HYBRID TOUCHDOWN BEARING SYSTEM

Invention relates to flywheel energy storage systems, where flywheels are levitated using a magnetic mechanism. The instant invention provides a system that negates damage to system components and bearing wear. The system is designed to protect flywheels and system components during touchdown events.

Upon operation, flywheel assemblies are released by mechanical backup bearings, which then normally remain disengaged until shutdown as the flywheel assembly is levitated by the axial magnetic field. However, during the shutdown process, flywheels often suffer a phenomenon known as 'touchdown' from the levitation state. This may induce power failure or other stimuli, leading to damage to components as well as casing.

Enhancements developed in this invention, through the introduction of the instant secondary hybrid touchdown bearing system, allow flywheels and other systems to retain rotational momentum and continue generation of energy. Further, the instant system negates damage to system components, as well as bearing wear.
FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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HYBRID TOUCHDOWN BEARING SYSTEM

CROSS REFERENCE TO RELATED APPLICATION

This application is for entry into the International Phase under the Patent Cooperation Treaty and claims priority to U.S. Patent Application No. 11/904,590 filed on September 28, 2007.

FIELD OF THE INVENTION

The present invention relates generally to flywheel driven power storage systems and particularly to enhancements developed for bearings, secondary or back up bearing systems relied upon during failure modes in order to sustain less bearing wear and impact damage and evince stronger recovery from power loss.

REFERENCES

In general within the art, descriptions of flywheel driven power storage systems and their various related elements can be found in Nos. 5,614,777 set forth by Bitterly et al; 567,595, 5,708,312, 5,770,909, and 58,644,303 by Rosen et al; 3,860,300 and 4,147,396 by Lyman; 3,791,704 and 4,088,379 by Perper; 5,627,419 by Miller; 4,910,449 by Hiyama et al; 5,760,510 by Nomura et al; 5,777,414 by Conrad; 5,319,844 by Huang et al; 4,444,444 by Benederti et al; 5,844,339 by Schroeder et al; 5,495,221, 5,783,885, 5,847,480, 5,861,690, and 5,883,499 by Post; 5,705,902 by Merritt et al; 5,044,944 and 5,311,092 by Fisher; 5,107,151 and 5,677,605 by Cambier et al; and 5,670,838 by Everton; plus 3,969,005, 3,989,324, 4,094,560, and 4,141,607 by Traut; and 4,799,809 by Kuroiwa.
BACKGROUND OF INVENTION

This invention relates to electric power storage, through power interface electronics and electromechanical energy conversion, in the inertia of a spinning flywheel, and by reciprocal means, stored kinetic energy conversion to electric power. The various component elements of the invention include: A high-speed motor/generator, with cooperative power electronics and magnetic bearings, electronic feedback control servos to stabilize the magnetic bearings, a vertical-axis flywheel, integral with the motor/generator rotor and rotatable magnetic bearing elements, to store kinetic energy, a vacuum enclosure to reduce air drag, mechanical backup bearings that are not engaged during normal service, and a stationary energy-absorbing installation site to safely house the flywheel and its enclosure.

As also illustrated in the above-referenced United States patents, such means as rechargeable electrochemical batteries offer some usages, but encounter huge problems involving key issues such as storage space, leakage and longevity. Therefore, flywheel driven systems may offer distinct advantages over such systems. However, as flywheel power storage system designs have evolved from smaller, physically limited structures with minimal storage capacity, to the high capacity systems employing industrial sized magnetic members prevalent today, material restrictions and other such inherent factors have arisen. Said considerations must be overcome in order to facilitate reaching the maximal energy storage and output to render flywheel energy storage systems a viable alternative.

In modern applications, due to the need for extremely large magnetic arrays and magnetic members, failure of high capacity flywheel systems can be triggered by
overloading and overheating of the touchdown ball bearing. When utilizing a pure electromagnet lift magnet, failure often occurs as the electrical power is tripped during normal operation due to the high lifting force requirement. As the lifting force dissipates, the heavy rotor will then sit on the ball bearings, and thus, due to the heavy load, will heat up the ball bearings in a short expanse of time. Thus, as the ball bearing fails, the high speed rotor loses the mechanical support, and rotates basically out of round, contacting the casing. Thus, wear, catastrophic at times and even explosions within the casing may occur.

