REED SWITCH BASED BRUSHLESS MOTOR:
A Second Year Development

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1. Statement Of The Problem:

In last year research a new type of an electric motor was invented, built, and tested. It is a reed switch based brushless motor. Different experiments demonstrated that the new motor was very reliable, stable, and powerful enough to be favorably compared to existing conventional motors. However, the prototype that was built last year needed many improvements and developments to be used in real applications, and more reliable experiments had to be accomplished.

2. Hypothesis

If the prototype reed switch based brushless motor with one electromagnet and one reed switch, built last year, showed good results, then adding extra circuits with another electromagnet and/or reed switch will improve the motor and its performance.

3. Working Questions For The Experiment

- Which circuit provides the best results?
  - 1 electromagnet and 1 reed switch
  - 2 electromagnets in serial connection with 1 reed switch
  - 2 electromagnets in parallel connection with 1 reed switch
  - 2 electromagnets controlled by separate reed switches
- Will the speed reducer allow the motor to do useful work?
- What is the weight limit for each circuit?
- How does the speed change under load?
- How does the voltage change affect motor parameters?

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). This is a big disadvantage of a conventional DC motor. There are other disadvantages of a conventional motor, such as a big noise.

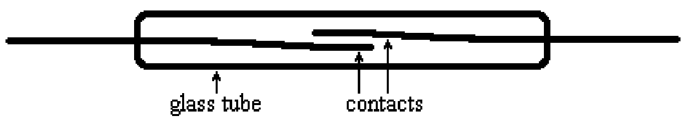
To avoid these problems several types of brushless motors were invented (Werninck, 1978). Most of them consist of four elements: the rotor, the stator, electronic commutator, and the rotor position sensor. The stator contains the armature (coil), and the rotor has permanent magnets.

Advantages of a brushless motor are:

- The reduced the 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 aren’t any 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.



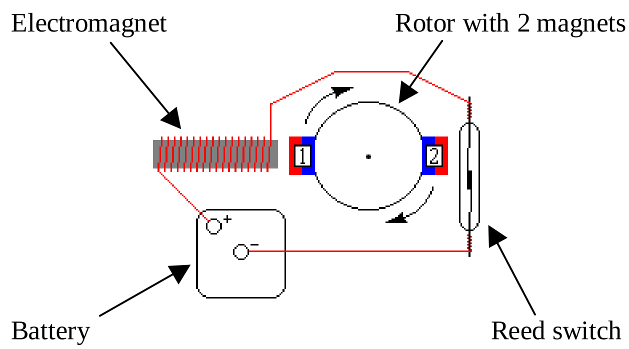
A reed switch consists of two magnetic contacts in a glass tube. When a magnet comes close to a reed switch the two contacts become magnetized and attract to each other and allow an electrical current to pass through. When the magnet is moved away from the reed switch the contacts demagnetize, separate, 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. However, they are designed for low currents, and a high current through the contacts causes an arc (spark), which may weld the contacts together after several hours of operation.

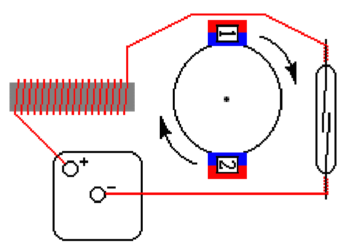
5. Principles Of Motor Operation

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

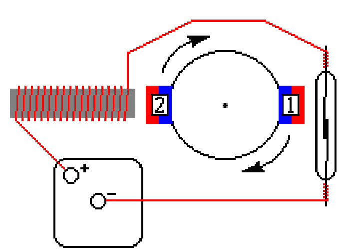
I. When magnet #2 gets close to the reed switch the two contacts inside the glass tube get magnetized and touch each other. This causes the electromagnet to push magnet #1away.



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



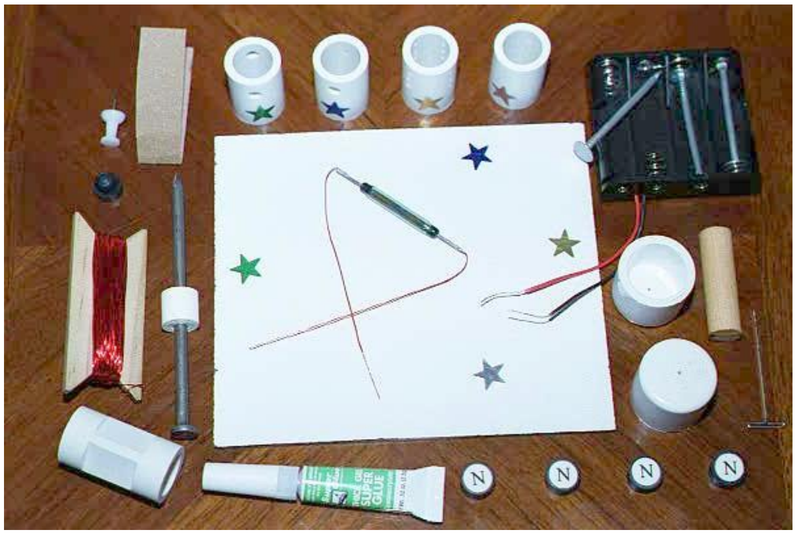
III. The magnets continue to spin due to inertia until magnet #1 gets in working range of the reed switch. It becomes magnetized again and its contacts connect together making the electromagnet push magnet #2 away.



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

6. Materials

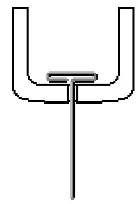
The prototype that was built and used for experiments in this research required some special tools and materials. However the simpler version of this brushless motor, based on a reed switch, may be built with the following materials:



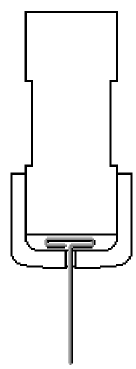
1. Reed switch with soldered wires
2. A spool of wire (70 feet of 26 gauge insulated copper wire)
3. 4 Magnets with North pole marked
4. Heavy-duty white board (approx. 5” x 5.5”)
5. 4 Stands
6. Rotor core with 4 flat surfaces for 4 magnets
7. 4” Nail with tape for the electromagnet
8. 2 Caps
9. T-pin
10. Wooden insert
11. Pushpin
12. Rubber plug
13. Super glue
14. Piece of sandpaper
15. Battery holder
16. 3 Metallic inserts (to change the voltages from 1.5 to 6 V)

7. Building Instructions

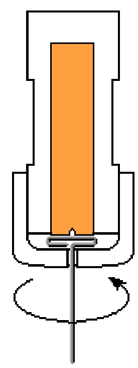
Insert the T-pin into one of the caps.



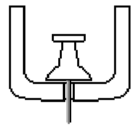
Insert the rotor core into the same cap. Apply some pressure to push the rotor core approximately ½” into the cap.



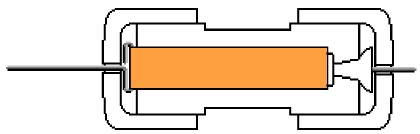
Put in the wooden insert. The side with the slit should face the T-pin. Hold the cap as shown below. Twist the T-pin slowly until it snaps into the slit. At this point the wooden insert will start rotating with the T-pin.



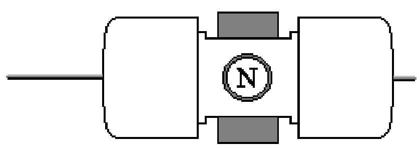
Insert the pushpin into the other cap.



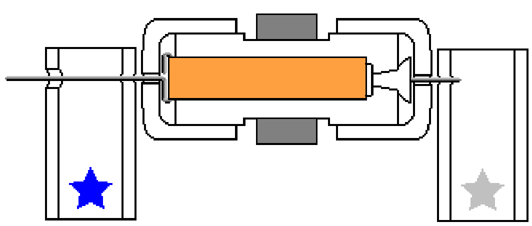
Put everything together as shown below. Push the caps towards each other until they can not move any more. The T-pin must be secured firmly. This process requires some strength. Be careful not to bend the T-pin or poke yourself.



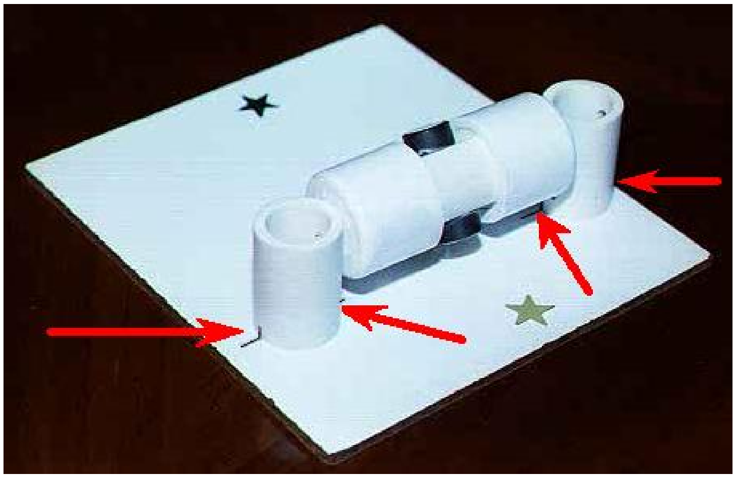
Glue the magnets to the flat surfaces of the rotor core with the letter 'N' facing outside.



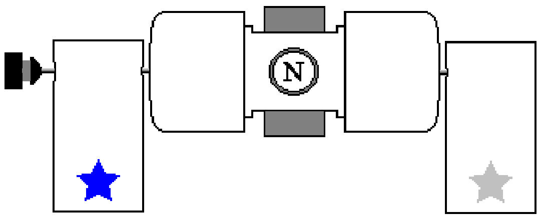
Insert the rotor into the stands as shown below. Hold the stands and test to see if rotor spins freely. Straighten the T-pin if necessary.



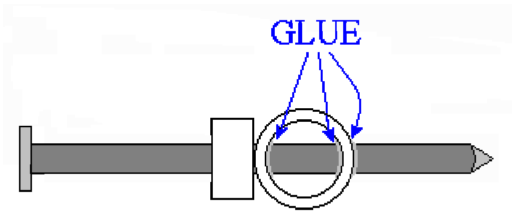
Glue one stand to the board. Align the marks on the stand with the line on the board as shown below. Remember: super glue bonds instantly, so be careful in these procedures.



