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Design, construction, and evaluation of transformer-based orbital shaker for coffee micropropagation

Edwin Romeroso Arboleda

Department of Computer and Electronics Engineering, Cavite State University
Indang, Cavite, Philippines

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Abstract

This study offers a novel solution to deal with the complicated electronic circuitry for speed controller and too complex mechanical design of rotating mechanism of an orbital shaker. The developed prototype used a transformer that varies the supply voltage to control the speed of rotation of the orbital shaker. The prototype has five speed levels which depend on the input voltage. These speeds are 180 rpm at 12 V, 258 rpm at 15 V, 360 rpm at 18 V, 427 rpm at 21 V, and 470 rpm at 24 V. The prototype was tested to run continuously for 48 hours for each speed level, with speed being measured every hour using a tachometer. Statistical computation shows that the speed remains constant for the entire 48 hour period. Evaluation of results shows that the speed controller and the novel mechanical design for the orbital shaking motion achieved their functions. For this reason, it can be concluded that the prototype is durable and safe for use in orbital shaking applications.

Keywords: DC motor; orbital shaker; rotating mechanism; speed controller; step-down transformer.

I. Introduction

In many scientific applications, the job of stirring or mixing containers such as beakers and flasks containing various liquids is performed by the orbital shaker [1]. One specific application of the orbital shaker is to stir cultures growing in beakers in constant orbital motion which will provide for the controlled growth of the cultures in the interior environment of the beakers [2]. The gentle, circular, uniform agitation in a controlled velocity is important to maintain a similar growth rate among batches of culture in different containers [3][4]. Orbital shakers have been used in different areas where agitation is necessary, ranging from medicines to agriculture [5].

Shaking bioreactors have been used to cultivate microorganisms since the turn of the century. Different types of reactor systems are classified as shakers with orbital motion or linear reciprocal movement. Linear reciprocal shaking motion was employed often in the past, but has waned in the last decade [6]. The mechanism of orbital shakers consists of a motor coupled to a platform. The orbit is attached to the motor and as the motor rotates in a circular motion, the orbit shakes the contents of the vessel. An orbital shaker's whole platform travels in a circular orbit. A number of orbital shaker designs that use the orbit-coupled-to-motor principle are available in open-source repositories such as the NIH 3D Print Exchange [6], Thingiverse [7], and Prusa Printers [8]. The commercially available orbital shakers [9] also use the orbit-coupled-tomotor principle.

The orbital shaker can be considered as the most important electronic equipment in tissue culture and the costliest. In coffee tissue culture, the orbital shaker is used to separate shoots from the mother callus by shaking for 24-48 hours. Browsing the product catalogs of suppliers of orbital shakers on the internet shows that its prices (for 48 flasks capacity) range from hundreds of thousands of pesos, not to mention that all these suppliers are outside the Philippines.

With the advent of social media and online training courses, many people are venturing into

* Corresponding Author. Tel: +63-9171246950
E-mail address: edwin.r.arboleda@cvsu.edu.ph

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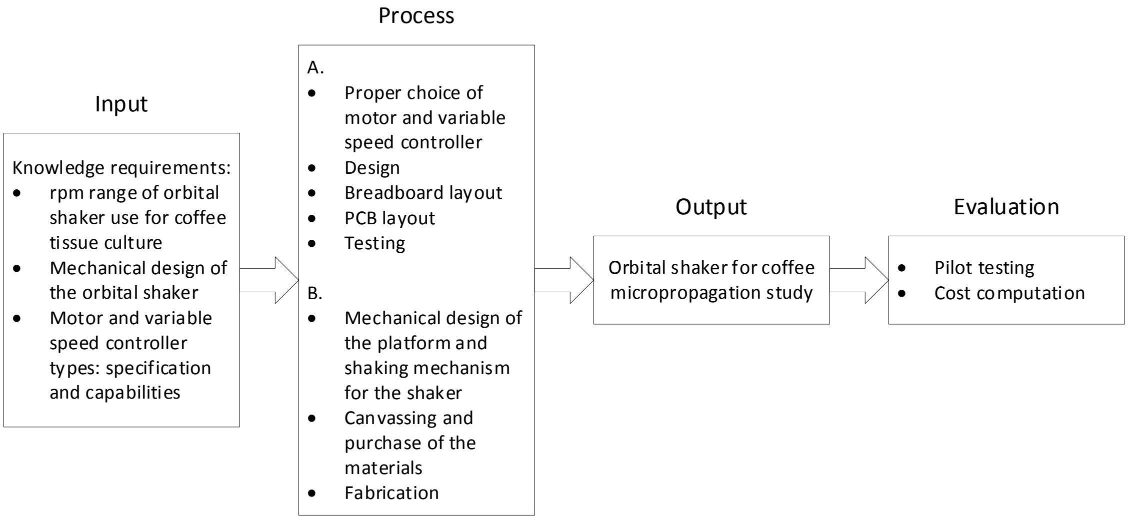

Figure 1. Conceptual model

home tissue culture. Gone are the days when people thought that tissue culture was exclusively done in clean, sophisticated dust-free laboratories. There were many social media groups whose members reportedly were successful in-home tissue cultures. One example is the tissue culture of Philodendron species [10][11][12]. This plant species is one of the most expensive plants in the exotic plant hobby but is now being propagated using tissue culture resulting in a major reduction in its price.

