Physics Through Laboratory: Voltage Calibration Using Optical Method

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Abstract

In this short article, we propose a simple, low cost and a novel optical method of calibrating DC motors and voltage sources by producing Lissajous-like spirograph patterns. Merits and limitations of the method are discussed. This experiment can be introduced to a 10+ course or to an undergraduate course with a modest budget.

1. Introduction

Low cost laser spirograph devices have been constructed earlier however they were used only to display the resultant patterns of light [1,2]. In such setups, both DC motors and DC power supplies are essential part for their working. However, calibration of DC power supplies from such setups had not been studied so far. In this article we propose a simple procedure for the said calibration.

Laser beam position on the mirrors and hence the position of the image pattern (Spirograph) on the screen could be controlled by adjusting mirrors inclination. A simple spirograph could be made by attaching a pair of mirrors to the shafts of DC motors [3,4].

A mathematical curve formed by combining two periodic vibrations at right angles to each other is called as a Lissajous figure. In an undergraduate lab these patterns were generally produced by feeding two signals from function generators to two channels of a CRO along X and Y. Technically, the patterns produced with the above set up may not be classified as Lissajous figures. First of all, there is only single beam involved in the process until the formation of final spirograph pattern and therefore the question of superposition of two waves were ruled out. However, the resultant spirograph describes similar variation in the final pattern as that exhibited by Lissajous pattern. Therefore here they are referred as the Lissajous – like figures.

Here the control parameters are the rotation speeds of DC motors. In this article, Lissajous-like figures are used for calibrating voltage of an unknown source with the help of a standard voltage source.

2. Image formation

A fine beam of laser from a laser pointer is shined on a spinning mirror that is attached to the shaft of a standard DC motor whose rotational speed is known. The reflected laser light will trace a circle on a projection surface and dependent on the speed of the motor being high enough, the laser path traced will appear to be a solid circle of variable frequency on the projection surface due to the persistence of vision. One can also consider it like a laser cone being reflected off of the rotating mirror. If we aim this reflected "laser cone" onto another rotating mirror, very interesting shapes begin to appear on the screen. The resultant shapes depends on the relative speed and hence on the applied voltage, of both the motors. When both mirrors are spinning, the circular patterns superimpose to produce such Lissajous like patterns. These patterns made to have integral number of loops, by adjusting the ratio of the two voltage sources to an integer. Further, since the speeds of the motors can be controlled by connecting the motors across variable voltage sources, voltage sources can be calibrated with the help of these Lissajous like figures [5-8]. If one of the voltage sources is a standard one then the voltage of the other source can be estimated. Let 'n' be the number of loops observed in the spirograph pattern when the voltage applied from the standard source is V_s. The voltage V of the power supply to be calibrated can be calculated using the relation

$$V = n \times V_s \quad (1)$$

3. Experimental Setup

3.1 Materials used

Two identical DC motors with a voltage rating of 9V, two ordinary flat mirrors of 0.5 inch diameter, two variable DC power supplies of 0 – 5 V, a rheostat, a laser diode, true RMS digital multimeter and connecting wires.

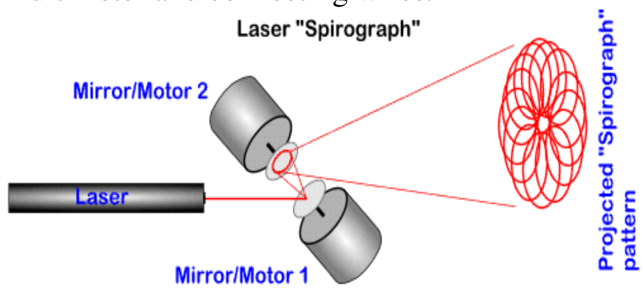

Figure 1: Schematics of experimental set up

3.2 Setup preparation

Initially, two flat mirrors each of 0.5 inch diameter were mounted at the ends of the DC motor shafts with the help of glue and allowed it dry completely. Then motors were mounted on wooden mounting brackets which are separated by short separation distance. These mounting brackets are arranged such that the mirrors face each other with some inclination and laser beam forms a Z-shaped path. The inclinations of motor/mirror assemblies can be tilted using adjustable screws to get patterns at a convenient position on the screen.

Then these DC motors were individually connected across two independent variable power supplies. Mirror /motor assembly were adjusted such that the circle of light from mirror 1 falls on mirror 2 and reflection from mirror 2 is projected onto the wall. Brilliant rotating spirograph patterns were observed as the voltages across the motor1 and 2 were varied.

3.3 Calibration of DC motors

In order to obtain only spirograph patterns two asynchronous DC motors are sufficient. On the other hand to carryout voltage calibrations using

these spirograph patterns two synchronous DC motors are necessary. To confirm this requirement the following procedure was used.
The workings of two mounted DC motors were tested independently by supplying suitable voltage to them.

