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Design and manufacturing of a test rig for measuring the torque required in soil drilling operations

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Abstract. Soil drilling operation has become one of the most important interests to researchers due to its many applications in engineering systems. Such as construction industry, soil samples for geological sciences and space sampling. The dominant factor in determining drilling parameters based on drilling operations experience or in some times based on proposed modelling techniques. As a result, soil drilling process using auger drilling is studied to obtain drilling parameters and then optimize these parameters to improve drilling performance which enables proper selection of machine for a required job. One of the main challenges that faces researchers during using modelling techniques to define the soil drilling problem is the complex nonlinear behaviour of the drilled medium itself due to its discontinuity and heterogeneous formation. This paper presents a developed apparatus that has been designed and manufactured to be used in measuring and recording the total torque required during soil drilling operation. A simplified auger drilling machine is built in soil-tool interaction laboratory, Military Technical College, to obtain experimental results that can be used to verify the presented models. Data acquisition measuring system is established to analyse experimental results using a. The Labview® program enables recording and displaying the output data collected mainly from sensors planted in the test rig. Results of both analytical and numerical models are then compared to experimental results to aid in developing the presented parametric study that can be used to define the working parameters during drilling operations in different types of soils.

1. Introduction

Auger drilling technique is used on a wide range in many flight twist drill into the ground to required profundity [1]. Continuous flight augur(CFA) piling is a broadly utilized heaping strategy offering both specialized and business favourable circumstances, when utilized suitably, in the correct ground conditions and task conditions [2]. Additional advantages of CFA are higher generation rates, flexible auger tallness, and movable twist drill width inengineering applications such as geological sampling, pile foundation engineering and space sampling. Also CFA fined to be appropriate for some kinds of soil, for example, mud, sand, residue and moderate rocks [3].. Auger drilling has many advantages such as it is considered a dry drilling method, continuous transportation of soil and the efficient construction [4, 5]. Soil is considered as a heterogeneous material, which prompts its complex behaviour[6]. For the ideal structure of soil interacting machines the genuine conduct of soil should be taken into consideration as it seriously affects large portion of parameters that portrays the hardware execution amid activity for instance weight on burden arms, pressure driven powers, footing on tire and conveyance of intensity...etc[7]. If the drilling rig couldn't satisfy the required feeding rate and auger rotating motion, the twist drills can "mine" the overlying frail soil to the surface and

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causesubsidence [8]. Drilling is generally utilized in heap establishment designing, geographical testing for sandy soil, alsoit is more convenient than other boring methodologies for planetarydrilling due to its high productivity and continuity in cuttings transportation [1, 4].
The key point of this paper, the construction of the test rig, which has been built to proceed the experimental work, is represented. The test rig mainly consists of the auger-drilling system, monitoring system and control unit. The experimental test rig is installed in the laboratory of the Mech. Equip.Department, Military Technical College, Cairo, Egypt.

The testing system shown in figure 1 will analyze and calculate the torque for the cutting and drilling of loose sand to a depth of 0.5 m. A continuous auger system consists of an auger powered by an AC motor, fitted with an speed reducer of a worm form, is applied to the soil. For control the AC motor speed an AC inverter is used.The AC engine is mounted on a wagon.It is acceptable to move vertically through four linear movement systems as shown in the figure. The vertical feed used to induce penetration is generated by a linear actuator. The penetration speed is about 5mm per second.Between the auger and the output shaft from the speed reducer, a torque transducer is attached.The steel frame structure is designed to contain all the components of the proposed system; the frame is attached to the main frame of the soil bin as shown in figure 1.

The speed of the three-phase AC motor is controlled by avariable frequency drive model AS 2 - 115 is used to control the speed of the three-phase AC motor. Alsoit is used to reverse the direction of rotation.A designed system using data acquisition is developed to allow the torque measurement. The transducer "T4A" uses a 4-wire link technology is inserted between the auger and the driving shaft.The T4A output signal is then forwarded to NI 9219 via a USB connection to the device via a compact acquisition system (DAQ).

