Electronic circuit for the concentric cylinder viscometer

Circuito electrónico para el viscosímetro de cilindros concéntricos

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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

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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.

Keywords: Bluetooth, Digital control, Fluid mechanics, Microcontroller, Rotational viscometer, TFT display.

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 esta 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.

Palabras clave: Bluetooth, Control digital, Despliegue TFT, Mecánica de fluidos, Microcontrolador, Viscosímetro rotacional.

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.

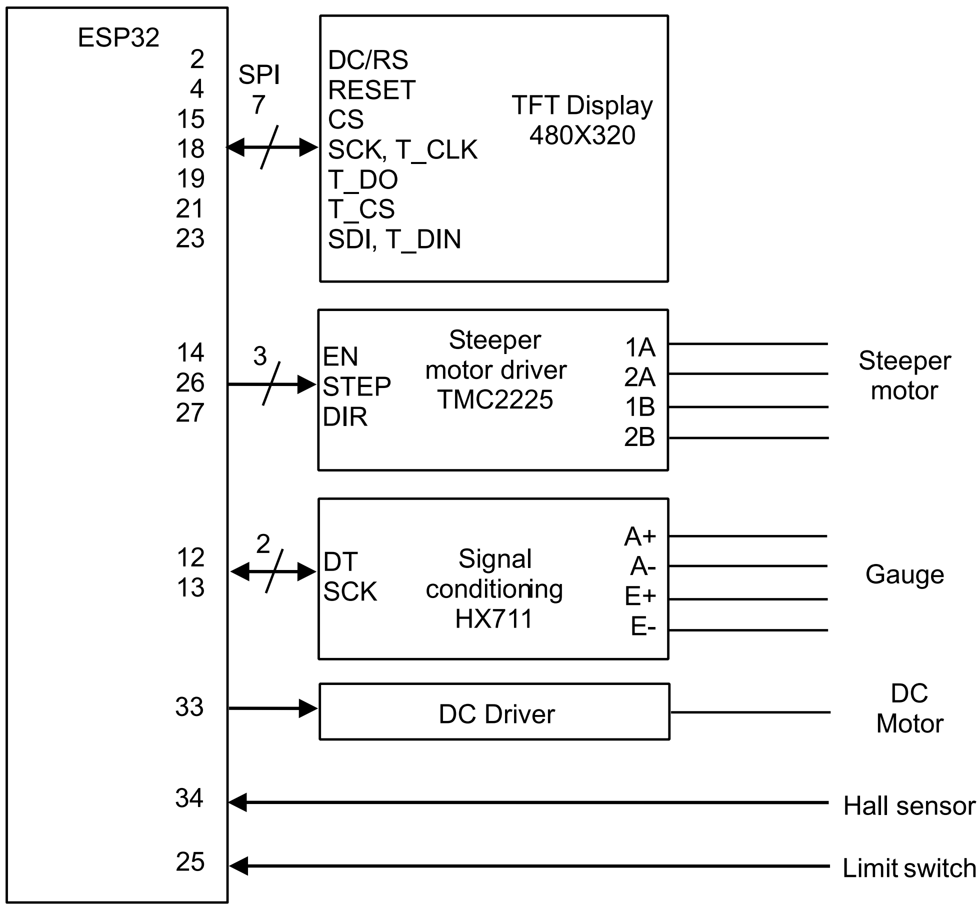

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Figure 1 shows the connection of an ESP32 microcontroller to the selected electronic devices to measure viscosity according to the concentric cylinder principle [2]. Describing each of the functional blocks in Figure 1:

- The TFT display is connected via its SPI (Serial Peripheral Interface) to the 7 GPIO (General Purpose Input Output) lines of the ESP32 microcontroller. The display requires two SPI channels, one for the graphic functions and one for the touch functions. The two shared SPI standard lines between the two channels are T_DIN with SDI and T_CLK with SCK, data and clock respectively. The independent lines to each channel correspond to the CS and T_CS selectors, the RESET pin, the touch channel data line T_DO and the display data line DC/RS. With this connection scheme, information is sent to be displayed on the graphic channel and pulses are received from the touch channel [3]. With these two elements it is possible to build a modern and friendly user interface for the viscometer.

