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A RESEARCH VISION

Electronic System for a Coaxial Cylinder-Based Viscometer

Sistema electrónico para un viscosímetro basado en cilindro coaxial

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ABSTRACT

Viscosity is the resistance that fluids have to move in conduction media and is a parameter of great importance for their study. In addition, in the industry, viscosity is a control parameter that allows evaluating the production processes of petrochemicals or food, among others. In this sense, viscosity is determined experimentally by means of equipment called viscometers. There are different types of viscometers, among which the following stand out: cup, U-tube and rotational. In this work we report an electronic circuit for a concentric cylinder rotational viscometer focused on laboratory practices in fluid mechanics at the bachelor's level. The circuit is developed on the basis of an ESP32 microcontroller and incorporates modern electronic devices such as: a touch graphic TFT display, signal conditioning for strain gauge with 24 bits of resolution, silent stepper motor driver, Bluetooth communication and speed control with Hall effect encoder. With these characteristics, it was possible to develop a measuring device with sufficient precision required in laboratory practices, high reliability and technologically modern. Qualitative results include the procedures for local operation (via touch screen) and remote operation (via Bluetooth wireless connection) of the equipment. Two quantitative experiments are also included, in which the performance of the force measurement and the repeatability of the speed control were evaluated.

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RESUMEN

La viscosidad es la resistencia que tienen los fluidos para desplazarse en medios de conducción y es un parámetro de gran importancia para el estudio de la realogía. Además, en la industria, la viscosidad es un parámetro de control que permite evaluar los procesos de producción de petroquímicos o alimentos entre otros. En este sentido, la viscosidad se determina experimentalmente mediante equipos llamados viscosímetros. Existen diferentes tipos de viscosímetros entre los que destacan los de copa, de tubo en U y rotacionales. En este trabajo reportamos un circuito electrónico para un viscosímetro rotacional de cilindros concéntricos enfocado a las prácticas de laboratorio de mecánica de fluidos en el nivel licenciatura. El circuito está desarrollado sobre la base de un microcontrolador ESP32 e incorpora dispositivos electrónicos modernos como lo son: un despliegue TFT gráfico táctil, adecuación para señal de galga extensiométrica con 24 bits de resolución, impulsor de motor a pasos silencioso, comunicación Bluetooth y control de velocidad con codificador de efecto Hall. Con estas características se consiguió desarrollar un aparato de medición con la precisión suficiente que se requiere en las prácticas de laboratorio, gran confiabilidad y tecnológicamente moderno. Como resultados cualitativos se incluyen los procedimientos de operación local (mediante pantalla táctil) y remota (mediante conexión inalámbrica Bluetooth) del equipo. También se incluyen dos experimentos cuantitativos en donde se evaluó el desempeño de la medición de fuerza y la repetibilidad en el control de velocidad.

1. Introduction

In the electronics used in viscosity measurement instruments that operate on the different types and principles of measurement [1], at least 4 fundamental variables can be found that must be determined and correlated to obtain an indirect viscosity measurement. For example, for rotational viscometers, both torque, from force sensors, and angular displacement, from encoders, must be measured electronically. Another example is the U-shaped and cup type viscometers where it is essential to record the time or frequency. These four variables, torque, angular displacement, time and frequency define the viscosity measurement of a fluid according to its measurement principle. Other variables that must be controlled during the viscosity measurement process are temperature and the speed at which the mechanical devices move [1]. Regardless of the measurement principle, microcontrollers are electronic devices with the capacity to record the four variables mentioned, as well as to control the temperature and angular velocity variables that contribute to uncertainty. Additionally, the most modern microcontrollers include advanced capabilities for connecting devices like: graphical touch displays, Bluetooth or Wifi peripherals and also high level data processing in the IoT (Internet of Things) cloud. In this work we report the electronic circuit developed and built to

indirectly obtain measurements of a rotational viscometer of concentric cylinders. The electronic circuit is based on an ESP32 microcontroller and force transducers, to determine the torque, and angular displacement transducers, to control the speed between cylinders. In addition, the electronic circuit can be operated locally by means of a TFT (Thin Film Transistor) graphic display with touch or remotely by means of a device with Bluetooth wireless connection. The circuit is capable of manipulating a linear displacement mechanism that will eventually be useful to position the fluid sample in the measuring device. With this scheme, a low cost instrument is developed and the precision and reliability in the measurements made in school practices are maintained. This paper is organized as follows. Section 2 of this paper presents the electronic design of the circuit. Section 3 shows the control and measurement algorithm that the microcontroller performs. Section 4 describes the process of building the printed circuit board on a router machine. Section 5 presents the qualitative and quantitative results that prove the performance of the electronic circuit. Finally, section 6 contains the conclusions and future work.

