Science, Engineering & Education, 10, (1), 2025, 31-34

Device for Measuring the Consistency and the Setting Time of a Grout

Svetlozar Nedev*, Ilian Lesev

University of Chemical Technology and Metallurgy, 8 Kliment Ohridski Blvd., Sofia 1797, Bulgaria

Received 10 October 2025, Accepted 31 October 2025
DOI: 10.59957/see.v10.i1.2025.5

ABSTRACT

The article presents the design and construction of a penetrometer, device that measures a material's resistance to penetration, which helps to determine its strength, consistency, or firmness. The device consists of standard components, including a needle, fixed load, and measurement system. The novelty of the design lies in the integration of a microcontroller that controls needle release, measures penetration depth, and displays the results. The lifting and lowering of the loaded needle are performed by an electromagnet, which has an additional function - it is also used to measure the depth of penetration into the material.
Keywords: penetrometer, microcontroller, electromagnet, displacement measurement.

INTRODUCTION

A penetrometer is a device used to determine the cohesion of different materials (soil, sand, clay etc.) [1]. In our case it is utilized to explore the process of hardening of a cement mixture according to the BDS EN 196-3:2017 standard. This standard, issued by the Bulgarian Institute for Standardization (BDS), is a national application of the European standard EN 196-3, which deals with cement test methods. A standard way to perform the analysis is to measure the depth of penetration of a needle attached at the lower end on a steel rod, which falls from a certain height [2].

The developed penetrometer comprises of a control unit (module) - the box in Fig. 1, an electromagnet mounted on a stand, steel rod with replaceable needle at bottom, which is lifted by the electromagnet and a dish for the cement mixture (Fig. 1).

The module is designed to control the electromagnet, which has a dual purpose: raises and drops the metal rod and measures the penetration of the needle into the cement mixture.

CONTROL UNIT

The control module includes two buttons - one for "Start/Stop" and a second one for "Reset". The distance is indicated in millimetres on a LCD display. The initial needle position is reset with the corresponding button. When the cement

**Correspondence to: Svetlozar Nedev, Department of Physics, University of Chemical Technology and Metallurgy 8 Kliment Ohridski, 1797 Sofia, Bulgaria, E-mail: nedev@uctm.edu*

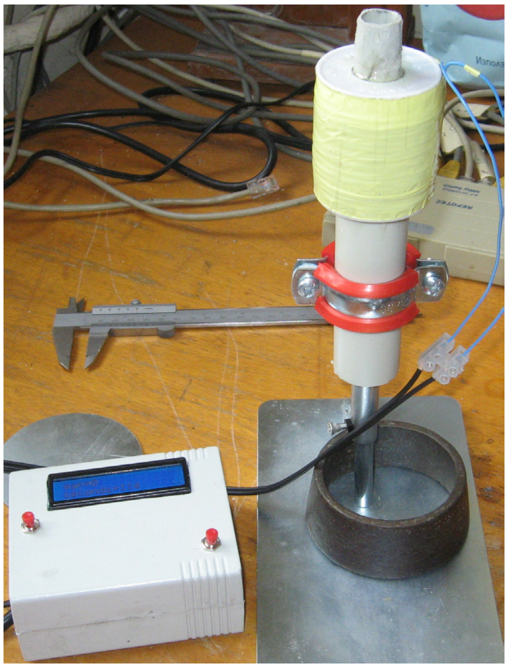

Fig. 1. Device to measure the hardening of cement mixtures.

mixture is ready, the "Start/Stop" button is pressed, the module turns on the electromagnet, and it raises the steel rod. When the same button is pressed again, the electromagnet is switched off, the rod falls and the level to which it has descended can be read on the display. If the "Start/Stop" button is not pressed again, the electromagnet will turn itself off after 20 s.

