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FINAL REPORT
US DOE Energy Related Inventions Program

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Flywheel Electric Battery
CE 15636
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What We Plan To Accomplish

Original Near Term Objectives

Thortek's initial business strategy is to obtain funding, either via the sale of company stock and/or by winning Government Research Grant, for development of a 2nd Generation Flywheel Battery Prototype designed for a specific application. Testing, verification, and certification of this prototype will yield a commercial product. Thortek plans to consult a Flywheel Design Center for verification of flywheel engineering and characteristics. Development of the magnetic bearings and integration and assembly of the battery will be conducted in house.

ESTABLISH PARTNERSHIP WITH STATE-OF-THE-ART COMPONENT MANUFACTURES

Thortek business strategy is to join forces by teaming agreements with the premiere leaders in magbearing and high performance composite flywheel technologies. Demonstrate these technologies in a complete flywheel system. Seek out and establish agreement with mass production manufacturers of composites and rare earth magnet material.

FABRICATE PROOF-OF-CONCEPT PROTOTYPE

In December 1993, Thortek will demonstrate a Proof-Of-Concept (POC) Flywheel Electric Battery with composite wound flywheel and permanent magnetic bearings. On 26 May 1993 NASA-Johnson Space Center in Houston, TX agreed to test the P.O.C. Prototype for Thortek. (A hypergolic fuel leak prevented any flywheel testing from being conducted at NASA JSC. The flywheel battery was relocated to NASA Lewis Research Center in December 1994 where budget problems and technical problems have prevented flywheel spin up. All technical problems have been solved.)

WIN FEDERAL GRANTS FOR PROTOTYPE DESIGN STUDY AND FABRICATION

Flywheels will not be able to financially compete against existing chemical batteries systems until many expensive flywheel systems and have been built and demonstrated. Very few companies are willing to provide the non-recurring cost of these first few flywheel systems and may have technical risks. Therefore, the reward of federal research and demonstration grants is essential to their success and the governments return on the flywheel investment they have already made.

Long Term Objectives

PILOT MANUFACTURING PLANT

Thortek intends on being a major manufacturer of Flywheel Energy Storage Systems, Permanent Magnetic Bearing Products and Permanent Magnetic Torque Coupler Products.

What Has Been Accomplished

Proposals & Contracts

Many proposals have been submitted to the government and businesses. While the proposals received high marks (19 out of 20; -1 point for "a one man shop") no contracts as yet have been awarded. Thortek has received a \$27,000 contract from NASA-LeRC to perform several tasks this summer which involves upgrading the Vacuum Chamber, fabricating the Magnetic Torque Coupler, and fabricating and automating the magnetic bearing test fixtures. Thortek has been notified by NASA-LeRC that it will be asked to perform a major (\$250,000+) flywheel development program later this fall.

Publications & Presentations

Thortek technologies and products have been published in *"Technology Assessments of Advanced Energy Storage Systems for Electric and Hybrid Vehicles"* 30APR1993 and 29FEB1996 by Abacus Technology Corp for DOE and our technology has been presented in *"Technologies for Energy Management"* by Cutter Information Corp. June 1996. Doug Thorpe made a presentation of Thortek technologies at the Flywheel Energy Workshop at Oak Ridge NL in November 1995.

Technology Advancement: Permanent Magnet Magnetic Bearings

Thortek has greatly increased its level of understanding of the permanent magnet, bull's eye pattern magbearing system. Magnetic test fixtures designed and fabricated by Thortek has produced extremely fine data on the magbearing characteristics. And although this magnetic bearing system was designed and developed by Precision Magnetic Bearing Systems, Inc. of Colonie, NY and is used by some FESS competitors, Thortek has tremendously improved the stability of this system by a patent pending process. Thortek flywheels with modified bull's eye pattern magbearings have been spun to 10,000 rpm which remained rock hard steady while seemingly unaffected by shocks or slight imbalance. Concern has been expressed by magbearing specialists that eddy currents produced by non-uniform magnetization would produce heat build-up and the magnets would self-destruct. Testing at 10,000 rpm in air has not legitimize this concern.