Further, advanced flywheels are generally vertically mounted rotors, which are levitated by magnetic bearing systems, either active or passive. These systems can be prone to failure due to power outage or overheating and during this type of event, the entire weight of the rotor may crash down upon and subsequently rests upon a mechanical backup bearing. Obviously, designing backup bearing systems to rectify these problems arising from power failure and/or overheating has become more challenging as flywheels become larger and operate at high speeds. Various types of mechanical bearings have been considered, designed and tested, but the extreme loads involved invariably cause the bearing to overheat, resulting in a very short life cycle and catastrophic failure.

What is needed is a backup bearing system which allows rotating systems to acquire and maintain high speeds and a high energy flywheel. What is additionally needed is a backup bearing system which can handle the full weight of the rotor upon failure, for an extended period so that no secondary damage occurs if there is a failure of the primary magnetic lift bearing.
Additionally, what is needed is a system, mechanism or method of operation, which minimizes the load on the ball bearings in the case where the rotor drops on the bearing for any potential failure mode.

SUMMARY OF THE INVENTION

The instant invention, as illustrated herein, is clearly not anticipated, rendered obvious, or even present in any of the prior art mechanisms, either alone or in any combination thereof. An auxiliary or secondary bearing system design for flywheel driven power storage system, adapted to compensate for the aforementioned drawbacks and limitations would afford significant improvement to numerous useful applications. Thus the several embodiments of the instant invention are illustrated herein.

The invention relates to an auxiliary, secondary or backup, hybrid mechanical bearings which will enhance the overall longevity of the system as the instant improvement exhibits protection and operability during power failure modes. In one embodiment, and by way of example only, a magnetic primary bearing has a secondary bearing system.

To avoid overloading and overheating of the backup mechanical bearing as the rotor drops on it, the instant invention incorporates a combination of mechanical and magnetic bearings for the backup system. The passive magnetic bearing is used to take the majority of the rotor weight (during a touchdown event) while a set of mechanical bearings provide the radial and axial positioning of the backup system. The combination of magnetic and mechanical bearings allows each to stay within its capability even at higher speeds and rotor weights.
It is an object of the instant invention to introduce a backup bearing system which allows rotating systems to acquire and maintain high speeds and high energy. It is additionally an object of the instant invention to provide a backup bearing system which can handle the full weight of a modern rotor mechanism upon the moment of power failure.

Furthermore, it is an object of the instant invention to provide a backup bearing system which can handle the full weight of a modern rotor mechanism for an extended period and thus ensure that no secondary damage occurs if there is a failure of the primary magnetic lift bearing.

It is an object of the instant invention to introduce a backup bearing system which allows flywheel systems, specifically, to acquire and maintain high speeds and high energy. It is a further object of the instant invention to introduce a system, mechanism or method of operation, which minimizes the load on the ball bearings in the case where the rotor drops on the bearing for any potential failure mode.

It is a further object of the instant invention to provide an auxiliary, secondary or backup, hybrid mechanical bearing system which will protect system components such the stator and rotor, and surrounding support mechanisms, from wear and/or catastrophic or elastic deformation during a power failure and subsequent rotor touchdown.

Additionally, it is an object of the instant invention to introduce a secondary bearing system which will allows a flywheel to maintain power generation through continued rotation upon a failure.

It is an additional objective of the instant invention to provide a flywheel power storage system possessing a motor/generator with minimal eddy current losses which
displays use of mechanical bearings only as temporary backup as a rotor integral primary
magnetically driven primary bearing system relieves wear on the mechanical bearings.

Further, as in any flywheel driven system, general objectives of this invention are
to provide improved long-life flywheel batteries without sizable power losses, excessive
internal heating, vacuum loss, extensive maintenance, explosion hazard and high cost.