Coffee is a major agricultural product and second in ranking as the most important export next to crude oil in the world market. Many farmers all over the world depend on coffee farming as their main source of livelihood. Coffee is a food product that is most commercialized and vastly consumed in the whole world [13][14]. Cavite Province is one of the top producers of coffee in the Philippines, that is the reason why the national coffee research and extension center (NCRDEC) is located in the Cavite State University. NCRDEC is one the pioneers in coffee tissue culture in the Philippines. NCRDEC has been successful in tissue culture of coffee and sharing this knowledge with coffee farmers is one of the objectives of the center. Tissue culture is the process of growing tissues or cells apart from the parent organism. Another name for this method is micropropagation. A liquid, semi-solid, or solid growth medium, such as broth or agar, is generally used [15]. Plant tissue culture is the process of cultivating plant seeds, organs, explants, tissues, cells, or protoplasts on a synthetic nutritional medium with chemically specified nutrients under sterile and regulated lighting, temperature, and humidity conditions [16][17].

The researcher envisioned through this study and with the cooperation of NCRDEC to design a low-cost orbital shaker and freely share this design with cooperatives and, most importantly, small-time coffee farmers who want to venture into the coffee micropropagation or tissue culture. The researcher made the design as simple as possible, both in its mechanical and electronic aspects, so that it can be a "build-it-yourself study" for those interested in developing their own.

II. Materials and Methods

The conceptual model shown in Figure 1 served as the guide of the researcher in the conduct of the study. The input serves as the basis for how the whole system was laid out.

The process part of the conceptual model deals with how the ideas and concepts in the input were transformed into actual functioning parts of the system. After combining all the processes, a functioning model of the device was created. To determine the device's accuracy, practicality, and acceptability, it was subjected to a series of evaluations. The system block is shown in Figure 2. It is composed of power supply, motor controller, input selector, motor and orbital shaker platform.

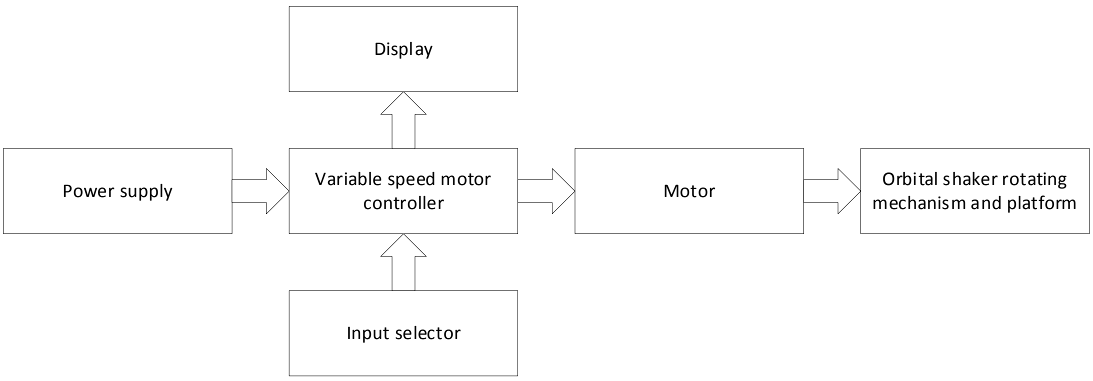

Figure 2. Block diagram

A. Design of the platform

The orbital shaker's platform was patterned on the orbital shaker currently being used at NCRDEC located in Cavite State University, Indang, Cavite, Philippines. The dimension of the platform is 85.09 cm x 65.41 cm, as shown in Figure 3. It was folded 2.54 cm on every side. The gap between the folds in every corner was welded.

Five holes with a 2 cm diameter were drilled on the platform. The placement of the holes is shown in Figure 4. One hole is located in the middle of the platform, in which the hole's center was placed 32.7 cm and 42.55 cm from the upper left corner of the platform, as shown in Figure 4. Four holes were drilled equidistantly from the four corners at 10.67 cm and 10.92 cm, as shown in Figure 4.

Figure 5 is the pictorial diagram of Figure 4, in which one screw was drilled in the center of the platform and four screws were drilled at the same distance from the four corners. The hole in the center holds the screw that connects the top platform to the rotating orbital shaking mechanism at the bottom. The four holes are for screws that stabilize the platform on a flat level while it rotates in an orbital shaking motion.

