An Electronic Hand-Operated Recording Penetrometer

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CONE penetrometers are used by many researchers to evaluate soil strength. In most situations the penetration force versus depth of penetration is desired. Several types of penetrometers are commercially available, and some researchers have developed special purpose units to suit their individual needs (1, 2, 3, 5)*.

Commercial penetrometers have several disadvantages such as: (a) no direct recording, (b) two or three men required for measuring and recording data, and (c) the recorded data must be plotted manually to obtain force versus depth curves.

While some special purpose penetrometers do record force versus depth, they have other disadvantages. These are: (a) too heavy or bulky for convenient field use, (b) "cocking" and displacement of springs may have effect on force measurement, and (c) difficult to operate.

Based on the disadvantages stated above, the following objectives were considered in designing the electronic recording penetrometer: (a) single man operation, (b) direct display and permanent recording of the force versus depth curve, (c) measuring and recording system in a single lightweight package, (d) simplicity of operation, (e) reliability, and (f) accurate measuring and recording.

Design and Construction

The design objectives for the penetrometer were used to develop the following specific design criteria: (a) a maximum force of 200 lb with recording in ranges of 0 to 200 lb, 0 to 100 lb, and 0 to 50 lb, (b) a maximum penetration depth of 24 in. with recording in ranges of 0 to 24 in., 0 to 12 in., and 0 to 6 in., (c) a cone with a 0.2 sq in. base area and a 30 deg tip angle, (d) a maximum weight of 10 lb for the penetrometer and recording unit, (e) a small X-Y plotter

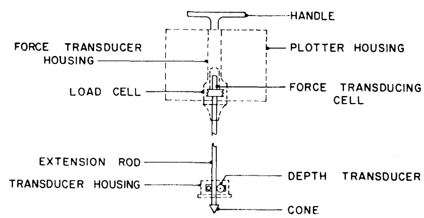

FIG. 1 Basic parts of penetrometer.

with a 4-in. by 6-in. plotting area as the method of display, and (f) a maximum inaccuracy of the recorded output of ± 2 percent of full scale.

Signal Sources

Fig. 1 illustrates the basic parts of the penetrometer. To measure the force, the cone and shaft are attached to a load cell that is mounted in a rigid housing connected to the handle. The force is measured by an unbonded strain gage load cell that has a maximum capacity of 200 lb. with a total displacement of 0.12 mm. Thus the output signal, which is proportional to the force applied to the cone, is obtained without appreciable deflection of the cone with respect to the penetrometer handle.

The depth transducer (a 10-turn potentiometer with ± 0.2 percent linearity) is mounted in a housing which rests on the soil, and through which the cone shaft passes. As the cone shaft moves through the housing the potentiometer is rotated by a friction disk against the shaft. Thus, the output signal of the potentiometer is proportional to the penetration of the cone into the soil.

Recording Electronics and Plotter

A basic two-bar X-Y plotter is used for recording. The axes are motor-driven and controlled by a closed-loop servosystem. A block diagram of the force measuring and recording electronics is shown in Fig. 2. The depth axis electronics are identical to the force axis electronics except the depth transducer does not require a pre-amplifier.

The closed-loop servo control consists of a pre-amplifier, summer, power amplifier, motor with gear train, and error detector. The preamplifier and summer are low-power operational amplifiers. The power amplifier is a single-pole, double-throw, center-stable relay. The electromechanical relay was used as the power amplifier because it does not present the usual problems of temperature drift encountered in an electronic d-c power amplifier. The motor is a low current-high torque d-c motor. The error detector is a three-turn potentiometer. The entire system is powered by small rechargeable batteries.

When a force is applied to the cone, the strain gage bridge becomes unbalanced, producing a voltage output proportional to the force. This voltage is amplified through the pre-amplifier and fed to the summer. The difference between the amplified transducer output and the error detector output produces an error signal which is fed to the power amplifier. The power amplifier converts the error signal into a power signal sufficient to drive the motor. The mechanical output of the motor is transmitted through the gear train to the plotter arm, and the arm is moved until the error signal is reduced to zero.

A signal conditioning circuit was designed to provide bridge balance, range selection, and calibration. This circuit consists of a calibrated d-c voltage to provide excitation for the transducers, a resistor network for bridge balance, and step attenuators for range selection.

A detailed analysis was carried out to determine circuit component values. After the values were determined, commercially available components were selected. The detailed design and analysis of the penetrometer can be found in a report prepared by Prather (4).