- The silent stepper motor driver TMC2225 requires three data signals as inputs: An enable signal EN, a signal indicating the step advance per pulse STEP and a signal indicating the clockwise or counter-clockwise advance direction DIR [4]. These signals are generated by the ESP32 microcontroller according to the measurement and control algorithm. The stepper motor driver in this scheme allows the internal cylinder to enter the external cylinder of the viscometer. The limit on the linear travel of the inner cylinder is determined by the limit switch.

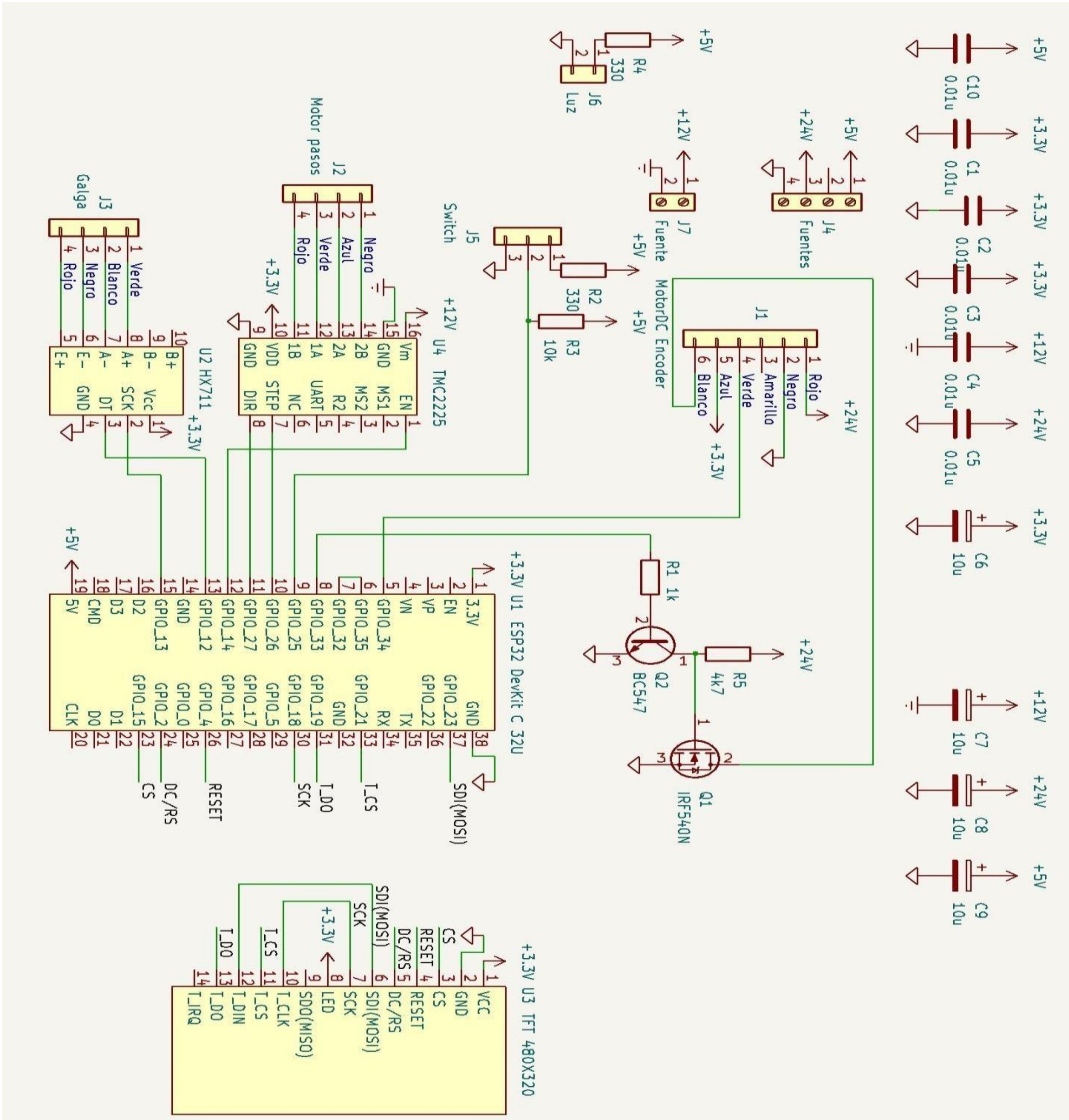
- The HX711 gauge signal conditioner communicates in a very similar way to the I2C serial standard, i.e. a DT line for datas and a SCK line for clock. With this bi-directional communication scheme it is possible to transfer force measurements on the gauge to the measurement algorithm in the ESP32 microcontroller [5]. Subsequently, and by developing a calibration exercise, the force on the gauge can be correlated with the viscosity of the fluid between the concentric cylinders.
- The DC drive in conjunction with the DC motor and the Hall encoder form a closed loop speed control scheme [6]. This scheme causes the inner cylinder of the viscometer to rotate at a constant and predetermined angular velocity. The rotation of the inner cylinder is important as it is the measuring principle in the concentric cylinder type of viscometer [7].