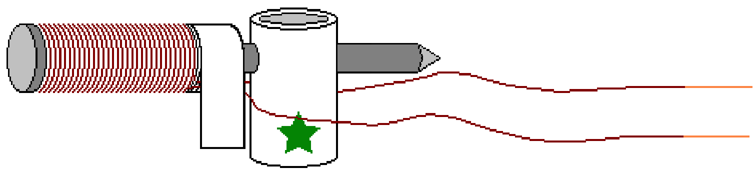
Insert the rotor into the stand. Glue it to the board the same way as the first stand. Leave a gap of about 1/16”(1/32” on each side) between the rotor and the stands. Test again to see if the rotor spins freely.



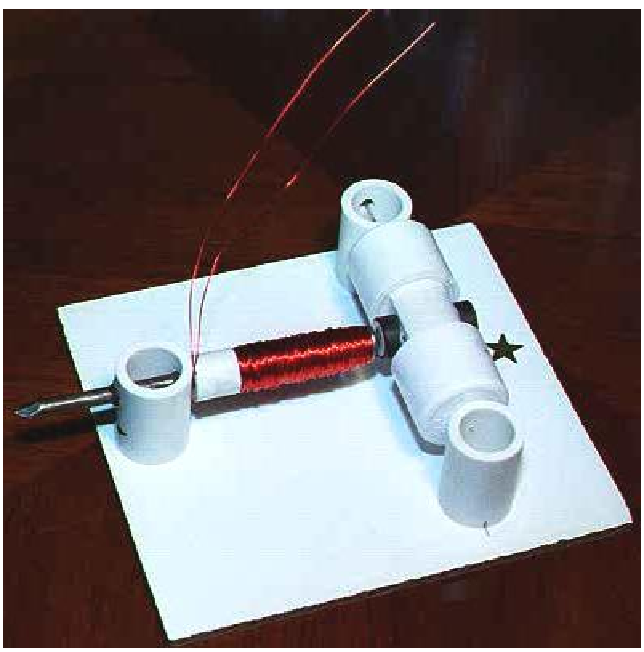
Insert the nail into the stand with big hole in it. Apply glue as shown below.



Use the spool of wire to wrap around the area between the tape and the head of the nail. Tape the end and beginning of the wire using the same tape and leaving open ends of wires about 6” long. Do not let the wire slide off the end of the electromagnet. Clean about 1” of the wire tips with fine sandpaper or a sharp knife to remove the insulation.



Glue the electromagnet to the board as shown below. Turn the rotor slowly to see if the magnets hit the electromagnet. If one or more do, move the electromagnet back until there is about 1/16” between the electromagnet and the closest magnet on the rotor.



The reed switch stand has 3 sets of 4 holes on 3 different heights from the board (diagram 1). You may experiment with these levels to change reed switch position, and, therefore, speed and direction of rotation. Level 2 is usually the fastest. Insert the reed switch wires as shown in diagram 2 below. Be careful not to break the reed switch, it is very fragile. Twist the wires as shown below in diagram 3.

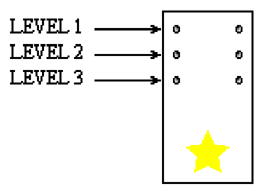


Diagram 1

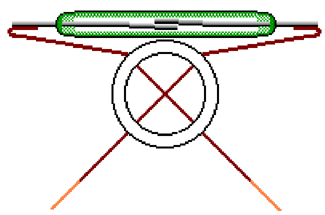


Diagram 2

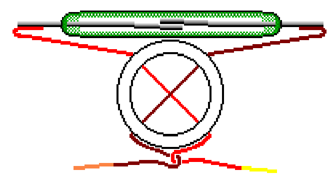
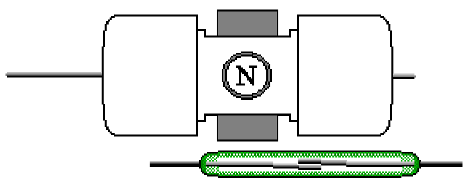
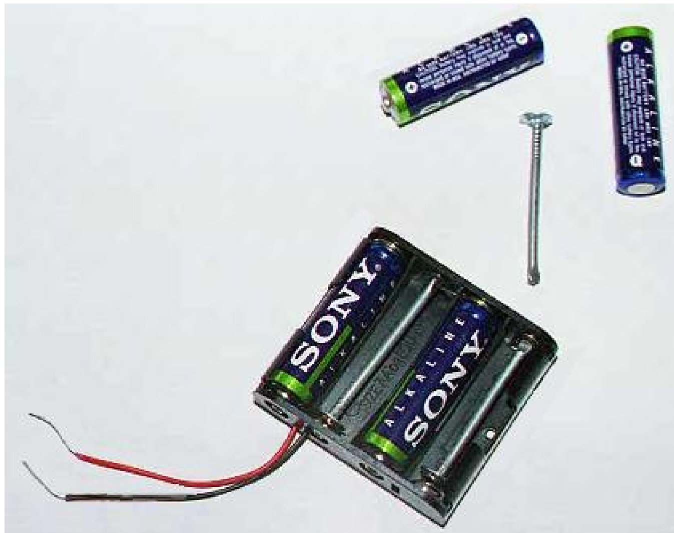


Diagram 3

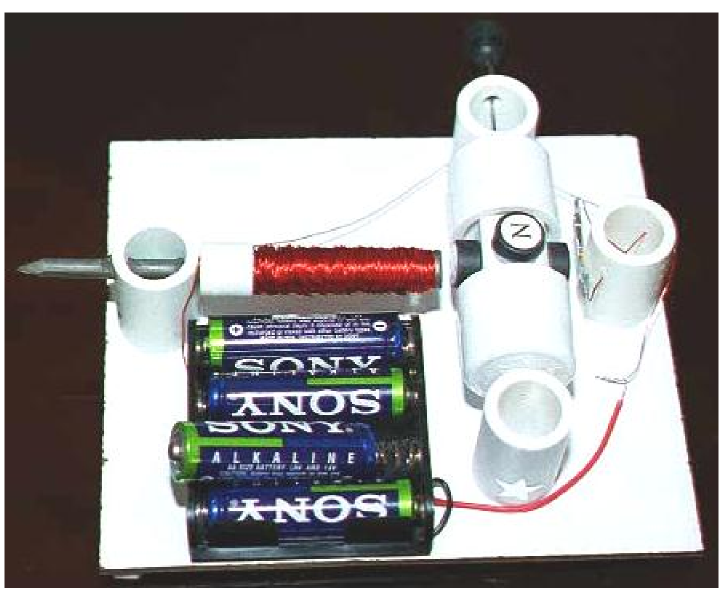
Glue the reed switch holder to the base. It should be located on a distance of about 1/8” from the closest magnet covering the corresponding star on the board. Check the rotation of the rotor to see if it does not hit the reed switch. The most sensitive part of the reed switch is not in the middle of it, but more to the side as shown below.



Attach the battery holder to the board. The battery holder allows you to experiment with 4 different voltage settings (1.5, 3, 4.5, and 6V DC). You will need 4 AA size batteries. Simply replace any battery for a metallic insert to lower the voltage, and replace a metallic insert for a battery to increase the voltage. Normally the best results come from 3 or 4.5 volts.

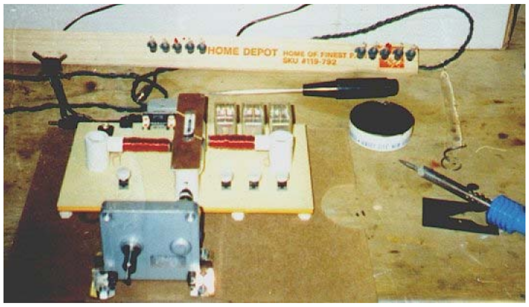


Before connecting everything together connect both wires from the electromagnet to the battery. If the electromagnet doesn't repel the permanent magnets away, switch the wires. When it repels, disconnect one wire and connect it to the reed switch. Connect the other end of the reed switch to the battery. You can connect the wire from the electromagnet to the reed switch through the bottom holes on the stand with the blue star.

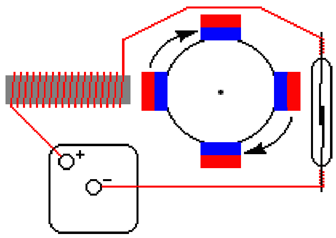


8. Experiments

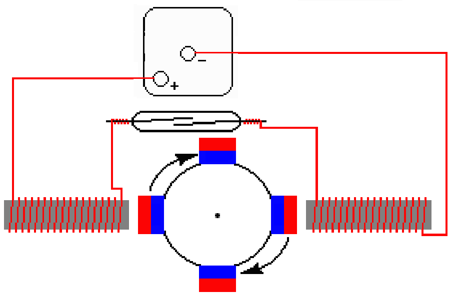
For most experiments in this research a complex model was designed and built.



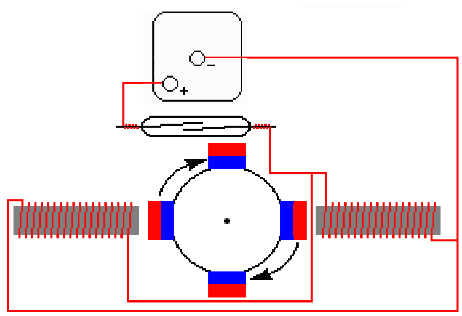
This model provided the ability to switch between four different circuits:



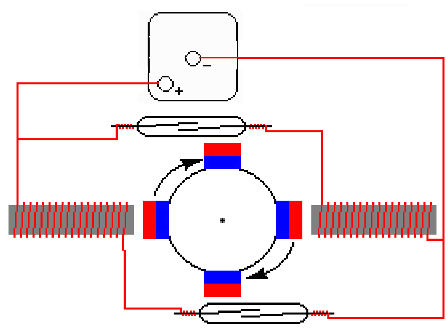
Circuit 1: 1 electromagnet and 1 reed switch (the original idea).



