REED SWITCH BASED BRUSHLESS MOTOR

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1. Statement of Problem

A major problem for common conventional motors is the presence of brushes, which limit the motor life to a few thousand hours and create friction and noise. Brushless motors eliminate these disadvantages but in most cases they are more expensive and too complicated. Is it possible to invent a new type of simple inexpensive brushless motor?

2. Hypothesis

If a new simple inexpensive brushless DC motor appears to be needed, then it is possible to invent a new type of a motor by using a magnetic proximity sensor (reed switch).

If a working prototype is built, then when testing its speed, torque, and efficiency for different voltages and number of magnets on the rotor, the new motor will outperform or show comparable results to existing motors.

3. Working Questions For The Experiment

- How does the voltage change affect the speed and torque of the motor?
- How many magnets on the rotor, two or four will provide the best results?
- Which reed switch position is best?

4. Background Information

An electric motor is a device that converts an electrical energy into a mechanical force, based on the attraction or repulsion of magnets. A conventional electric motor consists of two main parts: the rotor, which is the coil, and the stator, which are the magnets and brushes (Gardner, 1994). When current flows through the coil, it creates a magnetic field. The magnetic field of the rotor interacts with the magnetic field of the stator, and this causes the coil to spin.

The brushes in a conventional motor limit its life to a few thousand hours (Werninck, 1978). Under special conditions at low atmospheric pressures this type of motor may only last a few minutes. This is a big disadvantage of a conventional DC motor. There are other disadvantages of a conventional motor, such as a big noise.

To avoid these problems several types of brushless motors were invented (Werninck, 1978). Most of them consist of four elements: the rotor, the stator, electronic commutator, and the rotor position sensor. The stator contains the armature (coil), and the rotor has permanent magnets.

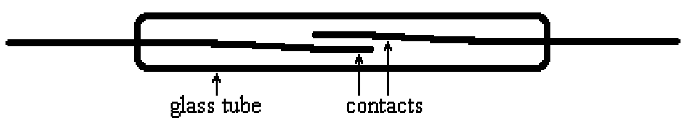
Advantages of a brushless motor are:

- The reduced amount of friction increases motor life significantly.
- The brushless motor has high reliability and a fast response.
- The brushless motor is more efficient that the conventional motor.
- The brushless motor makes less noise.

- The brushless motor needs little or no maintenance, because there are no brushes.

There are some disadvantages of the brushless motor, mostly related to the price or complexity of it. The brushless motor is more expensive than the conventional motor, because it requires an additional sensor to determine the rotor position and send a signal to change the magnetic field.

Several types of sensors can be used in a brushless motor. As the rotor is a permanent magnet a reed switch can be used for two purposes: to determine the position of the rotor and to serve as an electronic switch to alternate the magnetic field in a stator.



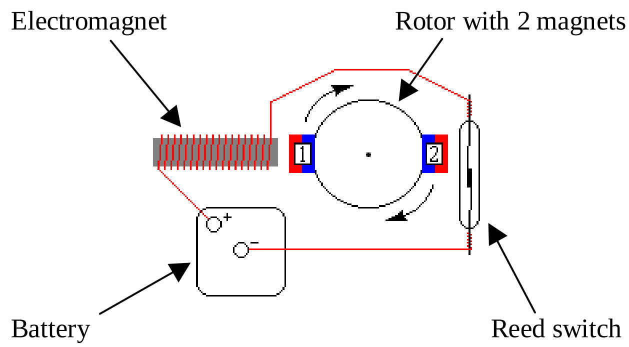
A reed switch consists of two magnetic contacts in a glass tube. When a magnet comes close to a reed switch the two contacts become magnetized and attract to each other and allow an electrical current to pass through. When the magnet is moved away from the reed switch the contacts demagnetize, separate, and move to their original position (Reed Electronics AG, 1997).

Reed switches are very reliable and last as long as 3 billion operations if used properly. They are designed for low currents. High current through the contacts causes an arc (spark) which may weld the contacts together.

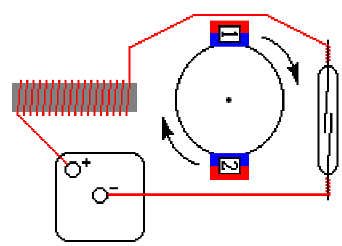
5. Principles Of Motor Operation

This is how brushless DC motor based on a reed switch works:

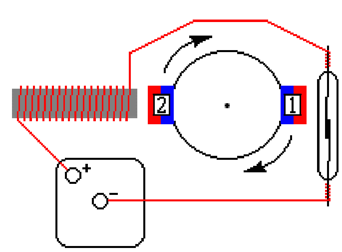
I. When magnet #2 gets close to the reed switch the two contacts inside the glass tube get magnetized and touch each other. This causes the electromagnet to push magnet #1away.



II. When the magnets spin away, the reed switch demagnetizes and gets disconnected. This creates an open circuit disabling the electromagnet.



III. The magnets continue to spin due to inertia until magnet #1 gets in working range of the reed switch. It becomes magnetized again and its contacts connect together making the electromagnet push magnet #2 away.



This process continues until the power source is disconnected or depleted, or the reed switch is moved out of working range.