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.



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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 [8]. 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.

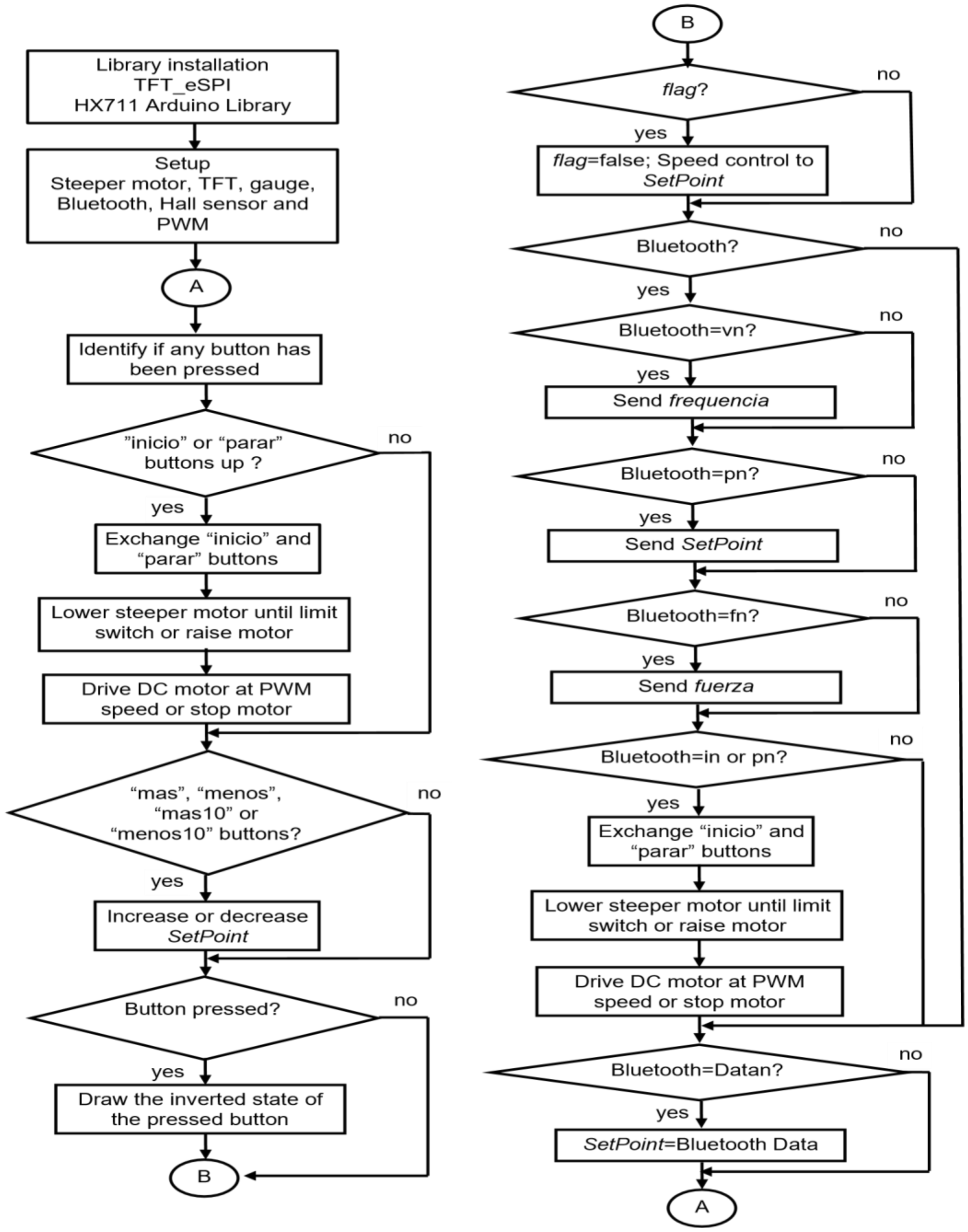
The algorithm in Figure 3 was programmed in C language within the Arduino IDE (Integrated Development Environment).