2. Circuit description

Figure 1 shows the schematic diagram of the electronic circuit for the concentric cylinder viscometer.

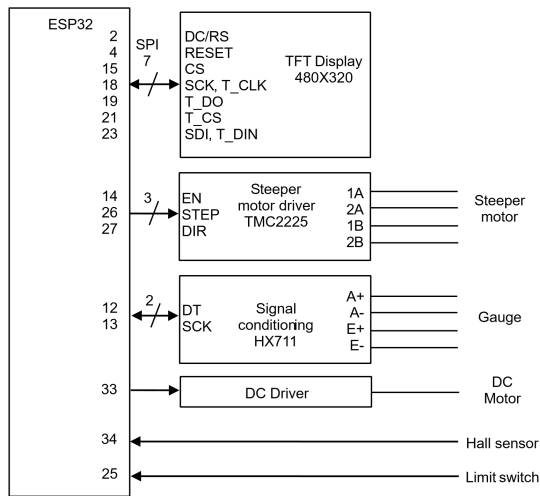


Figure 1: Schematic diagram of the electronic circuit for the viscometer.

Figure 1 shows the connection of an ESP32 microcontroller to the selected electronic devices used to measure viscosity according to the concentric cylinder principle [1].

The functional blocks shown in Figure 1 are described as follows:

- The TFT display is connected via SPI (Serial Peripheral Interface) to seven GPIO (General Purpose Input Output) pins of the ESP32 microcontroller. The display uses two SPI channels: one for graphic functions and another for touch functions. The shared SPI lines between both channels are T_DIN with SDI and T_CLK with SCK (data and clock, respectively). The independent lines for each channel include CS and T_CS selectors, the RESET pin, the touch data line T_DO, and the display data line DC/RS. This configuration allows sending information to the graphic interface and receiving touch signals from the user interface [2]. These components enable a modern and user-friendly interface for the viscometer.
- The silent stepper motor driver TMC2225 requires three input signals: enable (EN), step (STEP), and direction (DIR) [3]. These signals are generated by the ESP32 microcontroller according to the control algorithm. The driver enables the controlled vertical movement of the inner cylinder into the outer cylinder of the viscometer. The travel limits are defined by a limit switch to prevent mechanical overrun.
- The HX711 load cell amplifier communicates through

a protocol similar to a two-wire serial interface, using a data line (DT) and a clock line (SCK). This bidirectional communication allows force measurements from the strain gauge to be transferred to the ESP32 microcontroller [4]. After calibration, the measured force can be correlated with the fluid viscosity between the concentric cylinders.

- The DC motor drive system, together with the DC motor and Hall-effect encoder, forms a closed-loop speed control system [5]. This system ensures that the inner cylinder rotates at a constant and predefined angular velocity. This controlled rotation is essential, as it constitutes the fundamental measurement principle of the concentric cylinder viscometer [6].

Figure 2 shows the detailed electronic circuit diagram for the viscometer.

3. Measurement and control algorithm

The two variables of interest that must be processed with the concept in Figure 1 are the angular velocity of the inner cylinder, stored in frequency variable, and the force on the gauge, stored in fuerza variable. From these variables and some geometric constants it is possible to calculate the viscosity of any fluid that moves between the two concentric cylinders.

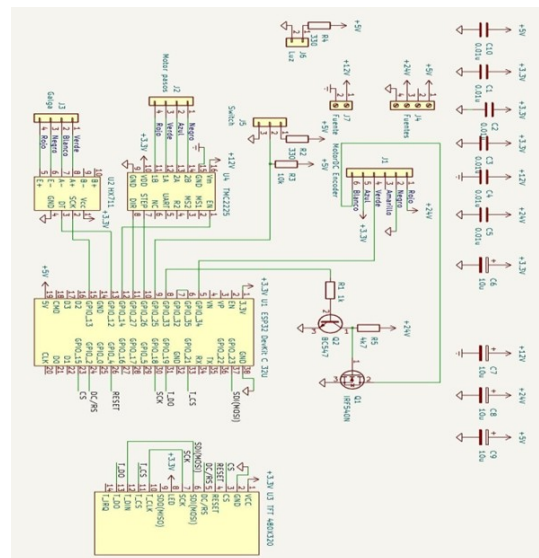


Figure 2: Electronic circuit diagram for the viscometer.