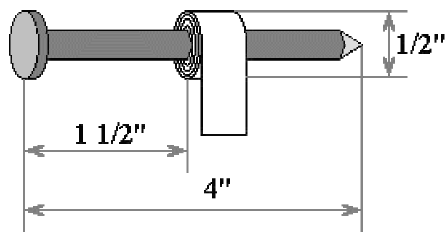
6. Materials

The prototype that was built and used for experiments in this research required some special tools and materials. However the simplified version of a brushless motor based on a reed switch can be built with the following materials:

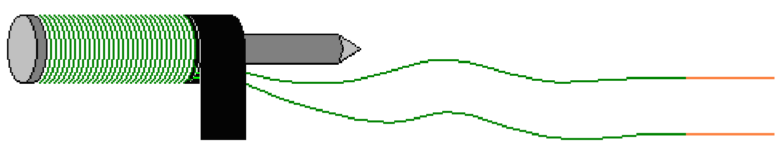
- One reed switch – I used a general-purpose reed switch with the total length of 2 3/8” (length of the glass tube 1 3/8”).
- Two magnets. I used two small circle ceramic magnets with diameter of 1/2” and height of 1/4”.
- Spool of magnet wire (26 gauge).
- A cork.
- A needle that is longer than the cork.
- Battery. I used a 6 volts lantern battery, but in my experiments I found that even 1.5 volts battery is sufficient enough to provide reliable operation.
- Two push pins.
- Tape. Electrical is advised, but scotch is fine.
- Long nail (3” – 6”, I used 4”) for electromagnet.
- Duct tape.
- Glue.
- Two matchboxes.
- A piece of firm cardboard or similar material for the base.
- A small piece of fine sandpaper, or a sharp knife. Used to remove the insulation from the wire.
- Two sturdy hardcover books or cardboard boxes.
- Optional: pliers, a small nail, and a lighter.

7. Building Instructions

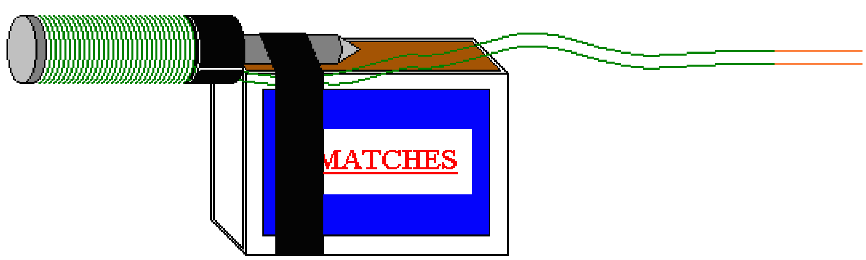
1. Take a nail and wrap it around with electrical tape (scotch may be used) to make a layer about 1/2" thick in diameter at the distance of 1 – 2" from the head of the nail.



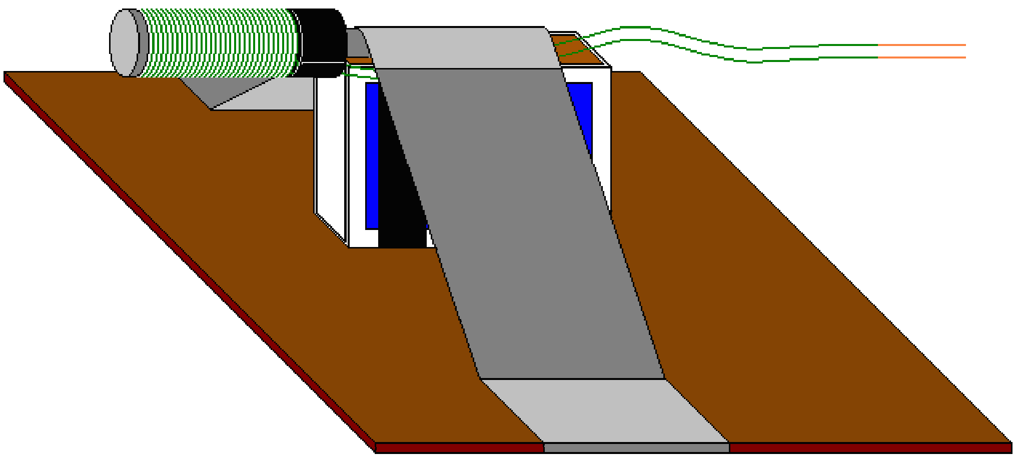
2. Use most of the spool of wire to wrap around the area between the thick layer of tape and the head of the nail. (Cut and leave a piece of wire about 10" long – you will need it later). Tape the ends of the coil to the same layer of tape leaving open ends of wire about 10" long. Clean about 1 1/2" of the wire tips with fine sandpaper or a sharp knife to remove the insulation.



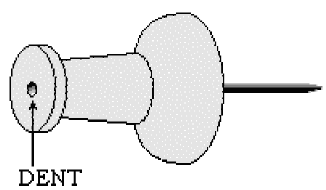
3. Tape the open end of the nail to the matchbox.



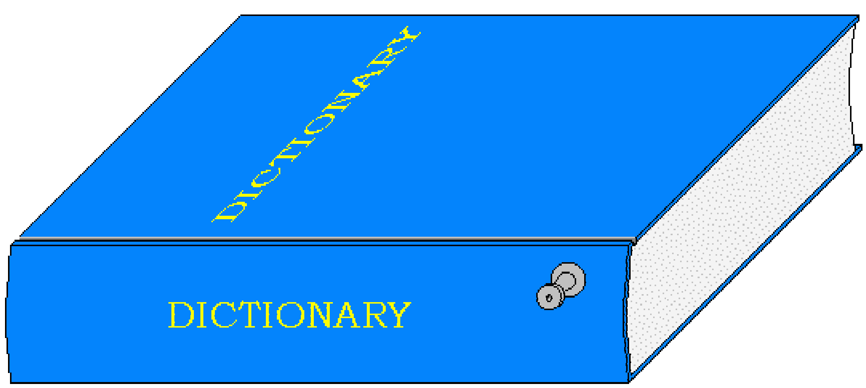
4. Using the duct tape attach the matchbox to the board as shown below.



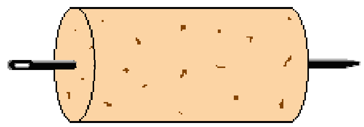
5. Make a small dent in the middle of each pushpin. Use one pushpin to make a dent in the other; or hold a small nail with pliers, heat it up using a lighter, and press the hot sharp end of the nail into the center of the pushpin.



