Passive Magnetically Assisted Bearing Flywheel

Final Report

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Abstract

Todd Becker, Robert Marshall, Scott Nye, and Brooke Stevens teamed up with Dr. Van Dyke to build a flywheel based energy storage system using passive magnetically assisted bearings. This design can be used for remote locations or perhaps as a low cost energy storage system. It is important because unlike batteries, a flywheel system does not use hazardous chemicals and can have a very long lifespan unaffected by temperature.

Table of Contents

1. Introduction

1.1 Description

Over the past several years, there has been an increased priority in finding and using alternate energy due to the fact of limited natural resources. With this comes the increased need for a way to store this energy. Currently most of this energy storage is done with chemical batteries. These batteries have several downfalls. The first downfall is that they degrade over many charges and recharge cycles, thus giving them a finite time period before they need to be replaced. The second is they often use toxic chemicals that can be very dangerous and even deadly to humans and extremely harmful to the environment if not disposed of properly. The third downfall is that they perform poorly in extreme temperatures. Two other options that can be used for energy storage are capacitors and fuel cells. Capacitors have problems when operating in extreme temperatures and fuel cells have high material cost that puts it beyond marketability in most situations. This leads to the flywheel design particularly using traditional magnetic bearings. These designs have many benefits such as a long life and low maintenance cost. However flywheel designs currently lack some reliability and have a very high initial cost due to the exotic magnetic materials and complex control systems. This project was spawned from the current magnetic bearing designs. Utilizing the current designs and the places where possible improvements could be seen, the following objectives were developed:

1. To design a flywheel able to store 20 Watt-Hours of energy
2. To design a flywheel with passive magnetically assisted bearings
3. To design a flywheel that will cost less than $500

4. To design a casing that can contain the flywheel incases of catastrophic failure

5. To design a flywheel with losses below 5% per day for a two week period.

1.2 Literature Review

The flywheel dates back to the early days of combustion engines and steam engines, but not until the 1970's has it become recognized as a possibility for long-term energy storage. Only now is flywheel energy storage becoming a realistic solution to energy storage. This is made possible by carbon nano tubes, carbon fiber, and computer control systems.

The flywheel energy storage system works on a principle of rotating mass. The kinetic energy stored in a disc flywheel is expressed by $KE = (.5)(I)(w^2)$. Usually there are magnetic bearings to keep friction in the system negligible. The magnetic bearings are usually actively controlled by computers. When the flywheel becomes off balance, electromagnets are used to realign it. However, a very limited number of systems have been developed using passive magnetic bearing systems. In these systems, the flywheel spins at lower speed, and is more sensitive to vibration, but they cost less and are more efficient

Flywheel energy systems are currently being developed in labs throughout the country, including companies and organizations such as NASA, AFS Trinity, Beacon Power and US Flywheel Systems. Beacon Power, in Massachusetts, has developed the most economically feasible system; running at 20,000 rpm; the 150 lb flywheel stores 2 kWh. However, the cost is still about $30,000. Their system has been used to keep telecommunications going during outages in Mexico, where extreme temperature has adverse effects on chemical batteries. NASA has developed the most exotic flywheels, weighing less than 30 lbs, rotating at 100,000 rpm and storing 3 kWh. These flywheels are designed to replace the batteries in the space station and will help provide attitude control. The most fascinating flywheel energy storage system has been developed by ASF Trintity. They are the only company to achieve a working passive system, with help from Dr. Post of Lawerence Livermore National Laboratory. The system finds a way to work around Ernshaw's Theorem, which states that passive magnetic levitation is impossible. The design uses a Halbach array, which is an arrangment that produces an almost perfect monopole and was developed in 1985.

Approaches to energy storage other than flywheels do exist. Chemical batteries and capacitors are also possible solutions. Capacitors have beneficial characteristic such as operating temperatures that go from –40^{o}C to 70^{o}C. Their losses are very low, close to .5% per day, and they do not degrade as a result of many discharge cycles. The best capacitor available to the public is the Powercache PC2500 capacitor. It is used in many military hybrid vehicles, especially when high power surges are needed. These capacitors have a 2700 Farad capacitance, which gives that ability to store 2.3 Wh. The specific energy of these capacitors is 3.2 Wh/kg; the specific power of the capacitor is 11.5 W/kg. Their specific powers are very high, making them beneficial when high current surges are needed. However, their specific power is somewhat low, and their cost.

