial lines using MAX-232. The linearity plot is displayed on the system monitor. *Copyright © 2010 IFSA.*

Keywords: Position sensor and transducer, Multiturn potentiometer, LPC 2103 ARM processor, Keil μVision3

1. Introduction

Linearity is the mechanical and electrical rotary error introduced while manufacturing and assembling a potentiometer. Factors that affect the linearity include shaft and bore tolerances, bearing run out, wiper positioning and element concentricity; it's typically given as a percentage of the output value.

Linear potentiometers are widely used in various applications such as linear voltage variations, position feedback control of aircraft's door in pressurizing the fuselage to provide comfort for passengers at high altitudes [1]. In such applications the linear variation of potentiometers plays an important role. There is no manual way of testing the linearity of a potentiometer accurately [2]. At the same time a linear potentiometer has to be used in vital applications as mentioned here. Keeping this in view point, in the present work, ARM processor based testing of the linearity of a potentiometer is designed, developed and tested.

The component that are used in industrial applications or in critical environments, have to be thoroughly tested for their accuracy, resolution, reliability and linearity [3]. Each component has its intrinsic advantage, the examination of which gives rise to product selection. It is the job of design engineer who has to choose a good product within the budgetary constraints. Certain terms involved in this design are [4]:

•Accuracy
•Resolution
•Electrical Angle
•Linearity

Accuracy: The manufacturer to express the mechanical and electrical rotary error introduced while manufacturing and assembling resolver uses this term. This includes factors such as shaft and bore tolerances, winding perpendicularity. Its units are arc-minutes.

Resolution: The encoder manufacturers to express the finite number of measurements that can be made in a single revolution use a term.

Electrical Angle: This term is widely used by the potentiometer manufacturers to express the devices measurement range. For a single turn pot, this term is slightly less than 360^0, and is applicable for each input shaft revolution. It exists to allow for the termination of the resistor coil/resistive materials.

Linearity: An important parameter that is used while manufacturing and assembling a potentiometer. Important related factors are: shaft and bore tolerances, bearing run out, wiper positions and element concentricity.

Multi-turn potentiometers are transducers that translate a rotary or linear displacement into a change in resistance. When wired as a voltage divider, the output voltage varies directly with position [5]. Most linear potentiometers are designed to specifications for total resistance, linearity and temperature coefficient. If the potentiometer has a linear relation ship between output voltage and deflection, the data will fit an equation of the form:

$$D = \frac{E+b}{KV},$$

where
D is the deflection;
E is the Output voltage;
b is the A constant to provide zero deflection (d=0) when output voltage is not zero;
K is the A constant for each potentiometer;
V is the Input voltage to each potentiometer.

K and b are solved by the method of least squares.

Thus, potentiometers can be used in determining the rotary position error and as a position sensor. Also potentiometers are widely used as user controls, and may control a very wide variety of equipment functions [6, 7]. The widespread use of potentiometers in consumer electronics has declined since two decades, with the digital control being more common. Nevertheless, potentiometer remains in many applications such as volume controls and position sensors in motor control etc.

Hardware and software are developed in the present work to evaluate the linearity of a commercial potentiometer using an ARM LPC 2103 mixed signal controller. The hardware can be used for other potentiometer testing also with a little change in mechanical arrangement.

2. Experimental Setup

The block diagram of the hardware developed in the present work is shown in Fig.1.

