Fabrication of a Simple Computerized High Power Supply for Magnetic Measurements

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Abstract: - A High current power supply was built and controlled by a personal computer using a simple design and a low-cost components for magnetic measurement applications. The design depends on the Arduino Uno board and Scilab software. Three Scilab block diagrams were given to simulate three magnetic tests, which are constant field block diagram (single field value), increasing and decreasing fields for FMR and magnetocaloric tests, and field for hysteresis loop test. Each Scilab block diagram contained different xcos blocks to control the Arduino output voltage and other blocks to sense, read, and calibrate the field value. This control was done via controlling pulse width modulation in the range (0-255). The output of each block diagram was simulated by measuring its variation with time using a cscope block display. The Arduino signal was amplified by a simple electronic circuit that involved two stages, BUL680 transistor as the first stage. Two high-power transistors EVK71-050 or Q50z were used in the second stage. The output of 107V-39.8A from the first one and 108V-39.7A from the second one produces a magnetic field of about 30000Oe. The linearity between the current and the field value is better for Q50z due to the variation of α with the wide variation of collector current.

Key-Words: - Computerized power supply, High current, Xcos Scilab, High magnetic field.

1 Introduction
1.1. Literature Review

The precise and fast methods of testing and evaluating magnetic materials require a computerized control of electric energy that feeds conducting coils. The main problem here is in the cost of such controlling, simplicity of the designed system, and maintenance of such system. Different researchers tried to design a new system based on a cheap simple microcontroller like atmega328 or atmega2560 in their common Arduino board. Jia Chunrong et al [1] designed a power supply of high voltage of fiber current transformer and adapted it to small current measurement, that is, combined solar energy and storage cell. The scheme has virtues such as steady operation, immunity to power network wave compensation and electromagnetism, and low noise. The scheme solved the problem of huge busbar current and dead band current. The experiment results indicated this scheme is highly precise and strong antijamming. So the scheme can supply power for a high voltage signal process system successfully. Z. Wang et al [2] designed a high-voltage DC power supply with wide-range output voltage up to 35kV for electrostatic applications composed of a boost power factor correction converter for improving input power factor, a voltage source full bridge inverter with series-parallel resonant control, a high voltage high-frequency transformer, besides the mathematical models of series-parallel resonant inverter have been described. A. Murtala [3] designed an uninterrupted power supply (UPS) for a personal computer (PC) to enhance portability in the design of personal computer desktop workstations. It could back up the source of power as an incorporated unit within the system and so it could reduce connection wires and make the whole computer act like a laptop. It was based on a microcontroller as an important part of the circuitry to eliminate the weight and space of components. J. Bai et al [4] presented a stable, low-cost, easy-to-construct virtual high-voltage power supply with the construction process, verification, test, and safety issues. Asynchronous communications between an embedded processor and a LabVIEW program running on a PC are also explained. A high voltage (HV) operational amplifier and Arduino board were used as the real-time controller with LabVIEW programming. The open-loop operation and closed-loop operation of the power supply are also demonstrated. L. Louis [5] explored the working principle and applications of an Arduino board. The main advantages are fast processing and an easy interface. M. J. Mnati [6] proposed a new smart voltage and current monitoring system (SVCMS) technique. It monitors three phases

electrical system using an Arduino platform as a microcontroller to read the voltage and current from sensors and then wirelessly send the measured data to monitor the results using a new Android application. The integrated SVCMS design uses an Arduino Nano V3.0 as the microcontroller to measure the results from three voltage and three current sensors and send them to the Android device by Bluetooth HC-05 through open-source MIT App Inventor 2 software. T. Özer [7] performed practice control algorithms and systems related to energy flow in a system consisting of solar panels, battery packs, fuel cells and direct current and alternating current loads based on Arduino microcontroller to use the generated energy effectively. Monitoring processes, saving of data, and control of the relays were performed via a LabVIEW program on the computer. The data were analyzed and the performances of these three control algorithms were compared to recognize the most effective and efficient energy usage. James P. Grinias [8] described the development and use of a low-cost and open-source USB data acquisition device (with 16-bit acquisition resolution) using simple electronic components and an Arduino Uno. The software written in Python is included so that data can be acquired by any PC with a simple USB connection. The device was used for a sophomore-level analytical experiment using gas chromatography and a capillary electrophoresis-UV separation on an instrument used for research purposes. Ismail Uyanik et al [9] presented low-cost experiments for modeling feedback control systems, proportional-integral-derivative (PID) controller design, root locus, and Bode plots using Arduino boards and Matlab/ Simulink as an interface. Dinesh Bista [10] presented an inexpensive Arduino-based PID (proportional, integral, and derivative) controller built in the laboratory to control the heat. The designer used Arduino UNO, a thermoelectric cooler, and electronic components, and C++ programming. The system can control the temperature with a tolerance of $\pm\,0.6°C$ with a very small deviation from the setting value. Established maintenance-free power supply systems, efficient power management and integrated energy harvesting and storage systems are required factors in designing power supply [11]. A controlled power supply with a high current has many applications in the fields of communication, ships, rail transit, and other fields [12].