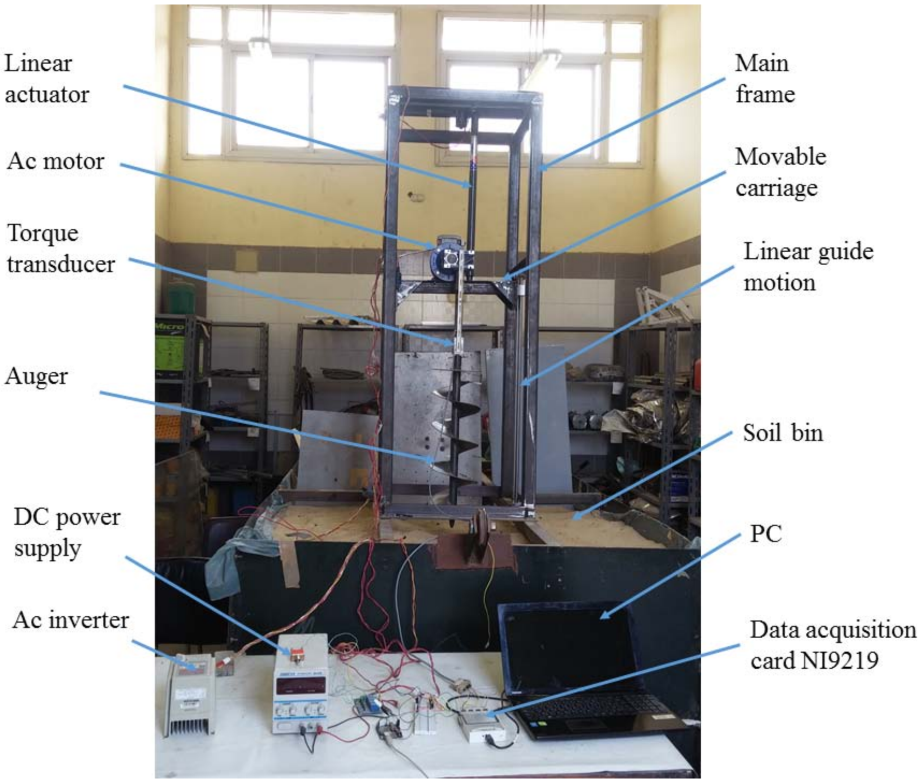

Figure 1. Specific configuration of the test platform [9].

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2. Test rig components details

This section introduces the components that have been used in the manufacturing process of the test rig along with their technical specifications and data.

2.1. Soil bin

Soil bin is a lab facility that is used to contain the tested soil for different experimental work. This soil bin is established in soil lab, mechanical equipment department, Military Technical College. The main dimensions of the soil bin are (3990mm,1584mm,1300mm) (length, width, height) with soil depth up to 700mm as shown in figure 2.

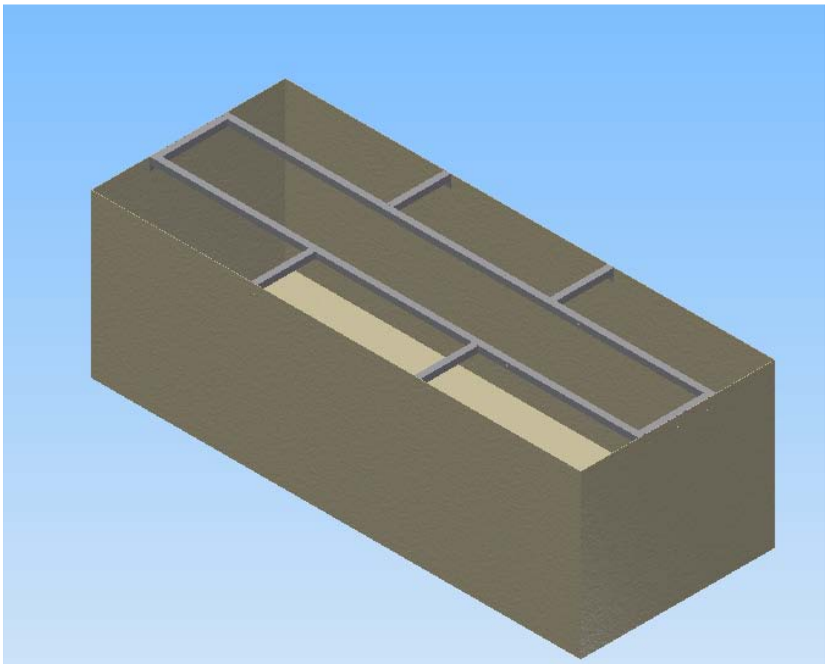

Figure 2. Soil bin.

2.2. Fixed frame

The fixed frame is considered as a skeleton of the test rig. It carries all the components that comprise the test rig with height up to1700 mm. It is equipped with an adjustable frame at its top to carry linear actuators. A hollow bar, with 5 mm thickness rectangular cross section, is the main component used in manufacturing the fixed frame as shown in figure 3.The fixed frame is attached to the main soil bin and is ready for assembly.

2.3. Movable frame

The movable frame is a simple frame used to carry the auger mechanism, which comprises of an AC motor and the auger. A mechanical linear actuator is attached to the movable frame to generate the up down motion as shown in figure 4. Four linear guide motions are used to keep a straight pass for the whole system during drilling operation.