The most typical device used for power storage is the chemical battery. The most advanced batteries currently available are lithium polymer batteries. On the cutting edge, 3M is in the process of developing lithium polymer batteries with energy densities of 200

Wh/kg. These batteries are part of a $32.9 million project lead by 3M to make energy dense batteries for electric vehicles. Current lithium polymer batteries actually available on the market are not quite as advanced. They typically have energy densities of 140Wh/kg. Their losses are only about .3% per day. The cost of such batteries is about $15 /Wh. This is quite high, but they, last through about 1000 full discharge cycles before they no longer work.

Capacitors and to a greater extent batteries are our current means of storing power. However, as a result of our research we believe that flywheels will soon reach lower initial costs, and they will begin to play a more important role in our society to meet our energy storage needs. They can endure harsh environments, reach specific energies of 200 Wh/kg, reach specific powers of 10,000 W/kg, and are able to last over 20 years. Flywheel energy storage systems will make alternative technologies, such as electric transportation, solar power, and wind power, economically feasible.

1.3 Solution

The feasibility of building a flywheel energy storage system was most likely. Batteries have been developed for over a century, so the likelihood of building a better battery over the course of two semesters was unlikely. Capacitors, like batteries have been developed, but also require process that could not be done without expensive and costly equipment. Because of the longevity and ruggedness of flywheel energy storage, and its relative simplicity, we concluded that we should try this approach to energy storage. However, we did not have thousands of dollars, and needed a way to make our project a more affordable. As a result of our experimentation and economic constrains, we decided to make a passive magnetically assisted bearing. This eliminated the need for great quantities of expensive NeFeB magnets. Even though we would have a friction point, we found that by reducing the weight of the flywheel on the friction point, we could reduce our friction to that equivalent to traditional passive and active magnetic bearing systems. The efficiency of our design could be seen in our small models.

2. Design Process

After the objectives were developed, the actually designing had to be completed. Three possible flywheel designs were developed. The first was a system that had a complete passive magnetic bearing system. This means that the flywheel would be suspended and spun using only passive magnets. This option was decided against because of the high cost for the machining of the magnets. This machining would involve less than a thousandth of an inch accuracy, which is beyond the majority of the shop equipment. The second system used was super conductors to both levitate and propel the flywheel, similar to maglev trains. This system was decided against because of the amount of energy needed to keep the super conductors at the low temperatures needed for operations. This energy would need to come out of the flywheel, which defeats the energy storage goal of the project. The third option looked at was a passive magnetically assisted bearing system. This system did not need as much precision, and did not need energy to continue spinning. This is the system that was chosen.

The passive magnetically assisted bearing system had very little available information. Much time was spent on experimentation to determine what setup would work the best to meet the objectives set out. The majority of the experimentation revolved around the placement of magnets. The magnet could be placed in several possible configurations (see appendix a). It was determined that arranging the magnet so that the attractive forces were pulling up on the flywheel would not only provide the most lift, but the most stability.

The next section that had to be looked at was the coupling system to connect the motor to the flywheel. This is important because the flywheel had to store energy and if the motor was permanently attached to the system, as soon as power stopped being delivered to the system, the motor would start drawing it back out of the flywheel. Originally it was thought that moving the motor away from the system would solve the problem, but with further investigation, this option would add to much instability to the system and could cause the flywheel to become unstable. Because of the stability problem, a magnetic coupling system was developed. This system allows for energy transfer without directly connecting the motor to the flywheel. This also allows for energy storage because the motor can be braked thus stopping it from drawing energy back out of the flywheel.

Once these two things were determined we where able to come up with our flywheel design using a passive magnetically assisted bearing system. This system works essentially as a spinning top. The first benefit this gives us is increased stability as the rate of spinning increases. The second benefit is one friction point, which allows reduced friction because of the lift on the flywheel from the magnets. This lift allows for improved performance of the system because as the flywheel weight is increased, the magnetic forces can be increase, which leads to the same friction force that the flywheel experiences. A complete drawing can be found in Appendix B.

