DESIGN, CONSTRUCTION AND EVALUATION OF A DIGITAL HAND-PUSHED PENETROMETER

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ABSTRACT

A cone penetrometer is widely used in tillage and off-road mobility research as an indicator of soil strength and density characteristics. Light-weight, manually operated units are especially useful in recording cone index determination at remote field locations. An electronically hand-pushed soil penetrometer with a microcontroller-based data logging system was designed and fabricated to provide a portable penetrometer for determining soil resistance to penetration in tillage studies. The device consists of three main components: a cantilever beam strain-gauge load cell held by housing to measure penetration force, depth measurement mechanism with a photodiode sensor, and a data logging system for amplifying, digitizing, and acquiring data. Data from data logging system can be downloaded into a personal computer by an RS232 cable and a software program. In evaluation stage, the performance of the developed penetrometer was compared with a commercial Eijkelkamp hand-pushed digital penetrometer in a controlled soil bin conditions. No significant difference was found (p<0.05) between the two penetrometers. The penetrometer performance was reliable and the penetrometer's mechanical and electrical parts worked well without any malfunctions. The device is very light, easy to use and more economical compared to the conventional types.

KEYWORDS:

Hand-pushed penetrometer, Penetration resistance, Load cell, Depth sensor, Data logging system

1. MAIN TEXT

In agricultural soil mechanics, most of soil properties are related to soil reaction against their exerted forces [1]. These characteristics are often related to soil strength and they change in a specific soil over a time, under climatic conditions, soil management and plant growth. These strength characteristics and also their changes in each type of soil as well as their changes can be measured by the shear strength of soil or soil penetration resistance. The values of these properties largely depend on bulk density and moisture content of the soil. Penetration resistance indicates the pressure needed to form a spherical cavity inside, to the extent that it surround steel cone and overcome the friction between the conical surfaces and the surrounding soil[2].

Plant roots cannot penetrate the soil with high compaction. Causes of soil compaction are: 1) the movement of heavy vehicles during tillage farm elasticity 2) the lack of organic materials and loss of soil structure due to excessive tillage 3) soil cohesion increase [3]. Equipment and tractors

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transportation, plow, disc handling, and soil may be lead to soil compaction. Compaction levels higher than 2 MPa prevent root growth or lead cross drainage problems and water crossing. This product will lead to lower performance [4].

Penetrometer equipped with a data recording system are common tools to measure soil cone index and gaining soil compaction profile in studies of soil physical properties and their effects on plant growth. The reason of these tools popularity are: 1) They are rapid, easy to use and affordable 2) they provide data for analysis 3) they are tools that they can be used be in undisturbed soil samples studies(field conditions) [5]. These portable penetrometers are very effective in cases that tractor penetrometers are invaluable or cannot be used very often for measuring. When the handheld devices are equipped with electronic data acquisition systems, they can record data on penetration resistance. Cone index is determined by measuring the resistance to penetration defined by 313.3 S ASAE standards. Cone index indicates the amount of force per unit area for pressing a steel cone with standard dimensions at a depth of soil. Steel cone is considered as the base level pressure. Steel cone has apex angle of 30 degrees and is made of stainless steel. Rod Attached to the cone is made up of AISI 416 steel. This index is a quantitative measure used to classify soil compaction and conditions of the tractive [6].

Recent advances in computer and electronics surprisingly increased ability of designers in the collection, processing and analysis of the penetrometer's data. Digital data acquisition systems and depth measurement equipment made it possible to measure strength and depth at the same time. In this context and with modern equipments, it is possible predict bulk density of soil, texture, moisture and soil color in the field conditions and without soil sampling.

In order to simplify the use of penetrometer many researchers used advanced measuring systems [7]. Wells et al. (1981) designed a handheld digital penetrometer equipped with a portable data acquisition system with a memory of the magnetic tape to increase data storage capacity at that time [8]. Morrison and Bartek (1987) designed a handheld digital penetrometer equipped with a potentiometer to measure the depth of the design. In this device, a data acquisition system (Omnidate Polycorder Version 4.5) was used to collect and store data. 7.4 kg was the total weight of the device with a data acquisition system that was portable by one person [9]. Garciano et al (2006) designed and established a portable unit that measures parameters such as shear strength, hollow cone index, as well as soil friction characteristics in a point. This electronic device (Bevameter) consist of a standard ASAE cone for measuring the cone index and the friction between the soil and the metal when it is wrapped in a specified depth in the soil, also a cone blade to measure the soil shear strength in specific depth, an ultrasonic sensor for the measurement of the depth and strain gauge transducers to measure penetration resistance and torque [10].