Circuit 2: 2 electromagnets in serial connection with 1 reed switch

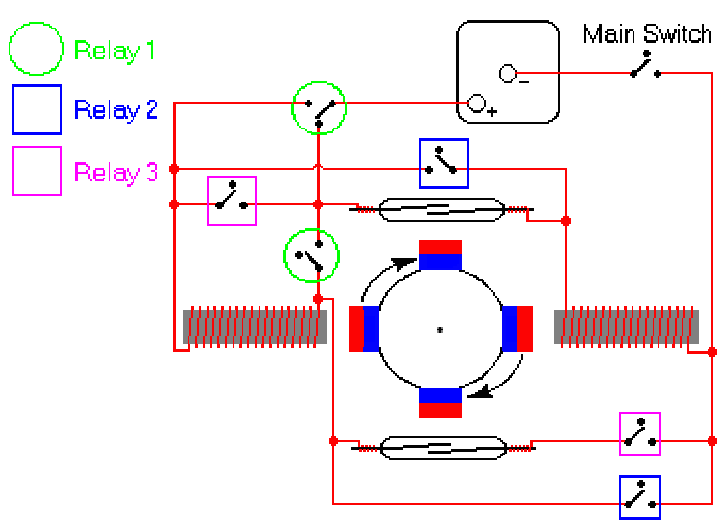


Circuit 3: 2 electromagnets in parallel connection with 1 reed switch

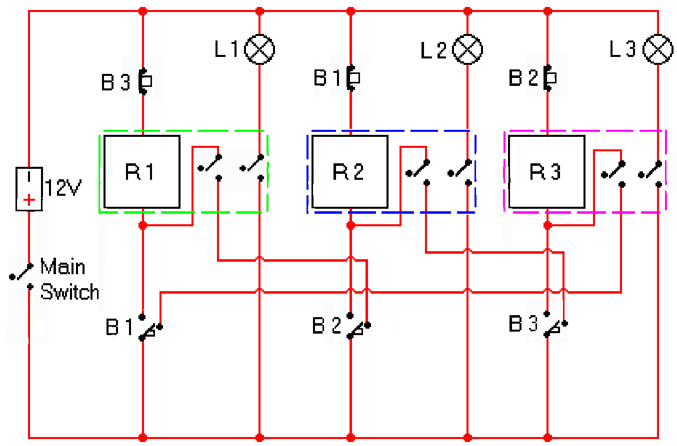


Circuit 4: 2 electromagnets controlled by separate reed switches.

The diagrams below show the electrical connections between the components of the model.



Three relays were used to switch between the circuits. The relays had four contact groups and were powered by a separate 12V power supply.



When the main switch is on, current passes through the first circuit. When button B_1 is pushed the relays connect components to form circuit 2. Buttons 2 and 3 perform the same task for circuits 3 and 4, respectively.

Last year research clearly showed that the position of the reed switch affected motor parameters. As a result of the experiments it was noted that the best position was opposite of the electromagnet. Since two electromagnets were used, the reed switches were put at 90° from them. For this purpose a 4-magnet rotor was used.

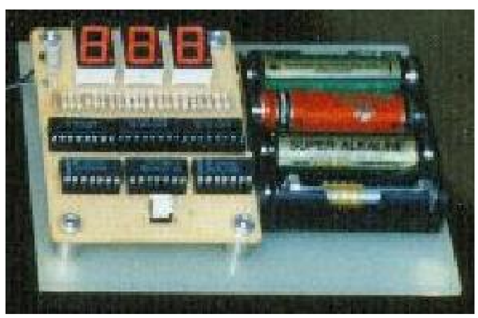
A major problem for the original motor, developed last year, was the presence of the "dead spot". The "dead spot" occurs when the rotor stops in a position where the magnets are outside the reed switch working range. In this case the motor can't restart. This year that problem was solved. All the motors were completely redesigned.

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, except few instances where the current exceeded 500mA.

The controlled variable in this experiment was the number of weights in torque testing.

The responding variables were the speed, measured in revolutions per minute and the current, measured in milliamps with a digital multi-meter.

Last year for speed measurements a 3-digit electronic decade counter was built. The spinning magnets on the rotor were used for calculating speed in revolutions per minute. To assist in finding the rpm value another reed switch was utilized. The signals from this reed switch were sent to the 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. To achieve this task the motor was attached to the speed reducer. One end of the piece of thread was affixed to the axle of the speed reducer, while the other end contained a hook, which was holding a plate. As the motor spun the thread was slowly winding onto an axle, this lifted the plate. The plate contained a specific number of weights.

The speed reducer increased the power of the motor, but decreased its speed.

Eight similar weights were used during the experiment for four different circuits under each voltage. Cans of tuna were used as weights, the weight of each can was 7.4 oz.

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

It is important to note that voltages in excess of 4.5 volts created a visible spark between the contacts inside the reed switch tube. As it was mentioned earlier, this may weld the contacts together.

This problem was encountered many times during the testing. After few hours, on high voltage settings, the motor would stop working for a few moments and restart. After several reed switches were damaged, heavy-duty reed switches were employed.

9. Results

The results for all the experiments were recorded in ten tables. The speed measurements were taken three times each to get accurate results, and then the average speed was calculated.

All the measurements were taken for seven voltage settings. It was noted that the current for circuits 3 & 4 exceeded the 500 mA limit of the power supply on voltages higher than 6V. Under load the current exceeded the limit for all 4 circuits on 6V or higher.

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 last column shows the power in watts. The way to find the power in watts is to multiply the current, in amps, by the voltage.

Voltage, V	Circuit	No Load						Load:0 (with speed reducer)					
		Speed, rpm			Avg	Current, mA	Power, W	Speed, rpm			Avg	Current, mA	Power, W
1.5	1	1255	1292	1303	1283	70	0.105	375	417	335	376	90	0.135
	2	1393	1437	1361	1397	55	0.0825	337	431	399	389	70	0.105
	3	1612	1493	1542	1549	145	0.2175	639	639	731	670	140	0.21
	4	2163	2159	2147	2156	150	0.225	819	817	819	818	150	0.225
3.0	1	2454	2435	2503	2464	80	0.24	1229	1229	1239	1232	133	0.399
	2	3247	3224	2855	3109	65	0.195	1361	1375	1321	1352	100	0.3
	3	3545	3557	3565	3556	260	0.78	1439	1431	1421	1430	250	0.75
	4	3747	3757	3858	3787	350	1.05	1578	1561	1555	1565	280	0.84
4.5	1	5819	5787	5935	5847	90	0.405	1847	1959	1829	1878	160	0.72
	2	6009	6969	6023	6334	70	0.315	2071	2053	1969	2031	130	0.585
	3	4724	4763	4741	4743	280	1.26	1893	1841	1833	1856	335	1.5075
	4	6135	5989	6023	6049	320	1.44	1867	1865	1897	1876	370	1.665
6.0	1	7776	7611	5953	7113	130	0.78	2779	2985	3031	2932	200	1.2
	2	9001	9543	6023	8189	110	0.66	3459	3435	3405	3433	170	1.02
	3	6373	6014	4741	5709	440	2.64	2459	2343	2493	2432	400	2.4
	4	6851	6941	6903	6898	440	2.64	2553	2535	2543	2544	470	2.82
7.5	1	7431	7637	7631	7566	180	1.35						
	2	9298	9092	9123	9171	125	0.9375						
9.0	1	11140	11126	10857	11041	210	1.89	Current exceeds 500 mA					
	2	12202	12218	12058	12159	175	1.575						
12.0	1	15345	15310	15498	15384	290	3.48						
	2	16415	16547	16383	16448	180	2.16						

Circuit 1: 1 electromagnet and 1 reed switch
Circuit 2: 2 electromagnets in serial connection with 1 reed switch
Circuit 3: 2 electromagnets in parallel connection with 1 reed switch
Circuit 4: 2 electromagnets controlled by separate reed switches

Voltage, V	Circuit	Load:1 (7.4 oz)						Load:2 (14.8 oz)					
		Speed, rpm			Avg	Current, mA	Power, W	Speed, rpm			Avg	Current, mA	Power, W
1.5	1	Unable to lift the weight						Unable to lift the weight					
	2												
	3												
	4												
3.0	1	685	695	737	706	150	0.45	575	589	476	547	190	0.57
	2	937	1215	1201	1118	120	0.36	729	641	683	684	130	0.39
	3	1211	1345	1203	1253	250	0.75	805	771	732	769	250	0.75
	4	1263	1323	1313	1300	270	0.81	865	781	803	816	270	0.81
4.5	1	1991	1999	1987	1992	175	0.7875	1357	1257	1349	1321	200	0.9
	2	2349	2419	2372	2380	120	0.54	1225	1319	1272	1272	150	0.675
	3	2309	2239	2267	2272	340	1.53	1225	1203	1149	1192	370	1.665
	4	2387	2419	2395	2400	360	1.62	1181	1141	1135	1152	410	1.845
6.0	1	2797	2684	2848	2776	240	1.44	2035	2283	2185	2168	250	1.5
	2	2579	2657	2481	2572	180	1.08	2315	2373	2377	2355	190	1.14
	3	2285	2247	2252	2261	430	2.58	1883	1895	1832	1870	435	2.61
	4	1985	1976	1992	1984	460	2.76	1727	1672	1681	1693	470	2.82
7.5	1	Current exceeds 500 mA						Current exceeds 500 mA					
	2												
9.0	1												
	2												
12.0	1												
	2												