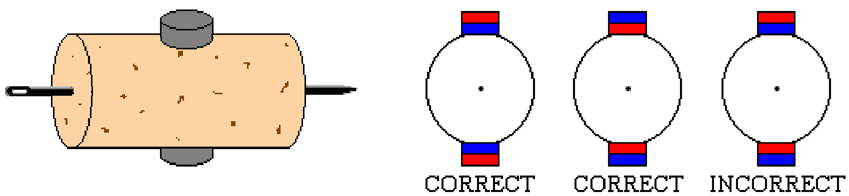
6. Insert two pushpins into two hardcover books or cardboard boxes as shown below. The center of the pushpin should be at the same level from the base surface as the center of the electromagnet.



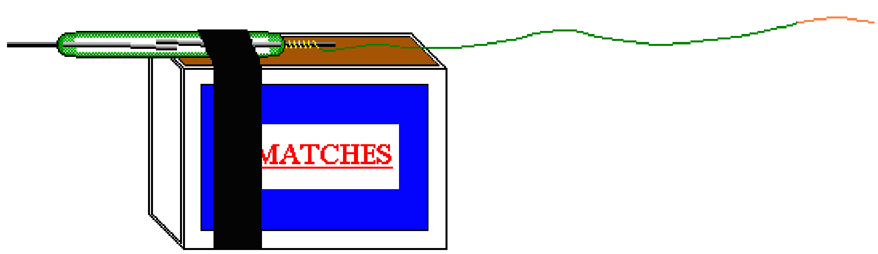
7. Take the cork and stick the needle through the center on one side and make sure that it comes out in the center as well. Try to be accurate, redo this step if necessary. Balance of the cork is very important as it affects the motor performance.



8. Find the same poles on the magnets and mark them. Same poles (North – North, or South – South) repel, while different poles attract. Find two repelling sides – they should face outside. Glue the magnets to the opposite sides of the cork. It really does not matter if North or South poles are facing up as long as they are the same.

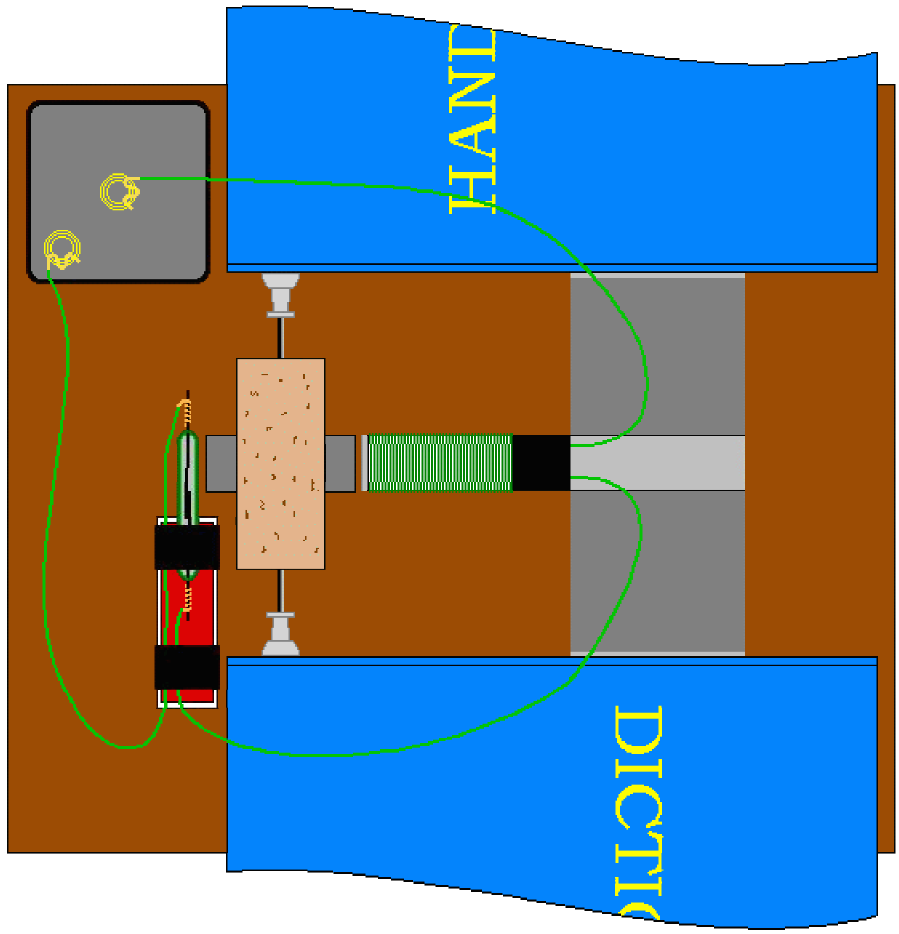


9. Take a 10" piece of wire (see #2) and remove 1 1/2" of insulation on both ends. Wind one bare end tightly around an outside contact of the reed switch. Tape the reed switch to a matchbox as show below.



10. Put the stator (the electromagnet on the base and the books with the pins inserted) and the rotor (the cork with the needle and attached magnets) together as shown below. Position the electromagnet as close as possible to permanent magnets on the

rotor. Adjust the books position to allow the rotor to spin freely without hitting the electromagnet.