The five screws used in the platform were sourced from a screw hardware store. It is a specialized screw commonly used for securing a clear glass tabletop to a table frame. The screw has two parts, the top part that contains the head and the bottom part. The two parts are detachable from one another. It was designed so that a glass of different thicknesses could be placed in the middle of the two parts. The screw also has a hole in the bottom part, which is very important because it is where the rotating orbital mechanism was to be inserted. As shown in Figure 6, the screw has a 2 cm diameter and an overall length of 4.54 cm. The top part has a length of 1 cm, and the bottom part has a 2.54 cm length. This means that variable thicknesses of material can be placed between them. Attached to the four screws are a stainless circular disc and a plastic spacer with a 2 cm diameter and 1 cm length. The circular disk is 8 cm in diameter. Figure 6 shows the head of the screw, the space in which the platform will be placed, the plastic spacer, the circular disc, and the bottom part of the screw. Figure 7 shows the actual pictorial diagram of the screws. It can be seen in Figure 7 that the platform was placed between the head of the screw on the top and the blue plastic spacer, then followed by the circular disc and the bottom part of the screw securing them together.

As shown in Figure 8, the screws are for fitting inside the spring. The purpose of the circular discs is to prevent the underside of the platform from touching the springs and to provide the space to keep the platform in a level position. The springs serve several purposes; aside from keeping the four corners of the platform level, the springs also prevent the screws from overshooting. Four screws