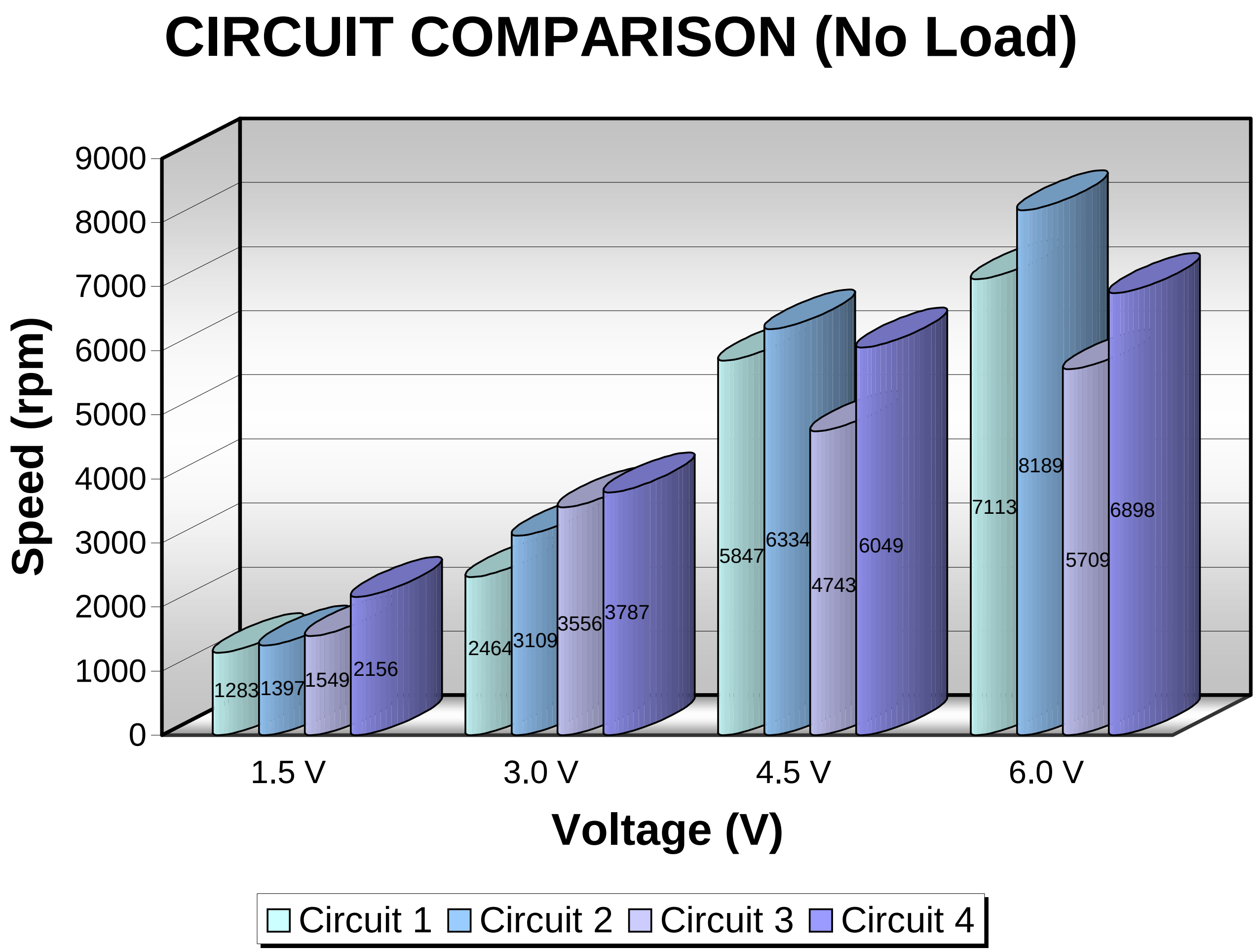
Voltage, V	Circuit	Load:3 (1 lb 6.2 oz)						Load:4 (1 lb 13.6 oz)					
		Speed, rpm			Avg	Current, mA	Power, W	Speed, rpm			Avg	Current, mA	Power, W
1.5	1	Unable to lift the weight						Unable to lift the weight					
	2												
	3												
	4												
3.0	1												
	2	541	551	572	555	130	0.39	473	483	461	472	110	0.33
	3	589	601	647	612	250	0.75	149	661	653	488	260	0.78
	4	645	645	682	657	290	0.87	511	523	641	558	275	0.825
4.5	1	811	769	803	794	200	0.9	1045	1057	1035	1046	150	0.675
	2	1099	1141	1105	1115	140	0.63	1451	1271	1373	1365	150	0.675
	3	1297	1133	1093	1174	380	1.71	1315	1227	1317	1286	370	1.665
	4	1119	1135	1094	1116	380	1.71	1241	1253	1230	1241	400	1.8
6.0	1	1773	1721	1775	1756	200	1.2	1269	1221	1197	1229	270	1.62
	2	1713	1787	1775	1758	100	0.6	1773	1625	1623	1674	180	1.08
	3	1805	1825	1792	1807	270	1.62	1407	1425	1349	1394	450	2.7
	4	1529	1611	1539	1560	370	2.22	1515	1393	1461	1456	470	2.82
7.5	1	Current exceeds 500 mA						Current exceeds 500 mA					
	2												
9.0	1												
	2												
12.0	1												
	2												

Circuit 1: 1 electromagnet and 1 reed switch
Circuit 2: 2 electromagnets in serial connection with 1 reed switch
Circuit 3: 2 electromagnets in parallel connection with 1 reed switch
Circuit 4: 2 electromagnets controlled by separate reed switches

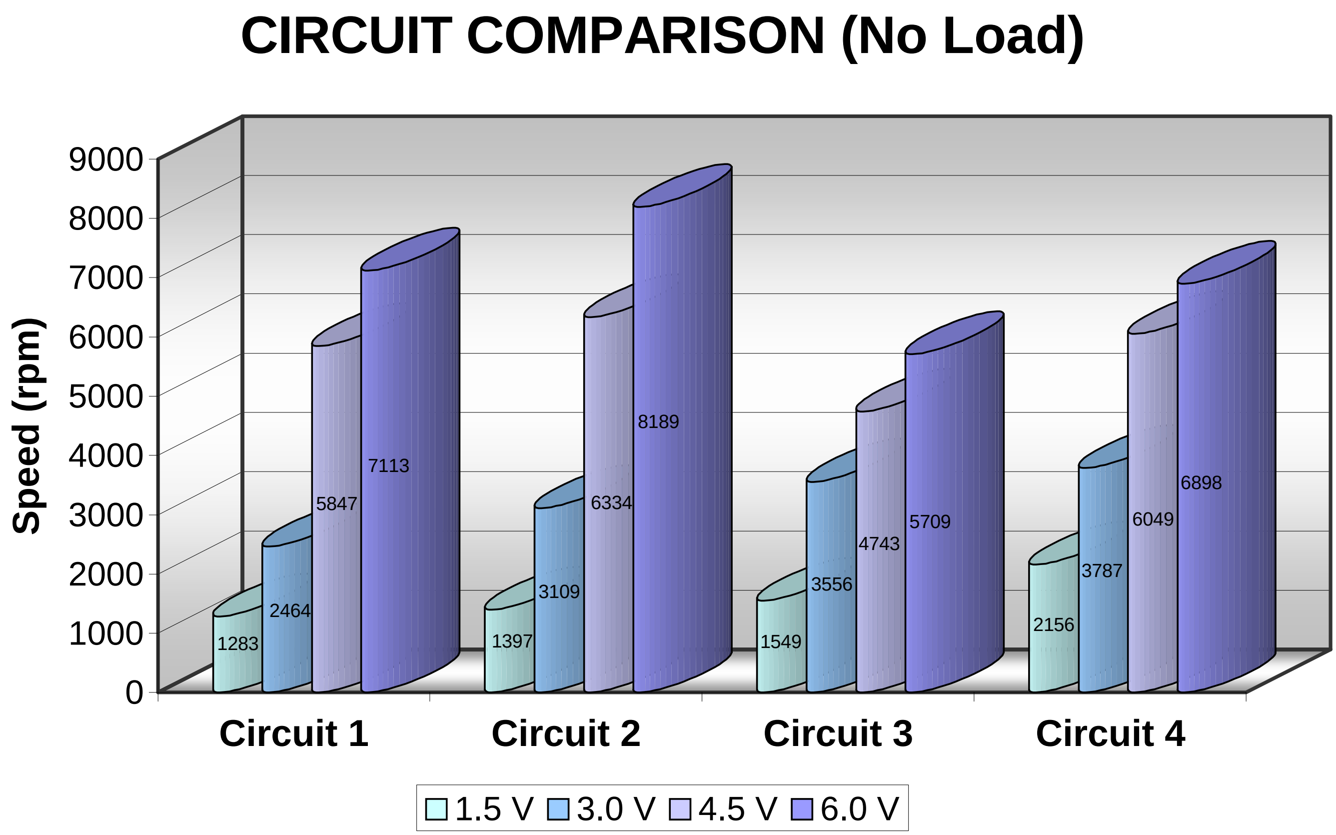
Voltage, V	Circuit	Load:5 (2 lbs 5.0 oz)						Load:6 (2 lbs 12.4 oz)					
		Speed, rpm			Avg	Current, mA	Power, W	Speed, rpm			Avg	Current, mA	Power, W
1.5	1												
	2												
	3												
	4												
3.0	1	Unable to lift the weight						Unable to lift the weight					
	2												
	3												
	4												
4.5	1												
	2	867	867	879	871	150	0.675	1085	937	959	994	140	0.63
	3	1293	1039	1145	1159	410	1.845	835	819	847	834	350	1.575
	4	759	549	431	580	390	1.755	747	755	765	756	380	1.71
6.0	1	Unable to lift the weight						Unable to lift the weight					
	2	1381	1393	1342	1372	170	1.02	1266	1283	1243	1264	160	0.96
	3	1107	1189	1139	1145	450	2.7	997	1027	895	973	440	2.64
	4	1501	1521	1499	1507	150	0.9	1389	1415	1493	1432	450	2.7
7.5	1												
	2												
9.0	1	Current exceeds 500 mA						Current exceeds 500 mA					
	2												
12.0	1												
	2												

Voltage, V	Circuit	Load:7 (3 lbs 3.8 oz)						Load:8 (3 lbs 11.2 oz)					
		Speed, rpm			Avg	Current, mA	Power, W	Speed, rpm			Avg	Current, mA	Power, W
1.5	1												
	2												
	3												
	4												
3.0	1												
	2												
	3	Unable to lift the weight						Unable to lift the weight					
	4												
4.5	1												
	2												
	3												
	4												
6.0	1												
	2	1101	1167	1163	1144	160	0.96	615	685	665	655	150	0.9
	3	814	843	821	826	400	2.4	Unable to lift the weight					
	4	943	971	951	955	500	3						
7.5	1												
	2												
9.0	1	Current exceeds 500 mA						Current exceeds 500 mA					
	2												
12.0	1												
	2												