Sun, Y., et al extended the conventional method with two-dimensional data analysis (map-based analysis) of four round bales, packed by a fixed chamber baler or a variable chamber baler [11].

In 2012 a group of researchers proposed a practical technique using a dual-sensor penetrometer for the simultaneous measurements of penetration resistance (PR) and moisture content (MC) in conjunction with image-based analysis [12]. Vertical penetration resistance of a cone is measured by a force sensor and logged versus the depth of penetration in 2013 [13]. Booth et al showed that soil bulk density in the top 5 cm and penetration resistance in the top 20 cm were similar ($P > 0.05$) among all three vegetation cover types, but soil particle-size distributions in the top

20 cm differed significantly ($P < 0.05$) [14]. Poggio et al designed a VisNIR soil penetrometer foreoptic that matched the optical performance of a commercial ASD (Analytical Spectral Devices Inc., Boulder, CO, USA) foreoptic and was compatible with any spectrometer having a fiber optic input (e.g. commonly used ASD field spectrometers) [15].A recent research suggested that at the assessment of soil conditions for root growth, ignoring the effects of depth is likely to give misleading penetrometer resistance [16].

One of the disadvantages of hand-pushed penetrometers is the non-uniformity penetration rate, which reduces measurement accuracy. There are hand-pushed penetrometers that send an acoustic signal to alert when the rate exceed a limit [9].

The aim of this study is to design, build and evaluate a portable electronic device for tillage studies. This paper describes design and use procedures of the device and comparison of the device and a commercial device.

2. Materials And Methods

In hand-pushed penetrations design**,** it is desirable that the weight is light and easily portable by one person**.** The other desired characteristics of the device is capability of storing large amount of cone index data in high level studies and eventually transferring the stored data to a personal computer for further analysis**.** Standard size of steel cone and rod attached to it in the 313.3 S ASAE standards is stated in two different sizes. 1- Cone diameter 27.20mm and bar diameter 88.15 mm for soft soils and 2- Diameter of the cone base 83.12 mm and rod diameter 35.9 for hard soils, in the device design smaller size and rod length 60cm and 30 degree cone is used. Cone and rod are made up of AISI 316 stainless steel, which are prepared by machining operations and in device design it is considered that in the soft soil condition cone and rode can be replaced with larger dimensions. The cone is reserved to the rod head; so when abrasion of cone exceeds the 3% based on the standards, it can be replaced.

3. Force Measurement

In this device a cantilever beam is used for load cell design (Figure 1). The maximum force applied to the load is considered 50 kg to be provided by a person. Maximum cone index to measure the force is 4 MPa. Elastic element is a piece of steel cubes with dimensions of 110×50×4 mm. According to load cell design principles, AISI 4340 steel with E=207 MPa is used. Two 120 ohm strain gauge in the upper surface and two at the bottom are attached. Four strain gauge are in Vetson Bridge with 6-volt input which it is provided by data acquisition system. The output of Vetson Bridge is connected to data acquisition system and stored with four stranded coated cable. The reason of using coated cable in the load cell is to reduce the effects of turbulence.