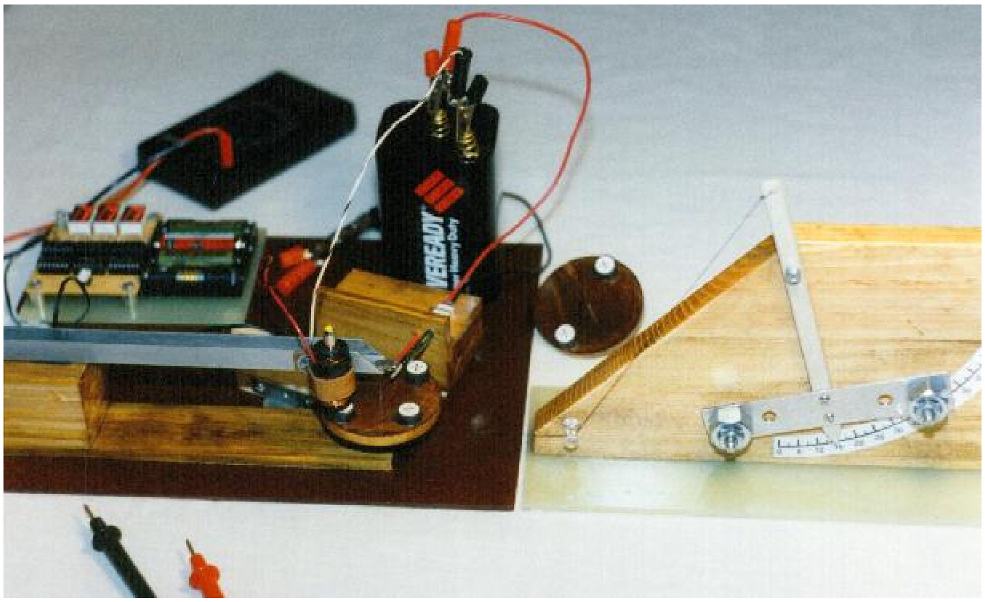


11. Before connecting everything together connect both wires from the electromagnet to the battery. If the electromagnet doesn't repel the permanent magnets away, switch the wires. When it repels, disconnect one wire and connect it to the reed switch. Connect the other end of the reed switch to the battery as shown on the picture above.

If you bring the reed switch close to the magnets the motor should start working immediately. If it doesn't work check all the connections – it is important to clean the insulation thoroughly; make sure the battery is fresh and connected properly; move the books to allow free rotation.

8. Experiments

In this project a simplified reed switch based brushless DC motor as described above was used for the speed tests only. For most experiments in this research a more complex model was designed and built.



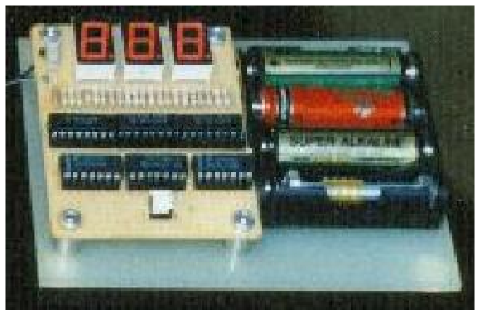
The experiments were performed separately for two and four magnets on a rotor. For that purpose two rotors were made as shown in the picture above.

The manipulated variable in the experiments was voltage. A small AC adapter with the switch allowed seven output voltages: 1.5, 3, 4.5, 6, 7.5, 9, and 12 Volts DC. This power supply provided enough electrical power for all the experiments.

The controlled variables were the number of magnets, the reed switch position, the type of reed switch, and the number of weights in torque testing.

The responding variables were the speed, measured in revolutions per minute; the relative power, measured as an angle on the torque testing device; and an average current, measured in milliamps.

After building the motor it was noticed that the spinning magnets on the rotor could be used for calculating speed in revolutions per minute. To assist in finding the rpm value another reed switch was used. The signals from the second reed switch were sent to specially built 3-digit electronic decade counter.



Although the counter shown above was built completely for these experiments only, it doesn't represent the main topic of this project, and therefore is not described here in details.

The speed in rpm was calculated as the ratio of the number of pulses in one minute displayed on the counter divided by the number of magnets on the rotor. It was noted how many times the number changed from 999 to 000 to add the corresponding number of thousands to the calculation.

One of the biggest challenges of this project was the torque measurement. Torque, a twisting force, is a very important characteristic of the motor. As this task is quite complicated it was decided to measure a relative power as an angle on a specially designed for those purposes device. It is shown on the picture at the beginning of this chapter on the right side of the motor.

In torque experiments one end of the string (heavy-duty thread) was taped to the bottom of the rotor, and the other end was attached to the top of a lever. The bottom end of the lever served as a pointer showing the angle on the dial. A lath was attached to the pointer end. Several holes in the lath were used for adding heavy bolts and nuts as weights to increase the lever resistance.

The spinning rotor of the motor was winding the string around the needle. The string was long enough to allow the motor to gain the speed before pulling the lever. The maximum angle was noted.

Two different combinations of weights were used during the experiment for four and two magnets on the rotor, as the four magnet rotor proved to be more powerful.

In this project the actual torque, or the twisting force of the motor, was not calculated and may be determined in future experiments. However, the angle measurements provided very reliable results for relative power estimations, as the motor with higher torque will turn the lever to a larger angle.