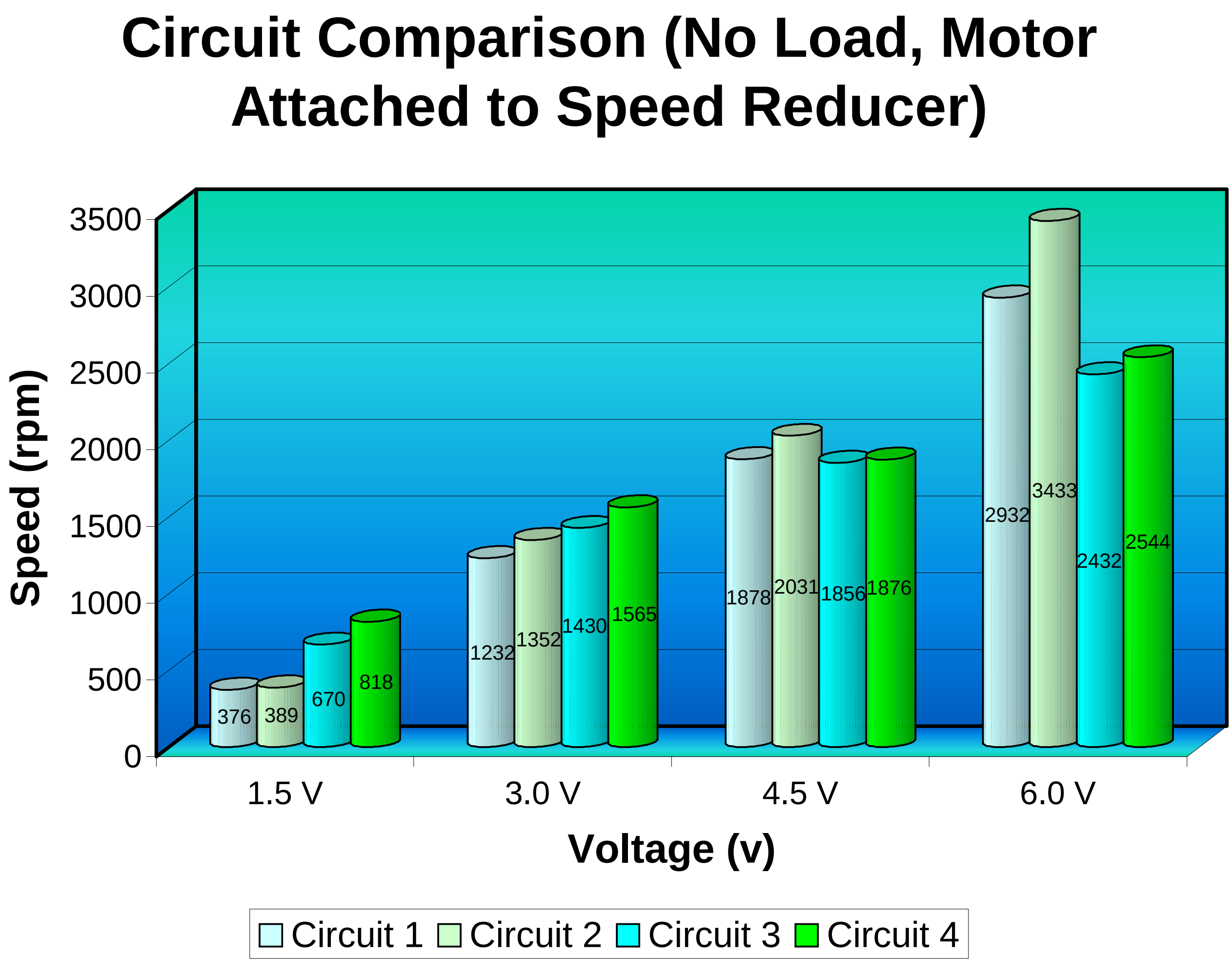
Circuit 1: 1 electromagnet and 1 reed switch
Circuit 2: 2 electromagnets in serial connection with 1 reed switch
Circuit 3: 2 electromagnets in parallel connection with 1 reed switch
Circuit 4: 2 electromagnets controlled by separate reed switches



This graph demonstrates how the speed increases with voltage growth for all 4 circuits. No load was attached to the motor during this testing. The speed changed dramatically from 1283 rpm at circuit 1 on 1.5 volts, to 8189 rpm at circuit 2 on 6 volts.

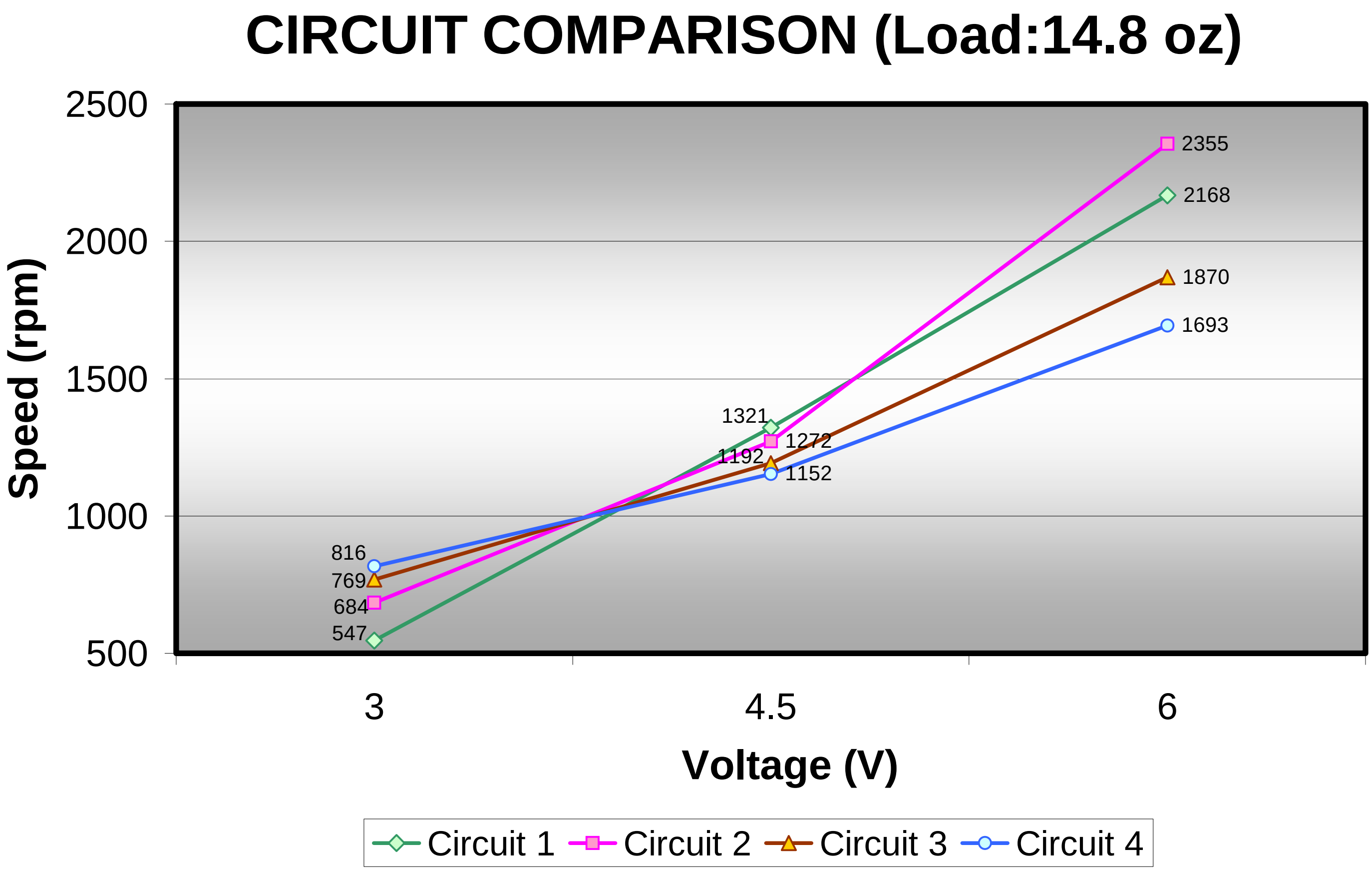


This graph is another representation of the diagram on the previous page. The circuits are shown in separate groups to highlight their comparison. Circuit 2 shows the fastest growth, while circuit 3 is the slowest.



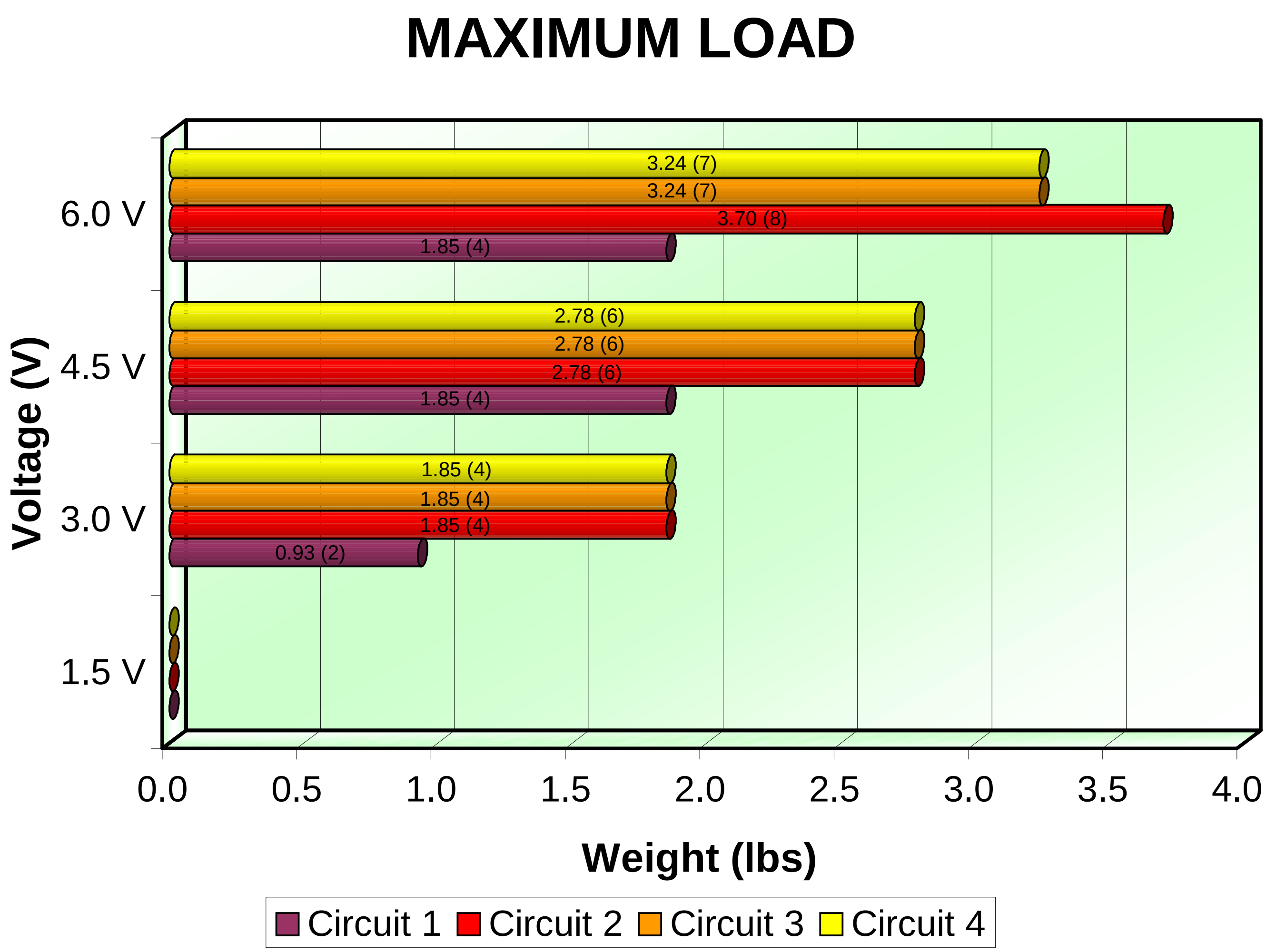
This graph is similar to the diagram on page 22. It also demonstrates how the speed increases with voltage growth for all 4 circuits. In this case the motor was attached to the speed reducer. It added a significant load. In this experiment there were no weights on the platform, however the friction of the gearbox slowed down the speed of the motor.