It is an added objective of the instant invention to prevent the high speed rotor
from becoming affixed to the stator due to extreme force and heat considerations
experienced under any potential failure mode.

Another objective is to eliminate need for lubricants in mechanical backup
bearings, to remove a cause of vacuum loss, frequent maintenance, and mechanical
bearing failures. It is a further object of the instant invention to introduce a device which
utilizes a combination of proven technologies, in order to achieve the above stated goals
and thus operate at high loads and high speeds and resist overheating.

The instant hybrid touchdown bearing is a hybrid as the system provides static
bearing weight support upon failure, but also allows the flywheel to continue rotation,
thus continuing power generation and minimizing power loss.

Accordingly, an improved flywheel battery system and accompanying
enhancements its component elements are herein described, which achieve these
objectives, plus other advantages and enhancements. These improvements to the art will
be apparent from the following description of the invention when considered in
conjunction with the accompanying drawings wherein there has thus been outlined, rather
broadly, the more important features of the vehicle monitoring system in order that the
detailed description thereof that follows may be better understood, and in order that the present contribution to the art may be better appreciated.

There are additional features of the invention that will be described hereinafter and which will form the subject matter of the claims appended hereto. In this respect, before explaining at least one embodiment of the invention in detail, it is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the drawings. The invention is capable of other embodiments and of being practiced and carried out in various ways. Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of the description and should not be regarded as limiting.

These together with other objects of the invention, along with the various features of novelty, which characterize the invention, are pointed out with particularity in the claims annexed to and forming a part of this disclosure. For a better understanding of the invention, its operating advantages and the specific objects attained by its uses, reference should be made to the accompanying drawings and descriptive matter in which there are illustrated preferred embodiments of the invention. Other features and advantages of the present invention will become apparent from the following description of the preferred embodiment(s), taken in conjunction with the accompanying drawings, which illustrate, by way of example, the principles of the invention.
BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. 1 illustrates a cutaway view of flywheel power storage system and particularly illustrates the location and coaction of the instant secondary bearing system when utilized in a flywheel power storage system; and

FIG. 2 illustrates an exploded cutaway view of the instant secondary or auxiliary bearing system as utilized in a flywheel power storage system.
The detailed description set forth below in connection with the appended drawings is intended as a description of presently-preferred embodiments of the invention and does not represent the only forms in which the present invention may be constructed and/or utilized. The description sets forth the functions and the sequence of steps for constructing and operating the invention in connection with the illustrated embodiments. However, it is to be understood that the same or equivalent functions and sequences may be accomplished by different embodiments that are also intended to be encompassed within the spirit and scope of the invention, such as flywheel systems with magnetic bearings used in a variety of applications.

In flywheel driven power storage systems, as well as in many other applications which involve shafts and other implements rotating at high-revolutions per minute, bearing overheating or power failure can create catastrophic damage to system components. In the past, through experimentation, various types of mechanical bearings have been considered and duly tested, but the large loads consistently cause the bearing to overheat, resulting in a very short life and eventual failure.

Therefore, the consistent system failure and component damage demands for the development of an ancillary or secondary bearing system, designed to protect and augment the standard primary bearing system during normal operation and additionally provide a means to continue operation and protect system components in the power failure situations. The instant system thus remedies the above discussed troubles exhibited in modern systems.
The salient objectives of the instant invention center around improvement of high capacity, flywheel energy storage systems and particularly around improvement upon inherent bearing wear and damage upon touchdown of a main system rotor. Thus, creation of a system, subsystem, mechanism or method of operation which minimizes the load on the ball bearings, in the case where the high speed rotor should release and begin to plummet down on the ball bearings during potential failure mode, is crucial. The proposed hybrid touchdown bearing system 60 is shown at the bottom of the flywheel in Figure 1 and in more detail in Figure 2.