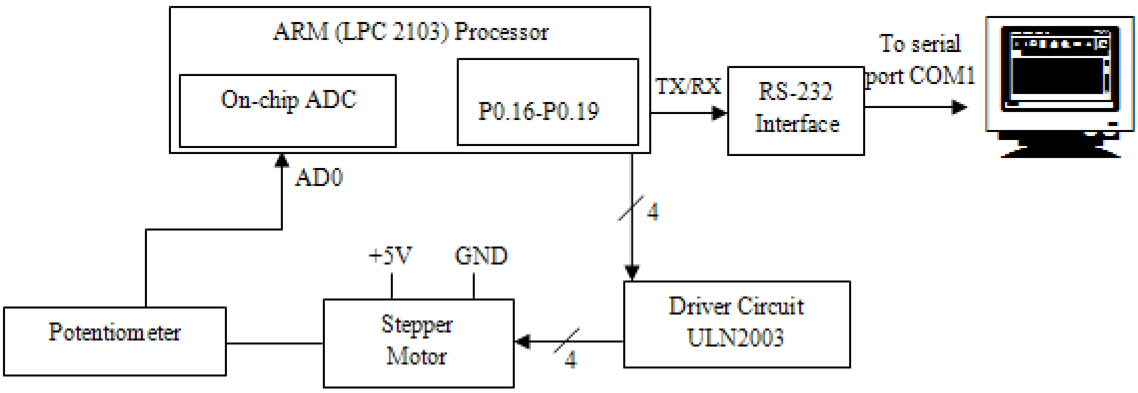

Fig. 1. Block diagram of hardware.

It consists of the following modules:

- ARM (LPC 2103) Processor;
- Analog to Digital Converter (ADC);
- Stepper Motor and its drive electronics;
- Potentiometer jig;
- RS-232 Interface;

Description of each individual hardware module is given below.

2.1. ARM (LPC 2103) Processor

The ARM7TDMI-S is a general-purpose 16/32-bit microcontroller, which offers high performance and very low power consumption [8]. The ARM architecture is based on Reduced Instruction Set Computer (RISC) principles, and the instruction set and related decode mechanism are much simpler than those of micro programmed Complex Instruction Set Computers (CISC).

This simplicity results in a high instruction throughput and impressive real time interrupt response from a small and cost-effective processor core. Pipeline techniques are employed so that all parts of the processing and memory systems can operate continuously.

Typically, while one instruction is being executed, its successor is being decoded, and a third instruction is being fetched from memory [9]. The ARM7TDMI-S processor also employs a unique architectural strategy known as Thumb, which makes it ideally suited to high-volume applications with memory restrictions, or applications where code density is an issue. The key idea behind Thumb is that of a super-reduced instruction set.

Device pins that are not connected to a specific peripheral function are controlled by the GPIO registers. Pins may be dynamically configured as inputs or outputs. Separate registers allow setting or clearing any number of outputs simultaneously. The value of the output register may be read back, as well as the current state of the port pins.

The ARM processor contains an on-chip 10-bit ADC, which works on the principle of successive approximation technique. A brief description of on-chip ADC is given below.

2.2. Analog to Digital Converter

The LPC 2103 contains on-chip analog to digital converter. It is a single 10-bit successive approximation analog to digital converter with eight channels. The APB clock provides basic clocking for the analog to digital converter. A programmable divider is included in each converter, to scale this clock to the 4.5 MHz (max) clock needed by the successive approximation process. A fully accurate conversion requires 11 of these clocks. On-chip ADC diagram is as shown in Fig. 2.

On-chip ADC was chosen since it possesses the following salient features:

- 10-bit successive approximation analog to digital converter.
- Power-down mode.
- Measurement range 0 V to $_{VDD\,(3V3)}$ (typically 3V; not to exceed V_{DDA} voltage level).
- 10 bit conversion time~2.44 μs.
- Burst conversion mode for single or multiple inputs.
- Optional conversion on transition on input pin or timer match signal.
- Dedicated result register for every analog input to reduce interrupt overhead.

On-chip analog to digital converter of LPC 2103 can be accessed using ADC registers. A complete description of the on-chip ADC of LPC2103 is available in literature of Philips Semiconductors [10].

2.3 Stepper Motor and its Drive Electronics

Now-a-days stepper motor finds many applications in instrumentation, computer peripherals and machine tool drivers. Stepper motors can be used for driving the hands of clocks, paper advance mechanism in line printers, for positioning the magnet read/write heads of floppy disk etc., Due to its accurate stepping angle even at small incremental steps; it is thought of to couple the stepper motor to a potentiometer in order to test the linearity. Hence it gives a precise stepping angle. The stepping motor used in the present work is one, which is dismantled from a 5-1/4 inch floppy drive board, which was used in old personal computer. The internal parts of stepper motor are shown in Fig. 3.