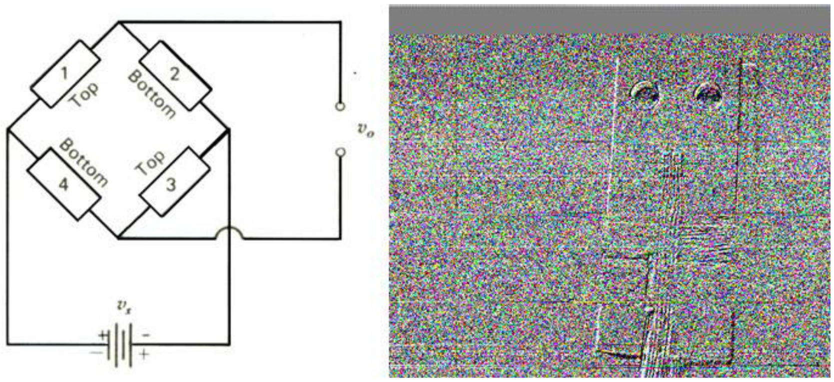

Figure 1 Cantilever beam load cell and Vetson bridge for force measurement

3.1 LOAD CELL CALIBRATION

converter should be calibrated to determine parameters such as sensitivity, the hysteresis, repeatability, and calibration coefficient. A fixture containing loading conditions similar to actual conditions of load cell loading provided and the calibration was performed. Load step from zero to 70 kg load was applied on load cell and the Vetson bridge output was measured using a digital multi meter. In order to enhance the calibration accuracy strain was measured with strain meter and to determine the amount of converter residual, after reaching the maximum permissible load, load was reduced stepwise to zero voltage and the resulting strains were recorded again.

3.2 LOAD CELL FRAME

Frame including the converter made of the upper part and the lower part in a way that consists of reactionary element and holds it. Upper part can be connected to a horizontal knob and the lower part encompasses shaft penetrates places it in contact with the elastic element. Linear bearings in the lower part absorb lateral stresses and only convey axial forces to the elastic element. Frame including the converter is designed in a way that can have the ability of using elastic elements with different thicknesses. It allows using of the device at different soil types and deeper places. The frames are made of very light and high strength compact PVC is shaped with turning and milling operations. Two frames connected by bolts and actually provide an anchor for the load cell.

4. DEPTH MEASUREMENT

In this device depth measurement is non-continuous operation and is done every 10 mm. Depth measurement action begins when the surface of soil penetrating cone reaches the land's surface. For measuring depth and applying cone index at certain points of penetration depth it is necessary to use a ruler or measuring index. For this purpose, two-millimeter-thick sheet was used that by bending it at angle of 90 degrees created a device and in every 10mm with 4 mm diameter obtained holes. Measurable depth by this mechanism is 55 cm. Components of this mechanism are: (1) conductive block (2) guide bar (3) base (4) depth indicator (5) optical sensor and (6) connector parts. Figure (2) shows device assembled of these parts. Depth measurement mechanism by two screws is connected to the device attaching the conductor block to the frame. The operation of this part is as follows. By applying force on the handle, mechanism attached to it (the bar and the frame included load cell) Scroll down and right at the moment that the base of the cone reaches the soil surface, base of depth measurement mechanism places on the soil surface; As a result base, guide bar, connector part and the depth index fixes on the soil surface. Following the movement of the cone penetrates the soil, conductivity block moves downwards. The value of cone penetration in soil is the distance conductor block passes on depth measurement index. Therefore depth can be measured by the distance conductor block passes on depth measurement index. With the installation of an optical transmitter and receiver sensor on the conductor block while cone falls down, passing sensor in front of each of the holes on the index and turning sensor light off and down, a pulse is sent to a data acquisition system which it is indicative of the 10 mm depth. After measurement, as the penetration bar comes out of the soil, depth measurement mechanism moves upward and places in its own original condition. A base that attaches to the bottom of the measurement ruler is the bearing on the soil and on the other hand is used for detecting of surface soil by data acquisition system.

5. DATA ACQUISITION SYSTEM

The data acquisition system is a digital system based on 8-pin microcontroller family of AVR (ATMEGA 32) ATMEL with 32 KB programming memory, 2 KB data memory (RAM) and 1 KB lasting renewable memory. The microcontroller processing speed limit is 16 MHz.