Once again circuit 2 outperformed the other circuits, and showed the fastest speed growth.



The line graph above shows how the speed increases with voltage change for each circuit when two 7.4 oz cans were put on the platform. This chart only has 3 voltage settings due to the fact that the motor was unable to lift this number of weights on 1.5 volts.

Again circuit 2 proved to show the best speed growth. Circuit 1 displayed the next best results, while circuits 3 and 4 demonstrated a slower increase of speed. Similar results could be observed for the other weights.

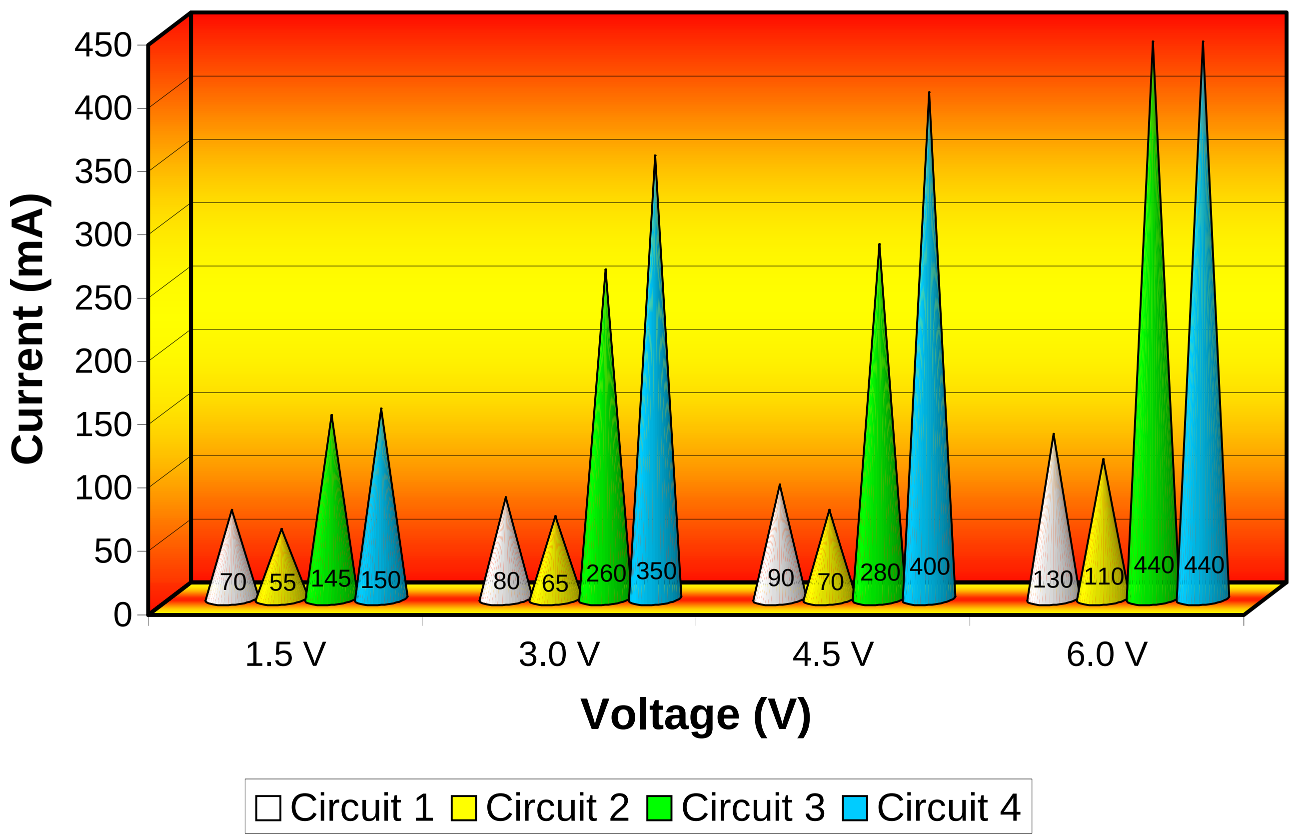


This graph shows how many cans each circuit can lift on four different voltage settings. It is easily noteable that the voltage growth increases the power of each motor. Circuit 2 showed the best results, while circuit 1 demonstrated the smallest power increase. Circuits 3 and 4 had equal power growth.

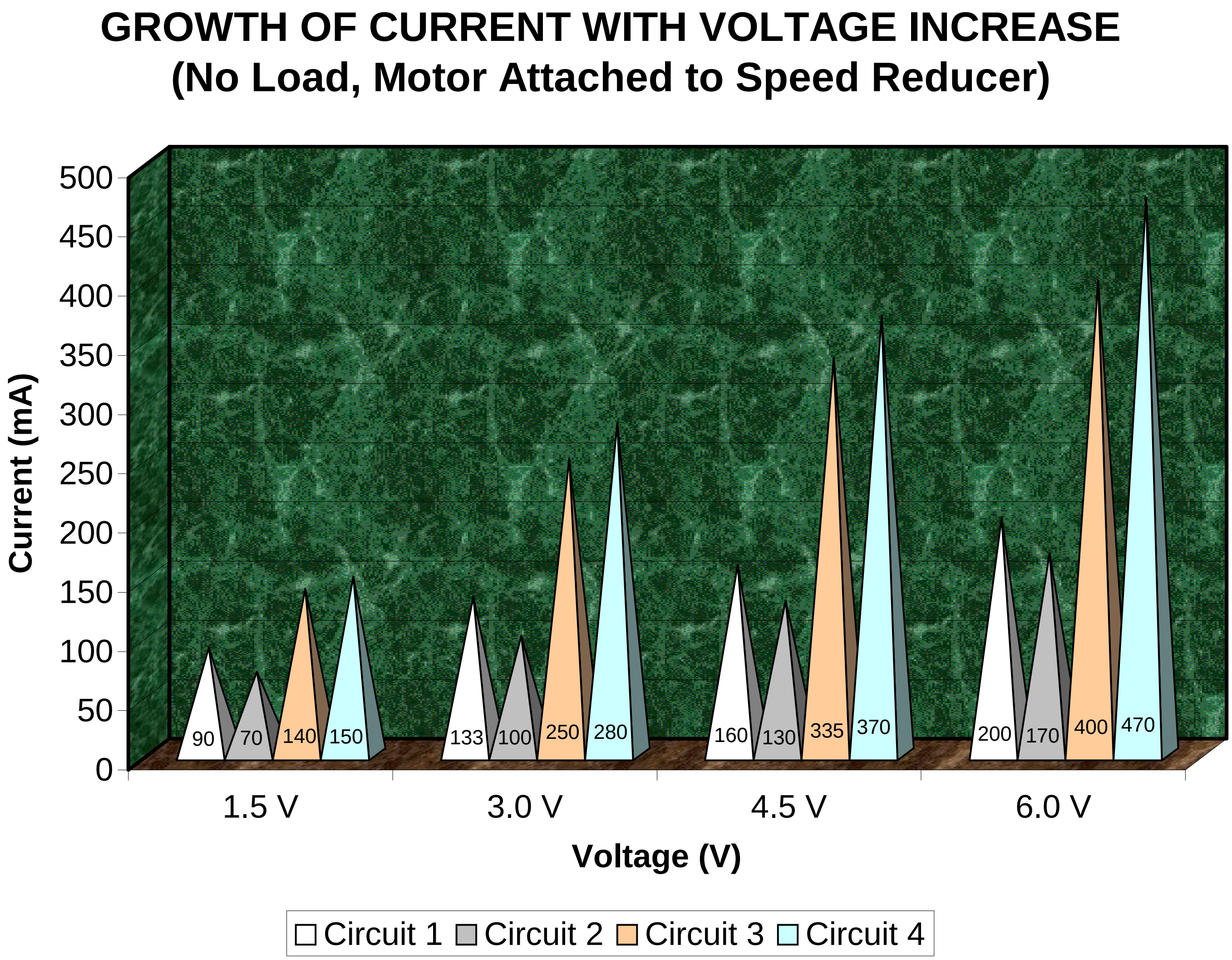
The increment in weight measurements was 7.4 oz, or 1 can. For the purposes of this project, it was not nessecary to determine the exact weight each motor can lift.

On 1.5 volts the motor was only powerful enough to lift the empty platform.