1.2. The Arduino Uno using PWM as a microcontroller

The purpose Arduino scheme is to produce a low-cost microcontroller board for a simple designer and researcher. Arduino boards have shields, which can

supply GPS, Bluetooth, diverse motors, and different services. More advanced step in Arduino boards was done when it can be linked with Android software. Now, about 13 different Arduino boards have existed that are considered as a primary option for the electronic designer. Arduino Uno as a primer Arduino board depends on ATmega328 microcontroller and a 16 MHz ceramic resonator. Additionally, the board has I/O digital pins for SPI and PWM (numbered 2 to 13), six analog inputs, an external power jack, an In-Circuit Serial Programming (ICSP) pins, a reset button, on board USB to serial converter. Fig.1 illustrates these board components [5, 6].
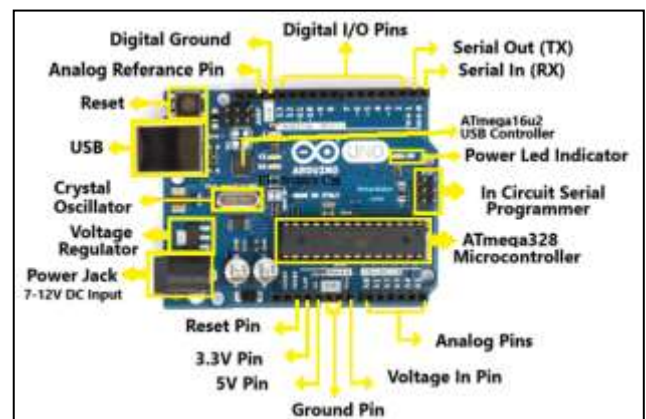

Fig.1. Arduino Uno components.

Arduino Uno's advantages are easy C++ programming, different I/O, simple connecting with other devices as well as low cost [13,14].

Pulse Width Modulation, or PWM, is a mechanism to produce an analog signal by using digital signals on digital pins. The digital signal is expressed by a square wave of high value (5V) and low value (0V). The voltages between 5V and 0V can be generated when one varies the fraction of the time at 5V against that for 0V. The pulse width is the time when the signal is at the value of 5V, which is changed to get values between 0 and 5V.

In Fig.(2a), the normal lines represent the periodic time and its reciprocal is the PWM frequency. By using the function "analogWrite()" in C++ programming language, one can specify the input to be in the range 0 – 255. If one uses analogWrite(255) this chooses the output pin to be at 5V (on), while analogWrite(0) makes the output at 0V. But when a 2.5V is required at the output, the switch-on time must equal the switch-off time and so on one can choose any value in between, as seen in Fig.(2) [15]. Arduino Uno has different pins that can produce PWM with data of 8 bits, so one can produce 256 different analog values between 0-5V. In other

words, the switch time on and off can control the average mediated voltage between 0 and 5V in a similar way to what happens in the switching mode power supply [16].
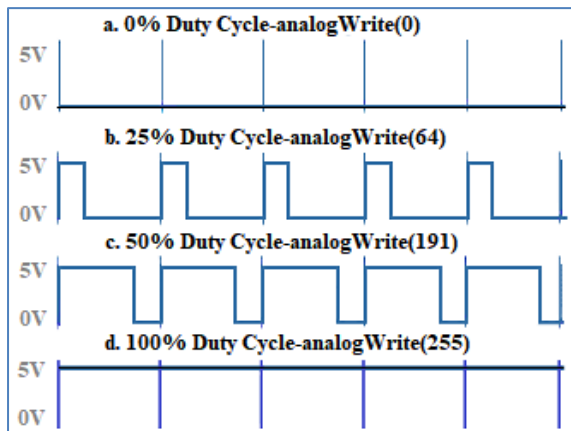

Fig.2. Pulse width modulation at four different periods.

1.3. Scilab Software

There are different software that can be used to satisfy the aim of controlling the period and in turn the output. Scilab comes in front as a free and open library simulation software to treat such applications, and it is released under General Public License (GPL) [17]. Scilab depends on the state-of-the-art linear algebra package and uses many functions which treat different fields like control system design. Scilab owns the ability to draw three-dimensional plots and a file conversion tool from Matlab to Scilab. Different programming languages are utilized in Scilab such as Fortran, C, C++, Python, and Java [18]. Scilab can be connected to Arduino by using toolboxes known as Arduino toolbox. The graphical programming as a part of Scilab is known as Xcos which is utilized for programming in designing and controlling dynamical systems. Xcos works as an interface to the different block diagram compilers like Arduino. The codes of the scheme can be assembled, compiled, and loaded using the graphical user interface GUI of Xcos [13]. The designer needs three main parts to accomplish a Scilab project by Xcos:

1-Xcos Screen: It is a screen where the designer makes the flow chart of the dynamic system of the blocks drawn from the palettes. One can use either the standard blocks or make a new one.