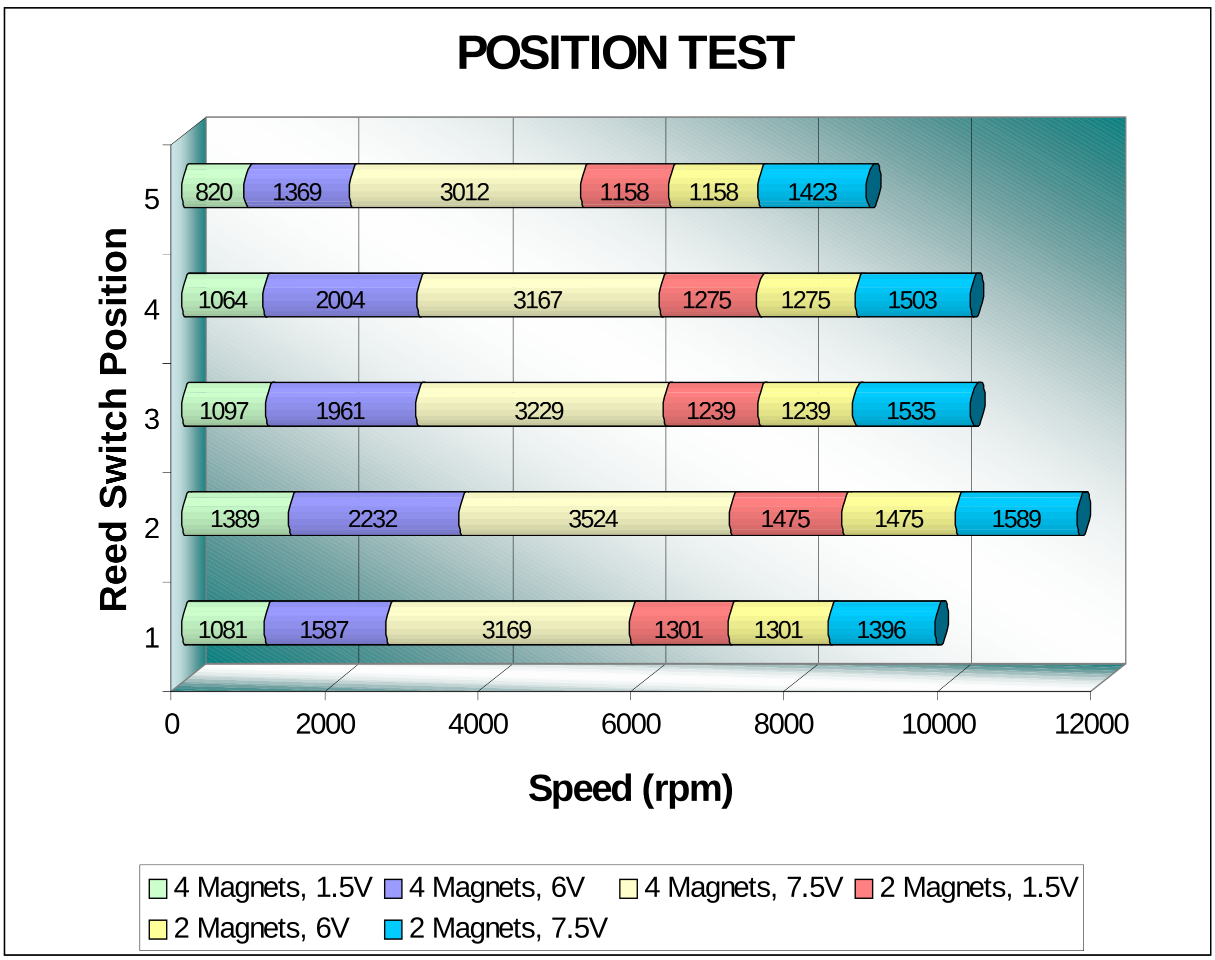
Current and the actual voltage on the coil, reed switch, and power source were measured with a digital electrical tester.

All the experiments were done at least five times each to get accurate results, and the average data was calculated and used for comparisons and conclusions.

9. Results

Before doing all main experiments it was necessary to determine the best position for the reed switch, where the rotor had the fastest speed. To assist in finding the speed the electronic counter was used.

Five marks were put onto the board for placement of the reed switch block. For each reed switch position the experiment was done five times for three voltages – 1.5V, 6V, and 7.5V DC. The average number of five measurements was calculated. The experiments were repeated twice for two and four magnet rotors. The results are shown in the graph below. They show that reed switch position number two was the best.



The table below shows the results of the simplified motor testing. The speed and current were measured.

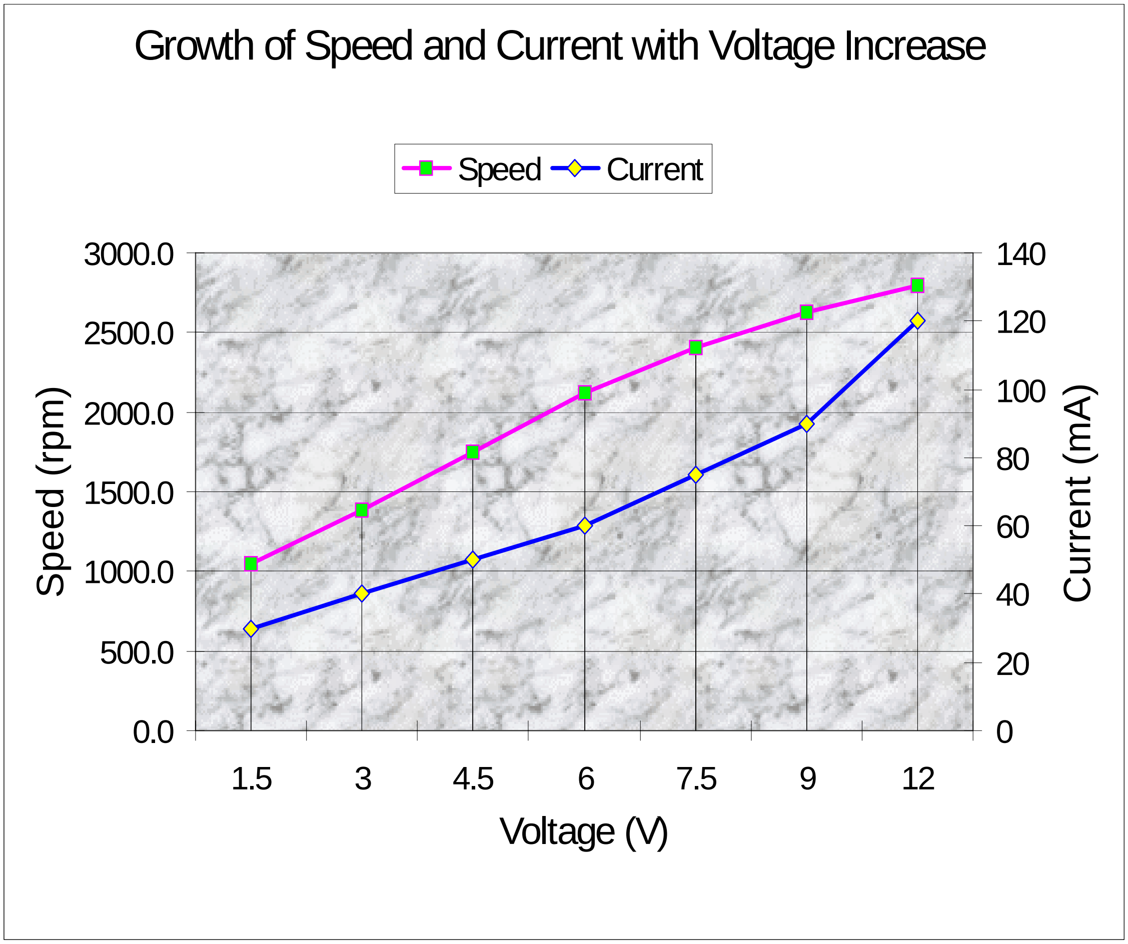
SIMPLIFIED BRUSHLESS MOTOR								
Speed measurements								
No.	Speed, rpm					Average speed	Voltage, V	Current, mA
	1	2	3	4	5			
1	1000	1096	1076	1040	1036	1049.6	1.5	30
2	1276	1486	1410	1370	1360	1380.4	3	40
3	1776	1692	1786	1794	1698	1749.2	4.5	50
4	2104	2202	2049	2132	2116	2120.6	6	60
5	2414	2376	2396	2404	2458	2409.6	7.5	75
6	2646	2604	2599	2624	2654	2625.4	9	90
7	2750	2814	2774	2794	2828	2792.0	12	120