GROWTH OF CURRENT WITH INCREASE OF VOLTAGE (No Load)

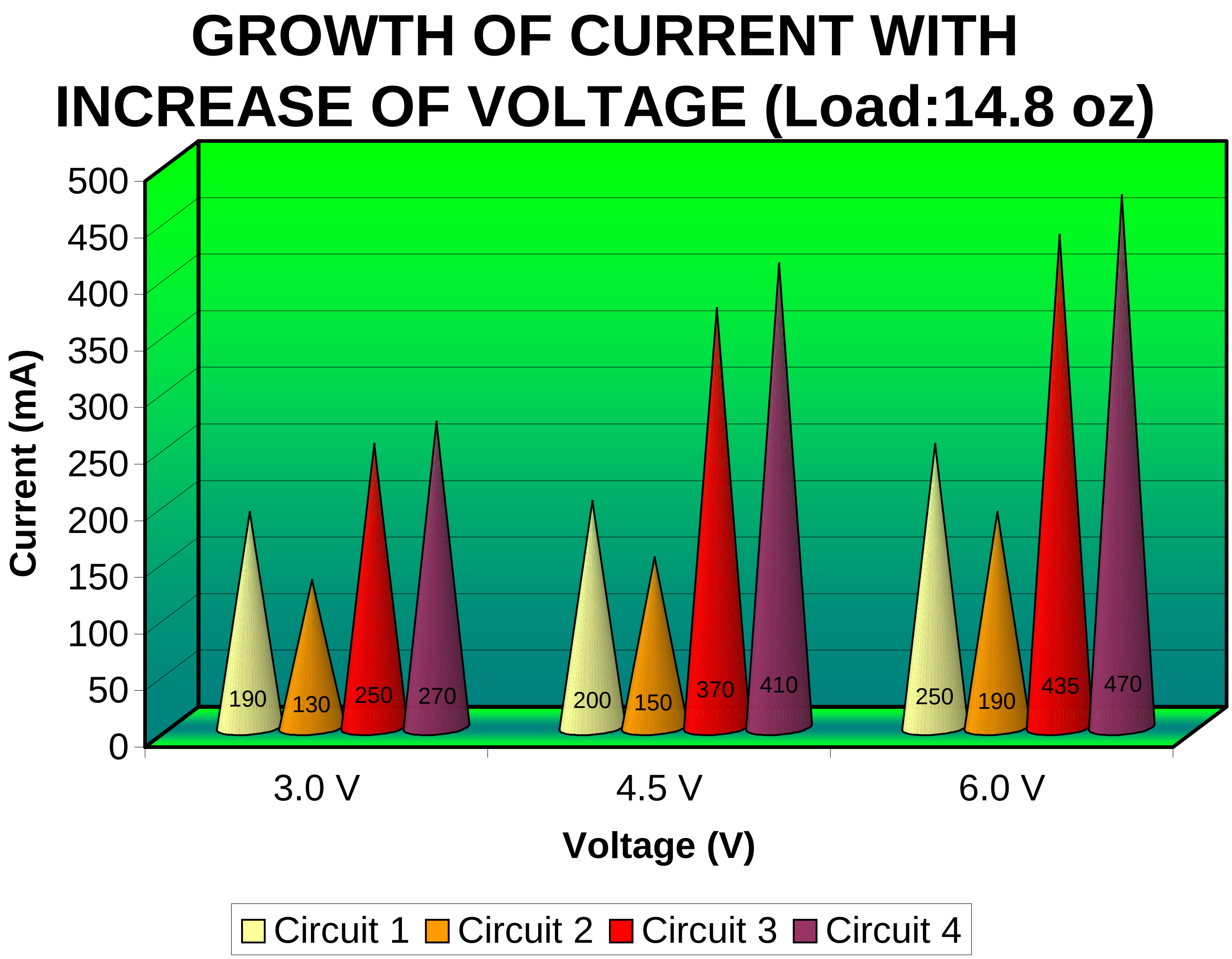


This graph demonstrates how the current increases with voltage growth for all 4 circuits. No load was attached to the motor during this testing. The significant growth of current was recorded for circuits 3 & 4. It is also visible that circuit 2 consumed less current than circuit 1. This means that circuit 2 outperformed the other motors in this testing, and circuit 1 also showed good results.



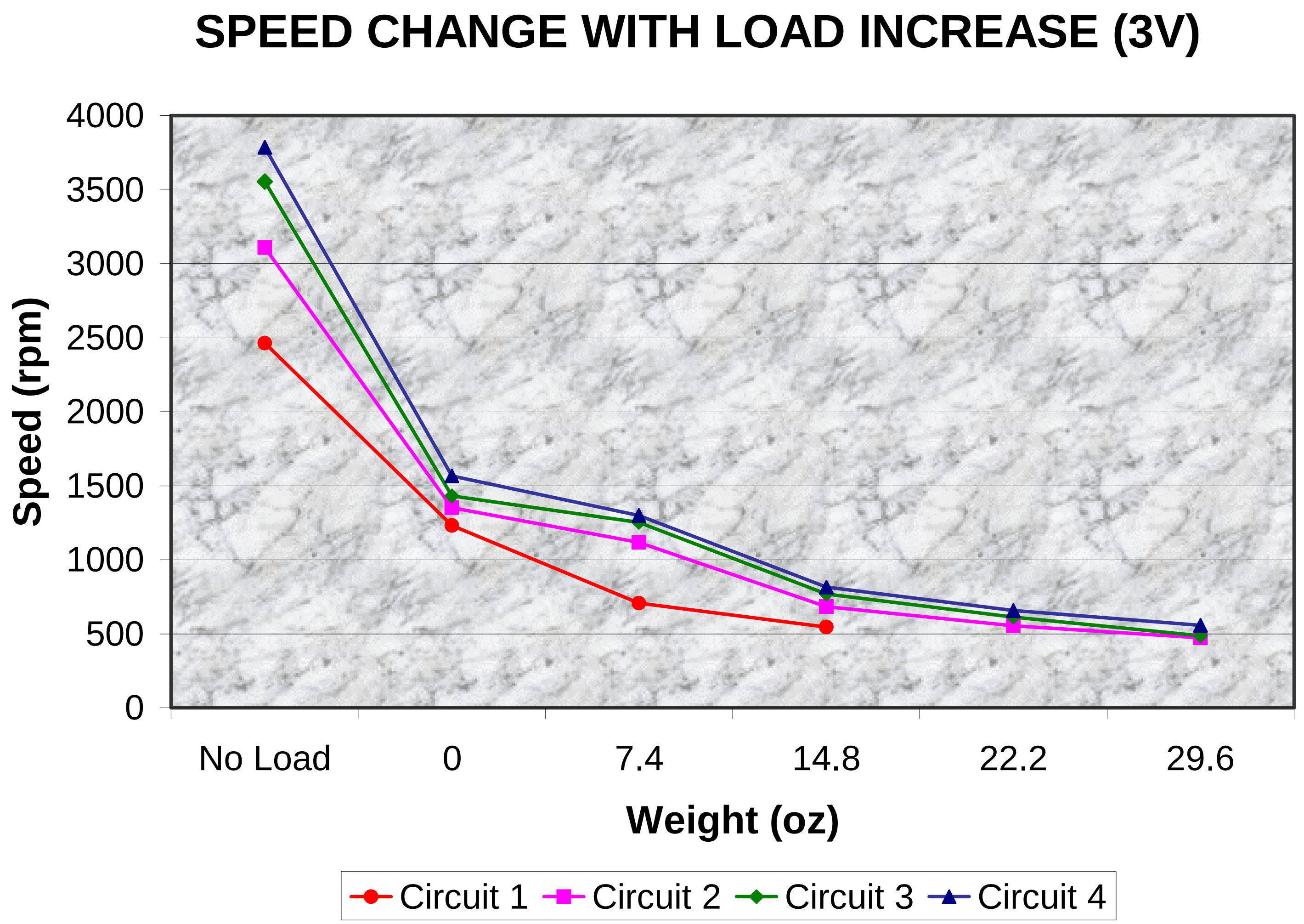
This graph is similar to the diagram on the previos page. It also demonstrates how the current increases with voltage growth for all 4 circuits. In this case the motor was attached to the speed reducer. It added a significant load. In this experiment there were no weights on the platform, however the friction of the decelerator made the motor consume more current to keep running.

Once again, circuit 2 outperformed the other circuits, because it used less current.



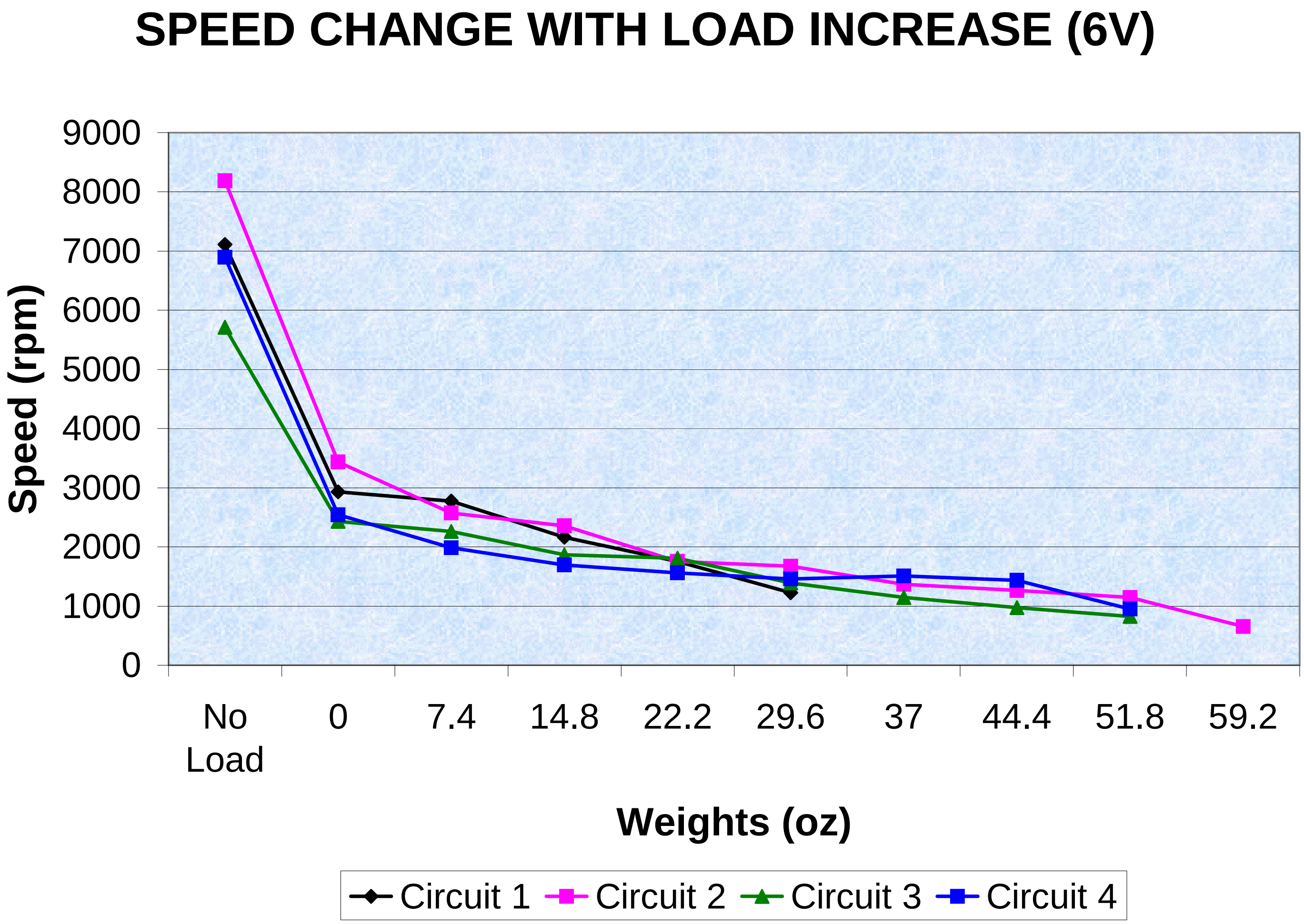
The graph above shows how the current increases with voltage change for each circuit when two 7.4 oz cans were put on the platform. This chart only has 3 voltage settings due to the fact that the motor was unable to lift this number of weights on 1.5 volts.