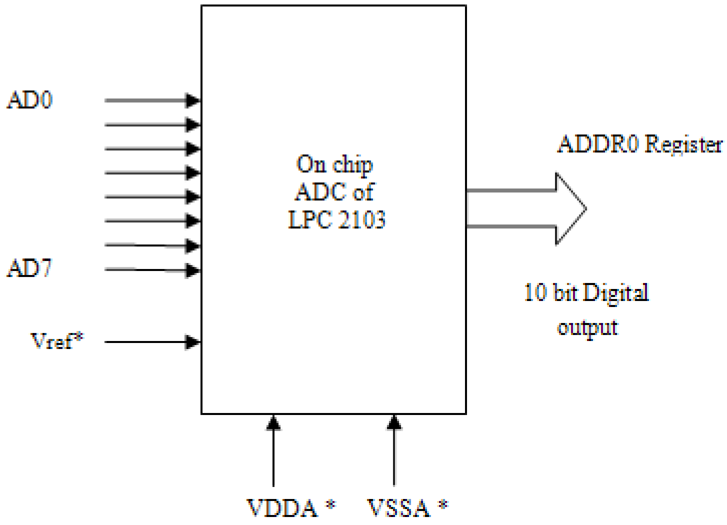

Fig. 2. Diagram of On-chip ADC.

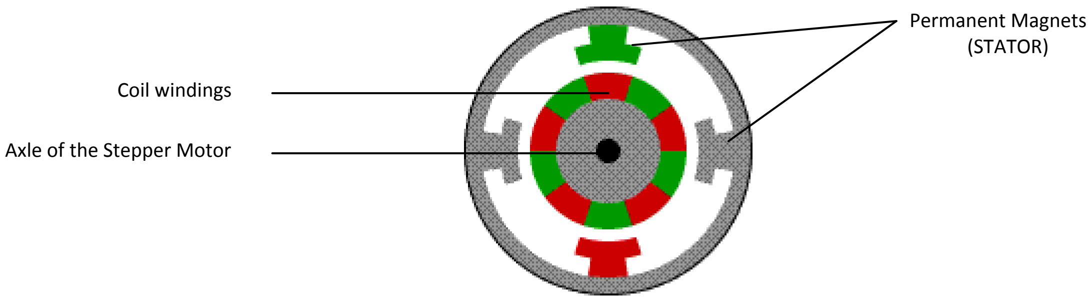

Fig. 3. Internal parts of stepper motor.

The stepper motor is widely used to translate electrical pulses into mechanical movements. Stepper motor is a brushless, synchronous electric motor that converts digital pulses into mechanical shaft rotation. Every revolution of the stepper motor is divided into a discrete number of steps, in many cases 200 steps, and the external hardware should send separate pulses to the motor for each step. The four leads of the stator winding data are represented in Table 1. The step angle is the minimum degree of rotation associated with a single step. Various motors have different step angles. The total number of steps needed to rotate one complete rotation is steps per revolution. Here the stepper motor rotates in wave drive 4-step sequence [11].

Table 1. Data for four leads of stator windings.

Step	Winding A	Winding B	Winding C	Winding D
1	1	0	0	0
2	0	1	0	0
3	0	0	1	0
4	0	0	0	1

The output port of ARM processor cannot drive the stepper motor directly. Hence a power driver interface of IC ULN 2003 is used at the output port. The IC ULN 2003 consists of a high voltage, high current Darlington array. This IC essentially consists of an array of seven open collector Darlington pairs with common emitters. Each channel of the array is rated at 500 mA, but can withstand peak currents of 600 mA. Suppression diodes are also built-in for driving inductive loads. This IC is also suitable for driving a wide range of loads including solenoids, relays, d.c. motors, LED displays, filament lamps etc.

The stepper motor can only take one step at a time and each step is of the same size. Since each pulse causes the motor to rotate by a precise angle, typically 1.8°, the motor's position can be controlled without any feedback mechanism [12]. As the digital pulses increase in frequency, the step movement changes into continuous rotation, with the speed of rotation directly proportional to the frequency of the pulses. Step motors are used every day in both industrial and commercial applications because of their low cost, high reliability, high torque at low speeds and a simple, rugged construction that operates in almost any environment.