2-Palette browser: It is a browser that contains screens of Xcos standard blocks that are classified according to their function (Mathematical operations, sources, electrical, sink, etc.).

3-Compiling and Simulation: Xcos affords a feature of designing a model for the simulation by using blocks of the downloaded toolboxes and giving property to check the model, display, and save the simulation and data graphically.

Xcos has advantages like simple and easy block connection, availability of different loop functions and the possibility to program a whole algorithm by completely utilizing Xcos blocks [19].

Magnetic properties are usually measured by two essential tests, magnetization-field (M-H) test (or magnetic hysteresis loop), isothermal caloric test, and ferromagnetic resonance (FMR) test [20,21]. The magnetization-Field test requires a magnetic field value to be increased linearly with time from zero to a maximum value and then drops to zero in a linear way too. Then, repeat the previous procedure but in the reverse direction. For the FMR test, the magnetic field is sweeping from zero to maximum, or the opposite is required.

2. Experimental Part

Scilab Xcos map was used to implement and control the field loop by Arduino card. Three-block diagrams were used for constant magnetic field generation, decreasing (or increasing) field generation for ferromagnetic resonance (FMR) test, and field for hysteresis loop generation.

The utilized software for implementing the project:
1- Arduino 1.8.13.
2- toolbox_arduino_v5.ino (downloaded from Scilab page) opened through Arduino.
3- Scilab 6.1.0 (64-bit).
4- Arduino toolbox (Arduino Communication through Serial), Version 1.8, February 16, 2020.

Simple low-cost electronic components were used to implement simple circuits for supplying and controlling the electric power and in turn the magnetic field. The implemented circuits are a DC power amplification circuit, field reading circuit, and polarity reversing circuit. Devices that were used to check the hardware and circuits are Victor 88E Digital Multimeter, and Digital Hall probe Omega HHG-23.

The description of some used hardware components in the construction of the circuits are:
1- Electric Coils: 2 coils, each one has a resistance of 5.3Ω. The coil dimensions: inner hall diameter is 10cm, outer coil diameter is 28cm, coil thickness 9.5cm provided by Cenco.
2- Power Diodes: 4 pieces of power rectifier cathode to stud diodes V200-12 200A 1200V HQ NOS, with a heat sink for each one. The diodes are connected in a bridge style.
3- Capacitors: as a filter, NTK PWC 2B, 15mF 100Vdc, 4 pieces, each two in series and the four are in parallel.

4- Magnetic Hall sensor: KY-024 module as a 49E719BG linear magnetic field sensor.
5- High current wires: a single copper wire gauged 2.5 mm. High power contactor (main): Schneider Electric A013247, 600V, 60A dc, 75oC, AWG 3-10 Cu, Torque 45 lb. in.

The other components will be mentioned later when the need arises.

3. Results and Discussion

3.1. Constant Field Block Diagram

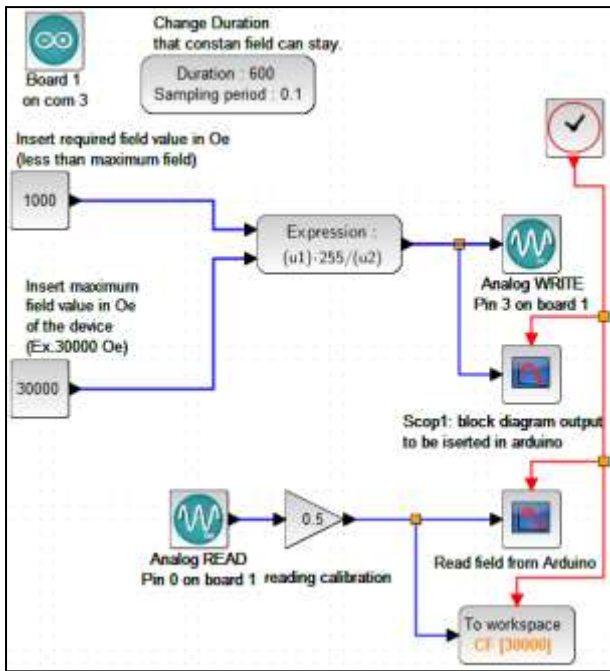Fig.3 illustrates the used Xcos block diagram. For the constant magnetic field.

Fig.3. Scilab Xcos block diagram of constant field generation.