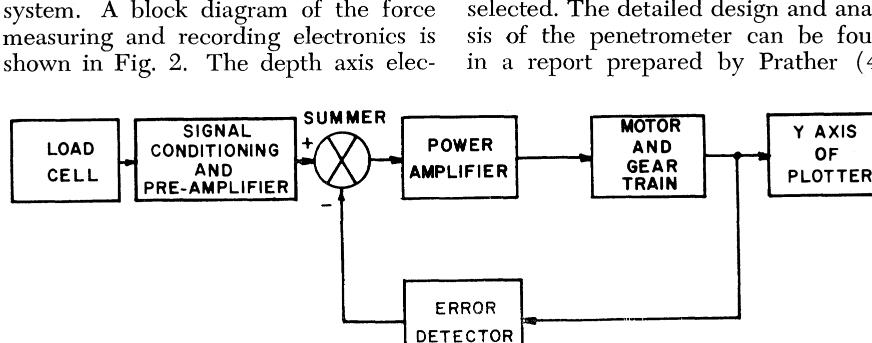

FIG. 2 Block diagram of force measurement system.

Paper No. 68-518 was presented at the Annual Meeting of the American Society of Agricultural Engineers at Utah State University, Logan, June 1968, on a program arranged by the Education and Research Division.

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* Numbers in parentheses refer to the appended references.

TABLE 1. PENETROMETER PARTS LIST*

Part No.	Description
A1, A2, A3	Burr-Brown Model 3001/15 Operational Amplifier
M1, M2	Clifton Precision Products Model DC-8-C-9 Motor
K1, K2	Potter and Brumfield Type MDP-1007 Relay
T1	Statham Model UC3 Transducing Cell
B1, B2, B3	Burgess Type CD22 Rechargeable Battery, ±6v.
B4, B5, B6	
P1, P8	IRC 500Ω 20-Turn Potentiometer
P2	IRS 10KΩ 20-Turn Potentiometer
P3, P4, P10	Bourns 2KΩ 20-Turn Potentiometer
P5, P11	Bourns 1KΩ 10-Turn Potentiometer
P6, P13	Bourns 1KΩ 3-Turn Servo-Mount Potentiometer
P7, P12	IRC 200Ω 1-Turn Potentiometer
R1	330Ω ± 10% 0.25W Resistor
R2	680Ω ± 10% 0.25W Resistor
R3	100KΩ ± 1% 0.5W Resistor
R4	47KΩ ± 10% 0.25W Resistor
R5, R7	10KΩ ± 1% 0.5W Resistor
R6	500KΩ ± 1% 0.5W Resistor
R8	20KΩ ± 1% 0.5W Resistor
R9	200KΩ ± 1% 0.5W Resistor
R10	1500Ω ± 10% 0.25W Resistor
R11	4700Ω ± 10% 0.25W Resistor
R12	249Ω ±1% 0.5W Resistor
R13	750Ω ± 1% 0.5W Resistor
R14	6000Ω ± 1% 0.5W Resistor
R15	30KΩ ± 1% 0.5W Resistor
R16	300KΩ ± 1% 0.5W Resistor

* Mention of a trade name does not constitute warranty of products or endorsement of products to the exclusion of other products not mentioned.

The complete circuit diagram and parts list are shown in Fig. 3 and Table 1 respectively.

Performance Evaluation

The overall performance of the penetrometer was evaluated in five basic areas: (**a**) short term total accuracy, (**b**) repeatability (**c**) stability with respect to time and temperature, (**d**) amount of continuous operation without recharging, and (**e**) compatability of the penetrometer data with data of other type penetrometers.

The short term total accuracy was determined by comparing the output of the force and depth axes with known inputs. These measurements were made with the transducers balanced and the recorder adjusted so there were no errors due to long term (greater than 5 min) time and temperature drift. For a given input, the maximum output error of either axis was less than ± 1.0 percent FS (full scale).

The repeatability of the system was determined by comparing the recorder output for a number of tests with the same input applied each time. The system was reset at the beginning of each test so that no errors were introduced by time and temperature change. For 20 test runs, the repeatability error was less than ± 1.0 percent FS.

The stability of the system was determined by measuring the change in the output over a given period of time and a given temperature range. The drift over an 8-hr period at a constant temperature was less than ± 0.4 percent FS, and for a ± 10 F temperature change it was less than ± 0.8 percent FS.