Stepper motor was chosen in this work, since it possesses the following salient features:

- The rotation angle of the motor is proportional to the input pulse;
- The motor has full torque at standstill (if the windings are energized);
- Precise positioning and repeatability of movement since good stepper motors have an accuracy of 3 to 5 % of a step and this error is non-cumulative from one step to the next;
- Excellent response to starting/stopping/reversing;
- Very reliable since there are no contact brushes in the motor. Therefore the life of the step motor is simply dependant on the life of the bearing;
- The stepper motors response to digital input pulses provides open-loop control, making the motor simpler and less costly to control;
- It is possible to achieve very low speed synchronous rotation with a load that is directly coupled to the shaft;
- A wide range of rotational speeds can be realized, as the speed is proportional to the frequency of the input pulses (over a limited frequency range).

2.4. Potentiometer Jig

A potentiometer is a circuit element comprising a resistor, which has a movable tap for adjusting the ratio of the resistances from the tap to the respective ends of the resistor. The use of a potentiometer to determine the position of a connected device has proven to be rather accurate [13]. The potentiometer employs either a rotary or a linear slide member connected to a variable resistor that changes resistance to be equated to the position of the device that is monitored. Potentiometers are frequently used as position sensors in various types of electrical control circuits and automobiles [14]. In particular, linear potentiometers are useful to translate mechanical motion into responsive electrical signals. If only two terminals are used (one side and the wiper), it acts as a variable resistor or rheostat. Potentiometers operated by this mechanism can be used as position transducers, for example, in a joystick.

Linear potentiometers are sensors that produce a resistance output proportional to the displacement or position [15]. Linear potentiometers are common contact transducers in the form of variable resistors with three leads. Two leads connect to the ends of the resistor, so the resistance between them is fixed. The third lead connects to a slider or wiper that travels along the resistor and the resistance between it and each of the other two connections varies. The circuit diagram of 1-kΩ potentiometer is shown in

Fig. 4. For example, with a 1-kΩ potentiometer, the resistance between the wiper lead and either of the other two leads can vary from zero to 1 kΩ depending on the position of the wiper.

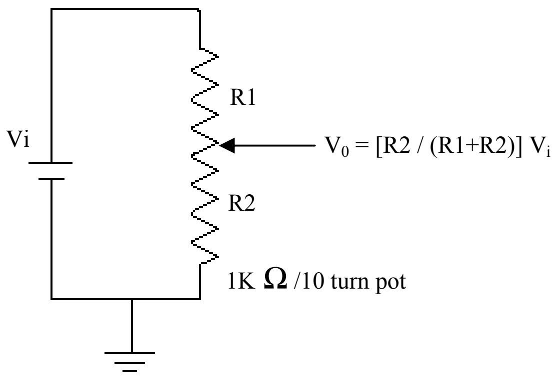

Fig. 4. Circuit diagram of 1kΩ potentiometer connected to a voltage source.

One form of rotary potentiometer is called a string potentiometer [16]. It is a multi-turn potentiometer operated by an attached reel of wire turning against a spring. It is used as a position transducer. Potentiometers can be obtained with either linear or logarithmic relations between the slider position and the end of the pot, called "tapers" [17].

In the present experimental setup, potentiometer knob is glued to the stepper motor axle and the entire assembly is fixed to an aluminum bracket. The mechanical assembly is flexible to mount any type of potentiometer. This arrangement is shown in Fig. 5.