Again circuit 2 proved to be the best. Circuit 1 displayed the next best results, while circuits 3 and 4 demonstrated a faster increase of current. Similar results could be observed for the other weights.



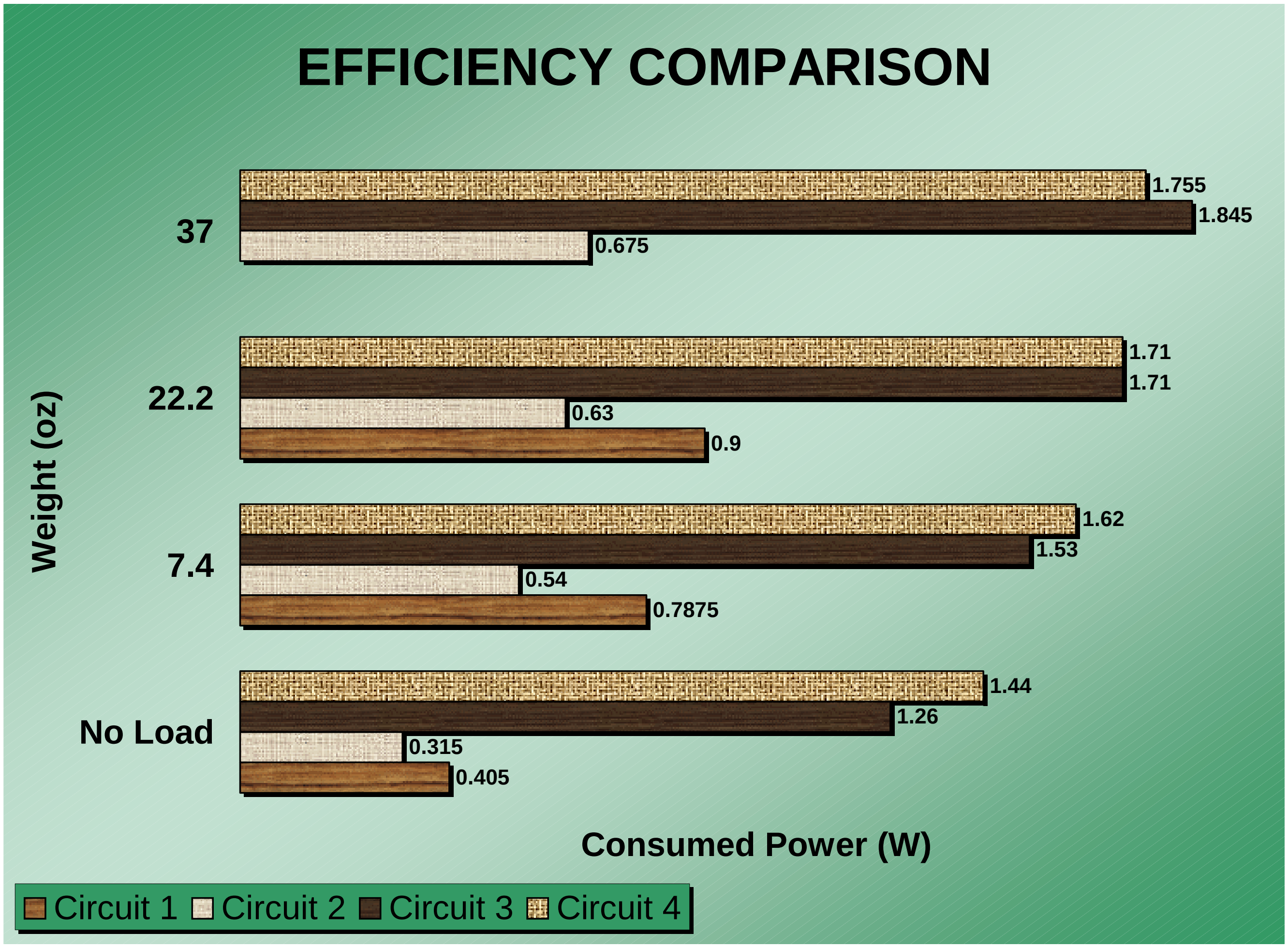
This line graph shows the decrease of speed with the increase of load for the four motors. The measurements were taken on 3V.

A big decline in speed occurs when the motor is connected to the speed reducer. The friction of the gears within it added a significant load to the motor. It is also visible that circuit 1 underperformed in this test as it could lift only 14.8 oz, or 2 cans. Circuits 2, 3, and 4 had results similar to each other. The decrease of speed slowed down after 14.8 oz.



This graph is similar to the one on the previous page. The measurements were taken on 6V.

Once again a big decline in speed occurs when the motor is connected to the speed reducer. It is also visible that circuit 1 underperformed in this test as it could lift only 29.6 oz, or 4 cans, while circuit 2 proved to be more powerful. It could lift 59.2 oz, or 8 cans. All circuits had results similar to each other, after being connected to the speed reducer. The decrease of speed slowed down after that.



It is known that the efficiency of a motor is the ratio of its useful output to its total input. Input power is the electrical power these motors consume. It was calculated in the tables at the beginning of this chapter. The output power is proportional to the torque of the motor. Therefore, the circuit that lifts the most weight and consumes less power to do it is proven to be more efficient.

This graph, taken at 4.5 volts, clearly demonstrates the efficiency comparison. It shows that circuit 2 is the most efficient, because it consumed less power to do the same work. Circuit 1, or the original motor, also had good efficiency, while circuits 3 and 4 showed only satisfactory results in this test.

For example, in order to lift 7.4 oz, circuit 1 consumed 0.7875 watts of electricity (175 mA at 4.5V). Circuit 2 showed the best results using 0.54 watts (120 mA at 4.5V). Circuits 3 and 4 used much more electrical power, they consumed 1.53 and 1.62 watts, respectively.

Similar results may be observed for other loads and voltages.

The most impressive result was achieved in no-load efficiency test: one of the motors (circuit 1) worked non-stop over 50 hours on one 1.5 Volts AA size battery. This result is better than most of industrial motors with comparable power can provide. The regular conventional motor, used in some toys, drained the same size battery in less than 19 hours.

The table below represents the summarized ranking of four circuits using all experiment data. The speed, torque, and efficiency ranks are based on the tables and graphs on the previous pages. Complexity is ranked by the number of parts in each circuit.

Circuit Classification

	Speed	Torque	Efficiency	Complexity	Overall Rank
Circuit 1	4	4	2	1	3
Circuit 2	1	1	1	2	1
Circuit 3	3	2	3	2	2
Circuit 4	2	2	4	4	4

Circuit 2 showed the best overall performance in speed, torque, and efficiency testing, However, circuit 1 (the original motor) was still the most simple and least expensive.

10. Conclusion

In the first year research a new simple inexpensive brushless DC motor based on a reed switch was invented, built, and tested. The results of the experiments showed that the new motor was very reliable, stable, and powerful enough to be favorably compared to existing conventional motors. However, that prototype needed many improvements and developments, and more reliable experiments had to be accomplished.

The second year study was devoted to the development of this motor. The motor was completely redesigned. Extra circuits with another electromagnet and/or reed switch were added to the prototype. According to the results of the experiments this year hypothesis, that it will improve the motor and its performance, was proven.

A complex model was designed and built for the experiments in this project. This model allowed an easy and effective switch between the following circuits:

- 1 electromagnet and 1 reed switch as a control circuit representing the original idea
- 2 electromagnets in serial connection with 1 reed switch
- 2 electromagnets in parallel connection with 1 reed switch
- 2 electromagnets controlled by separate reed switches.

The manipulated variable in the experiments was voltage. The controlled variable was the number of weights in torque testing. The responding variables were the speed, measured in revolutions per minute, and the current, measured in milliamps.

According to the charts and graphs based on the experiment data, the motor with 2 electromagnets in serial connection showed the best overall performance in speed, torque, and efficiency testing, However, the original motor was still the most simple and least expensive, while providing comparable results.

Several motors were built and tested many times, and all of them worked well. The new design eliminated the “dead spot” problem encountered in last year research. Very reliable and innovative methods were used to measure speed and estimate torque of the motors. When attached to the speed reducer, the motors were tested in a real application. 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 in the speed reducer, small changes in reed switch position after replacement, and changes in applied voltage.

The results of the experiments showed that the motor is 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 (based on transistors or other solid state technology) allowing to control big voltages and currents with small signals. It should also eliminate the spark inside the reed switch tube.

In future development it is planned to design a small portable version of the reed switch based brushless motor to be used in real life applications, for example in toys. Some other suggested areas for the future usage may include portable computer systems and cameras, because of their efficiency requirements. This motor may also be used as an educational kit to demonstrate principles of electricity and magnetism.

With proper modification 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 dad showed me how to use relays in my model to switch between different circuits.
- Last year 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! I used this counter in this year project.
- 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 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.

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