So in a regular viscosity measurement activity, the fluid to be analyzed must first be introduced between the concentric cylinders and then the desired angular velocity between cylinders must be specified. This desired velocity is called

SetPoint. Figure 3 shows the flow diagram that the ESP32 microcontroller develops as part of the control and measurement algorithm. The algorithm in Figure 3 is basically a poller of the touch screen status and the data received by Bluetooth to execute the indicated activity. The flag variable is used to prevent the reading of the Hall encoder count from being wrong during the sampling process [7]. The flag variable is set to false in the reading process and returned to true in the interrupt service routine generated by incoming digital pulses. The algorithm in Figure 3 was programmed in C language within the Arduino IDE (Integrated Development Environment).

4. Construction on routing machine

The construction process using a routing machine starts with the schematic and PCB (Printed Circuit Board) design using the free software KiCad [8]. Figure ?? shows the PCB layout of the electronic circuit for the viscometer.

From the printed circuit design, Gerber and Excellon files are generated to manufacture the PCB. These files are then converted into G-code using the free software FlatCam [9]. The parameters used in FlatCam for the Gerber file are shown in Table 1, while Table 2 presents the parameters used for the Excellon file.

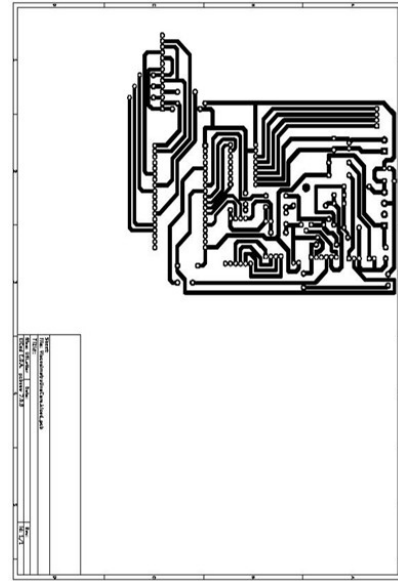


Figura 4: PCB layout of the electronic circuit for the viscometer

Cuadro 1: Gerber FlatCam parameters

Process	Parameter	Value
To generate ISO geometry	Offset	(-0.3, 0.65)
	Tool diameter	0.0053
	Width (passes)	1
To generate CNC object	Pass overlap	0
	Cut Z	-0.0028
	Travel Z	0.1
To export G-code	Feed rate	3
	Tool diameter	0.0053

Cuadro 2: Excellon FlatCam parameters

Process	Parameter	Value
To generate CNC geometry	Offset	(-0.3, 0.65)
	Tool size	1-6
	Cut Z	-0.0026
To export G-code	Travel Z	-0.0026
	Tool diameter	0.0053

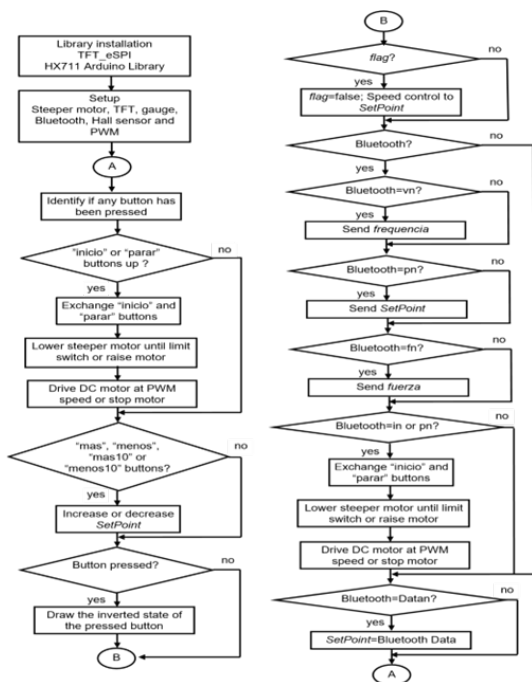


Figura 3: Flow chart of the measurement and control algorithm

Finally, the generated G-code is loaded into the Candle software [10] for routing machining.

5. Results

Figure 5 shows the circuit developed for the concentric cylinder viscometer. Independent evaluation exercises were carried out for each of the modules that make up the electronic circuit for the viscometer. This guarantees the reliability of the instrument for viscosity measurement once the circuit is integrated into an electromechanical measurement system. The modules that we can identify for independent evaluation from Figure 1 are the following:

- User interface.
- Stepper motor and limit switch.
- Strain gauge.
- DC motor and Hall encoder.