As it was already mentioned above, the experiment was done five times for seven different voltage settings. After getting all the results the average speed was calculated.

The electronic counter was used to measure the speed of the rotor; the digital tester was used to measure the current.

The current represented the average value as due to the nature of the motor the current goes through the coil only when the reed switch is closed.

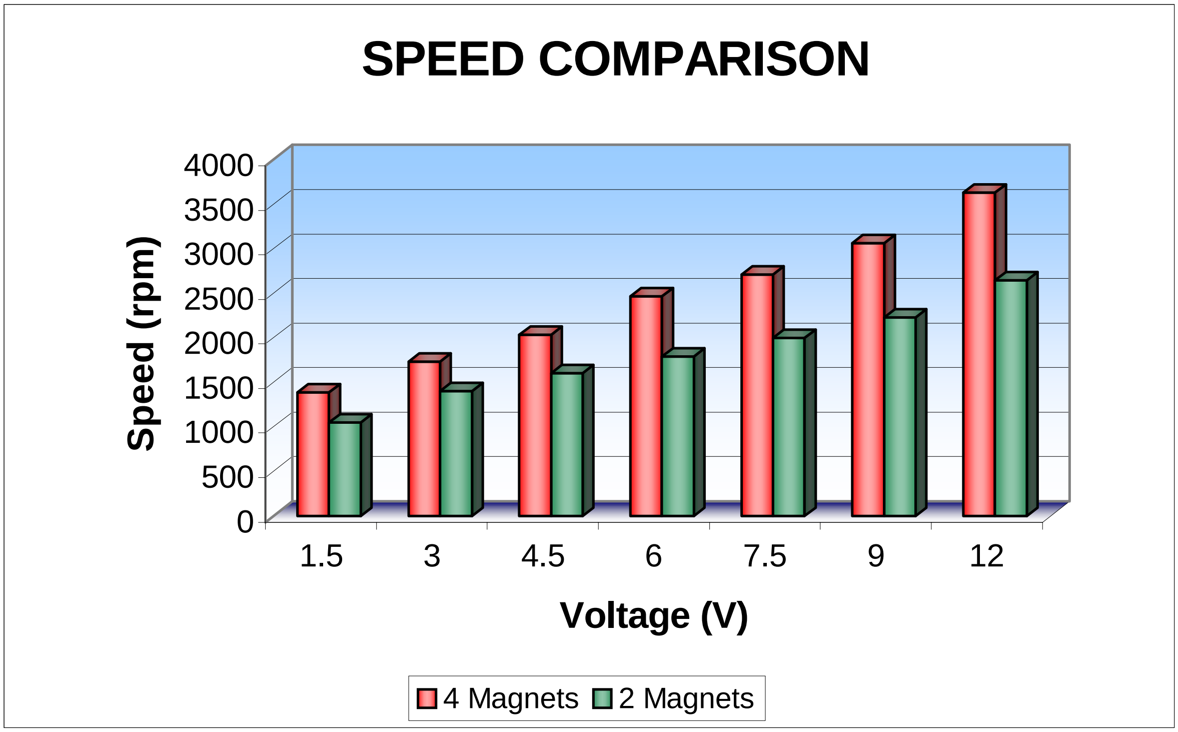
The data from the table above was used to construct the graphs showing the growth of current and speed with increasing voltage.