The schematic diagram of the module is shown in Fig. 2. For control, an ATtiny26L microcontroller is used and LCD display WH1602B-TMI-CT# with a screen of 2 lines of 16 characters is connected. Two outputs control IRF540 transistors, which turn on/off 2 relays, and a signal from a LC generator implemented with the LM324N operational amplifier is fed to the INT0 input of the microcontroller. The circuit generates rectangular pulses with

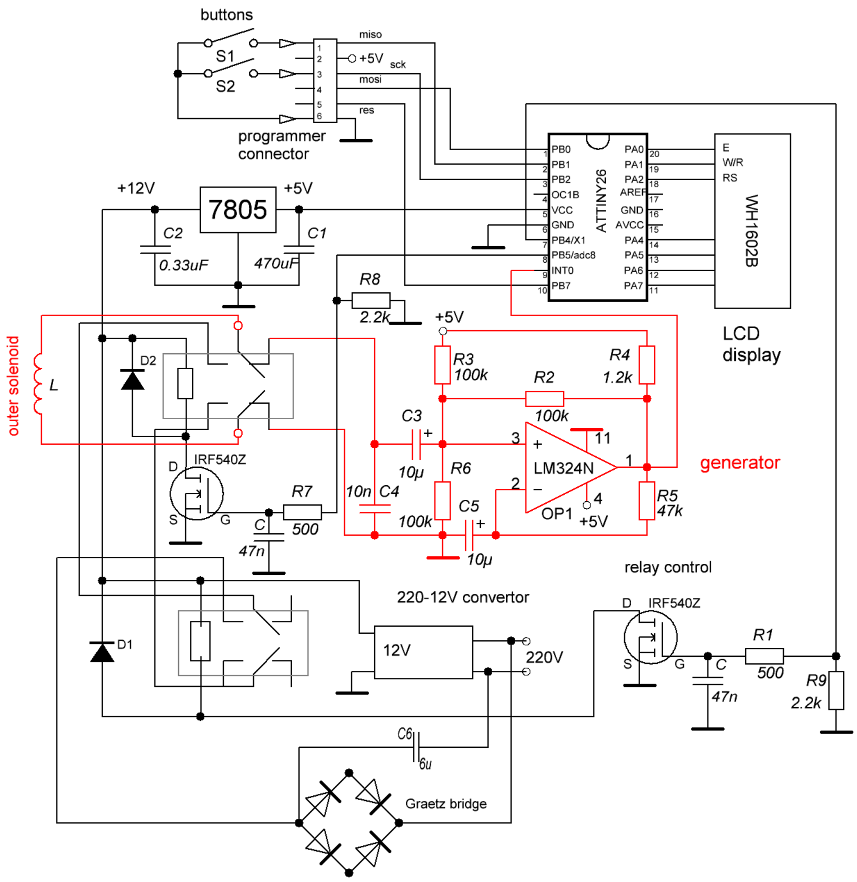

Fig. 2. Schematic diagram of the control module.

frequency $\omega = 1/\sqrt{LC}$. The capacitance is C=10 nF (the capacitor is labelled C4 in Fig. 2) and L is the inductance of the electromagnet, which is external to the module and connected to it by a cable.

The electromagnet has a dual function. It can be connected to the capacitor C4 and then the microcontroller measures the frequency of the generator, which depends on the inductance L, proportional to the position of the metal rod inside it. The rod is made of steel, with a relative magnetic permeability of about 3.5, therefore L, and hence the frequency of the generator, changes greatly when the position of the rod changes. When the coil is disconnected from the generator via one relay, it can be connected to 220 V via another relay - then it works as an electromagnet and attracts the metal rod. The two relays allow the disconnection of the coil from the generator and its connection to 220 V to be separated in time (in the microcontroller's program this interval is fixed to 250 ms). This protects the low-voltage operational amplifier from damage if the relays did not operate quickly enough, preventing 220 V from being supplied to its input.

The microcontroller operates under the control of a program written in C, which monitors the button presses, controls the electromagnet, and displays messages on the screen.

The module is powered by alternating voltage 220 V. The microcontroller and the display are powered with 5V obtained from the stabilizer 7805, which is supplied with 12V from a converter powering 12V relays.