2.4. Auger

The auger is the main working tool in the test rig. The tool consists of a 70 cm long hollow stemmed tube sharpened at its end. A continuous helix of “flights” is located all along the tube.The pile diameter and the hole diameter both equal to horizontal space between flight edges (20cm) and The vertical flight distance is the pitch(15cm) as shown in figure 5.

Figure 3. Fixed frame.

Figure 4. Movable frame.

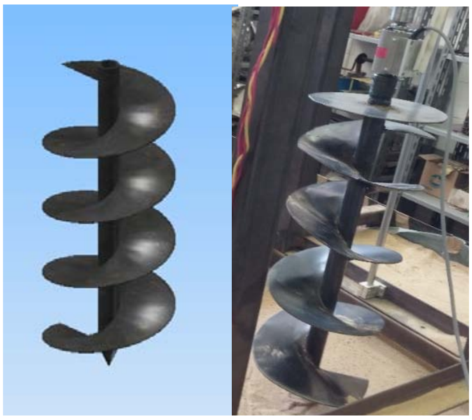

Figure 5. Auger.

2.5. Linear guide motion system
To assure the vertical motion of the movable frame, which carries the auger drilling system, a four linear guide motion system is used as shown in figure 6. They are fitted to the fixed frame by using (16-end) support. The movable frame is supported by eight bearings, which allow it to move along the linear guide motion. Bearings are installed as two bearings for each linear guide rod.

2.5.1. Linear bearing. Figure .7 shows a SCS16UU closed type linear ball bearing with aluminium block mounted. Its inner diameter is 16 mm to mount on 16mm diameter linear shaft, which is a common choice for linear motion applications. The linear bearing consists of two main parts: self-aligning aluminium block and linear bearing. The self-aligning aluminium block permits the compensation of any misalignment of inaccuracy in the final assembly. The bearing cage is made from special polymers allowing smooth and noiseless operation. It is convenient and low cost solution for machinery that require smooth motion with minimum friction and at the same time high rigidity and less vibration with affordable cost and easy to assemble operation

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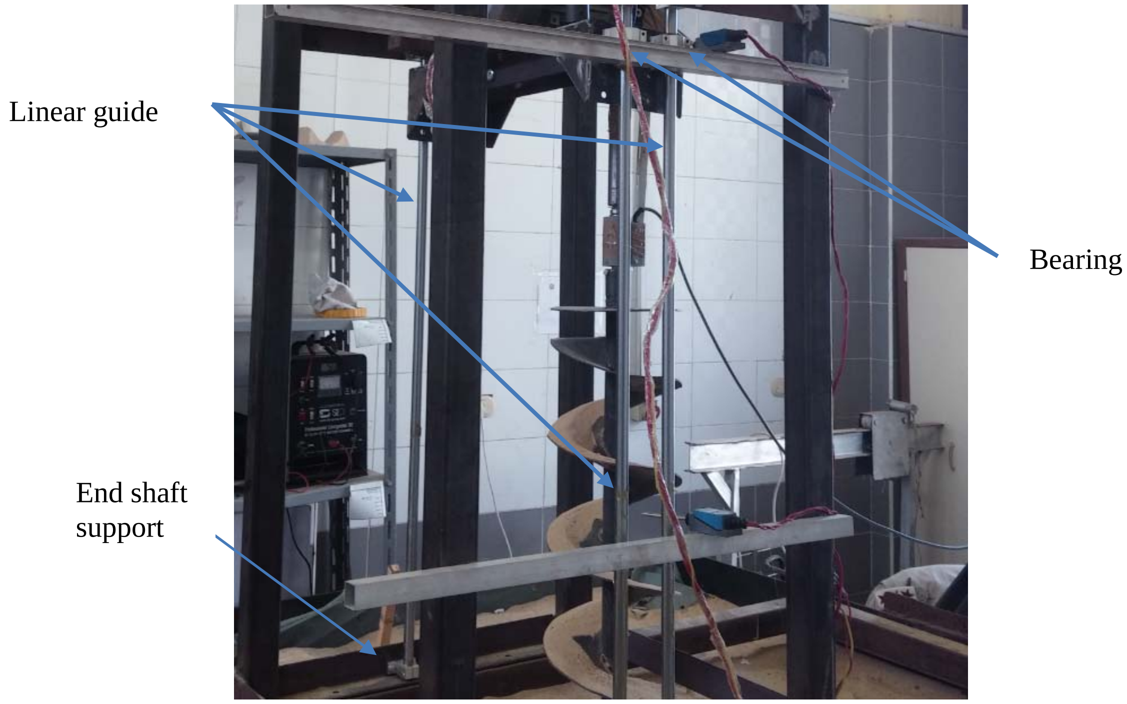

Figure 6. The linear guide motion system.