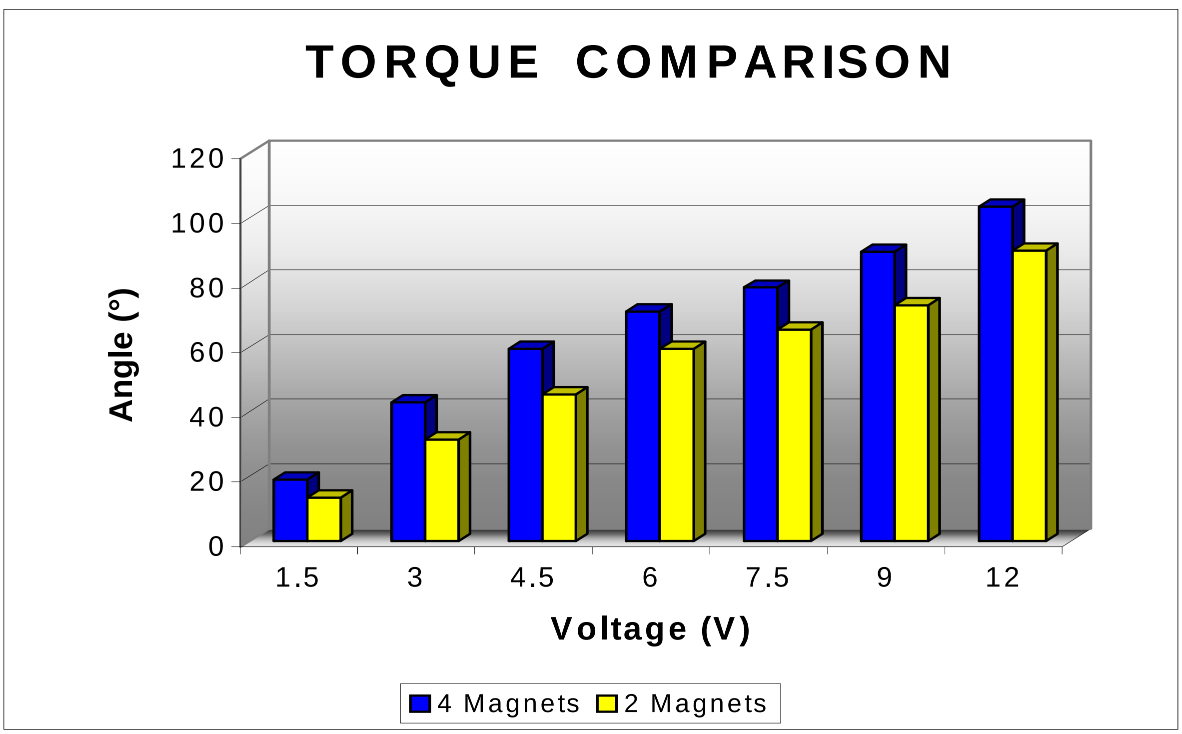


The graph above demonstrates that the speed grows almost proportionally to the applied voltage, but the consumed current grows as well.

It is important to note that voltages in excess of six volts created a visible spark between the contacts inside the reed switch tube. As it was mentioned earlier in chapter 4, this may weld the contacts together. However in the experiments this problem was not experienced. Nevertheless it is recommended to use designed brushless motor under low voltages and currents to provide most reliable operations.

Similar tables were created for the results of the experiments with the prototype system were speed and relative torque were measured for two and four magnet rotors. The comparison graphs are shown below.





Both graphs clearly show that the rotor with four magnets outperformed the rotor with two magnets in both speed and torque experiments for all voltage settings.

In the first preliminary experiments the rotors with 3, 6, and 8 magnets were tested as well. The three and two magnet rotors showed almost identical results; therefore the three-magnet rotor is not represented in this research. The rotors with six and eight magnets did not work very well, as the space between magnets was too small and the reed switch stayed closed most of the time. It did not allow the motor to run properly.

As a result of this testing it was noted that the distance between the magnets on the rotor should exceed the reed switch working range. For selected diameter of the rotor four magnets showed the best results.

Finally, the designed reed switch based brushless motor was compared to an industrially built conventional DC motor. Simple DC motor with working voltage range of 1.5 – 4.5 volts used in many toys was selected for that purpose.

Four voltage settings – 1.5, 3, 4.5 and 6 Volts (6VDC was applied for a short time only) – were used for the torque angle measurements the same way as it was done previously for the brushless motor. Current was measured as well.

Unfortunately, it was impossible to measure the speed of the selected conventional motor using the method described above. That is why the actual speed comparison was not done. However, according to available technical information the speed of this motor type may vary from 1000 to 3500 rpm depending on load and applied voltage. That compares very well to designed brushless motor.

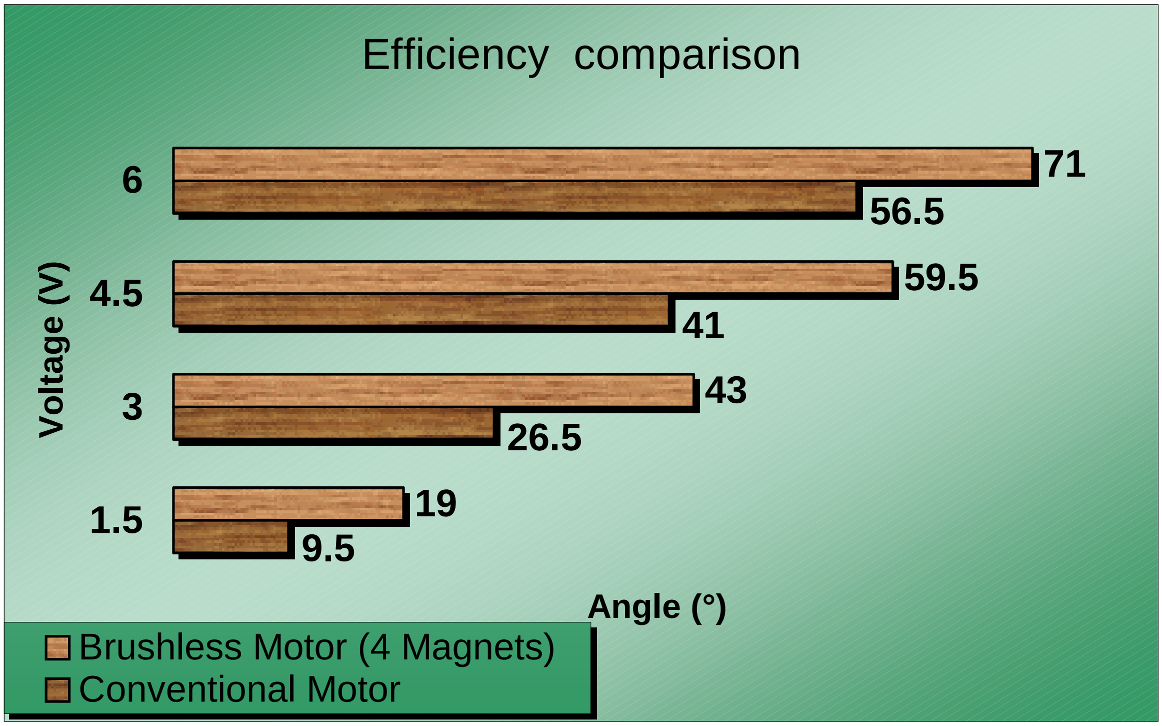
Angle measurements for both brushless and conventional motors are shown in the table below.