ELECTROMAGNET

The solenoid of the electromagnet consist of 5400 turns at length of l = 5.4 cm, inductance L_0= 422 mH and ohmic resistance of R=126 W. The steel rod has a relative permeability m_r = 3.5. The force with which the coil acts on the core is given by the approximate Eq. (1) [3]:

$$F = (\mu_r - 1)\frac{LI^2}{2l} \tag{1}$$

The inductance of a solenoid with an inserted at a distance x steel rod is (Eq. (2)):

$$L = \left(1 + (\mu_r - 1)x\right)L_0 \tag{2}$$

When it operates as an electromagnet, the solenoid is connected to an alternating voltage of 220 V. The equivalent circuit of a solenoid consists of inductance and resistance connected in series. It has impedance $\sqrt{R^2 + (\omega L)^2}$ and from the above formulae it follows that the force F will decrease when the steel rod is inserted inside the solenoid. To inverse this dependence a capacitor with C=6.6 mF in series with the solenoid so that the impedance changes to $\sqrt{R^2 + (\omega L)^2\left(1 - 1/\omega^2 LC\right)^2}$ was put. This impedance decreases when the rod is inserted but the force increases considering the obtained data.

Experimental results indicate that when 220 V AC is applied to the solenoid, the steel rod starts to heat up and make a loud buzzing sound. This is the result of two effects: eddy current induction and hysteresis losses due to repeated demagnetization when the direction of the magnetic field changes. To reduce these losses, a Graetz scheme was used. The alternating 220 V voltage is applied to one arm of the bridge, and the solenoid is connected to the voltage from the other arm (Fig. 2). The current through the solenoid is still variable, but it flows only in one direction, which reduces hysteresis losses (the magnetic field does not change direction). It turned out that with such a switch-on, the heat disappears and the noise emitted by the core of the electromagnet is significantly reduced.

MEASUREMENT OF THE DISPLACEMENT

The frequency $\omega = 1/\sqrt{LC}$, generated by the circuit depends on the position of the steel rod x , which allows measurement of its displacement.

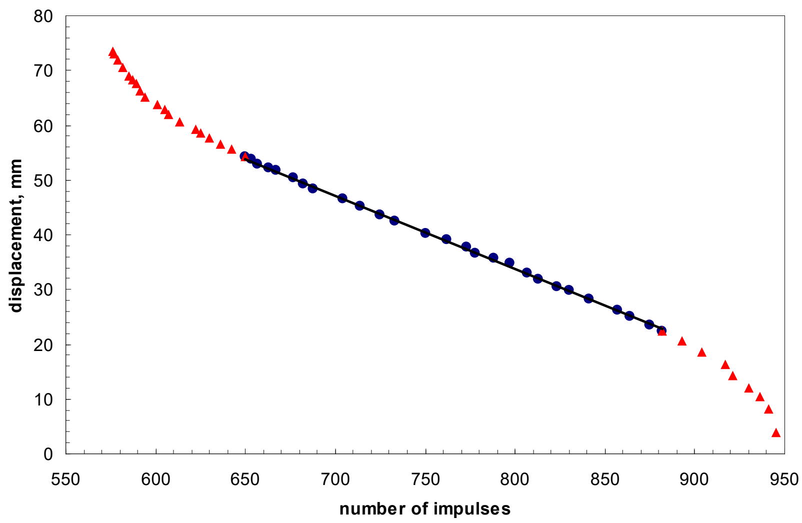

Fig. 3. Calibration curve - dependence of the displacement of the needle on the number of received pulses.

This is done when the microcontroller counts the pulses received at the input INT0 for 1.6 ms (Fig. 2). The corresponding dependence is shown in Fig. 3. It is seen that the central region can be approximated by a straight line.

To measure the penetration of the needle in a cement mixture, an accuracy of the order of a millimeter is sufficient, therefore the measured displacement is rounded and displayed with such an accuracy. The measurement error is about 0.25 mm. The selected scheme of displacement reading allows much greater accuracy - increasing the pulse counting time will increase the accuracy, but then it will be necessary to make a more accurate calibration.

To perform measurements, the electromagnet must be positioned so that the displacement is in the region of the straight line of the curve in Fig. 3.

CONCLUSIONS

An inexpensive microcontroller-based penetrometer for measuring the hardening of cement mixtures was successfully developed. Main benefit is that the set-up is with a simple principle of operation - a steel rod with a given weight and a needle at its lower end that falls from a certain height onto the mixture. Thus, the depth of penetration of the needle is measured and the hardness of the mixture can be evaluated.

Acknowledgment

The authors gratefully acknowledge the financial support by the project BG051PO001-3.3.06-0014: "Center of mathematical modelling and computer simulation for training and development of young researchers" with beneficiary UCTM Sofia.

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