The program begins with entering the required field and the maximum field in Oe, which is in this study is 30000 Oe and depends on maximum AC applied and coils resistance. Then the entered values are transformed to a new value Tv to be in the range 0-256 by expression block with the mathematical expression:

$$Tv = (u1 \times 255)/u2 \qquad \ldots\ldots \qquad (1)$$

Where u1 and u2 are the upper and lower expression blocks respectively. The TV value, in turn, entered to Arduino board to supply an adequate output voltage at the analog pin 3.

The program also provides a reading the field through a magnetic hall sensor connected to pin 0 on the Arduino board. This step affords a chance to correct the field value to a more precise field value by changing the entered value. The read-value is

calibrated to show the real value by amplification block. As an example, Fig.4 illustrates Tv (the board input value) at an entered field of 1000Oe and a maximum field of 30000Oe. the user must input the maximum field obtained according to software and hardware condition and components respectively. In this study, the maximum field is about 30000Oe.
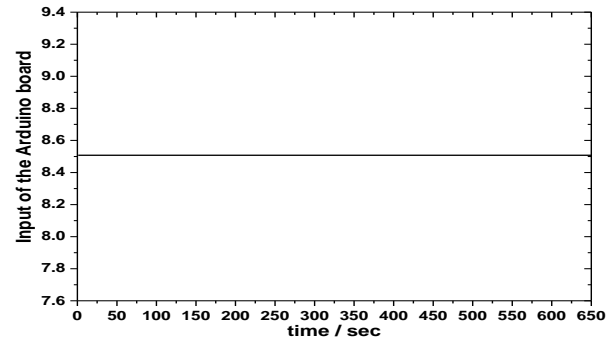

Fig.4. Arduino board input (scope chart) of the constant field block diagram at entered constant field value of 1000Oe.

As expected, the value is constant as the calculated one within a certain given time. Here, the operating time or what is called duration is the time for the system to be staying at the specified value of the field.

3.2. Increasing and Decreasing Fields

For increasing and decreasing fields as a field source for the FMR test, the used block diagram to achieve this purpose is given in Fig.5. One of the FMR requirements is determining the beginning and the end scanning fields in good design devices. To implement this step, two mathematical expressions blocks, a counter block and "relationalop" (relation operator) block were used.

For the field-increasing process, the beginning field of scanning is entered in the upper constant value block, then this value is transformed to Tv as in eq.(1), which is entered into one of the summation block inputs. The other input is connected to a counter, which is set to 255 as a maximum value. The summation block will add the increasing values of the counter to the Tv. A relationalop (relation loop operator) block will compare the summation output with the Tv of the entered "End field value". If they are equal, a zero output will produce and will be multiplied by the summation output to drop it to zero at the end of scanning. Of course, the readings of the field by the Hall sensor with calibration are present.

For the field decreasing process, the entered begin field value must be higher than the end one. The second input of the summation block must be

changed to be negative. This is done by choosing the sign vector to be [1,-1] while setting the parameter of the summation block. Here, the summation block will subtract its values from the Tv value of the beginning field value. To ensure that the last point is measured properly, a few seconds were added to the simulation time. The block diagram of the decreasing and increasing field is shown in Fig.5.

Gain blocks are used to calibrate the scope chart as the real field. The scopes charts of Fig.5 are shown in Fig.6. The Y-axis in all charts represents the signal intensity, here the field range 10000-20000Oe corresponds the Tv range 85-170.
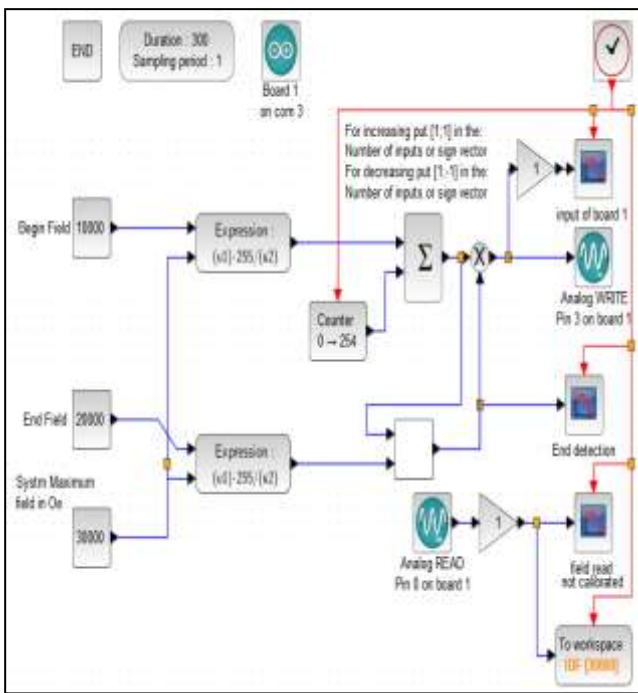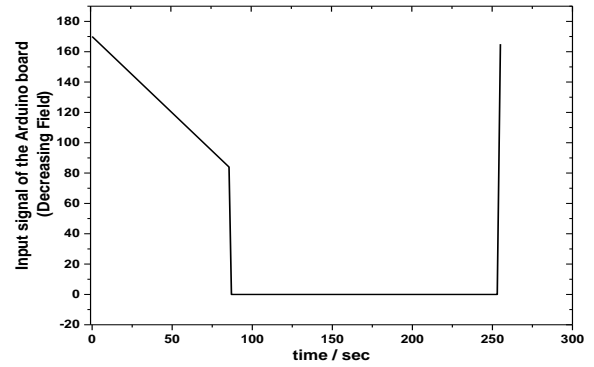