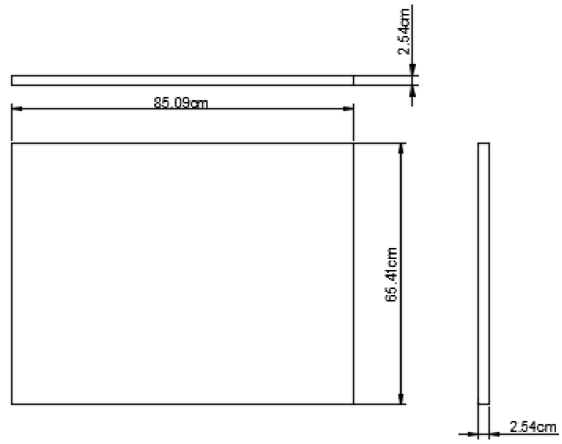

Figure 3. Dimensions of the platform

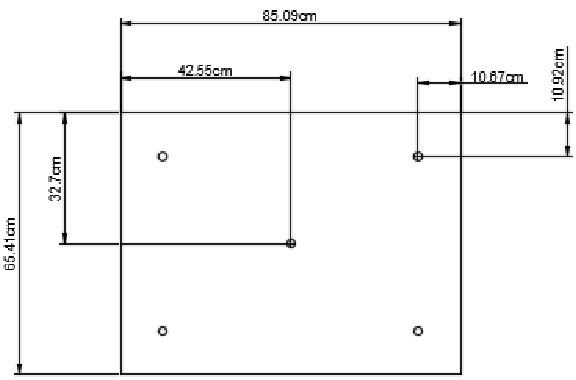

Figure 4. Top view of the platform

Figure 5. Bottom view of the platform

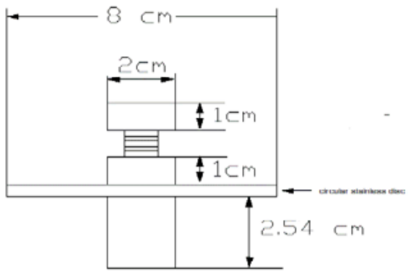

Figure 6. The screw

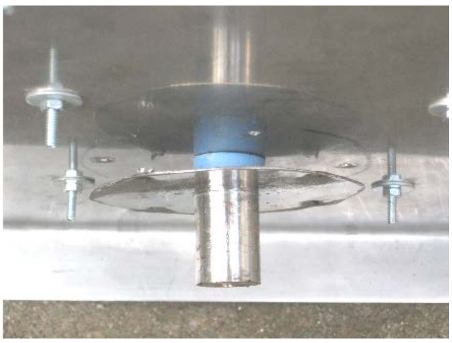

Figure 7. Pictorial diagram of the screws

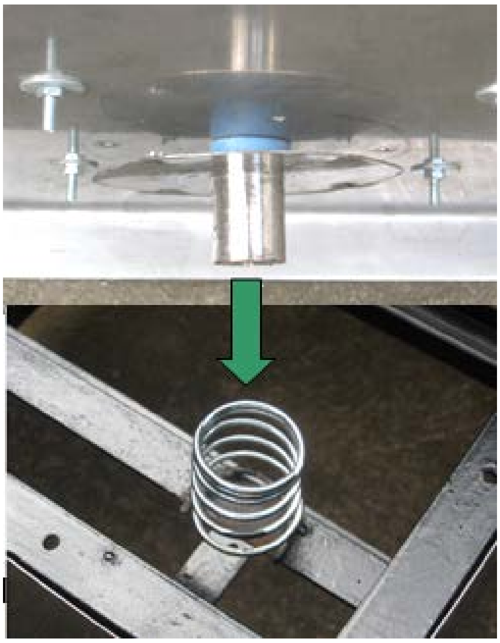

Figure 8. The screws are to be inserted at the spring

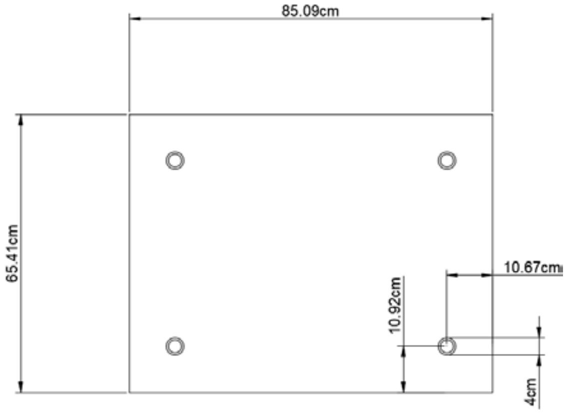

Figure 9. Placement of the springs

and four springs were placed, as shown in Figure 9. The springs have a diameter of 4 cm and their center were placed at 10.67 cm and 10.92 cm from every corner, as shown in Figure 9.

Figure 10 is the pictorial diagram showing the actual placement of the springs. The four springs were welded in a metal bar with the same distance from every corner. The spring has a 5 cm height, as shown in Figure 11. The 5 cm height is just enough to maintain the height of the platform when it is fully loaded with samples.

Figure 10. Pictorial diagram of placement

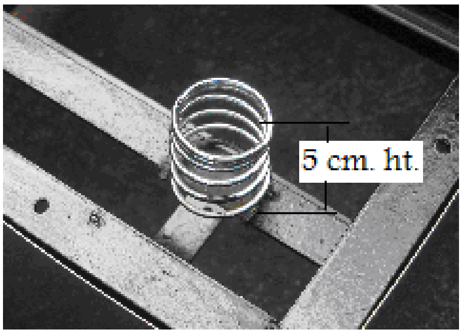

Figure 11. Spring height

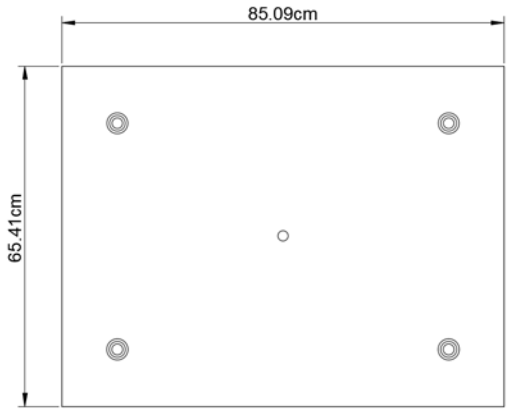

Figure 12. The platform on the top of the frame

As shown in Figure 12, the screws are to be inserted into the spring. The diameter of the spring is dependent on the diameter of the screw and the size of the orbit of the rotating mechanism.

B. Design of the frame

The frame dimensions are shown in Figure 13. It has an 85.09 cm length, 59.69 cm width, and 59.69 cm height. It was made from a 2.54 cm metallic

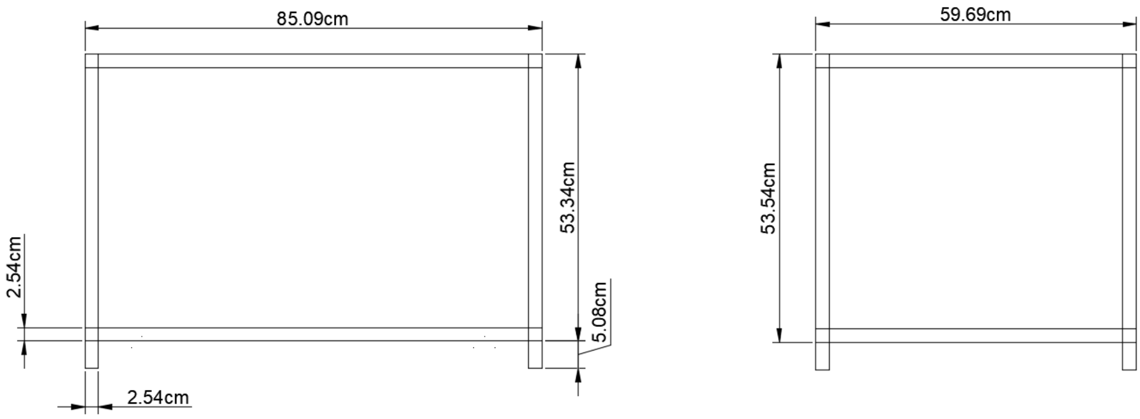

Figure 13. Dimensions of the frame

Figure 14. Side view of the shaker

angle bar and welded together. The front view and side view of the frame is shown in Figure 14 and Figure 15, respectively. It can be seen in Figure 14 and Figure 15 that high-grade stainless steel was used as the material for the prototype. This is not only for aesthetic purposes but also for easy cleaning. The stainless-steel plates were screwed to the metallic frame.

