Introducing
Pentadyne Power Flywheel Energy Storage System

David Townley[1]

Historical Overview

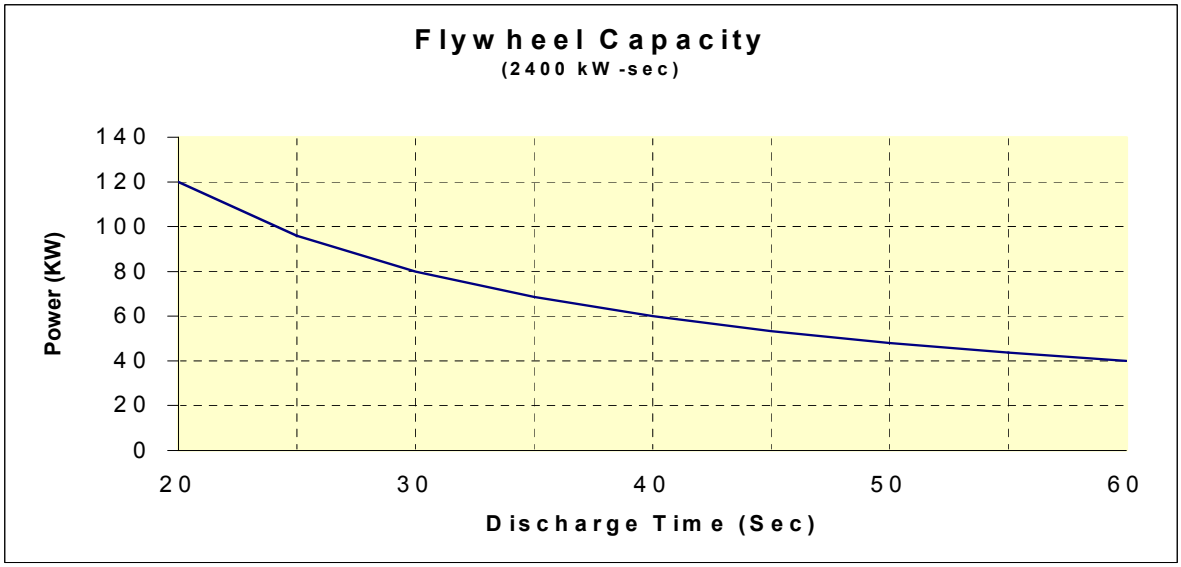
Pentadyne Power Corporation (Pentadyne) was chartered in 1998 to commercially produce the flywheel energy storage system for stationary and mobile applications. A predecessor company from 1993 through 1997 completed the core technology R&D. The flywheel system integrated with a Capstone MicroTurbine™ engine and a hybrid electric drive system was installed in a GM Saturn and demonstrated in January 1997 on the Willow Springs Race Track in California (and was the subject on two network TV shows in 1997).

The Pentadyne flywheel "technology demonstrator" has been operating since January 2001. This demonstration unit exhibits high-speed, carbon fiber flywheel technology operating as a "stiff" voltage source. This is the mode of operation needed for power quality as well as transportation applications. Pentadyne's Engineering Units exhibit the performance and packaging available in the Beta Unit systems that will be shipped beginning Q4-2002.

Pentadyne Power currently has requests for 10 Beta flywheel systems representing the first "field" demonstrations of the stationary power and hybrid bus applications.

Pentadyne Power Flywheel System –Description & Performance

Pentadyne Power Corporation's high-speed flywheel is comprised of a multi-layer carbon-fiber composite cylinder attached to a nickel alloy shaft through a titanium hub, and is capable of delivering 2/3 kilowatt-hour of DC electricity. Three sets of magnetic bearings (five-axis control) levitate the entire rotating assembly and allow high rotational speeds (60,000 design rpm) with high reliability and near-zero maintenance. Two touch down shafts act as back-up support during transit and non-operation. An integrated vacuum pump virtually eliminates aerodynamic drag. The flywheel's mechanical energy is converted to electrical form through a synchronous reluctance motor stator. The rotor is integrated with the shaft, which directly couples the flywheel to the motor. The high power synchronous reluctance motor is capable of transferring over 120 kilowatts of 3-phase variable frequency AC power in or out of the flywheel. The power controller converts this power into constant voltage DC. Following is a graph showing a portion of the power and time combinations available from the Pentadyne flywheel system:



[1] Pentadyne Power Corporation, Sun Valley, CA. Email: davidtownley@pentadyne.com

The Pentadyne flywheel system is a compact, lightweight system needing far less maintenance and requiring much less power to operate than other energy storage systems. This saves the end user thousands of dollars per year in costs over the life of the machine. These advantages are achieved with the following designs:

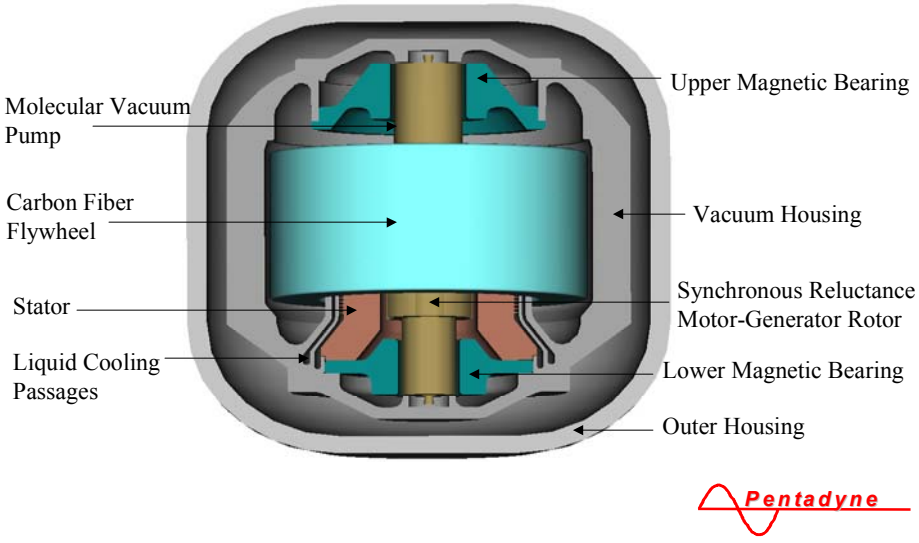
- A five axis active magnetic bearing system resulting in a fully levitated rotor (no bearing to replace or maintain);
- Internal vacuum system eliminating maintenance and parasitic load losses;
- Synchronous reluctance motor/generator eliminating eddy current losses during quiescent operation and avoiding high costs of rare earth magnets; and
- A proven safety system resulting in safe operation near people and machines.

Following is a performance summary table and a cross-section for the Pentadyne Flywheel Energy Storage System:

DESCRIPTION	VALUE
Max. Sustainable Power	120 kW
Duration of Max. Power Delivery	20 sec
Useable Energy Storage	0.67 kW-hr (2400 kW-sec)
Max. Recharge Rate	120 kW
Total Weight	340 kg (750 pounds)
Dimensions	71 x 71 x 163 cm (28 x 28 x 64 in.)
Operating Temperature	-20°C to 50°C (-4°F to 122°F)
Non-operating Temperature	-20°C to 80°C (-4°F to 176°F)
Operating Noise Level	< 50 dBA from 1m
Typical Idle Power Consumption	120 W
Output Voltage	500-900 VDC*
Voltage Regulation (DC)	+/- 5%
Weatherproof Enclosure	Available
Forklift and Crane Compatible	Yes

* Parameters are set by the user through the user interface.

The Pentadyne Flywheel



For indication of the size and layout of the “Beta” package, following is a 120 kW DC package under construction. The outer housing is installed in the lower part of the cabinet. The outer housing contains the cooling fluid and the vacuum housing (that in turn contains the flywheel and magnetic bearing systems). The bi-directional power conversion system is housed within the drawer in the middle of the cabinet. The motor-generator controller and the magnetic bearing controller are housed behind the door in the upper package. The cooling system heat exchanger is behind the controller package and the disconnect switch is installed in the opening at the top of the Beta cabinet.

Pentadyne Power Flywheel System -Applications

The Pentadyne Power Flywheel Energy Storage System is being integrated into other products for applications in several markets. Market applications under active development currently include:

- Power Quality and Reliability
    - UPS "ride through" power source;
    - Distributed Generation voltage stabilization during standalone operation;
    - Distribution Grid "premium power" delivery service; and
    - Variable Speed Drive, DC Circuit, & Robotics Drive "ride through" power source;
- Urban hybrid electric bus & truck drive systems;
- Urban Rail Power recycling.

The initial Beta systems are going into UPS, DG, and Hybrid Electric applications.

Working with a major UPS manufacturer, the Pentadyne flywheel system is being packaged into a modified UPS battery cabinet for integration with the UPS manufacturer's power electronics. Initial Beta applications by utility affiliates and energy service companies using the modified UPS battery cabinet include 80 kW to 108 kW systems in the lower power product as well as 120 kW and 240 kW systems in the higher power product. Integrated with the UPS power electronics, the flywheel system provides "ride through" power during a power disturbance. This "ride through" energy allows the UPS customer to remain unaffected by 98-99% of the grid disturbances. In a grid power interruption lasting longer than 5 or 6 seconds, the customer can start and transition to on-site standby generation or proceed with an orderly shutdown of equipment and processes.

Working with a micro-turbine manufacturer, the Pentadyne flywheel system is being integrated into a 100 kW micro-turbine for voltage stabilization during standalone operation as well as "black-start" energy. Working with a utility affiliate and a fuel cell manufacturer, the Pentadyne flywheel system will provide circuit voltage stiffness by operating in parallel with the fuel cell while the circuit is isolated from the grid. With either application, the flywheel system can provide "ride through" energy during a transition from the grid to the standalone on-site generator. After the transition, the flywheel continues to provide voltage support for the circuit during load changes such as equipment starting or stopping. Discussions continue with other manufacturers and integrators for operation with and integration into other DG sources.

Working with Enova Systems, the Pentadyne flywheel system is being integrated into the Enova 120 kW hybrid electric drive system. The integrated drive system will be installed into an urban transit bus. Benefits expected include increased power performance, better fuel economy, and lower emissions. The flywheel system will react to high power demands such as when accelerating. Additionally, the flywheel will assist in braking by absorbing energy during braking. The energy absorbed is then recycled during the next acceleration.

Pentadyne Power Corporation is moving from a development-stage company to a revenue-stage company as it begins to ship Beta flywheel systems later this year. The applications demonstrated by the Beta systems will introduce a number of new choices for customers and integrators looking for improvements over the existing chemical battery solutions.