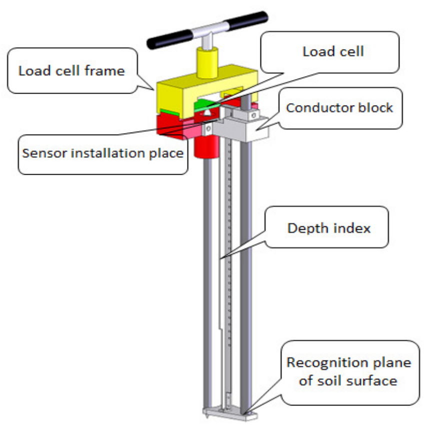

Figure 2 simulated hand-pushed penetrometer schematic

The system software design was done by CODE VISION AVR and with C programming language. All functions of the program are attached as separate files. These functions let you enter positive and negative decimal numbers as well as display system messages to the user and are capable of receiving options chosen by the user. Side memory used is an ATMEL EEPROM with memory of 256 KB. Data and commands transfer is performed by EEPROM through dual port Philips Protocol (Philips, 12C). Therefore, the necessary files to communicate through the protocol are also attached. In addition, necessary functions for memory management are provided by programmer and by means of them random access is existed anywhere in memory and the operation is carried out easily. These functions are designed in a way that in each use, 10 bytes are used simultaneously to record the date, farm number, block number, the depth and the force converter and for each 2 bytes are used. PROTUES was used as simulation software. As a result, many of the errors were identified and fixed before making the machine. PROTEL DXP-2004 was used for electrical circuit design. Circuit design is performed for the production of metallized and two-sided electronic board. Board dimensions are 20 × 15 cm and there is appropriate location on board for installing the screen and keyboard is drilled. For noise reduction both sides of the board and just wires paths were cleaned by acid and the coated parts of both sides of the board were grounded. This method is called POWER-PLAIN. The designed system is shown in Figure 3. The data stored in the system memory is coded by Visual Basic 6.0 and is received by the computer using RS-232 serial cable. 6V input voltage is provided by a rechargeable battery for data acquisition system power supply.

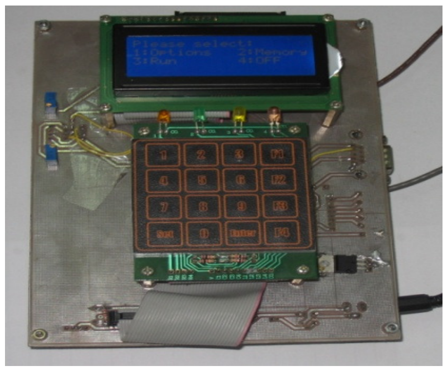

Figure 3 Data acquisition system

6. WORKING PRINCIPLE OF THE DEVICE

The device is user friendly enough to be used by any person for cone index measurement. When in a field, the operator selects a point for data extraction, before beginning of measurement process parameters such as load cell calibration equation, the required measurement depth (number of holes on the cone measurement index and distances between them) as well as parameters like date, farm number, block number, the number of repetitions are entered and stored to the system by keyboard. In this case, the operator chooses RUN to keep the device in standby mode for receiving the data. As the cone base reaches to the soil surface, the first pulse which indicates zero depth is sent to the data acquisition system by photocell sensor and when the cone reaches to predetermined depth, the system asks a question about data storage. By selecting YES key, the data stores in the device memory. At the end of measurement phase in field, data acquisition system in the laboratory is connected to a personal computer using RS-232 serial cable. The data is sent to computer and to receive data in computer we wrote a Basic 6 Visual program (PENETROMETER DATA RECORDER) that receives data in an Excel file and shows in six columns.

7. TEST AND EVALUATION OF THE DEVICE

To evaluate the device and ensure the accuracy of the measured data, an experiment was done in soil tank of Institute of Agricultural Engineering in Karaj. Soil in the tank was clay loam and with 12% moisture. Prior to Penetration test, we used a soil processor unit to create a compact layers at the desired depth and to reach soil moisture content to expected value and compacting completed in 10-20 cm depth. A commercial cone penetrometer (Eijkelkamp) was used as a control device (It is shown in Figure 4). It has a S-shaped force transducer to measure the penetration force and also an ultrasonic sensor to measure the penetration depth. Furthermore, a data acquisition unit is installed on the device which was capable of showing soil compaction profile during measurement.

Before the test, both devices acquisition systems were programmed and saved 28 points data. In these places and in two rows side by side, penetrating to a depth of 55 cm was measured by both.