2.5.2. Linear guide rod. A chromed steel bar is utilized in states of high pressure and severe conditions. In like manner, the nature of the base metal and resulting surface treatment are of principal significance. Wear obstruction, surface smoothness, high return quality and uniform quality are basic properties of chrome plated bars. Chromed plated linear rods are delivered from steel bars joining high quality with good machinability and weld capacity. Regular applications are found in direct movement, programmed apparatus, CNC machines, and injection moulding machine, farming machinery and production equipment as shown in figure8.

2.5.3. End shaft support. The Aluminium end support block can be utilized for end or irregular shaft support. The anodized aluminium end support is lightweight and solid, and can be utilized with all rod types as shown in figure9.

Figure 7. Linear bearing

Figure 8. Linear guide rod

Figure 9. End shaft support.

3. Actuating motors

Actuating motors are responsible for two types of motion, linear motion, which can be interpreted for feeding rate and rotary motion. Electric motors are used to establish the test rig, and represent the advantage of low cost and easiness to be controlled

3.1. Linear actuator

Two super-jack regular actuators mounted on the top of the fixed frame are employed to produce the feeding action. The end of the extended cylinders are attached to the movable frame as shown in figure 10 Super-jack actuator is used as the source of the linear motion or feeding. This type is characterized by low noise and high performance with a stroke up to 0.61 meter. The operating voltage is up to 36 volt and Load capability is 136 kilogram. Rated, (250-kilogram dynamic/454 kilogram. static).The two linear actuator are powered by a DC power supply with maximum volt equal 30 volt.

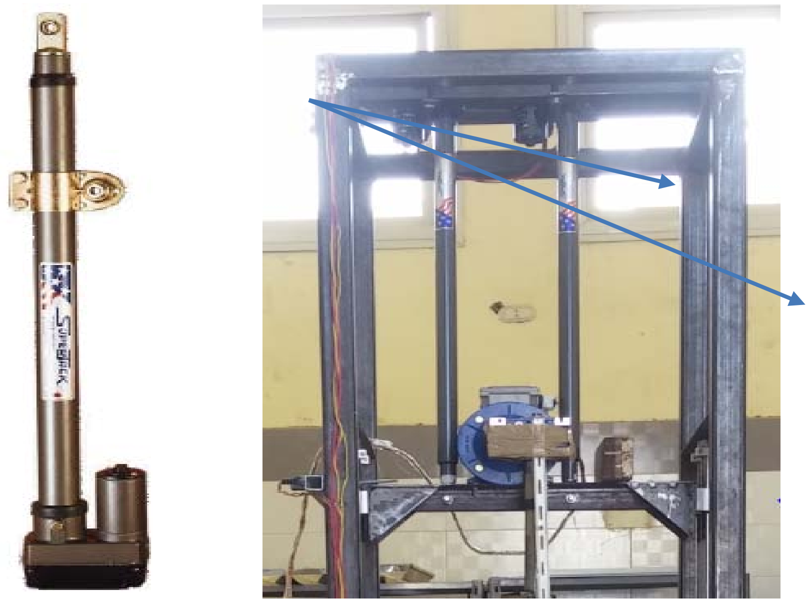

Figure 10 Super lack linear actuator.

3.2. A three phase AC motor

A three-phase AC motor, shown in figure 11, is responsible for developing the rotary motion. The motor base is fitted to the movable frame with four bolts. A worm gear set is attached to the motor output shaft giving the advantage of self-lock with a reduction ratio 1:20.

An AC inverter is used to control the motor output speed which by its role controls the auger rotating speed. The motor power is 0.75 hp and the output shaft speed is up to 1500 rpm.

3.3. AC inverter

To control the 3-phase AC motor an AC inverter is used as shown in figure 13. This inverter is responsible for reversing the direction of rotation of the AC motor from clockwise to counterclockwise and vice versa. An AC inverter model AS 2 – 115 is used to control the 3-phase motor by changing the inverter frequency. The input voltage is 220 volt and the output voltage obtained from the inverter is 360 volt.

Figure 11..A three phase AC motor.