Figure 1 depicts a cross-section of a typical vertically mounted flywheel system for larger applications. The key elements of said system can be summarized as the flywheel static structure 10, top bearings 20; axial magnetic lift bearing 30, flywheel rotor 40, and the bottom radial bearing 50. Typical systems would possess all of the static hardware, rotor, axial magnetic lift and some version of top and bottom radial bearings. Thus, typical flywheels possess each of these components, except the proposed secondary or auxiliary touchdown bearing system as introduced herein as the hybrid touchdown bearing system 60.

The specific components included in the instant hybrid secondary or auxiliary hybrid touchdown bearing 60 are illustrated in Figure 2. Figure 2 exhibits the flywheel shaft 11, the mechanical interface between the flywheel rotor and the secondary rotor 41 and the bottom radial bearing 50. The elements making up the auxiliary or secondary hybrid touchdown are illustrated including the auxiliary or secondary static housing 61, the auxiliary or secondary touchdown mechanical bearings 62, 63, a touchdown shaft 64,
a static housing 61 with a passive attractive permanent magnet 65 and rotating disk 66.

The touchdown mechanical bearings 62, 63 may be a pair of angular contact bearings.

In differing embodiments of the instant hybrid system, the bottom radial bearing 50 may be configured as a mechanical bearing used in the event of an axial lift failure to support the rotor weight. If the radial bearings are magnetic, then a separate mechanical bearing would be added to support the rotor weight in the event of an axial lift failure. In either of these cases, a mechanical bearing would support the rotor weight in the event of an axial lift failure. However, as the flywheel designs become larger and the rotor weight analogously gets heavier, the load will exceed the capability of this mechanical bearing.

Various mechanical bearings including angular contact, duplex ball bearings, tapered roller bearings and hydrodynamic bearings have been used or considered for use on an individual basis. However, each of these has a limited load capability. This capability of each of these types of bearings incrementally reduces as the rotor speed is increased, such as in the case of utilization of advanced high energy density flywheels.

Moreover, the addition of the passive attractive permanent magnet 65 and rotating disk 66 represent additional novelty, which clearly departs from typical touchdown bearing configurations. In past operation, the mechanical bearings would, as stated above, possess a limited load capability, particularly in high-speed applications. During normal operation of the instant invention, which encompasses utilization of a functioning lift bearing, the touchdown shaft and bearings would be stationary and only encounter the small preload between bearings. How, once a failure of the lift magnet occurs, the flywheel rotor would drop to the touchdown shaft, accelerating the shaft to the identical speed as the flywheel shaft and additionally transferring the weight of the rotor to the
touchdown system. In the case where only the mechanical bearings are incorporated, this load would overheat the bearings, thus causing failure in a matter of minutes.

Presently, with the addition of the magnetic bearing system, the load on the mechanical bearings is reduced. Within the instant system, the rotor and bearings would be stationary during normal operation, which includes a functioning lift bearing. The addition of the magnetic bearing would actually increase the load upon these bearings during this mode, as in past configurations the shaft would not be rotating.

However, unlike in past designs, the instant bearings can handle very large static loads. Herein, when an axial lift bearing fails, the touchdown shaft contained in the instant invention again accelerates up to the flywheel speed and transfers load to the touchdown bearings. Thus, in the instant invention, the load counteracts the touchdown magnet forces and the mechanical bearings only experience the difference between the flywheel rotor weight and the magnetic bearing force. Furthermore, with proper selection of component size, this difference approaches negligible, thus leaving only a small load for the mechanical bearings. And, because the magnet does not generate significant heat, this system supports the load without causing the mechanical bearings to overheat.

The proposed configuration utilizing a combination of magnetic and mechanical bearings is unique. Functionally the system can handle higher rotor loads than a mechanical bearing alone. This allows acceptable failure modes for flywheels comprising higher rotor weights and rotating at greater revolutions. Magnetic bearings are typically used for the main rotor support and mechanical bearings are added for the case of a failed magnetic bearing. Prior to the inception of the design herein claimed, the concept of using a hybrid bearing for touchdown has yet to be perfected. Lower load on
the mechanical bearings will allow the other bearings to sustain higher loads for a longer
time and avoid overheating during the rotor spinning down.