(See appendix a) The power is applied through a DC motor in order to spin the flywheel at a very high rotational speed. The motor is connected to the flywheel by magnetic coupling. As discussed earlier, this allows for energy transfer without adding the friction in the motor to the flywheel system. Once the flywheel is powered up, the motor is braked; this is to keep the motor from pulling energy off from the flywheel. To retrieve the energy from the flywheel, the motor is allowed to spin by the flywheel through the magnetic coupling. For safety reasons, the flywheel will be encased in a container that will contain the flywheel if by chance, the flywheel were to fail.

Once the actually design was finished, the building materials needed to be chosen. For the most part, the materials needed were everyday building materials. For the flywheel frame, square steel tubing was used. For the casing, concrete was used. The magnets are an assortment of ferrite and pot magnets. The only part of major concern was the actual flywheel. This is because the flywheel needed to be able to hold up against great stresses introduced by spinning it at high speeds. For this 7075 aluminum was used.

3. Implementation

3.1 Construction

Once the designing was finished, we developed a plan on how to manufacture the prototype most efficiently. First was the work on the flywheel disc. This part would take the greatest amount of time, and was the critical part needed before anything else could be assembled. From there, the project branched into different sections consisting of the casing, the frame, and the magnetic coupling. These had their own priorities, because the frame had to be finished before the casing could be made to ensure that the frame would fit within the designed casing. At the same time the casing was being built, the magnetic coupling was worked on, because that was needed in order to test any of the system. Because of these interdependencies, extra time was allotted for each part of the flywheel system.

To begin the construction of our flywheel, we needed to first turn our central shaft. We needed to first turn the central shaft because in order to machine the flywheel on the lathe, the flywheel needs to have an axis to rotate on. We turned the shaft and added different steps to accommodate our various press fits. Once our shaft was turned, we started to focus on the flywheel. The flywheel started as an 18"x18"x1/2" plate of 7075 Al that we cut down to a 16" circle using the band saw. Once we had our flywheel rough cut, we milled the center hole and press fit it onto out shaft. Now that we had our flywheel pressed onto the shaft, we placed it on the lathe and began our machining. When we began to face the flywheel, we ran into deflection problems. To solve these deflection problems, we machined a collar to go beneath the flywheel itself to provide a sturdier base. This extra collar aided in the effectiveness of our press fit and did not affect our design. Now that the collar was added, we place the flywheel back on the lathe and our deflections were greatly minimized. Although using this collar minimized our deflections, we still had too much chatter to face off the sides of the flywheel. We attributed the remaining deflections to a crown in our plate. To solve this problem we needed to unpress the flywheel and place it on the milling machine. By using the milling machine with the rotary table base, we were able to machine the to and bottom of out flywheel to eliminate the crown. Now that our flywheel was faced on both sides, we pressed it again onto our shaft and continued machining. To finish our machining, we faced off one side of our iron disk and pressed that side on to of the flywheel ensuring a clean interface between the two different disks. Once the iron was pressed, we faced off the remaining side and finished the remaining machining.

After the flywheel was machined, we focused our attention on the replaceable tip and base. These two pieces were machined from the same stock as our central shaft. The tip is tapered to a point that rides in the cup shaped base ensuring that the flywheel can move slightly and self correct itself.

The frame is constructed entirely out of 1" square mild-steel tubing that is welded together. The frame has three separate sections, the top, bottom, and magnet assembly. Each part was constructed separately for ease of assembly and adjustment. The to consists of the motor housing and it also provides a support for our magnet assembly. The magnet assembly contains two pot magnets, which are press fit into the rectangular housing. The reason for the press fit is due to our inability to drill into he magnets in fear of disrupting the magnetic field. The final section of our frame is the bottom. This structure provides most of the support and is full adjustable for level.

The containment system was constructed from reinforced concrete, molded into a cylinder with a clear top. The clear top is made of Lexan and is bolted on the top using the threaded rod that runs throughout the concrete structure.

The magnetic coupling was the last part made in the construction process. It was made using the CNC milling machine due to the fact that the holes needed to all line up perfectly in order for the magnetic fields to interact correctly. The coupling was made in 4 pieces and is held together using threaded rod and the taped threads in the 4 pieces.