4. Construction on routing machine

The process of construction on a router starts with the schematic and PCB (Printed Circuit Board) designs in the free software called KiCad [9]. Figure 4 shows the PCB drawing for the electronic circuit for the viscometer. From the printed circuit, the Gerber and Excellon files are generated to build the PCB.

The Gerber and Excellon files are transformed into G-code using the free software called FlatCam [10]. The parameters in FlatCam for the Gerber file are those in Table 1 and Table 2 shows the parameters for the Excellon file.

Figure 3. Flow chart of the measurement and control algorithm.


Library installation
TFT_eSPI
HX711 Arduino Library
Setup
Steeper motor, TFT, gauge, Bluetooth, Hall sensor and PWM
A
Identify if any button has been pressed
"inicio" or "parar" buttons up ?
no
yes
Exchange "inicio" and "parar" buttons
Lower steeper motor until limit switch or raise motor
Drive DC motor at PWM speed or stop motor
"mas", "menos", "mas10" or "menos10" buttons?
no
yes
Increase or decrease SetPoint
Button pressed?
no
yes
Draw the inverted state of the pressed button
B
B
flag?
no
yes
flag=false; Speed control to SetPoint
Bluetooth?
no
yes
Bluetooth=vn?
no
yes
Send frequencia
Bluetooth=pn?
no
yes
Send SetPoint
Bluetooth=fn?
no
yes
Send fuerza
Bluetooth=in or pn?
no
yes
Exchange "inicio" and "parar" buttons
Lower steeper motor until limit switch or raise motor
Drive DC motor at PWM speed or stop motor
Bluetooth=Datan?
no
yes
SetPoint=Bluetooth Data
A

Source: own

Figure 4. PCB of the electronic circuit for the viscometer.