Magbearing Test Results

Two charts have been provided from the test fixtures developed by Thortek. The Radial Load vs Airgap & Displacement Chart shows that magnets #5 and #7 generate a maximum 37 lbs of shear correcting force when they are 0.062" in displacement and there is 0.001" airgap between them. Please note: the magnets are normally operated at 0.010" airgap and no more than 0.020" displacement. This data enabled us to generate a formula which will define shear correcting force parameters from one data point. The Magnetic Flux Density vs Radial Position Chart shows the 5 north pole and 4 south pole fields that are present on the bull's eye pattern magnets. (NASA LeRC has a much more expensive automated test fixture and has also performed this test, but not to the same degree as presented here.) NASA LeRC has also performed a rap test and found the first significant critical speed of the POC flywheel as 69,000 rpm which is greater than the maximum operating speed (22,900 rpm), thus the flywheel would not pass through high vibrational speeds during its normal operation.

Strategic Teaming Arrangements: Composite Flywheels

Thortek has joined forces with the world's premiere composite flywheel developer, Flywheel Energy Systems, Inc. of Ottawa, Canada. Together this team has worked to develop a commercial grade, high speed flywheel that has an energy density of 65 wh/kg (the Thortek POC flywheel had an energy density of 40 wh/kg) yet the new flywheel will cost the same to manufacture per kg as the poorer performer.

Thortek has made teaming arrangements with large composite manufacturers, ALCOA Composites and Lincoln Composites, who could fabricate large quantities of flywheel rings should an order be placed. Mass production suppliers have also been located for the aluminum flywheel hub, ALCOA Forging Products, Cleveland, Ohio; raw magbearing disks; and vacuum chamber end plates.

Partnership & Facilities

The greatest advancement of Thortek came when a partnership was forged between Thortek and Delta Engineering Co owned by Walter L. Denton. From this partnership Thortek now has the equipment and facilities to perform the research, testing, and manufacturing of Flywheel Energy Storage Systems and magnetic products. A photo-write up and floor plan of the facility has been included in this document.

This is a chronological calendar of the events since the ERIP Grant commenced on 18 June 1995:

- 12 July Upgraded 486-33 computer to 1,200 mb HD, 130 mb 2nd HD, 16 mb ram, 256 K cache.
- 14 July: Achieved Soft Float of 90 lb flywheel (flywheel was levitated by the magnetic bearings, but just barely.) This was work that had been performed with NASA Lewis Research Center.
- 24 July: Flywheel spin down test from air and bearing friction - 120 to 60 rpm in 22 minutes.
- 25 July NASA Kennedy Space Center requested a proposal to replace lead-acid battery UPS system with flywheel before the end of the fiscal year. Project was postpone, due to lack of engineering support at KSC. (I initiated this project before I left KSC in March 1993.)
- 4 August NASA performed rap test and found critical speeds of flywheel (69,000 rpm) were greater than the maximum operating speed (22,900 rpm), thus the flywheel would not pass through high vibration speeds.
- 14 August Received 16 NdFeB magnets from Magnetic Component Engineering for Co-Axial Gap Magnetic Torque Coupler.
- 28 August Received 12 of 16 spare bull's eye pattern magnets from Precision Magnetic Bearings, Inc. of Conoe, NY. NASA-LeRC preformed a series of tests on two of these magnets.
- 29 August Submitted proposal to Van Doorne's Transmissie of The Netherlands for Hybrid / flywheel propulsion vehicle.
- 5 September Delivered Removal & Assembly instructions on individual components of FESS as part of a contract to NASA LeRC.
- 11-26 Sept Designed and fabricated assembly for attaching vacuum chamber to electric motor and for enclosing magnetic torque coupler.
- 27 September Received notification the Thortek/Sundstrand team were finalized in \$8 M Nasa Space Station contract which involves flywheel research.
- 27Sep-15 Oct Designed test fixtures that measured radial force and magnetic attraction force vs airgap capacity of magnetic bearings.
- 28 September Designed and fabricated glass membrane to co-axial gap magnetic torque coupler. Tests indicated commercial glass was not uniformed in thickness and could not withstand high vacuum.
- 1 - 15 Oct Consulted with Flywheel Energy Systems, Inc. of Ottawa, Can on the 2nd Generation High Performance Composite Flywheel for Thortek's FESS.
- 15 - 25 Oct Performed radial forced capacity and magnetic attracting force vs axial airgap tests.
- 27 October Purchased (semi-non running) commercial passenger vehicle with Van Doorne's Transmissie Continuously Variable Transmission for conversion to hybrid/flywheel propulsion vehicle test bed.
- 1-3 Nov Attended and made presentation at the Flywheel Workshop at the Oak Ridge NL.
Conference was attended by Ford & GM, most DOE Labs, magnetic bearing and flywheel competitors. As a result of conference, I submitted a proposal to Abacus Controls, Inc. as part of their work on a Remote Site Photovoltaic UPS Project for a DOE SBIR and a proposal was submitted to Interstar of Quebec, CAN as part of a 1,000 city bus conversion program.
- 16Nov-21Dec Contacted University of Tennessee (as a result of meeting at Flywheel Workshop), wrote and submitted proposal to DOE Small Business Technology Transfer Program; "*Flywheel Hydrostatic Ring Containment System*". Containment was the hottest topic at the Flywheel Workshop.
- 10 December Received 6 magnet rings from Premag magnetized by the latest equipment to produce the bull's eye pattern.
- 23 December Purchased gaussmeter and probe for measuring flux capacity of magnets and magnetizer.
- 23 December Purchased additional precision instrumentation for use on the Magbearing Test Fixtures.
- 23 December Purchased 99.97% Pure Iron Plates for tests on high temperature magnetization of NdFeB

magnets.

5 Jan 96 Wrote and submitted proposal to DOD/ARPA SBIR; *"High Temperature Rare Earth Permanent Magnet Magnetizer with Bull's Eye Pattern."* This innovation was the result of the radial capacity tests conducted in October.

8 to 18 Jan Received consultatory contract to design 676 lb, 48" OD steel flywheel for 4,500 rpm motor-generator flywheel UPS System.

12 January Received request for proposal from Van Doorne's Transmissie for Flywheel Vehicle using CVT and evaluation of supplied CVT vehicle thesis.

January Starting working with Delta Engineering Co.

12 February Magbearing Shear Force vs Airgap & Displacement was fabricated. All 12 available magnets were extensively tested. This data enabled us to generate a formula which will define shear correcting force parameters from one data point.

19 February Magbearing/Flywheel Demonstrator was modified.

5 March Magbearing Flux Density vs Radial Position was fabricated.

19 March Sent proposal to Van Doorne's Transmissie for Flywheel Vehicle

19Feb-28May Received components, fabrication and assembling of Rare Earth Magnetizer.

Mar-May Fabrication and testing of modified bull's eye pattern magnets on Flywheel Test Article (steel flywheel 6" OD x 2" L; with extension testing to 10,000 rpm in air which yielded a run down time of 36 minutes).

5 June Submitted requested proposal to Bell Atlantic Network Services, Inc. on four Flywheel UPS systems for powering communications equipment for 10 hours in possible quantities of up to 1,000,000 units per year.

14 June 1996 Formed partnership with W. L. Denton and Delta Engineering Co.

June - present Fabrication of 2nd Flywheel Test Article (same flywheel as above, but magbearings are 4" apart instead of 2").

Future Activities

- * Complete Rare Earth Magnetizer
- * Optimize the modification of the bull's eye pattern magbearing by completing the characterization of its effects.
- * Complete Flywheel UPS demonstrator using 2nd Flywheel Test Article.
- * Modify POC Flywheel Battery and spin up to maximum operating speed.
- * Optimize Hydrostatic Ring Containment System and verify conceptual validity of technology by failure of one high speed composite flywheel. (Government funding is essential to this test.)