3.2 Operation

We have done some initial testing, however we have not pushed our project to failure. We have spun our flywheel up to a rotational speed of 1000 RPM, through the use of our magnetic coupling. The vibration that occurred was minimal, and it became more stable especially at rotational speeds above 1000 RPM. We do not wish to push the system to its specifications because the lifting magnet is not working properly due to the poor magnets. Spinning the flywheel to 11,500 RPM would ruin the tip, since the full weigh of the flywheel is currently resting on it. The flywheel could not reach 11,500 rpm because of the increased friction, and hence increased load on the motor. We also did not want to spin it up, because if there were a failure at high rotational speeds, there would be little left of the project for future work. There would also be little learned from the testing since the main lifting magnets are not working properly. The metal in the flywheel alone cost about $200. Damage to it would significantly increase costs to any possible future work

When we spun our flywheel up to 1000 RPM it took about 25 minutes to come to a stop. The coupling worked very well, and provided stability for the flywheel. This was encouraging, since the main magnet was not providing the stability it should. To make our project work as it was designed, a large round doughnut magnet is needed for the main lifting magnet. After this it should work properly, and it would be useful to test the whole system to its limits.

4. Schedule

See attached Gantt chart for proposed schedule and actually schedule. Appendix b

We had two setbacks to our planed schedule. The first was loss parts; the materials reached the college, but could not be found. Because of this, we were forced to delay the manufacturing of our project. The second problem was the actual machining of the flywheel. This took a lot more time than anyone expected due to unforeseen machine limitations. We also only had one group member who had experience machining so they had to do most of the complicated parts

5. Budget

Our total cost before factoring the estimated values of gifts comes to $438.58. This means that our project met the objective of costing less than $500 dollars. If the estimated cost of gifts, our total would be greater than $500. This overall cost would be decreased though because items such as bolts, steel, polycarbonate, and other such items would be bought in bulk and would therefore be less expensive. Below is a table of our expenses.

Qty.	Description	Specification	McMaster Supplies	Other Sources	Total
1	7075 AL Plate	18” x 18” x ½”	$ 157.82		
1	Polycarbonate	48” x 48” x ¼”	$ 90.35		
1	7075 AL Rod	¾”Od x 36”	$ 33.11		
2	POT magnets	2.5” 190 lb	$ 70.86		
1	Motor	12000 rpm		$ 3.49 *	
1	Steel for Frame	10’		$ 10.00	
1	Concrete	½ cubic yard		$ 20.00 *	
1	Rebar	20”x20”		$ 5.00 *	
4	NeFeB Magnets	½”x ½”x ½”		$ 25.00	
	Bolts/nuts			$ 32.00	
1	Steel Disc	6” OD x ½ “	$ 28.94		
	Hardware and casing framing cost			$50.00*	

	Totals		$ 381.09	$ 67.49**	$ 438.58**

*Estimated cost of a gift

** Total does not include gifts

6. Conclusions

Our group was quite successful in achieving our goals. We were able to meet all of our objectives except for the first and last ones. This is because of a problem with the magnets that we purchased and not with the design. The magnets that we acquired did not create the magnetic field that we needed to create the lift needed on the flywheel. Even so, we were able to achieve high speeds on the flywheel and relatively long spinning durations. During this project all of our group members were reminded of the time it takes to precision machine in the shop. We were also reminded that many of the delays that happen along the way in a project have nothing to do with the group its self. We ran across delays that could not be controlled or prevented by any member of the group. Overall the project went well and would be a great place for a future group to pick up.

7. Future Work

There are several areas that can be further developed to improve our flywheel energy storage system. The first area would be an electronic control system, which would deliver power to the motor when charging and then retrieve the power when discharging. A second aspect is a brake for the motor. While this was included in our design, it has not been built and implemented into the system. The brake would keep out the added friction losses due to the motor. A third area to work on is the size of the actual flywheel. With our design, the friction stays the same when the flywheel size increases because the magnetic force will also increase. Increasing the size of the flywheel would create a more efficient system. Finally, attaining better magnets for the main "lift" of the flywheel would reduce the friction at the tip increasing the efficiency of the flywheel.