C. Design of the rotating mechanism

The rotating mechanism is shown in Figure 16. It is composed primarily of a bull bar fabricated at the machine shop for it to fit at the holes of the pulley and the two bearings. On the topmost part of the rotating mechanism, a nail was welded 0.45 cm from the center. The nail ensures that the rotating mechanism is securely fastened to the top platform by inserting it at the bottom hole of the middle screw. The actual rotating mechanism is shown in Figure 17.

The Rotating mechanism is composed of the DC motor with a pulley, a tubular bar inserted into a pulley, a bearing on the lower end of the tubular bar, and a belt. When the DC motor rotates, the pulley attached to it pulls the belt attached to the tubular bar. The tubular bar is tightly secured by the bearing on the lower end, which also rotates as the pulley rotates. On top of the tubular bar is a 2 cm long nail welded 0.3 cm from the center.

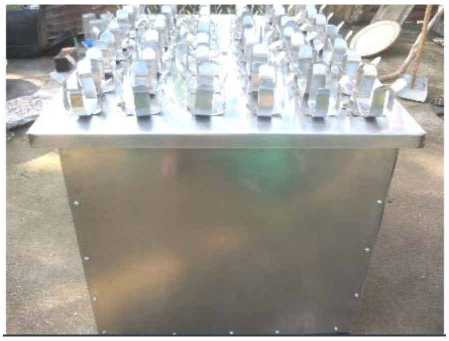

Figure 15. Front view of the shaker

There are two pulleys used in the orbital shaker, as shown in Figure 18. The drive pulley (right) was fastened to the DC motor and the driven pulley was fastened to the rotating mechanism. The actual picture of the rotating mechanism is shown in Figure 19. The drive and driven pulley arrangement allow for regulated speed control as compared to connecting the orbit composed of the nail directly on top of the DC motor. Also, this arrangement was designed for a small orbit like the 0.3 cm diameter orbit used in this prototype.

D. Design of the holder

The holder secures the Erlenmeyer flask to the platform. It is made from 2.54 cm wide and 22 cm long stainless-steel sheet cut and folded, as shown in Figure 20. The holder is composed of 2 stainless steel sheets placed on top of one another and secured by a screw in the platform.

The orbital shaker is composed of 48 pairs-of-holder. The pictorial diagram of the holder is shown in Figure 21. The holder tightly secures the Erlenmeyer flasks in an upright position as the platform rotates in orbital motion. The orbital movement of the platform makes the liquid inside the Erlenmeyer flasks stirred in a constant speed circular movement.