In the setup, the voltage V_1 across one of the motors was kept at zero and the voltage V_2 across the other was varied in steps of 0.05V from the threshold voltage (0.45 V) to 0.65 V. The voltages from the power supply are measured from a true RMS digital multimeter. For each input, the time taken by the reflected spot of light to complete 20 rotations was noted for two trials and their average time 't' was determined. Then time period 'T' and the frequency 'f' of rotation of the DC motor were estimated from t and are tabulated in table 1. This study was limited to 0.65 V, as it was found difficult to trace the light spot at higher rotation speeds due to higher voltages. A plot of rotational frequency f of DC motor versus the applied voltage V_2 is drawn (see figure 2).
This procedure is repeated even for the second DC motor with the same power supply. The second DC motor was found to have same threshold voltage to start rotation.
Later, two mirrors were connected to the same power supply, one directly and the other through a rheostat, so that independent control of powering the two motors could be achieved. Input voltage was kept sufficiently above the DC motor threshold value. The voltage across second mirror was increased using the rheostat from 0. At certain voltage to the second DC motor a circular pattern was obtained, indicating the rotational speeds are equal. At even higher voltages, spectacular Lissajous like regular optical patterns were observed. They were correlated to the applied voltages.
For e.g.: when the voltage across motor 1 was 0.5 V and that across motor 2 was 1.5 V, then 3 loops were observed on the screen. The ratio of the two voltages (1.5/0.5) gives 3, as expected for a Lissajous like pattern.

4. Calibration of an unknown power supply

Now, two motors are connected to two independent power supplies, one of them is used as a reference power supply. By keeping fixed voltage of 0.5V from the standard supply, we have varied the voltage from the other unknown source. When the voltage was increased from zero, we have observed a circular image on the screen. This is possible only when both the mirrors are spinning at the same speeds. Since identical DC motors are used in this work, the voltage delivered by the unknown power supply should be, now, exactly same as that of the reference source.

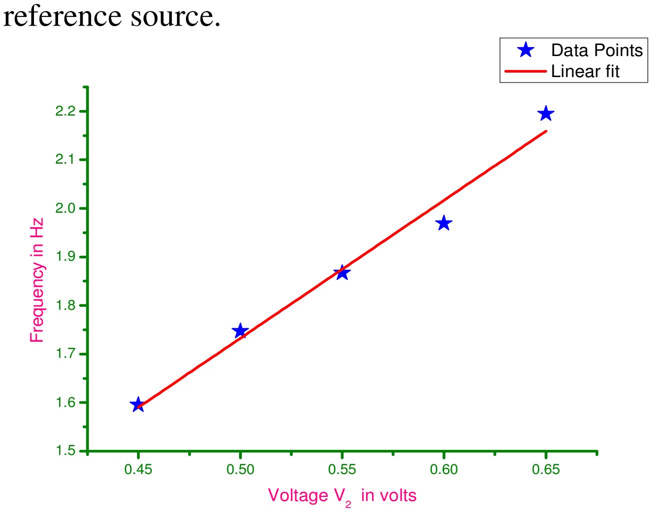

Figure 2: Calibration of one of the DC motor as a plot of f versus V.

The voltage across the second power supply was further increased until an integral number of regular loops were observed. The voltage of the power supply to be calibrated was estimated by the relation (1). These values were cross verified by measuring the voltage across the power supply using a digital Multimeter, when integral numbers of loops were observed.

5. Observations.

Table 1: Data showing relation between frequency of rotation of the pattern and the applied voltage

Voltage across the motors in V		Time for 20 rotations in s				Frequency of rotation f in s^{-1}
V_1	V_2	t_1	t_2	$t=(t_1+t_2)/2$	Period, $T=t/20$	
0	0.45	12.6	12.47	12.54	0.627	1.595
0	0.50	11.37	11.53	11.45	0.573	1.747
0	0.55	10.72	10.69	10.71	0.536	1.867
0	0.60	10.18	10.13	10.16	0.508	1.969
0	0.65	9.19	9.03	9.11	0.456	2.195

Calibration of voltage source:

Table 2: Data showing the voltage levels applied to DC Motors and number of loops found on the pattern.

Reference voltage, V_1 in volts	No. of loops observed	Voltage V_2 in volts	
		Calculated using (1)	Measured from DMM
0.5	1	0.5	0.5
0.5	2	1.0	1.0
0.5	3	1.5	1.5
0.5	4	2.0	2.0
0.5	5	2.5	2.5
0.5	6	3.0	3.0
0.5	7	3.5	3.5
0.5	8	4.0	4.0

6. Results and Discussions

The frequency of rotation of the spirograph pattern found to increase linearly with the applied voltage across the DC motor which serves to calibrate the DC motor. .

Main limitation of this method is that, only low voltages can be determined from this method as it becomes extremely difficult to notice the number of loops in the spirograph patterns at high voltages.

The voltage from the unknown power supply estimated using (1) as inferred by the spirograph pattern found to match exactly with the value of the voltage measured using a digital multimeter. This serves to calibrate an unknown power supply.

7. Conclusions

This is an alternate inexpensive optical method for the calibration of low voltage sources and hence to determine the rotational speeds of DC motors. Further the experiment can be improved to obtain Lissajous-like patterns using AC power supplies and calibrate the AC power supplies.

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