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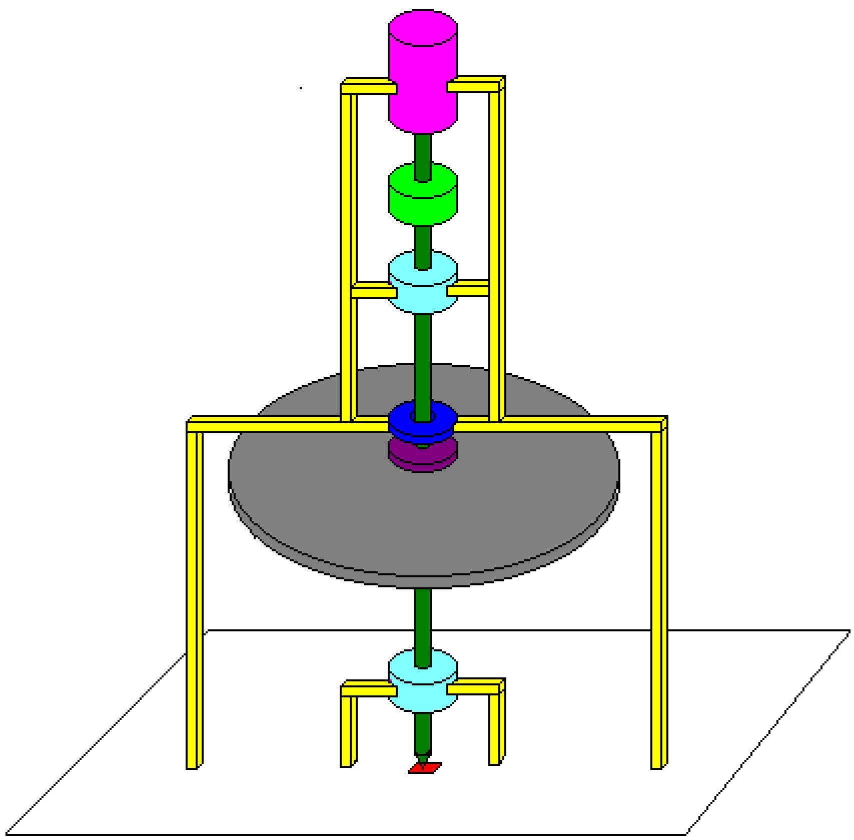
Appendix

A.