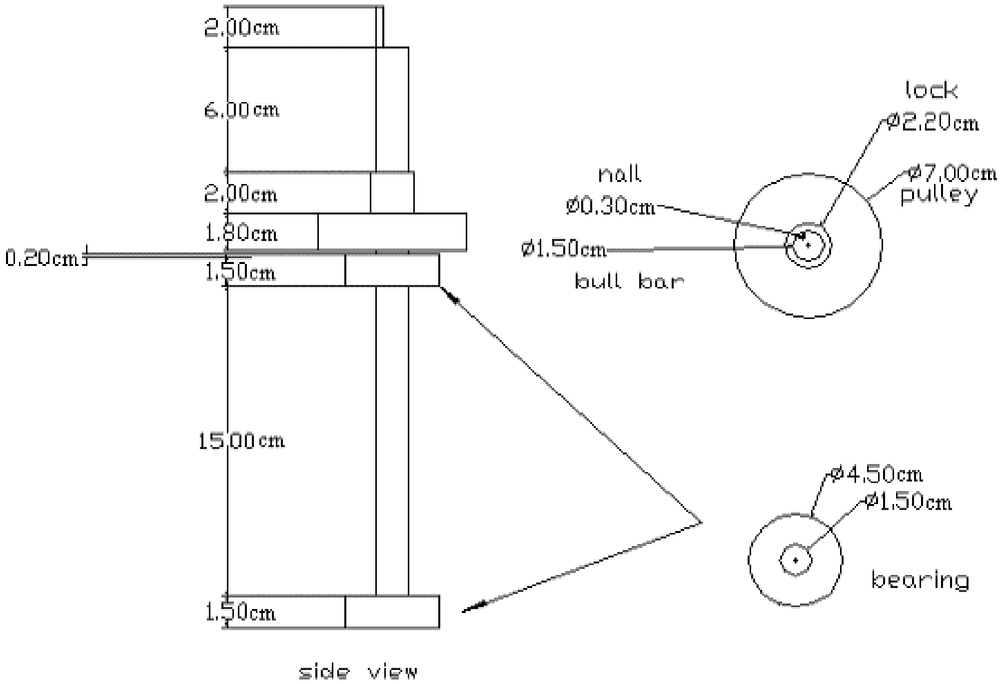

Figure 16. Rotating mechanism

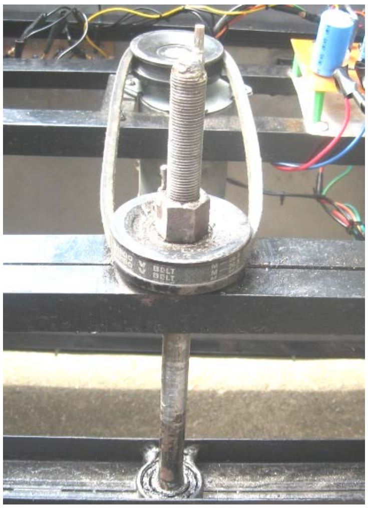

Figure 17. Pictorial diagram of the rotating mechanism

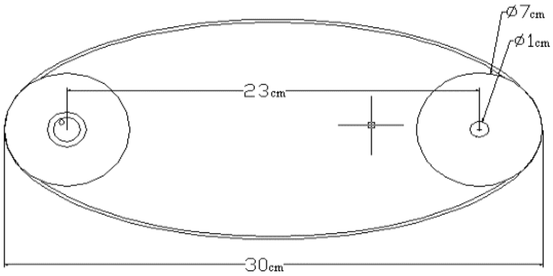

Figure 18. The drive and driven pulley arrangement

Figure 19. Pictorial diagram of the pulley arrangement

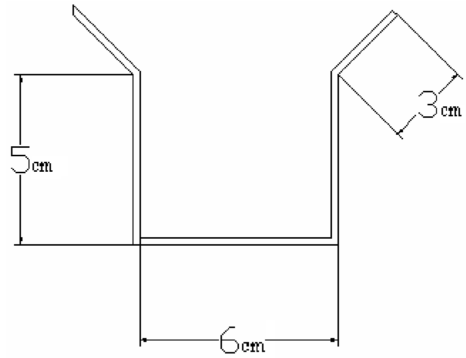

Figure 20. Dimensions of the holder

E. Design of the speed control

Figure 22 shows the schematic diagram of a speed controller for the orbital shaker. A customized 3 A variable transformer was used with secondary windings 24 V, 21 V, 18 V, 15 V, and 12 V. The transformer was connected to four diodes (1N5400) that formed the bridge and the ripple was filtered by two 4700 µF capacitors and a 1 kΩ resistor. The capacitor passes AC and rejects DC, thus filtering DC voltage. The use of a resistor is for to stabilize the time constant of the circuit and reduce the charging and discharging time of the circuit output.

It was connected to the DC motor and varying voltage is as easy as turning a knob. This speed control design is simple, and voltage setting adjustment is instant with just a turn of the knob. There are no problems encountered from high to low voltage adjustments and vice versa.

F. DC motor

This orbital shaker used a DC motor. DC motors are more costly than AC motors, but their speed drives are cheaper and use simpler

Figure 21. Pictorial diagram of the holder

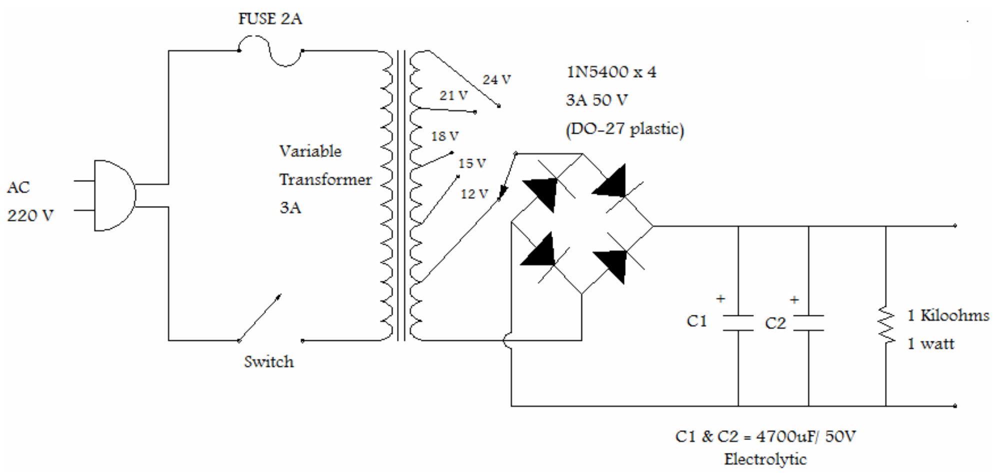

Figure 22. Schematic diagram of speed controller

circuits [18][19][20]. The speed of a DC motor is easier to control with simpler electronic circuits [21][22][23] as compared to AC motors that have complicated speed controllers [24][25]. Based on the data gathered, the speed 350 to 400 rpm can be achieved using the Matsushita 24 volts, 3 amperes DC motor.