Fig.5. Scilab Xcos block diagram of increasing and decreasing field generation.
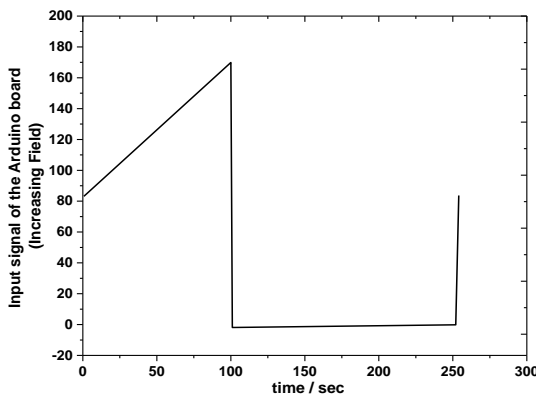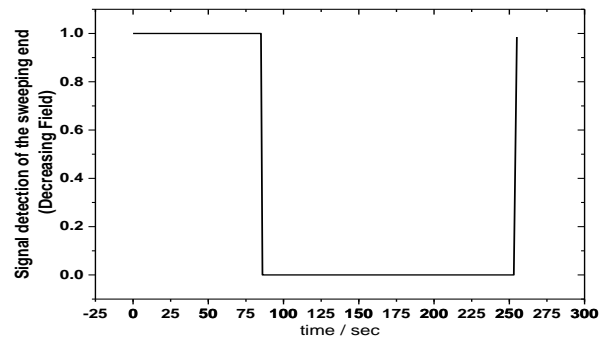

(a)
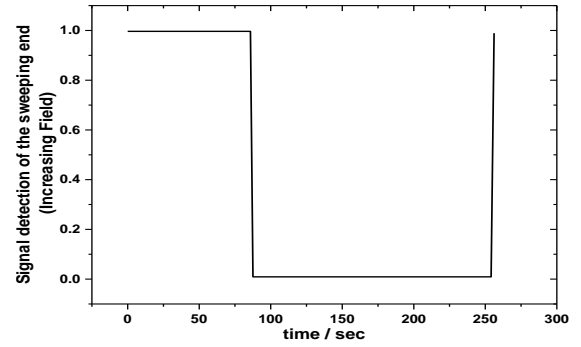
(b)

(c)

(d)

Fig.6. Scope charts of the input signals of the Arduino board (block diagram output) for the increasing and decreasing fields in the range 10000-20000 Oe. (a) Increasing field and (b) decreasing field, (c) and (d) signal detection of the sweeping end for increasing and decreasing field respectively.

The end abrupt line at 254 sec of figures (c) and (d) can be deleted by replacing 254 with 255.

3.3. Field for Hysteresis Loop Test

Fig.7 shows the Xcos block diagram program for the magnetic field that is used for the magnetic hysteresis loop (M-H test). The upper counter is used for the field growing from zero to maximum, while the lower one is to drop the field to zero. The two counters begin to count simultaneously but just the upper one count passes through the m-switch block to pin3 of the board until it reaches 254. In this period the lower one counts down from 509 to 255. At this

moment, the threshold parameter condition of the m-switch is satisfied, so the lower input of the switch is passed to its output and continues to count down till reaches zero.

This procedure was done for half of the loop (for example the positive half). The second half has the same procedure, but it needs to exchange the polarity of applied voltage on the coils.