12,00 RPM 12v Motor/generator

Magnetic coupling

Axle, 6061 aluminum

Motor/Magnet bracket

Emergency bearings

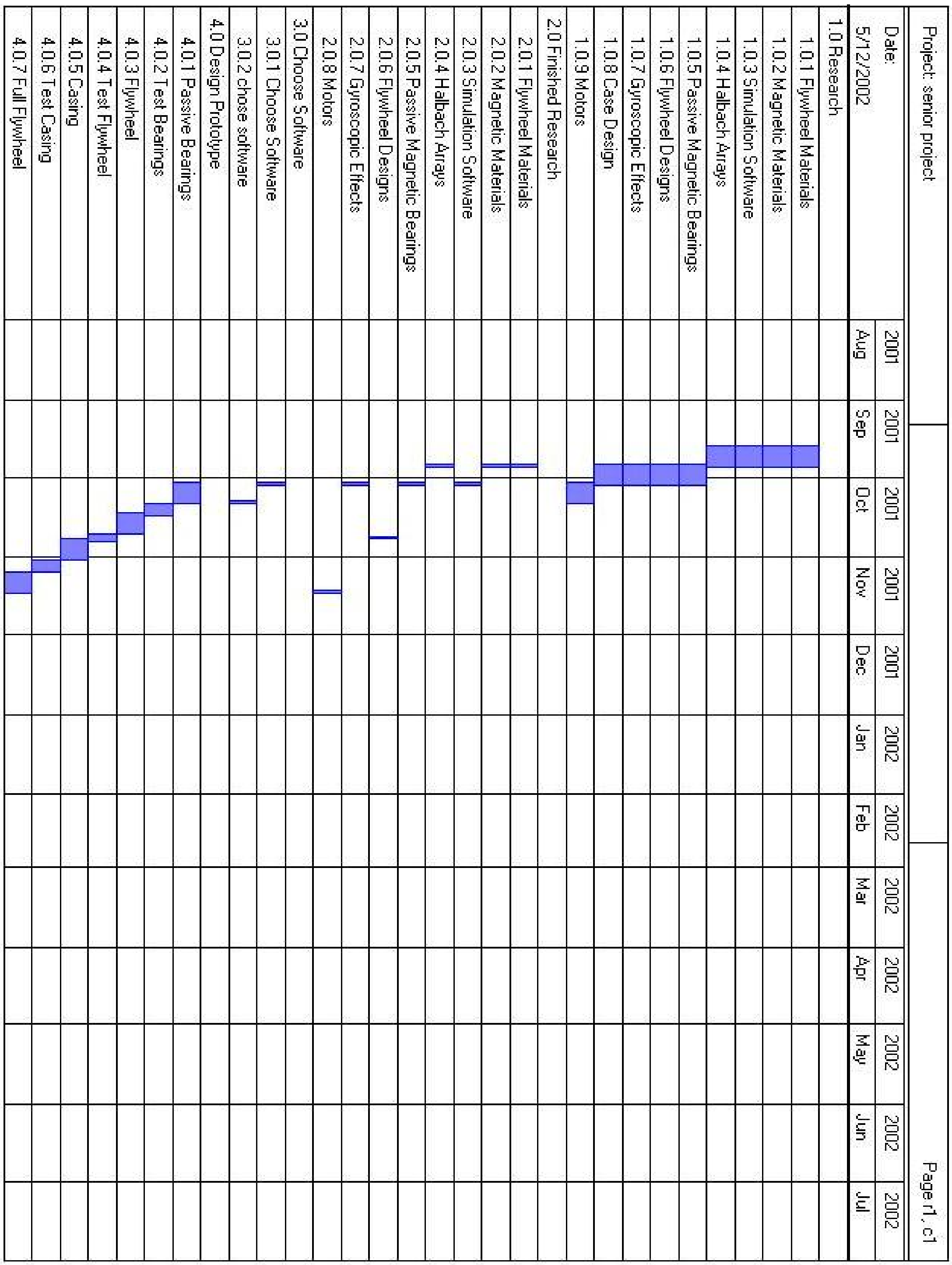
Force reducing magnet

Iron disc

Flywheel, 6061 aluminum

Industrial diamond tip and platform

B.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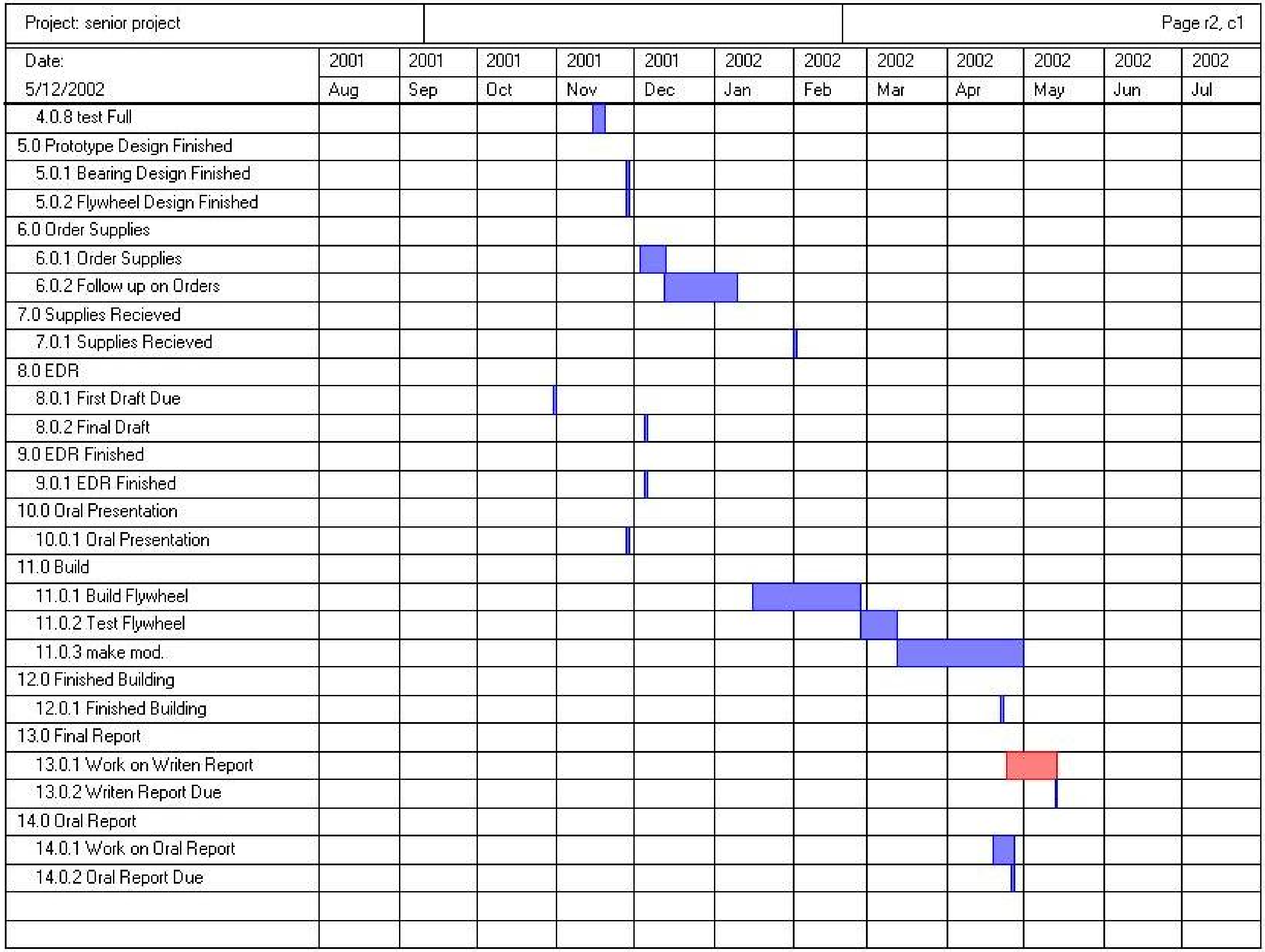
Page r1, c1
Date:
5/12/2002
2001 Aug
2001 Sep
2001 Oct
2001 Nov
2001 Dec
2002 Jan
2002 Feb
2002 Mar
2002 Apr
2002 May
2002 Jun
2002 Jul
1.0 Research
1.0.1 Flywheel Materials
1.0.2 Magnetic Materials
1.0.3 Simulation Software
1.0.4 Halbach Arrays
1.0.5 Passive Magnetic Bearings
1.0.6 Flywheel Designs
1.0.7 Gyroscopic Effects
1.0.8 Case Design
1.0.9 Motors
2.0 Finished Research
2.0.1 Flywheel Materials
2.0.2 Magnetic Materials
2.0.3 Simulation Software
2.0.4 Halbach Arrays
2.0.5 Passive Magnetic Bearings
2.0.6 Flywheel Designs
2.0.7 Gyroscopic Effects
2.0.8 Motors
3.0 Choose Software
3.0.1 Choose Software