III. Results and Discussions

Table 1 shows the measured speed level in rpm when the platform is not attached to the rotating mechanism. Because the rotating platform speed required for coffee tissue culture is within the range of 300 to 400 rpm, the developed prototype satisfied the speed requirement of the orbital shaker suitable for coffee micropropagation.

A. Cost computation

The direct costs amounted to 10,110.15 pesos. The total cost of the study is the sum of the direct and indirect costs of the study, which is equal to 25,110 pesos. The cost of NCRDEC shaker is 86,000 pesos. There is a 60,890 pesos difference between NCRDEC shaker and the low-cost orbital shaker developed by the proponent.

B. Evaluation of the orbital shaker

The evaluation has three phases: the pilot test, the performance test, and the final test. The pilot test involves the presentation of the device to the tissue culturists and the director of NCRDEC. During this test, the researcher explained the design of the device and demonstrated the functions of the control. The orbital shaker was loaded with Erlenmeyer flasks containing coffee tissue culture and the different speed levels were tested to see if the shaking of the media inside the flasks was orbital.

Since the coffee micropropagation process involves shaking the culture media for a maximum of 48 hours, the orbital shaker was operated for 48 hours continuously at its maximum speed level. After the 48-hour test period, the device was presented again to NCRDEC tissue culturists and they were all convinced of the durability of the shaker. Seeing that the device is durable, as confirmed by the pilot test, NCRDEC adviser suggested that the device's reliability needs to be tested as well. The performance test is designed to determine the relationship between shaft speed in relation to the 48 hours operation time. The performance test involves operating the orbital shaker for 48 hours and measuring the speed every hour for speed levels 1 to 5.

The final test involves loading the low-cost orbital shaker with 48 pieces of Erlenmeyer flasks containing coffee tissue culture media. Using speed level 3 (the equivalent speed used by NCRDEC shaker), the device was operated for 48 hours. After the final test and being convinced of the reliability and durability of the low-cost orbital shaker, a certificate of user acceptance was signed by the director and all the tissue culturists of the center. The low-cost orbital shaker was endorsed by the director of NCRDEC to be used in its coffee micropropagation study.

C. Performance of speed level 1 to 5

In order to determine if the orbital shaking mechanism of the prototype maintains a constant speed, it was operated for 48 hours for every speed level. The 48 hour is the time used in coffee micropropagation to separate the new coffee plants from the mother callous. The speed level 1 to 5 of the developed prototype was evaluated by measuring and recording the shaft speed per hour using a digital tachometer. With the top platform removed, the author placed the digital tachometer on the surface of the driven pulley to record its rotations per minute speed. The speed was measured per hour for 48 hours for speed levels 1 to 5. Figure 23 shows the shaft speed of the orbital shaker for 48 hours for the five speed levels. For speed level 1, the range of shaft speed is 177 to 182 rpm. For speed level 2, the range of shaft speed is 254 to 261 rpm. For speed level 3, the range of shaft speed is 358 to 362 rpm. For speed level 4, the range of shaft speed is 425 to 430 rpm. For speed level 5, the range of shaft speed is 467 to 472 rpm. The regression lines for levels 1, 2, 3, and 5 slightly lean upward, while for speed level 2, the regression lines lean slightly downward.