Each row length is 14 meters and points chose with 0.5 m intervals. The lateral distance between the rows was selected 10 cm. Commercial penetrator device is programmed by factory in a way that records the depth at intervals of 10 mm. 30 degree cone is used during measurement for both devices. Stored data in the devices memory transferred to a computer and saved for analysis.

Figure 4 built device in left and commercial type in right both in soil tank

8. RESULTS

Force- power converter voltage calibration curve is shown in Figure 5. Coefficient showed very good linear relationship between power and voltage. The residual of calibration was ignorable in a way that recorded residual for strain was obtained 32.3 microns averagely. The high value converter sensitivity of 5.0 mV/N was achieved. ±25/0% force measurement precision obtained by load cell. The converter function for repeatability test ran and each experiment was repeated three times and there was little difference in the results.

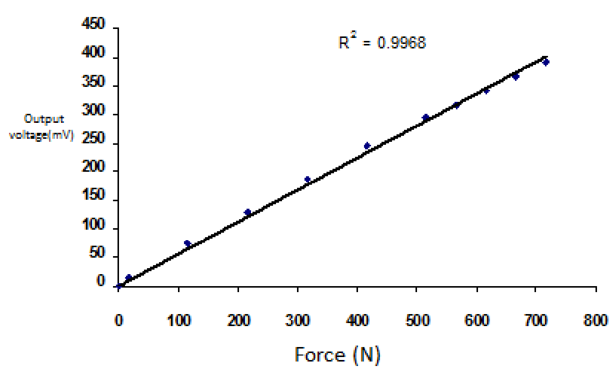

Figure 5 Load cell calibration graph

To evaluate performance of the built device, data obtained from the two tests performed to mean comparison test. Figure 6 shows mean of the data graph. It can be seen that there is a layer of compacted soil in depth of 10-20 cm that it was created at first in soil preparation unit. Table 1 related to mean comparison test T. The results showed that mean comparison test between the two devices is not significantly different at the 95% confidence level. Before the T test, F test for equality of variances mean cone indexes was done which had not significant difference between variances mean; so T test was performed with equal variance. Mean measured cone index with built device was 73.1 and for commercial type was 82.1 MPa. Figure 7 shows the correlation between the measured data of the devices. High correlation factor and crossing origin point is indicative of high correlative of the devices. Also during the measurement in the soil tank the time required by each device in all measurement points was measured which it was equal for both devices and was about 20 minutes for 28 points.

Table 1. Average comparison test results

Device	Ejkelkamp	built device
Average	1.82	1.73
Variance	0.488	0.487
num of observations	55	
degree of freedom	108	
T	1.66	
Probability	0.255	