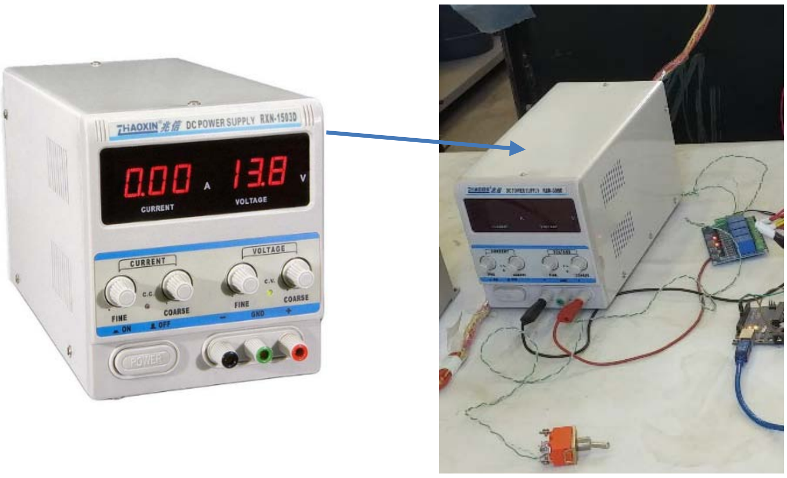

Figure 12.DC power supply.

Figure 13. The variable frequency drive AS 2– 115.

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3.4. Torque transducer
Torque can be identified as a rotational force that represents the rate of change of angular momentum of an object[10]. The requirement for torque estimations has prompted a few strategies for gaining trusted data from items moving. A torque sensor or transducer changes over torque into an electrical signal.

The most well-known transducer is a strain gauge that changes over torque into a change in electrical resistance. The strain gauge is glued to a bar or basic part that misshapes when a torque or power is connected. Deflection encourages a stress that variates its resistance. A Wheatstone bridge changes over the resistance change into an electrical signal. The structure of a response torque cell looks to take out side loading and is sensitive just to torque loading.

Other generally acknowledged strategies for measuring torque depend on mounting transducers in the machine train or on the turning shaft, these strategies use strain gauges. Every strategy has preferences and confinements, a lot of which are application dependent. The best arrangement requires a top to bottom comprehension of the application.

Two regular approaches to get torque measurements are by strain-gauging the shaft and by utilizing in-line torque transducer. Both have two technical obstacles: getting capacity to the measures over the stationary turning hole and recovering the signal. The strategies to overcome any issues are either contact or non-contact.

The used transducer in this research is a screw torque transducer model (T4A) as shown in figure 14. This model characterized by the ability of measuring torque in any direction also any angle of rotation and any rotational speed. Nominal torques 5, 10, 20, 50, 100, 200, 500 and 1000 N.m. The transducer "T4A" uses a 4-wire link technology is inserted between the auger and the driving shaft. The T4A output signal is then forwarded to NI 9219 via a USB connection to the device via a compact acquisition system (DAQ).

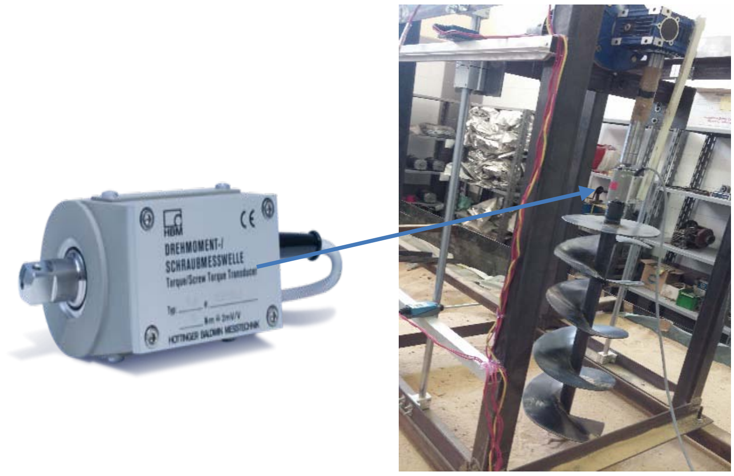


Figure 14. The T4A torque transducer.

3.5. Limit switches
In order to detect the feeding speed, two limit switches are used as shown in figure 15. The output signal from limit switches are sent to Arduino toolkit. The distance between the two limit switches equal to the proposed hole depth (0.5) meter. The feeding speed can be calculated by dividing the distance between the two limit switches by the time calculated from the limit switches output

3.6. Arduino
The ArduinoUno rev.3 board show in figure 16It is an ATmega328-based microcontroller board. The system consists of 14 digital pins, 6 of which can be used for PWM outputs, 6 Analog inputs, the 16 MHz oscillate, a USB interface, an ICSP Header and a reset button. The device also has a USB

connection. It contains all the microcontroller needs; simply connect it to a USB cable device or power it to continue using an AC-to-DC converter or a charger.