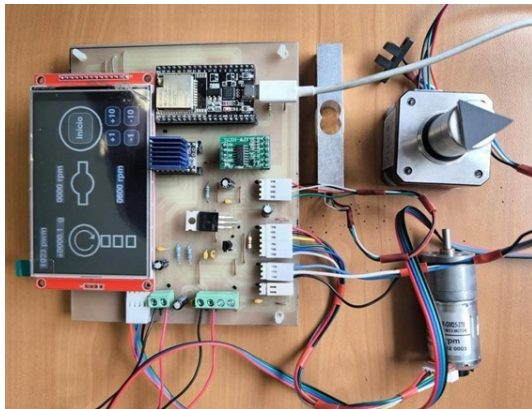


Figure 5: Electronic circuit for the concentric cylinder viscometer.

The first two modules are evaluated qualitatively while the last two are evaluated quantitatively as described below.

5.1. Qualitative results

A viscosity measurement simulation was performed with 200 gr of reference weight at an angular velocity or SetPoint of 1000 rpm. Figure 6 shows this process performed locally by manipulating the TFT display and Figure 7 shows the same process performed remotely through an Android application with Bluetooth connection [11]. Figure 6. Local measurement.

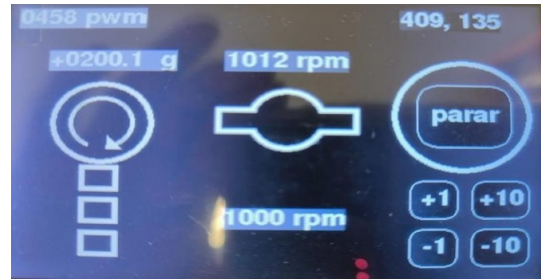


Figure 6: Local measurement.



Figure 7: Remote measurement.

As a result of the local measurement, it can be observed from Figure 6 that the force measurement is 200.1 gr and the speed measurement is 1012 rpm, very close to the desired speed of 1000 rpm. With this data it is possible to calculate the viscosity measurement indirectly.

On the other hand, and from Figure 7, the result of the remote measurement via Bluetooth shows 200.27 gr of for-

ce and 1015 rpm of speed, values very close to 200 gr and 1000 rpm. In the local and remote measurement tests, the performance of the stepper motor was demonstrated by turning clockwise to start the measurement and counter-clockwise to finish the measurement.

5.2. Quantitative results

Two quantitative experiments were performed, one to evaluate the force measurement and the other to evaluate the speed control. Table 3 shows the results of the experiment that consisted of placing 200 gr standard weights on the gauge and observing the reading reported by the electronic circuit. The experiment was performed five consecutive times starting at zero and ending at zero through values of 200 and 400 gr. Table 3 shows a maximum deviation of 0.3 gr and excellent repeatability of zero. Table 4 shows the results of the experiment that consisted of specifying various target or SetPoint speeds and measuring the actual speed reached by the speed control algorithm, three consecutive times.

Cuadro 3: Force measurement

1	2	3	4	5
0.0	0.0	0.0	0.0	0.0
199.9	200.1	200.0	199.9	199.9
400.2	400.3	400.1	400.1	400.2
0.0	0.0	0.0	0.0	0.0

Cuadro 4: Speed control

Setpoint (rpm)	Velocidad real rpm	Velocidad real rpm	Velocidad real rpm
	1	2	3
250	252	246	242
500	501	497	508
750	745	758	748
1000	1008	991	1003
1250	1231	1260	1252
1500	1459	1515	1502
1750	1757	1749	1748
2000	1992	1996	1980

Table 4 shows adequate performance for speed control with some opportunities to improve it.

6. Conclusions

The development and construction of an electronic circuit for the concentric cylinder viscometer was presented. Some relevant characteristics include quality in force measurement,

modern operating interface with TFT graphic touch display, quieter or less noisy operation and Bluetooth connection.

In the electronic circuit, free hardware and software tools were used for its development and construction. The performance of the circuit was evaluated qualitatively and quantitatively, which ensures its proper functioning once this is integrated into an electromechanical measurement system. One of the objectives is to incorporate this measuring instrument into the teaching of rheology, where students can manipulate this low-cost and easy-to-maintain equipment without the risk of causing costly damage to other laboratory equipment.

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