An AND gate block was chosen to produce a signal for the board to change the polarity. It compares a constant value source of value equal to 1 with a lower counter value. When this counter is counting down and reaches a value of 1, AND gate (program) produces a signal to the board that appeared at the digital pin13 that is, in turn, transferred to a hardware polarity reversing circuit. The signal is kept at a value of 1 to win a second for the hardware polarity reversing circuit to change the polarity. Here again, a read block of the Hall sensor with the reading scope is provided.
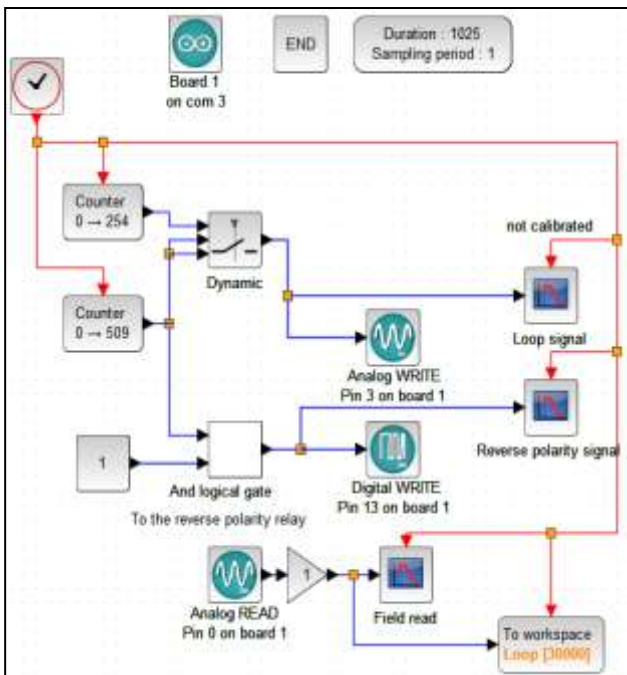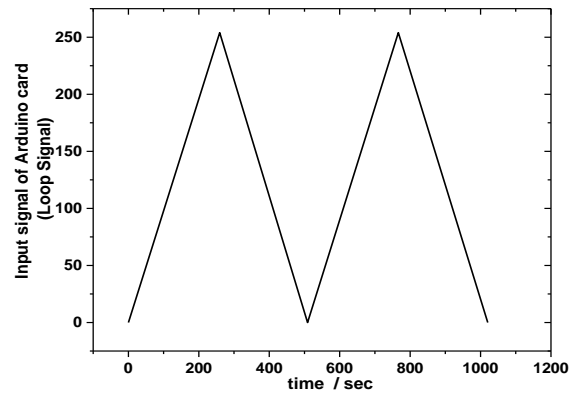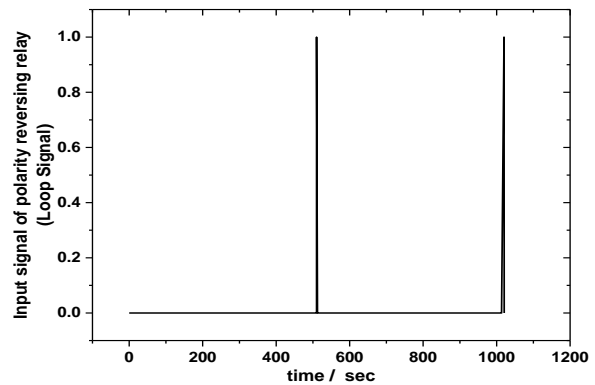
Fig.7. Block diagram of the full loop.

The Arduino board input block diagram (output of the m-switch of Fig.7) and the AND gate output are drawn by the scopes and shown in Fig.8 (a) and (b) respectively.

(a)

(b)

Fig.8.Scope charts of (a) the input signal of Arduino card, (b) the input signal of polarity reversing relay.

The two parts (positive and negative) of the loop appear in the positive part due to this chart is just for the software when no polarity reversing. It has appeared the two parts are symmetric and completely identical as is required for such a test. The signal of the AND gate output is a spike one generated after each 510 Sec. The spike signal continues for 1 second, which is enough to ignite the reversing polarity circuit.

3.4. Hardware Circuits

First of all, the output of the Arduino Uno board was checked by increasing the Scilab block diagram with the voltmeter to ensure the linearity of the signal of pin3 with the variation of the counter count, which represents the time. The result of this measurement is shown in Fig.9.

The hardware block diagram of the whole power supply is given in Fig.10a. There are four stages in this design. They begin with a personal computer, owning Win10 (or Win7) as an operating system, having Scilab Xcos Arduino toolkits and Arduino software 8.1. The second stage is the Arduino Uno board as an interface and control unit followed by stage three which is a handmade circuit to amplify signals and implement other missions like switching.

The Arduino board as an interface and the Scilab software were used in different fields to monitor and control physical systems [19]. The fourth stage includes electric coils and field measuring by a Hall sensor where the signal is read through an Arduino board.
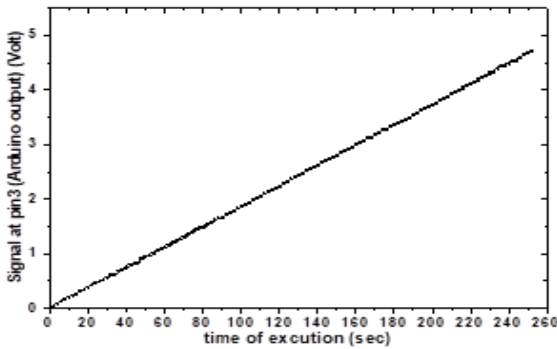

Fig.9. Pin3 (bv] Xcos block diagram.