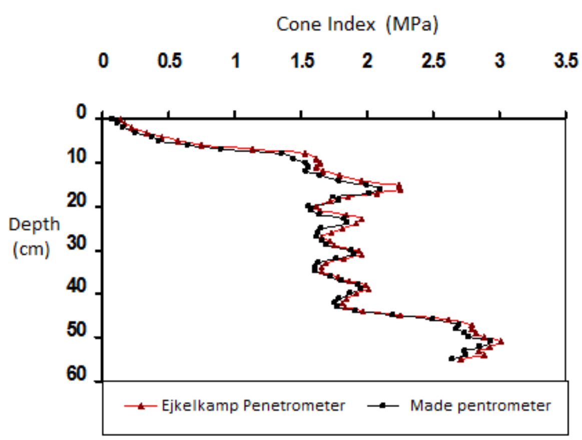

Figure 6 Average of measured data with both devices

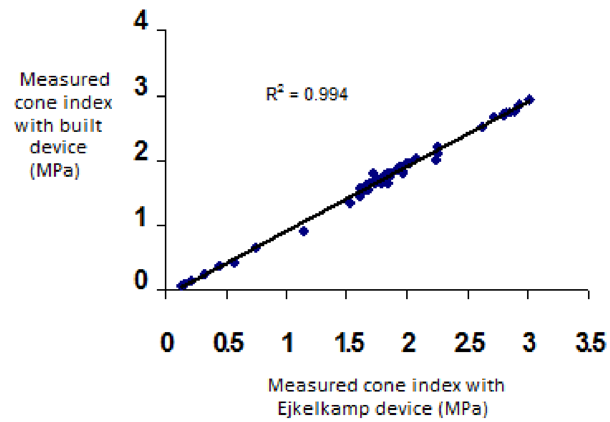

Figure 7 Correlation between measured data of both devices

9. CONCLUSION

Using penetrometers equipped with a data acquisition system allows high volume fast and easy measurement. In order to measure the soil cone index in field condition in a way that can be stored and displayed, a digital hand-pushed penetrometer was built. Performed tests on the device showed accuracy of the data. The device can be used in studies of soil compaction and effect of traveling. This device can be used by a person capable of storing data of 300 points until depth of 55 centimeters. Time required to measure the cone index of 28 points until depth of 55 cm is about 20 minutes which is desirable. With total weight of 6 kg it is a portable device. This device is registered in State Organization for Registration of Deeds and Properties Intellectual Property Center (number 45165) in 1386.10.10.

ACKNOWLEDGEMENTS

These and the Reference headings are in bold but have no numbers. Text below continues as normal.

REFERENCES

[1] Rashidi, M., Keyhani, A., and Tabatabaeefar, A., 2005. Multiple penetration tests to predict soil pressure-sinkage behaviour under rectangular region. International Journal of Agriculture and Biology. V(8): 5-9

[2] Vaz, C.M.P., Bassoi, L.H., and Hopmans, J.W., 2001. Contribution of water content and bulk density to field soil penetration resistance as measured by a combined cone penetrometer-TDR probe. Soil and Tillage Research. V(60): 35-42

[3] Bowen, H.D., 1981. Alleviating mechanical impedance. In: Modifying the root environment to reduce crop stress. ASAE Monograph No. 4, ASAE, St. Joseph, MI 49085

[4] Randy, R.P., and Jeremy, T., 2003. Development of a frame to outomatically insert a hand-held penetrometer. ASAE Meeting Paper No. 031077. St.Joseph. Mich

[5] Perumpral, J.V., 1987. Cone penetrometer applications- A review. Transaction of the ASAE. V(30): 939-944

[6] ASAE Standard S313.3, 2006. Soil cone penetrometer.ASAE St. Joseph, MI 49805.

[7] Raper, R.L., Washington, B.H., and Jarrel, J.D., 1999. A tractor-mounted multiple-probe soil cone

penetrometer. Applied Engineering in Agriculture. V(15): 287-290
[8] Wells, L.G., Lewis, C.O., and Distler, R.J., 1981. Remote electronic acquisition of soil cone index measurement. Journal of Terrramechanics. V(18): 201-207
[9] Morrison, J.E., and Bartek, L.A., 1987. Design and field evaluation of a hand-pushed digital soil penetrometer with two cone materials. Transaction of the ASAE. V(30): 646-651
[10] Garciano, L.O., Upadhyaya, S.K., Jones, R.A., and. Jersey, S.R., 2006. Development of an instrumented device that measures shear, sinkage and friction properties of soil in-situ, ASAE Paper No: 061093, St. Joseph
[11] Sun, Y., et al. "An improved penetrometer technique for determining bale density." Biosystems engineering 105.2 (2010): 273-277.
[12] Sun, Y., et al. "Image-based comparison between a γ-ray scanner and a dual-sensor penetrometer technique for visual assessment of bale density distribution." Computers and electronics in agriculture 82 (2012): 1-7.
[13] Büscher, Wolfgang, et al. "Dichteuntersuchungen von Rundballen-Silage mit einem Penetrometer-Prüfstand." landtechnik 68.1 (2013): 26-29.
[14] Rezaee,A. "Using Genetic Algorithms for Designing of FIR Digital Filters ",ICTACT journal on Soft computing , 1(1)(2010): 18-22.
[15] Poggio, Matteo, David J. Brown, and Ross S. Bricklemyer. "Laboratory-based evaluation of optical performance for a new soil penetrometer visible and near-infrared (VisNIR) foreoptic." Computers and Electronics in Agriculture 115 (2015): 12-20.
[16] Gao, Weida, et al. "A simple model to predict soil penetrometer resistance as a function of density, drying and depth in the field." Soil and Tillage Research 155 (2016): 190-198.