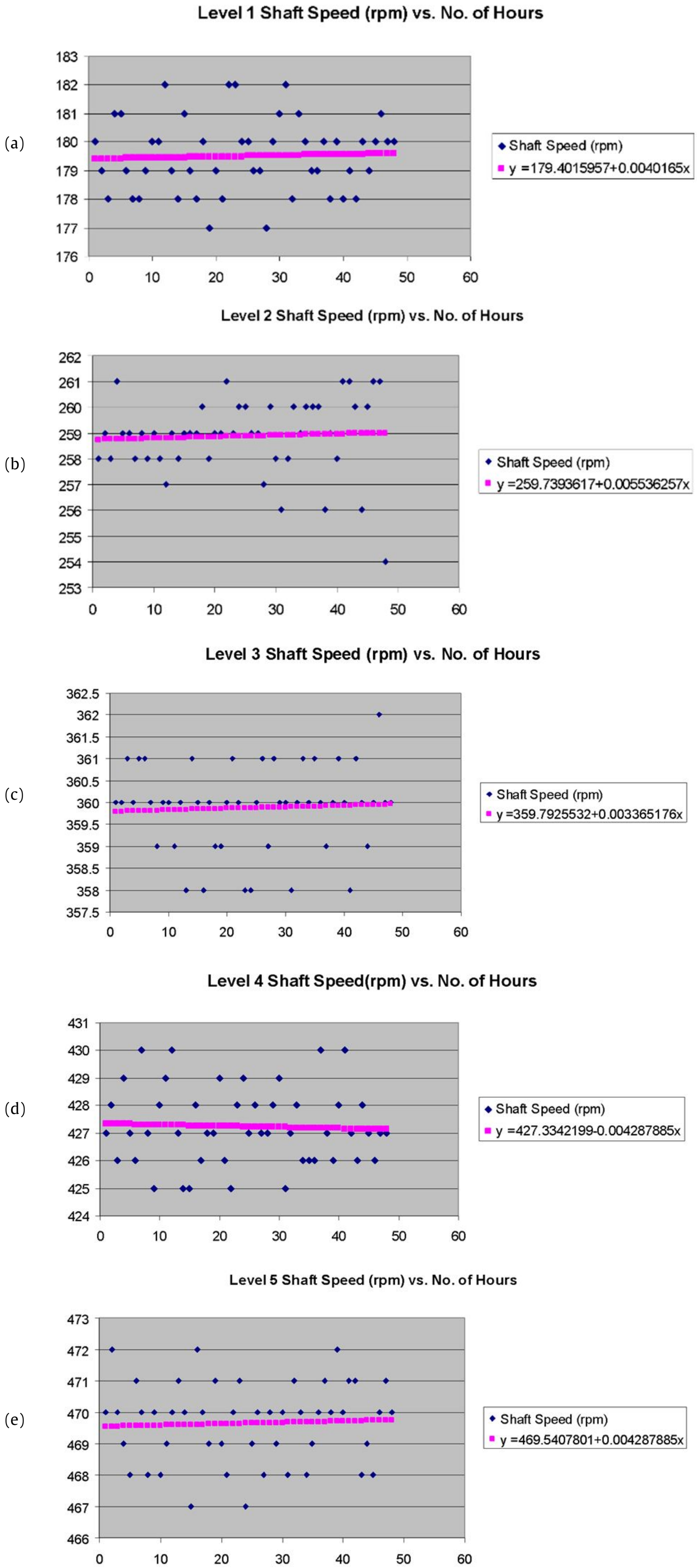

Figure 23. Scatter diagram with regression lines for speed: (a) Level 1; (b) Level 2; (c) Level 3; (d) Level 4; (e) Level 5

Table 1.
Speed range of the orbital shaker

Speed Level	Input voltage to the DC motor (V)	Speed (rpm)
1	12	180
2	15	258
3	18	360
4	21	427
5	24	470

Table 2.
Analysis of variance for speed levels 1 to 5

Speed level	Sources of variation	Sum of squares	Degrees of freedom	Mean square	Computed *f*	*p*-value
1	Regression	0.148610508	1	0.148610508	0.085610074	0.2131
	Error	79.85138949	46	1.7358997772		
	Total	80	47			
2	Regression	0.28234911	1	0.28234911	0.126137277	0.2131
	Error	102.9676509	46	2.238427193		
	Total	103.25	47			
3	Regression	0.104320452	1	0.104320452	0.106294574	0.2131
	Error	45.14567955	46	0.981427816		
	Total	45.25	47			
4	Regression	0.169371472	1	0.169371472	0.084401527	0.2131
	Error	92.30979519	46	2.006734678		
	Total	92.47916667	47			
5	Regression	0.169371472	1	0.169371472	0.101433518	0.2131
	Error	76.80979519	46	1.669778156		
	Total	76.97916667	47			

The data gathered were statistically analyzed using analysis of variance, as shown in Table 2. For all speed levels, the computed f is less than the p-value at $f < f_{\alpha}\ (1, n-2)$, where $\alpha = 0.05$ the null hypothesis that there is no significant change in the shaft speed of the orbital shaker in relation to the 48 hours of operation of the shaker is accepted. This means that at speed levels 1 to 5, the orbital shaker maintained a constant speed for the whole 48-hour period.

D. Overall performance of the orbital shaker

It can be noted that the test for all speed levels yields the same results. The statistical tests showed that for all speed levels, the orbital shaker maintained constant speed at a 95 % level of accuracy.

IV. Conclusion

The prototype Orbital Shaker was designed and developed for the coffee micropropagation study of NCRDEC, Bancod, Indang, Cavite. The study has the objective of sharing the developed technology of a low-cost orbital shaker with farmers and cooperatives who want to venture into the tissue culture production of coffee seedlings. After the evaluation, the low-cost orbital shaker was found to be satisfactory, applicable, and recommended for use in the coffee micropropagation study. NCRDEC's previous experience led them to believe that orbital shakers are naturally expensive. However, through this study, it was proven that the sophisticated orbital shaking motion could be provided and controlled with an inexpensive DC motor. The researcher found out that the speed of orbital shaking motion was not solely dependent on the capability of the motor. There is a relationship that exists between the size of the orbit and the speed of the orbital shaking motion. With the same motor speed, a little increase in the orbit causes an increase in speed in the orbital shaking motion. The researcher recommends that further study should be done to determine that relation in the future.

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Declarations

Author contribution

E.R. Arboleda contributed as the main contributor of this paper. The author read and approved the final paper.

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Competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Additional information

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