The electronic circuit for Arduino signal amplification, reversing polarity, and Hall sensor is shown in Fig.10b. The function of C1 is filtering the PWM by passing direct component. Here, C1 represents a simple filter type to satisfy the aim of the a simple power supply. T1 is an npn transistor, it forms, with R1 and E1, the primary stage for current amplification. T2 is a power transistor, it represents the second stage of the DC amplification. S1 is high power 2way contactor, that works with the relay S2, the transistor T3, thyristor D2, and resistors R3, R4, and R4 besides M which is an AC 220V source as a latch circuit to reverse the applied voltage polarity. Relay output is connected to a two-way contactor, where the contactor is chosen to be directly connected to a high-current load (coils) compared to relay. The input signal of the polarity reversing relay is repeated each 509 sec.

Hall sensor denoted by (HS) is supplied by 5V from a PC power supply, which is calibrated by the software as in Figures 3, 5, and 7. With no magnetic field, Hall output is 2.6V, and it rises to about 4.5V in case of field increase. When the polarity is reversed, the output drops from 2.6 to about 0.2V when the field is increased in the reverse direction. The reasons behind using more than one DC supply are to get high voltage stability and high safety whereas pc desktop power supply has good stability and cannot get from the handmade high power supply easily [16]. Calibration can be done by software and hardware components to give real values.

The electronic components and sources that are used in the hardware and given in Fig.10 are: E1 and E3 are two DC sources contained in a desktop PC power supply, which are chosen to provide high stability with different outputs of 12V and 5V respectively. E2 is a DC source that contains: the main transformer with different outputs connected to provide AC 108V, push-bottom starting switch with indication lamp, rectifying bridge of 4 power diodes (type V200-12) with heat sinks, 2 large capacitors with specification, wires single gauge 2.5mm, heat sinks, fans, a coolant fan of 20W for cooling the transformer and diodes bridge. A fixed digital voltmeter is connected in parallel with the coils through variable resistance.
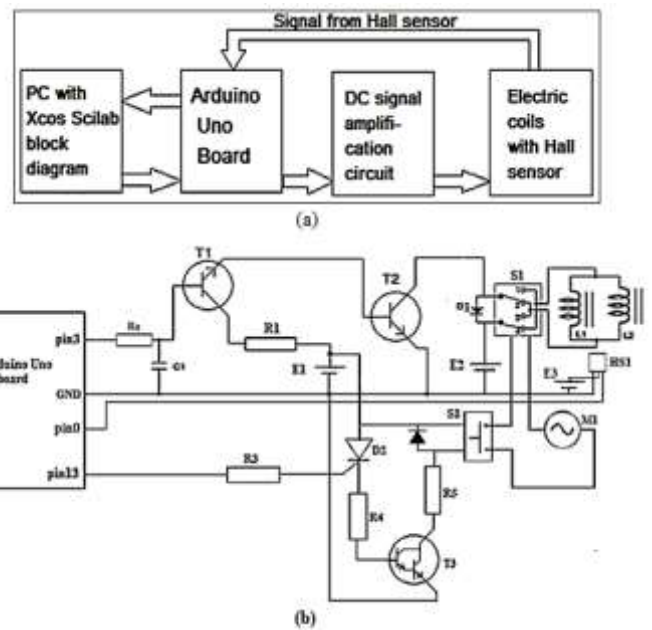

Fig.10. Hardware used: (a) Block diagram of the overall power supply, (b) Electronic circuit.