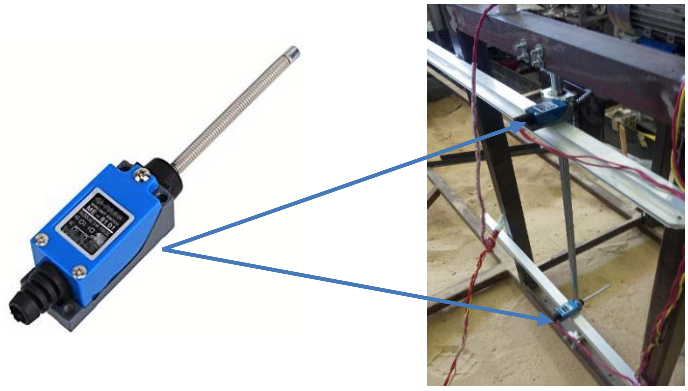


Figure 15. Limit switches mounting on test rig.

Figure 16. Arduino Uno.

3.7. Relay

RK4 is a basic, inexpensive module of a relay motor. It supports eight output relays, which control electrical AC and DC devices including lights, engines and keys, as shown in the Figure 17, for the control of the path of the linear actuator. The 5V, 12V or 24V DC supply RK4 can be operated.

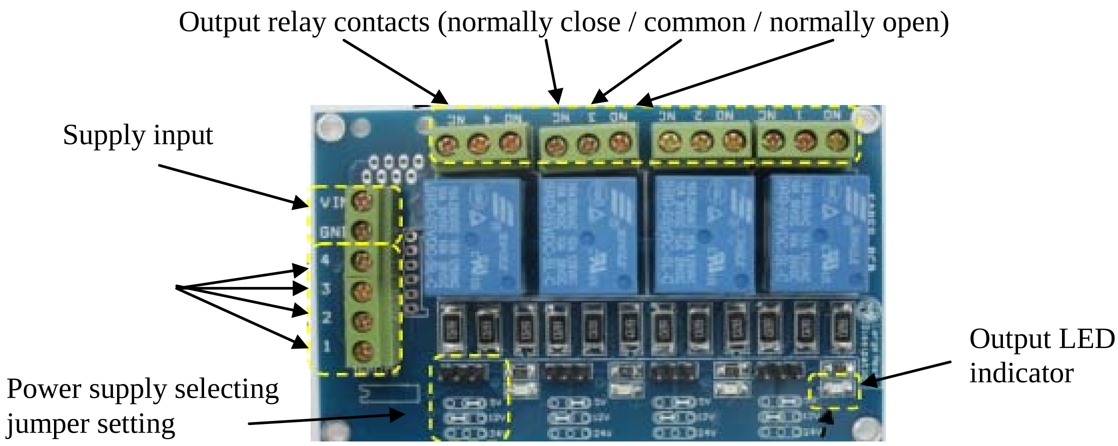


Figure 17. The RK4 layout.

3.8. Computer based data acquisition (DAQ)

Figure 18 shows the NI 9219 Compact DAQ, which is a universal C series module. Signal from torque transducer can be measured easily with a simple Labview® program as shown in figure 19. The range of measurements for each method of measurement is special, with voltage up to ±60V and current up to ±25 mA.

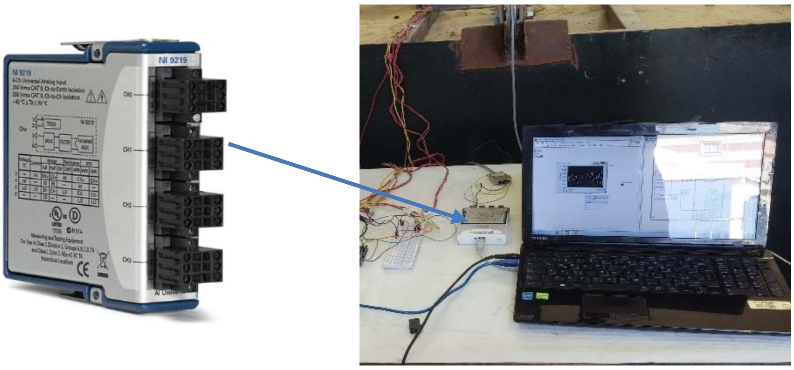


Figure 18.NI 9219 Compact DAQ.