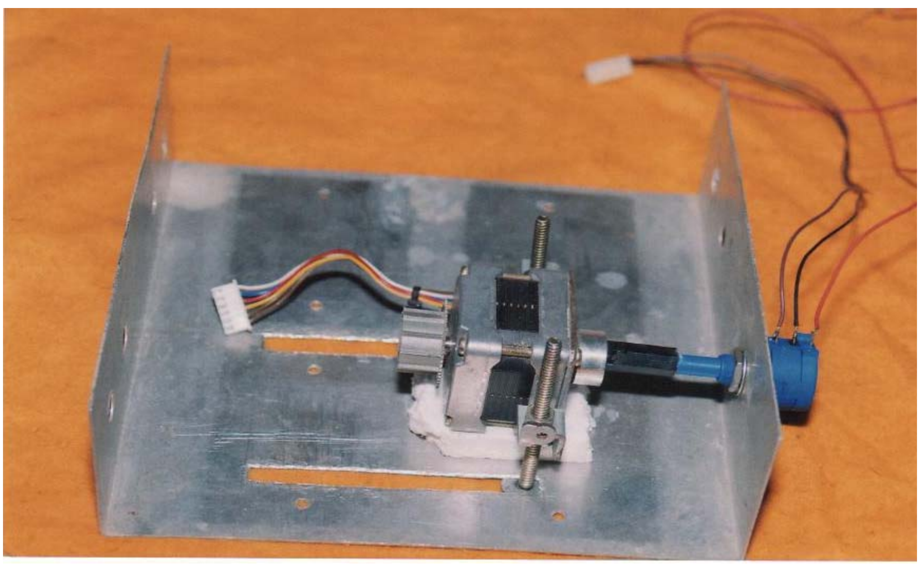

Fig. 5. Photo of Potentiometer jig.

2.5. RS-232 Interface

The data acquired using LPC 2103 is sent on P0.0 (TX) to the PC for analysis via MAX 232, as shown in Fig. 6.

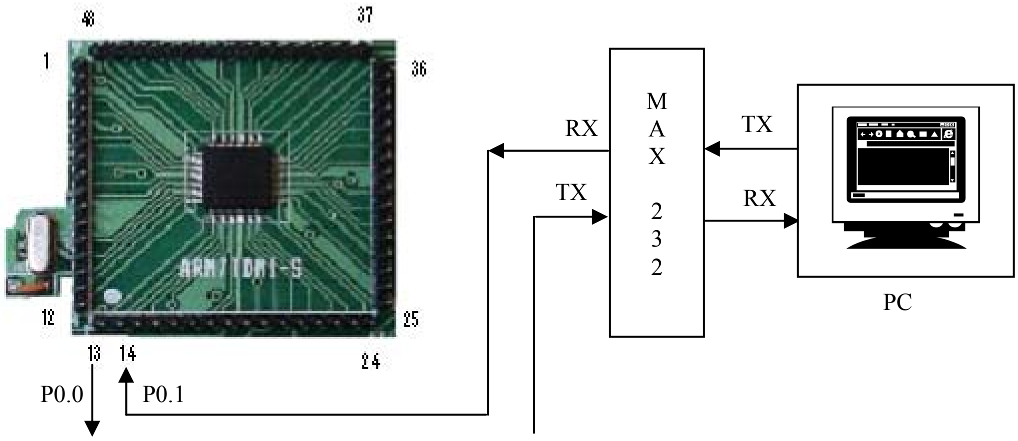

Fig. 6. PC Interface of ARM7TDMI-S processor.

3. Data Acquisition

3.1. Hardware Description

As mentioned earlier, the potentiometer connected to the stepper motor is 1KΩ – 10 turn – BOURNS, USA make [18]. This potentiometer is found to be more linear and accurate. The ends of the potentiometer are connected to 3V DC. The resolution in terms of voltage and resistance can be calculated as follows.

Angle through which the shaft of the stepper motor rotates in one step = 1.8^0
Number of steps for one full rotation = 200
Variation of resistance per step = 0.5Ω
Variation of voltage per step = 1.5mV

The on-chip ADC with 3 V supply and 10-bit resolution gives 1.5 mV resolution (3 V / $2^{10} \approx$ 3 mV). Thus the potentiometer linearity is measured in terms of voltage. The complete data acquisition circuit diagram to evaluate the potentiometer linearity is shown in Fig. 7. Pins P0.24 through P0.31, which are totally eight pins are used as data and control pins for the LCD module. The LCD is used in 4-bit mode. Pins P0.0 and P0.1 are connected to the serial pins of COM1 port of PC via MAX 232. Pins P0.16 – P0.19 (4 pins) are connected to the Darlington driver IC ULN 2003. The corresponding output pins are connected to stepper motor windings. The shaft of the stepper motor which is connected to potentiometer rotates the slider terminal of the potentiometer. The variable terminal is connected to the analog input (AD0) of the on-chip ADC.

3.2. Software Description

The software is developed for rotating the stepper motor in clockwise and anti – clockwise directions with 1.8^0 /3.6^0 stepping angle. Measuring voltages from 0V to 3V for every 1.8^0 /3.6^0 rotations tests the linearity of potentiometer. The flowchart of the data acquisition program is shown in Fig. 8. The entire program is developed and tested using Keil µVision3 IDE compiler. The hex file is dumped on to the LPC 2103 using JTAG under the ISP mode.