The PWM signal is translated from the Arduino board to the hardware circuit through a current limiting resistor of 1kΩ. The transistor BUL680 is used as T1, it gives Ic-max of 0.177A at R1=30Ω (3W). During PWM variation in range (0-255) the I_E of T1 varies from 0.003 to 0.0176mA. This current is considered as I_B of T2. Two different transistors were tried to implement high current stage amplification, they are EVK71-050 and Q50z. According to the variation of PWM, the supplying voltage and current to the coils by EVK71-050 as T2 are given in Fig.11. These parameters are measured based on the circuit in Fig.10.
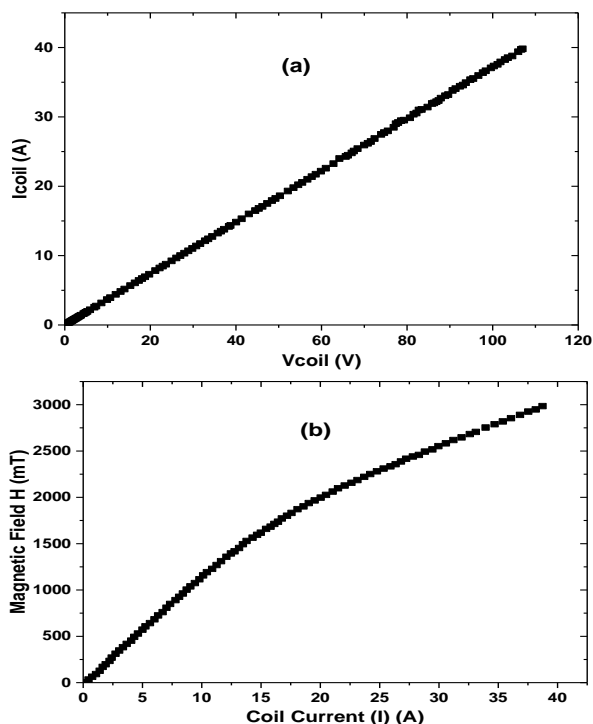
Fig.11. Using EVK71-050, (a) Coil current versus coil voltage, (b) Produced magnetic field as a function of coil current by increasing field generation block diagram.
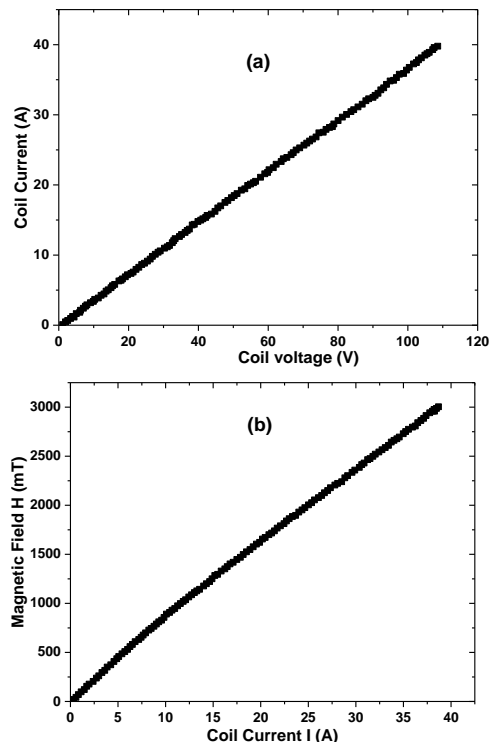

Fig.12. Using a Q50z transistor, (a) Coils current versus coil voltage, (b) Produced magnetic field as a function of coil current by increasing field generation block diagram.

In Fig.11(a) one can recognize the good linearity of coil voltage-current. This means the coil's resistance is stable and constant with this range of the used current. It is important to mention here, there is a water chiller system was used, which may have had a significant role in this behavior. In Fig.11.(b), the behavior is different, where a clear curvature is observed. It is believed this curvature is related to the DC gain (H_{fe}) variation of the transistor in this range of collector current (I_c) as given in the datasheet of EVK71-050 transistor [17]. This transistor and its equivalents are Darlington pair and so have high H_{fe} with high variation in H_{fe} with I_c. Keeping in mind, a transistor with constant H_{fe} really not exist and a design consideration that depends on a low variation in H_{fe} is also impossible due to the wide I_c range used in this design.

Fig.12(a) illustrates coil voltage-current curve supplied by the proposed power supply with a Q50z power transistor. A linearity again appears between coil voltage and current due to the same reasons mentioned previously. The produced magnetic field (H) by using this transistor and Scilab xcos increasing field generation block diagram is shown in Fig.12(b). The current gain (H_{fe}) variation of the transistor in this range of collector current (I_c) has a lower effect on the behavior of these parameters than that for the transistor EVK71-050, which makes it more suitable for this application.

This curvature can be minimized by using a negative feedback suitable circuit but this may demand an additional amplification stage due to the expected reduction in H_{fe}. On the other hand, this nonlinearity is not a big problem because the important thing is field measured value and measuring material response against each field value in magnetic properties measurements. In addition, one can take equidistant field values and find the corresponding values of counter output, then save them in a matrix used as input data to the Arduino instead of the counter.

Finally, it is important to mention some notes: there is a drop in the DC capacitor voltage due to load applying, for example, a drop from 103V (no load) to 85 (coils loading). Also, the non-stability of the main power produces a tolerance in the DC capacitor voltage by 1.5% at 103V of the DC capacitor voltage. A delay block can be added as desired for some applications that need a longer time for measuring or need an average value of more than one measurement.

4. Conclusion

The proposed system can provide high current as a high power for large electric coils successfully and produces a magnetic field of about 30000Oe. The used software is available for free and is easy to be

programmed. Different block diagrams can be employed to perform such functions. The used hardware components are low-cost and simple to be designed in a circuit. The linearity of high current with time (or PWM variation) determines the linearity between the magnetic field and time. Different high-power transistors show a different proportion between the output current and the produced magnetic field value depending on the transistor DC current gain variation with collector current.

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