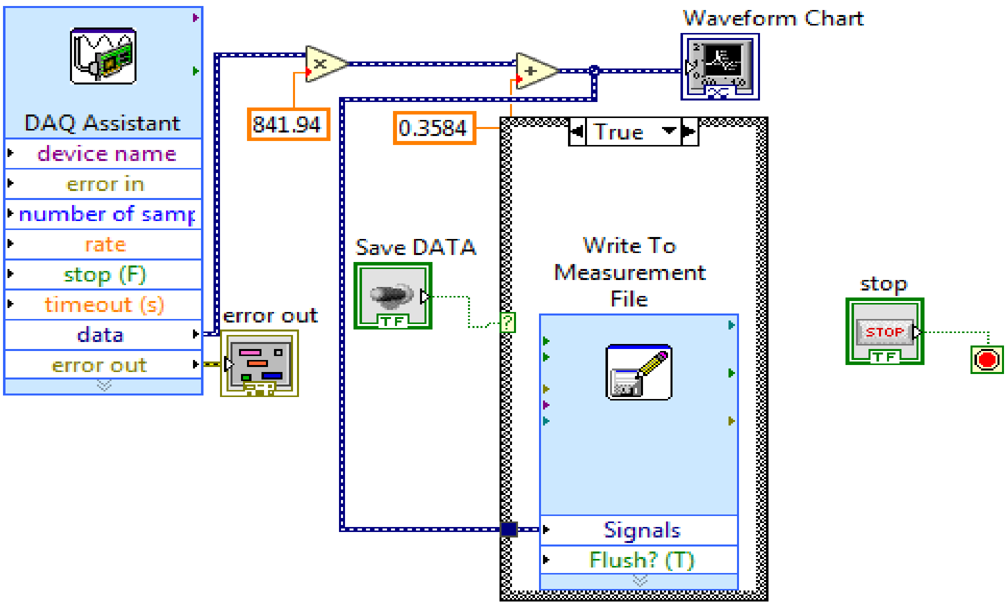
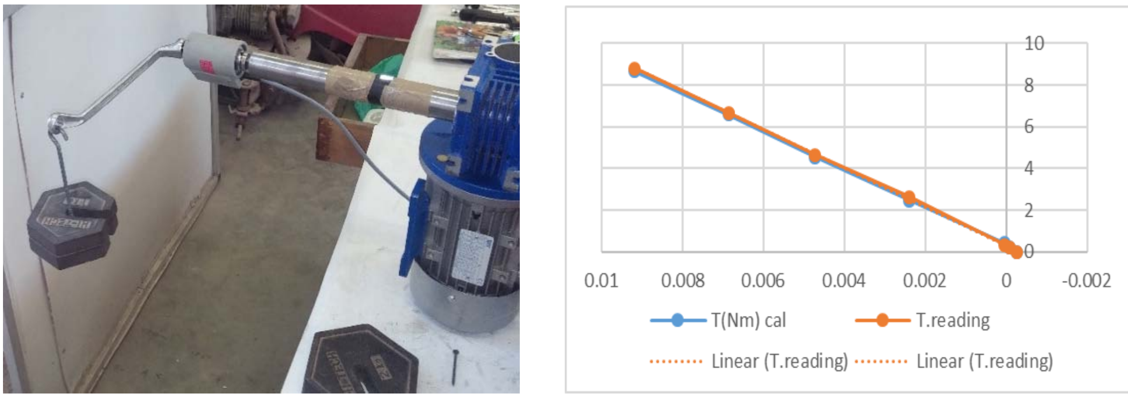


Figure 19. Labview program.

4. Torque transducer calibration process

In order to increase the accuracy of drilling torque measurements, torque transducer is calibrated and sensor calibration curve is deduced. The calibration process is conducted by using different known weights, which are hanged at a certain distance to produce torque action as shown in figure 20. (a). The Labview ® Software Package is used to design a data acquisition system to allow the viewing and recording of the output data directly from the transducer. The output readings from torque transducer is then exported to excel. The loads generate torque, which is calculated by multiplying the hanged load weight by the orthogonal distance between the axis of symmetry of the hanged load and torque transducer. Finally, both torque value obtained from torque transducer output signal and calculated by multiplying hanged weights by distance are recorded and plotted to obtain the torque transducer calibration curve as shown in figure 20. (b).



(a) (b)

Figure 20. Torque transducer calibration process.

5. Data processing flow chart

A simple program is created by using Labview® program to enable recording and viewing the collected data. Figure 21 shows the general configuration of the flow map of the drilling test rig[11].

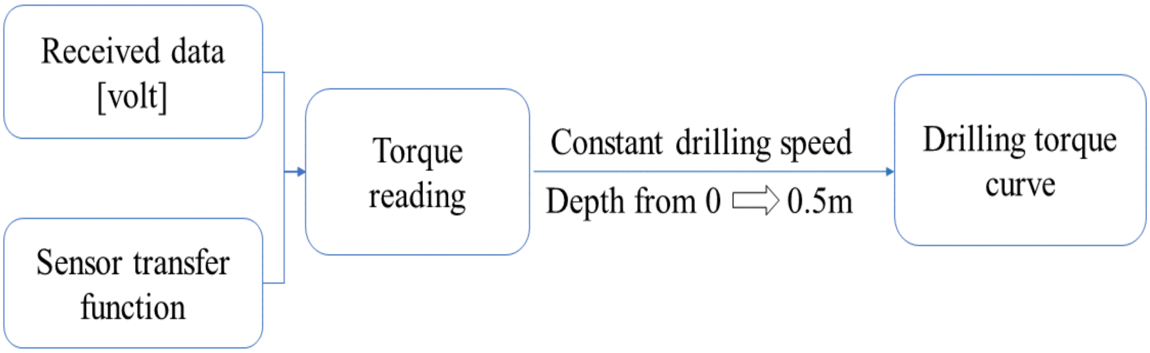


Figure 21. General configuration of the flow map of the drilling test rig.