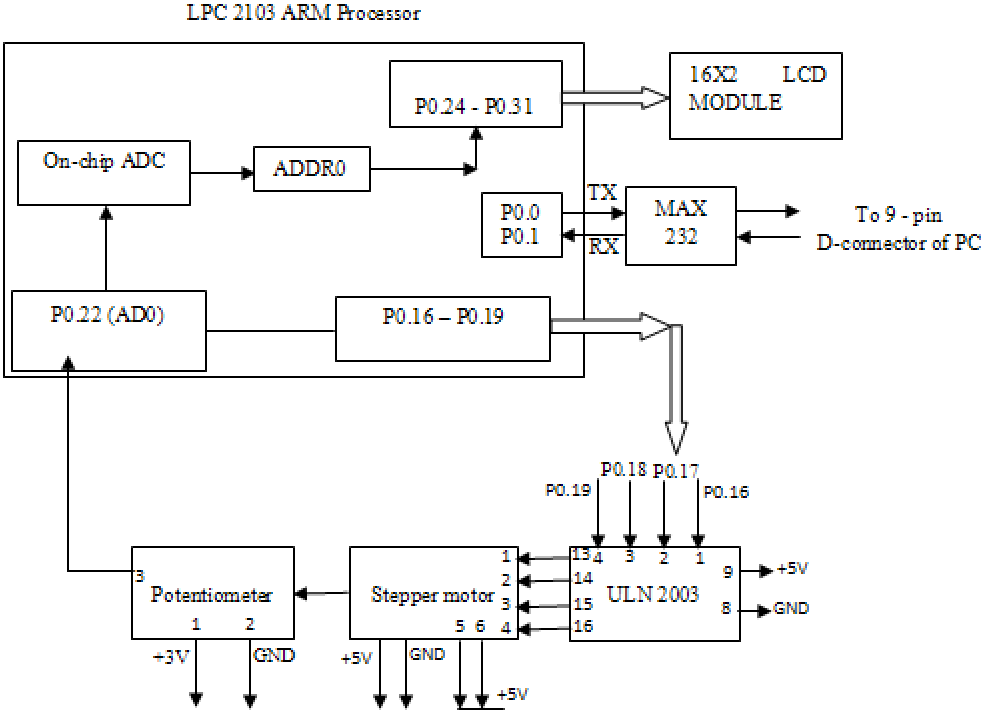

Fig. 7. Total circuit diagram of pot linearity.

4. Results and Discussions

The results obtained after execution of the program is shown in Table 2. In order to reduce the length of the table, only values at the end of each rotation are given. The graph obtained by plotting the values using ORIGIN software is shown in Fig. 9.

Table. 2. Results of pot linearity Continuous conversion.

Turns	Output voltage, (V)
1	0.296
2	0.596
3	0.896
4	1.196
5	1.496
6	1.796
7	2.096
8	2.396
9	2.696
10	2.996