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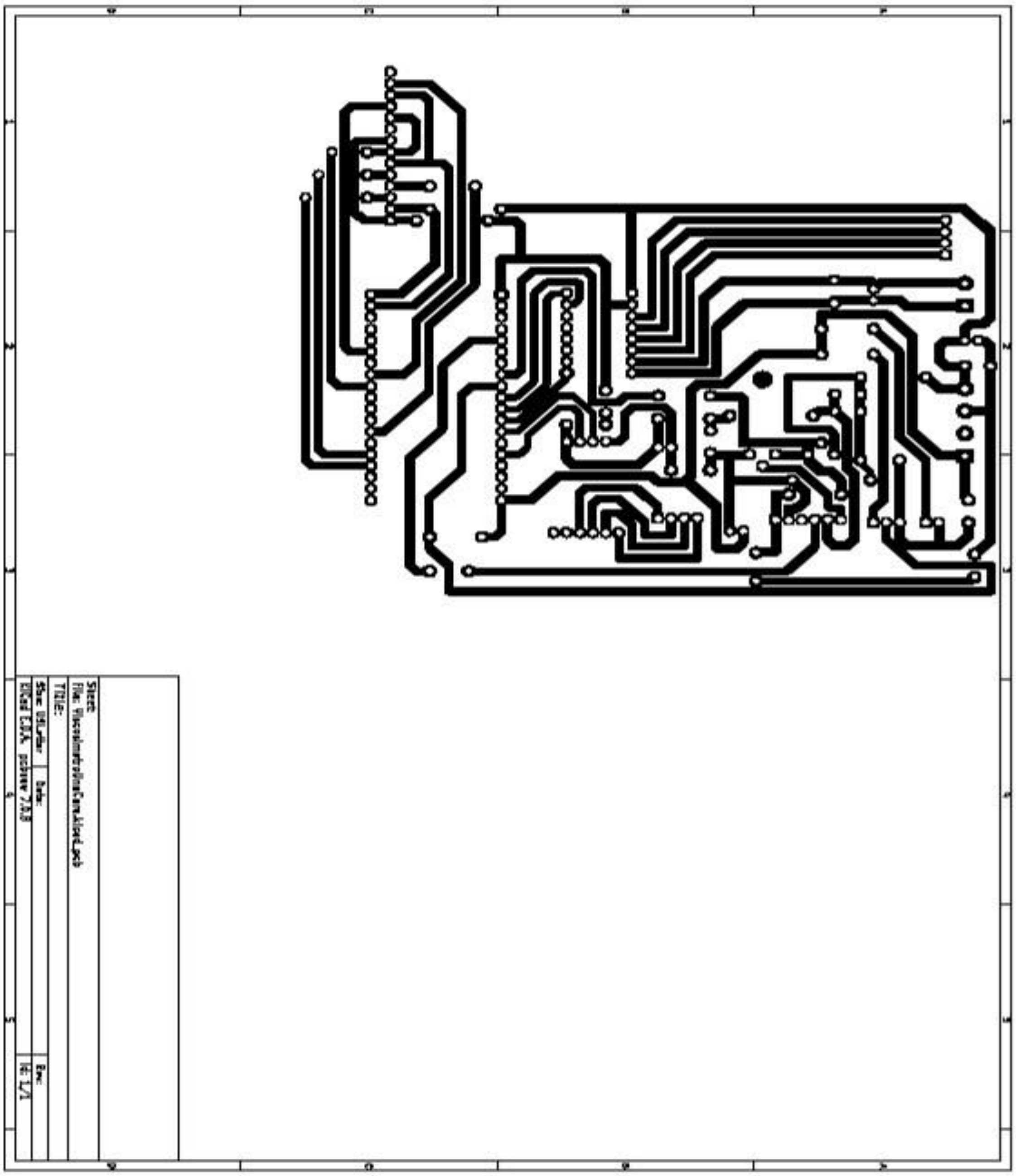

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Table 1. Gerber FlatCam parameters.

	Parameter	**Value**
	Offset:	(-0.3, 0.65)
To generate the ISO geometry	Tool día:	0.0053
	Width (# pases):	1
	Pass overlap:	0
To generate the ISO CNC object	Cut Z:	-0.0028
	Travel Z:	0.1
	Feed Rate:	3
	Tool día:	0.0053
To export the G code	Tool día:	0.0053

Source: own.

Table 2. Excellon FlatCam parameters.

	Parameter	**Value**
	Offset:	(-0.3, 0.65)
To generate the ISO CNC object	Tools:	1-6
	Cut Z:	-0.0026
	Travel Z:	0.1
To export the G code	Tool día:	0.0053

Source: own.

Finally, the G-code is loaded into the software called Candle [11] for routing machining.

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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.