6. Uncertainty calculations and results

The main cause for measuring uncertainty is to know the measurement range. The uncertainty of the measurement operation has been studied thoroughly in separate paper [11]. Type A uncertainty, type B uncertainty and combined uncertainty are calculated. Expanded uncertainty is calculated by multiplying a coverage factor to the combined uncertainty.

The required torque for drilling in sandy soil is calculated analytically and measured experimentally for 0.5 meter depth and plotted as shown in figure 22. The auger speed is 50 rpm and the feeding rate is 5 mm/sec. To achieve 95% confidence level the standard uncertainty has been multiplied by a coverage factor = 2, then error bars have been added to the measured values of the required drilling torque as shown in figure 23[11].

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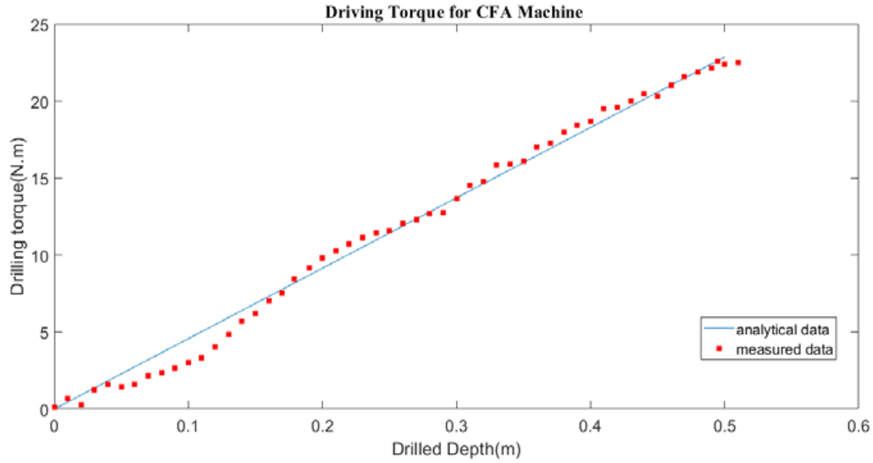

Figure 22. Drilling torque required in CFA machine.

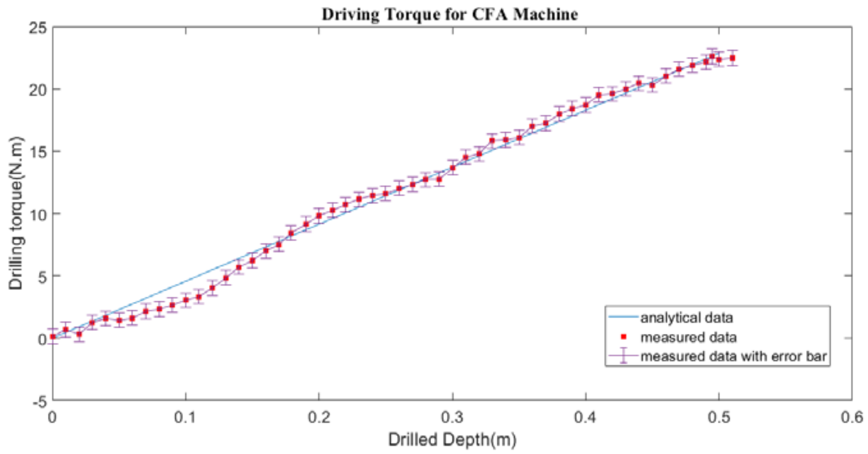

Figure 23. Drilling torque required in CFA machinewith error bar.

7. Conclusion

A test rig is set up to calculate the torque of the auger during soil digging, and uses a variety of mechanical systems, control circuit and many sensors. Using the Labview ® software package to view and monitor the calculated data directly via the transducers, a simple data acquisition program is developed. To have the validity of measurements and the sensor sensitivity scale, the torque transducer is calibrated. To order to calculate performance, the uncertainties of type A and type B are calculated. Both forms are mixed for determining the disparity in readings from different sources. The overall device precision of the drilling torque is dependent on the calculation of calculated torque uncertainties. An error bar with 95 percent conviction is given for each reading showing the potential variance. Comprehensive measurement of the driving torque during the drilling is determined according to the directly calculated values on a continuous flight auger unit.

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