3.0.2 chose software
4.0 Design Prototype
4.0.1 Passive Bearings
4.0.2 Test Bearings
4.0.3 Flywheel
4.0.4 Test Flywheel
4.0.5 Casing
4.0.6 Test Casing
4.0.7 Full Flywheel


Project: senior project
Page r2, c1
Date:
5/12/2002
2001 Aug
2001 Sep
2001 Oct
2001 Nov
2001 Dec
2002 Jan
2002 Feb
2002 Mar
2002 Apr
2002 May
2002 Jun
2002 Jul
4.0.8 test Full
5.0 Prototype Design Finished
5.0.1 Bearing Design Finished
5.0.2 Flywheel Design Finished
6.0 Order Supplies
6.0.1 Order Supplies
6.0.2 Follow up on Orders
7.0 Supplies Recieved
7.0.1 Supplies Recieved
8.0 EDR
8.0.1 First Draft Due
8.0.2 Final Draft
9.0 EDR Finished
9.0.1 EDR Finished
10.0 Oral Presentation
10.0.1 Oral Presentation
11.0 Build
11.0.1 Build Flywheel
11.0.2 Test Flywheel
11.0.3 make mod.
12.0 Finished Building
12.0.1 Finished Building
13.0 Final Report
13.0.1 Work on Writen Report
13.0.2 Writen Report Due
14.0 Oral Report
14.0.1 Work on Oral Report
14.0.2 Oral Report Due