By adding the magnetic bearing the load on the mechanical bearings is reduced.
As with the system in the above paragraph the rotor and bearings would be stationary
during normal operation with a functioning lift bearing. The added magnetic bearing
would actually add load to these bearings during this mode were the shaft is not rotating;
however the bearings can handle very large static loads. When an axial lift bearing fails
the touchdown shaft again accelerates up to the flywheel speed and transfers load to the
touchdown bearings.

While several variations of the present invention have been illustrated by way of
example in preferred or particular embodiments, it is apparent that further embodiments
could be developed within the spirit and scope of the present invention, or the inventive
concept thereof. However, it is to be expressly understood that such modifications and
adaptations are within the spirit and scope of the present invention, and are inclusive, but
not limited to the following appended claims as set forth.
What is claimed is:

1. A secondary touchdown bearing system for a flywheel power storage and release system comprising a pair of mechanical bearings annularly disposed around said touchdown rotor shaft, a stator assembly comprising a static housing comprising an annular passive attractive permanent magnetic bearing, a rotating disk disposed to rotate at a controlled gap in relation to said stator assembly, and an interface mechanism disposed between a flywheel rotor shaft and said touchdown rotor shaft.

2. The secondary touchdown bearing system for a flywheel power storage and release system of claim 1 wherein said pair of mechanical bearings comprises angular contact bearings.

3. The secondary touchdown bearing system for a flywheel power storage and release system of claim 2 wherein said annular passive attractive permanent magnet is used to take the majority of the rotor weight during a touchdown event.

4. The secondary touchdown bearing system for a flywheel power storage and release system of claim 3 wherein said set of mechanical bearings provides radial and axial positioning of said backup touchdown bearing system.
5. The secondary touchdown bearing system for a flywheel power storage and release system of claim 4 wherein a combination of magnetic and mechanical bearings allows said magnetic and mechanical bearings to stay within respective capabilities at higher speeds and rotor weights.

6. A bearing system for a flywheel power storage and release system comprising an upper radial bearing, an axial lift bearing, a lower radial bearing and a lower touchdown bearing system.

7. The bearing system for a flywheel power storage and release system of claim 6 wherein said lower touchdown bearing system comprises a touchdown rotor shaft; a pair of bearings annularly positioned around said touchdown rotor shaft; a stator assembly comprising a static housing comprising an annular passive attractive permanent magnet; a rotating disk; and, an interface mechanism disposed between a flywheel rotor shaft and said touchdown rotor shaft.

8. The bearing system for a flywheel power storage and release system of claim 7 wherein said pair of bearings annularly positioned around said touchdown rotor shaft comprises angular contact bearings.

9. The bearing system for a flywheel power storage and release system of claim 8 wherein rotating disk is disposed to rotate at a controlled gap in relation to said stator assembly.
10. A flywheel driven power storage system comprising:

- a motor/generator means;
- a flywheel rim in communication with a vertical-axis spindle in communication with a rotor mechanism;
- a magnet ring assembly;
- a stator housing;
- a magnet array for providing axial flux;
- a coil mechanism; and,
- a set of bearing mechanisms, wherein upon actuation of said system, the attraction of said rotor mechanism to said magnet ring lifts said vertical-axis spindle, which lifts said flywheel rim off of said set of bearing mechanisms, allowing said flywheel rim to operate substantially independent of said set of bearing mechanisms; and,
- a lower touchdown bearing system disposed to support the weight of said flywheel rim and continue rotation of said flywheel rim upon failure and touchdown of said flywheel rim.

11. The flywheel driven power storage system of claim 10 wherein said lower touchdown bearing system comprises:

- a touchdown rotor shaft;
- at least one angular contact bearing annularly positioned around said touchdown rotor shaft;
- a stator assembly comprising a static housing comprising an annular passive attractive permanent magnet;
a rotating disk disposed to rotate at a controlled gap in relation to said stator assembly; and,
an interface mechanism disposed between a flywheel rotor shaft and said touchdown rotor shaft.