BRUSHLESS vs. CONVENTIONAL									
Angle measurements									
No.	Angle, °					Average Angle	Voltage, V	Current, mA	Power, W
	1	2	3	4	5				
Brushless motor with 4 magnets									
1	17.5	17.5	20	20	20	19	1.5	50	0.075
2	45	45	42.5	42.5	40	43	3	70	0.21
3	60	57.5	60	60	60	59.5	4.5	90	0.405
4	70	70	70	72.5	72.5	71	6	110	0.66
Conventional motor									
1	10	7.5	10	10	10	9.5	1.5	80	0.12
2	20	25	30	32.5	25	26.5	3	140	0.42
3	45	40	40	42.5	37.5	41	4.5	240	1.08
4	55	57.5	62.5	55	52.5	56.5	6	560	3.36

It is known that the efficiency of a motor is the ratio of its useful output to its total input. The last column in this table represents how much power these motors consume. This is input power. The output power is proportional to the torque of the motor. Therefore, the motor that turns the lever on the used device to a bigger angle and consumes less power to do it is proven to be more efficient.

The table above shows that the reed switch based brushless motor turned the lever 43° consuming 70 mA at 3V. At the same time a regular conventional motor consumed 240 mA at 4.5V to turn the lever only 41°. A similar comparison may be observed for other voltages.

The following graph based on the table data clearly demonstrates the efficiency comparison.



10. Conclusion

The original hypothesis that a simple inexpensive brushless motor can be invented and built was proven. The magnetic proximity sensor (reed switch) was used in design of this new motor. According to the results of the experiments, it was proven also that the working model of the new motor outperformed or showed comparable results to industrially built conventional DC motors.

The manipulated variable in the experiments was voltage. The controlled variables were the number of magnets, the reed switch position, and the number of weights in torque testing. The responding variables were the speed, measured in revolutions per minute; the relative power, measured as an angle on the torque testing device; and an average current, measured in milliamps.

The experiments were performed separately for two and four magnets on a rotor, and the motor with four magnets proved to be the best. The results also clearly showed that the new motor was very reliable, stable, and powerful enough to be favorably compared to existing conventional motors.

Two different motors, regular and a simplified version, were built and tested many times. Both of them showed very good results. Very reliable and innovative methods were used to measure speed and estimate torque of the motors. All these are the strengths of the experiments.

There were some weaknesses. Some factors were not taken into consideration because of their complexity or little influence on this experiment. These factors include the friction and the different diameter of the needle; inability to gain full speed before torque testing; small changes in reed switch position and applied voltage.

Many aspects of this project can be improved in future experiments. There is a possibility, although quite small, that the rotor may stop in the dead spot where the magnets are too far from the reed switch working range. Adding one or more additional reed switches and electromagnets may solve this problem. It will require more precise future experiments to design this type of motor with several circuits.

The results of the experiments showed that the motor should be very reliable when the voltage and current are low. That limits the power of this motor. To increase the power of this type of motor future experiments may include an addition of special circuits allowing to control big voltages and currents with small signals.

Torque and efficiency of the motors in this project was measured as a relative number represented by an angle on the torque measuring device. In the future experiments it would be a good idea to calculate the actual torque of these motors.

Both motors in this project are demonstration units and need to be redesigned for real life applications. Some suggested areas for the future usage of reed switch brushless motor include small fans for computer systems and chips. Also this type of motor should be very efficient under special conditions at low atmospheric pressures, for example, in airplanes.

With proper modification after future development, a reed switch based brushless DC motor can be used for almost any application where high stability, reliability, and efficiency are required.

11. Acknowledgements

This project represents many hours of hard work and could not have been done without the help of many experts for whose time, knowledge, patience, and enthusiasm I am most grateful.

First of all I would like to thank my dad for spending a tremendous amount of his time helping me with this project. He helped me to go all the way from my initial ideas to the present stage of this task. I need to credit my dad for the following:

- My dad discussed all my project ideas and advised on how to conduct the experiments.
- He taught me how to select and use the correct tools for the right task when building the motors.
- My father designed an electrical counter, explained to me the principles of its operation, and helped me to assemble it. I soldered most of it myself!
- He suggested using a lever for torque measurements.
- My dad insisted on making me redo any step that was not perfect (or close to it).
- And finally he was always there to support me when I needed it.

I also want to express my gratitude to Mrs. Aufleger, my science teacher. She had so many students in all her classes but always found the time to help me realize my potential.

I wish to thank my mom for her patience and extremely valuable help in soothing tensions between my dad and me in her efforts to calm down our overheated arguments.

Finally, special thanks to my grandparents for not letting me continue my project hungry. Without them I would have probably starved to death long before the fair!

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