The amount of continuous acceptable performance was determined by running a given number of penetrometer tests and measuring the output error due to battery deterioration. It was determined that approximately 400 tests or 10 hr of testing can be achieved with an error of less than ± 1.0 per-

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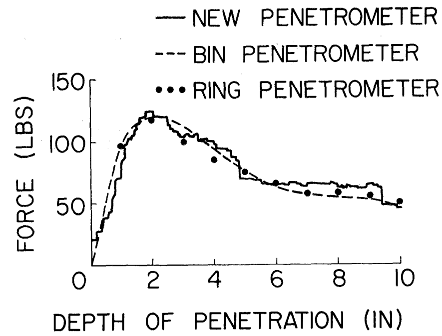

FIG. 4 Comparison of different type penetrometers.

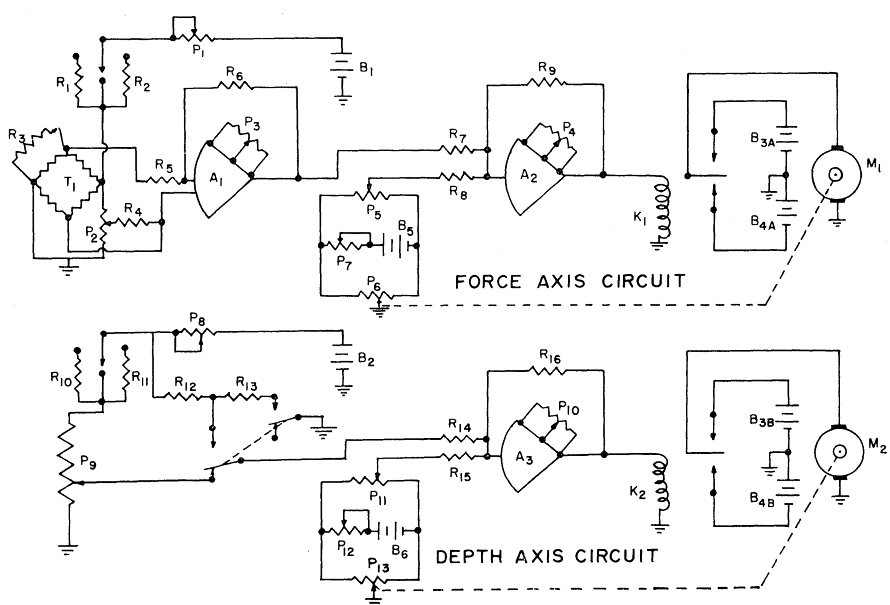

FIG. 3 Complete circuit diagram.

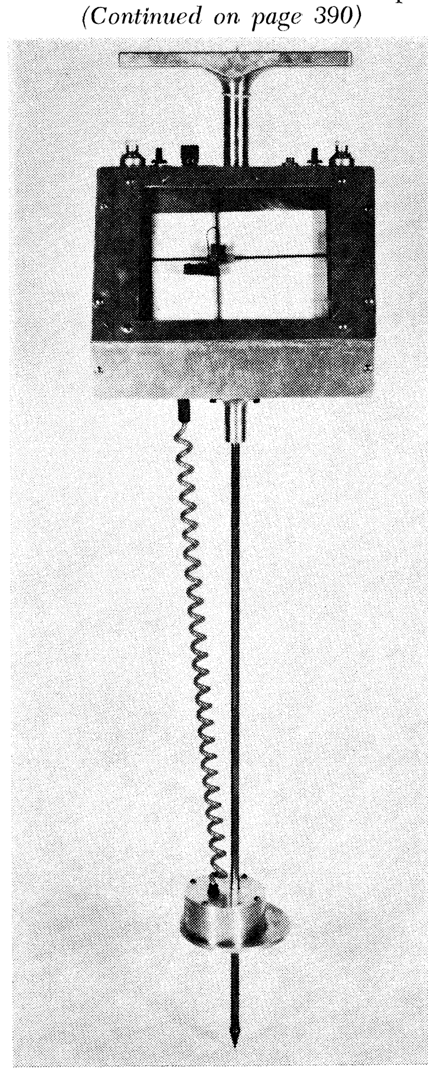

FIG. 5 Electronic recording penetrometer.

ELECTRONIC RECORDING PENETROMETER

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cent FS without recharging the batteries.

The method used to determine the compatability of the penetrometer was to compare its data with data obtained with other types of penetrometers. The penetrometers used for this comparison were a carriage-mounted, hydraulically controlled penetrometer used for bin testing at the National Tillage Machinery Laboratory, and a hand-operated proving ring penetrometer. A typical plot comparing the three units is shown in Fig. 4.

Conclusions

The completed penetrometer, which met the design objectives, is shown in Fig. 5. The light-weight penetrometer operates reliably and provides an accurate permanent recording of force versus depth. It can be easily operated by one man.

References

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