12. The flywheel driven power storage system of claim 11 wherein said at least one angular contact bearing further comprises a pair of angular contact bearings annularly positioned around said touchdown rotor shaft and disposed one bearing axially above the other in relation to said touchdown rotor shaft.

13. The flywheel driven power storage system of claim 12 wherein a combination of an annular passive attractive permanent magnet and said pair of angular contact bearings produces a hybrid system exhibiting the strength and speed capacities greater than existing mechanical bearings operating in a vacuum.

14. The flywheel driven power storage system of claim 13 wherein said passive magnetic bearing absorbs the majority of the rotor weight during a power failure.

15. The flywheel driven power storage system of claim 14 wherein said set of mechanical bearings provides radial and axial positioning of the touchdown bearing system.

16. The flywheel driven power storage system of claim 15 wherein utilization of said combination of said passive magnetic bearing and said set of mechanical bearings allows
said flywheel driven power system to operate at higher speeds than systems employing purely mechanical backup bearings.

17. The flywheel driven power storage system of claim 16 wherein utilization of said combination of said passive magnetic bearing and said set of mechanical bearings allows said flywheel driven power system to support greater rotor weights than systems employing purely mechanical backup bearings.

18. A secondary bearing system comprising: a primary system shaft, an auxiliary rotor shaft, an interface mechanism disposed between said primary system shaft and said auxiliary rotor shaft, a first bearing annularly disposed about said auxiliary rotor shaft; a second bearing annularly disposed about said auxiliary rotor shaft and arranged axially juxtaposition to said first angular contact bearing in relation to said auxiliary rotor shaft; a stator assembly comprising a static housing and further comprising an annular passive attractive permanent magnet, and a rotating disk disposed to rotate at a controlled gap in relation to said stator assembly.

19. The secondary bearing system of claim 18 wherein said secondary bearing system encompasses the capacity to support the full weight of a flywheel mechanism upon loss of power.
20. The secondary bearing system of claim 19 wherein said secondary bearing system encompasses the capacity to support the full weight of a flywheel mechanism upon loss of power and allow said flywheel to rotate.

21. The secondary bearing system of claim 20 wherein said secondary bearing system encompasses the capacity to support the full weight of a flywheel mechanism upon loss of power and allow said flywheel to rotate for an extended period of time.

22. The secondary bearing system of claim 21 wherein said secondary bearing system encompasses the capacity to support the full weight of a flywheel mechanism upon loss of power and operates in a vacuum at high loads, high speeds without overheating.

23. The secondary bearing system of claim 22 wherein said primary system shaft and said auxiliary rotor shaft are adapted to rotate at high speed with respect to one another while withstanding contact with one another through said interface mechanism disposed between said primary system shaft and said auxiliary rotor shaft.

24. The secondary bearing system of claim 23 wherein said first bearing annularly disposed about said auxiliary rotor shaft and said second bearing annularly disposed about said auxiliary rotor shaft comprise angular contact bearings.

25. The secondary bearing system of claim 23 wherein said first bearing annularly disposed about said auxiliary rotor shaft and said second bearing annularly disposed about said auxiliary rotor shaft comprise duplex ball bearings.
26. The secondary bearing system of claim 23 wherein said first bearing annularly disposed about said auxiliary rotor shaft and said second bearing annularly disposed about said auxiliary rotor shaft comprise tapered roller bearings.

27. The secondary bearing system of claim 23 wherein said first bearing annularly disposed about said auxiliary rotor shaft and said second bearing annularly disposed about said auxiliary rotor shaft comprise hydrodynamic bearings.

28. The secondary bearing system as set forth in claim 23, wherein the primary and secondary bearing shafts are components of power storage generation system.
INTERNATIONAL SEARCH REPORT

A CLASSIFICATION OF SUBJECT MATTER

IPC(8) - H02K 7/09 (2009.01)
USPC - 310/90.5

According to International Patent Classification (IPC) or to both national classification and IPC

B FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC(8) - H02K 7/09 (2009.01)
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Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Google Patent, PatBase

C DOCUMENTS CONSIDERED TO BE RELEVANT

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