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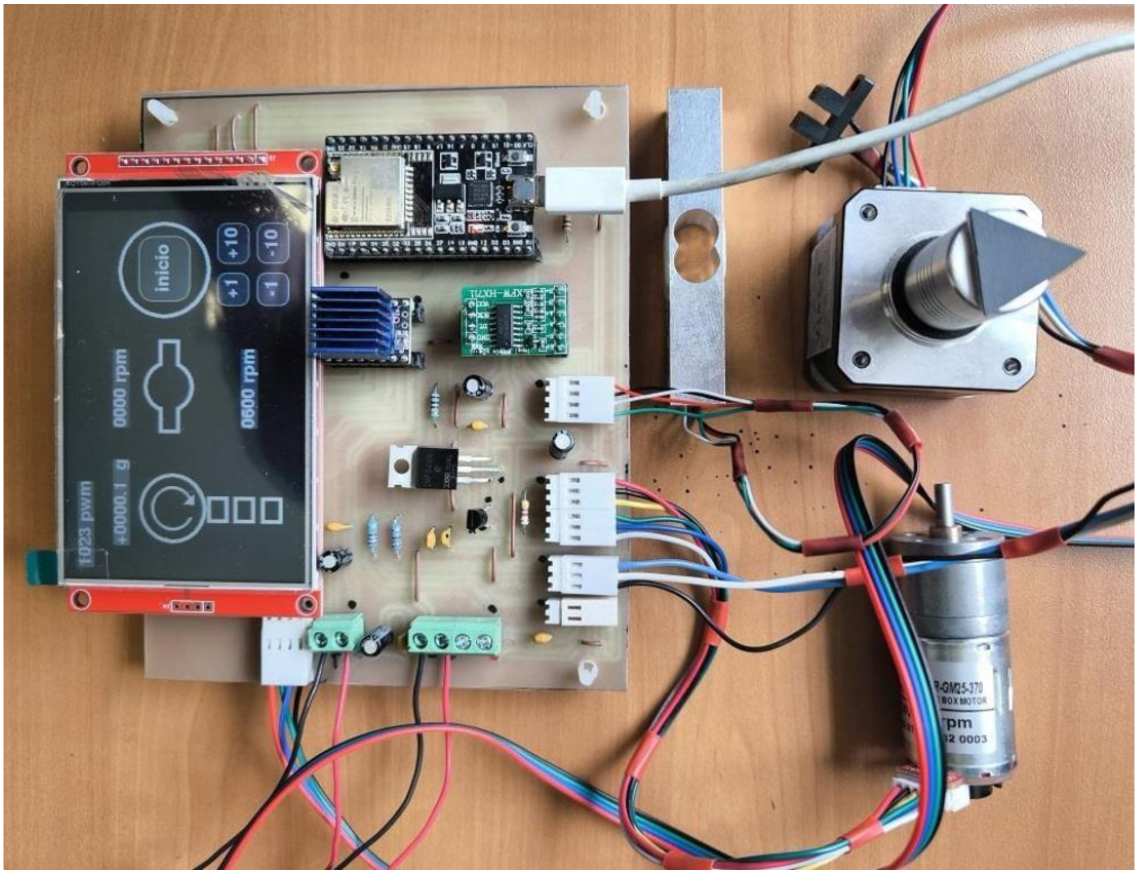

The first two modules are evaluated qualitatively while the last two are evaluated quantitatively as described below.

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

Source: own.

manipulating the TFT display and Figure 7 shows the same process performed remotely through an Android application with Bluetooth connection [12]. **Figure 6.** Local measurement.

Source: own.

Figure 7. Remote measurement.

Source: own.


1:04
Terminal
vn 0.00
fn 0.00
pn600
1000n1000
invn1015.00
fn200.27
sn
M1
M2
M3
M4
M5
M6
M7
sn
sn
sin
son
?123

Source: own.

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 force 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.

Source: own.

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.

Source: own.

Table 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

Source: own.

Table 4. Speed control

SetPoint 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

Source: own.

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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