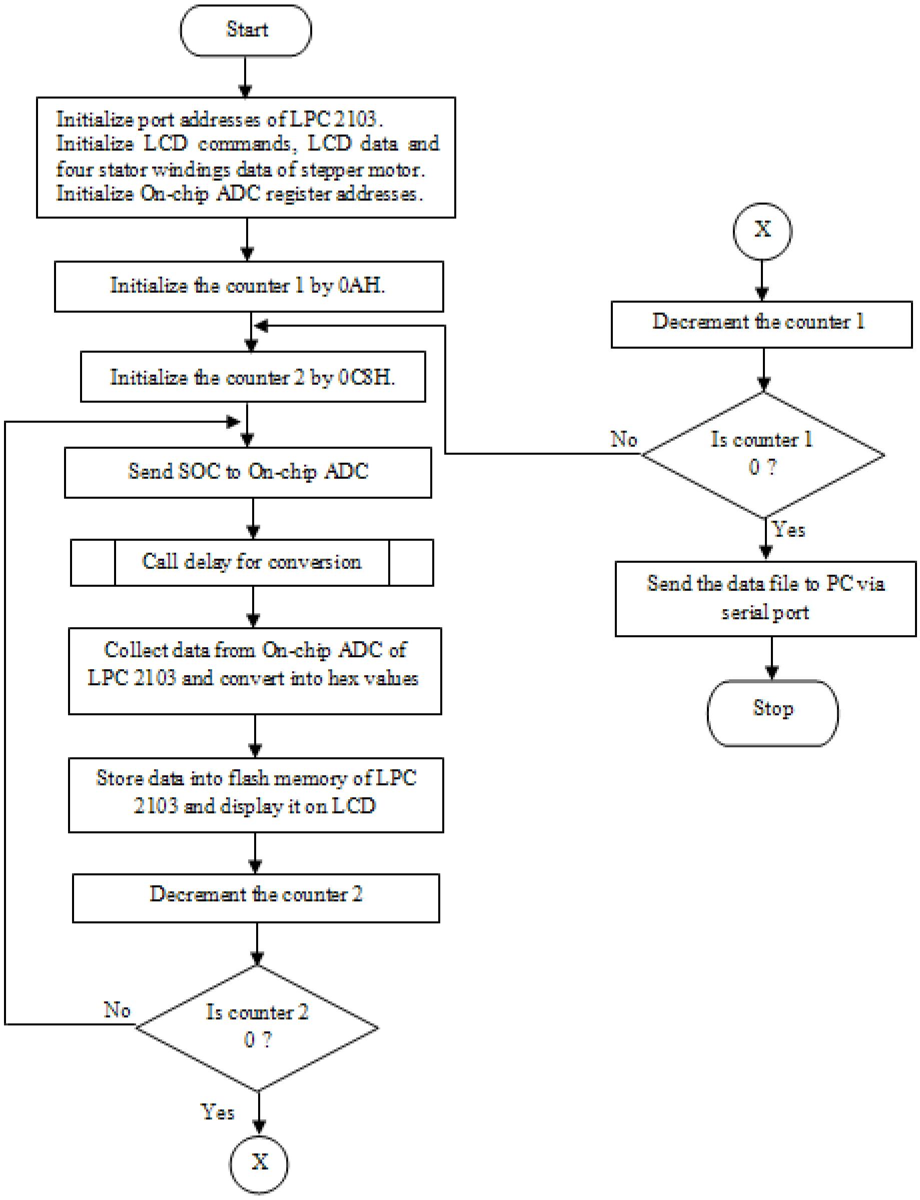

Fig. 8. Flow chart of the total program.

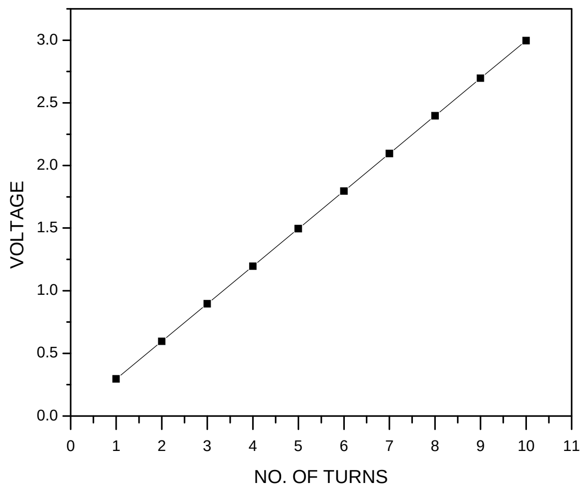

Fig. 9. Experimental results for BOURNS potentiometer.

5. Conclusion

An inexpensive hardware and software are developed using LPC 2103 mixed signal controller to measure the linearity of the potentiometer. As a case study BOURNS potentiometer was chosen and the results are discussed. The chosen potentiometer exhibited a good linearity.

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Guide for Contributors

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- Digital, frequency, period, duty-cycle, time interval, PWM, pulse number output sensors and transducers;
- Theory, principles, effects, design, standardization and modeling;
- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
- Sensors interfaces, buses and networks;
- Signal processing;
- Frequency (period, duty-cycle)-to-digital converters, ADC;
- Technologies and materials;
- Nanosensors;
- Microsystems;
- Applications.

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