

WHITEPAPER

# Ensuring the safety of large flywheels used to stabilize electrical networks



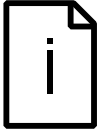
Safety must be a priority in the design, installation and operation of large flywheels. Potential risks should primarily be addressed by inherently safe design, or when applicable, by protective devices.

Inherently safe design incorporates a number of aspects, including sufficient design margin, qualification of material, and system fault protection. However, recommended practices for the safe design and operation of flywheels also take the position that safety requirements should be satisfied during abnormal events, including containment of a loose but mainly intact flywheel rotor. Such containment can be arranged as a safety enclosure which is either integrated or provided externally by means of a concrete or similar structure.

From the viewpoint of the contractor and work to be performed on site, an external safety enclosure may add complexity and cost, as well as the need for additional space. An integrated safety enclosure has the advantage of being able to manage the flywheel and provide protection in a single unit. Such an enclosure may be the preferred solution in terms of installation, predictability of cost, and space requirements.

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## Introduction



Large flywheels provide valuable stabilization to electrical networks, but high levels of safety observed in the design and installation are important

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01 ISO 12100:2010  
Safety of machinery –  
General principles for  
design – Risk assessment  
and risk reduction.

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02 SANDIA, D. Bender.  
Recommended Practices  
for the Safe Design and  
Operation of Flywheels.  
Sandia National  
Laboratories, USA, 5.  
SAND2015-10759.

Large flywheels can provide valuable stabilization to electrical networks. However, due to the considerable amount of energy they store it is important that high levels of safety are observed in the design and installation of such flywheels and that potential risks are properly addressed.

While standards have long been available for large rotating electrical machines, in practical terms there do not exist any standards or norms for flywheel applications.

As a basis, ISO 12100:2010 “Safety of machinery – General principles for design – Risk assessment and risk reduction”<sup>01</sup> provides important principles for design and risk management.

In addition, Sandia National Laboratories, operating on behalf of the U.S. Department of Energy, published the report “Recommended Practices for the Safe Design and Operation of Flywheels”<sup>02</sup>. This report provides recommendations for flywheel design practices and therefore complements the ISO standard.

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## General principles for risk assessment and safe design



The basic principles for safe design determine the limits of the machinery, identify potential hazards and estimate the risks

The basic principles for safe design as described in ISO 12100:2010 are to determine the limits of the machinery, identify potential hazards (potential sources of harm) and estimate the risks. This standard defines risk as the combination of the probability of the occurrence of harm and the severity of that harm. Risks shall be adequately reduced, and the order of risk prevention shall be determined. If a hazard cannot be totally eliminated, it shall primarily be addressed by inherently safe design measures or secondarily by guards or protective devices. In some cases it may also be necessary to provide information to the user on residual risks.

As stated above, risk is defined in terms of the combination of probability and severity. However,

there is no unambiguous procedure for the measurement of risk. In practice risk is measured as the product score of probability and severity, with detectability sometimes also included in the risk score. Consequently, risks can be reduced by affecting these parameters. A common approach is to determine an acceptable threshold for the total risk score, such that a risk score below the threshold level is considered acceptable. In addition, the concept of “ALARP” (As Low As Reasonably Practicable) is applied. In practical terms ALARP means that risks should be reduced at least to the extent that the effort required to further reduce the risk significantly exceeds the benefit gained through increased safety.

# Principles for the safe design of flywheel rotors



There is also a need for recommended safety practices for flywheel design and operation

While ISO 12100:2010 focuses on general principles for design, risk assessment and risk reduction, there is also a need for recommended safety practices for flywheel design and operation.

The report published by Sandia National Laboratories takes the position that it is not practical to contain flywheel rotor bursts (based on the ALARP philosophy) and that flywheel rotors must be designed to avoid burst events for their complete design life. However, the design should include safety functionality to address the possibility of a mainly intact loose rotor event.

Therefore, two main thrusts are recommended:

1. **Qualification** of the flywheel rotor design to avoid failures for all reasonable situations during the design life;

2. **Satisfy safety requirements during abnormal events**, including containment of a loose but mainly intact flywheel rotor event.

**With regard to the first thrust, “qualification”,** the report recommends qualification and design safety aspects including design margin, ability to withstand externally applied loads, protection against overspeed, system fault tolerance, homology of test article with respect to product, and product acceptance safety testing.

**With regard to the second thrust, potential “loose rotor events”,** it is recommended that safety arrangements are properly designed and dimensioned to provide safe conditions in case of a loose rotor event.

# Recommended practices and implementation



The best practice is to perform qualification by calculations and simulations that correspond to qualifying type of tests

Some of the Sandia National Laboratories report’s recommendations are based on the assumption that flywheels can ultimately be tested to failure in order to perform qualifying type tests. However, it is not considered practical and sometimes not even viable to test large flywheels to potential failure in order to achieve such qualifying type tests.

A practical alternative is to perform qualification by calculations and simulations that correspond to such qualifying type tests. The most important recommendations in the Sandia National Laboratories report are examined below. This section also explores how the recommendations can be implemented to achieve practical and safe designs for large flywheels.

### Design margin

- A sufficiently large design margin should be used. The recommended procedure is to perform an overspeed qualification test on the flywheel rotor and then limit the operation speed of the flywheel to an appropriate percentage of the qualified overspeed. However, following the discussion above, it may be necessary to use calculations to replace such tests to establish the desired design margin. This calculation approach is commonly used for other heavy rotating equipment.
- Fatigue effects that typically occur in all steel components should be taken into account, including the relevant number of fatigue load cycles for the complete design life. This is an approach commonly taken by suppliers of rotating machinery.
- It is recommended that rotor–dynamic behavior is analyzed and designed for safe operation. Rotating machinery suppliers would preferably do this by utilizing the existing expertise and tools that they apply to their conventional large rotating machines.
- Another concern for flywheel suppliers is to define safety requirements for the forging material. Ultrasonic testing is typically used for the verification of such requirements. Suppliers of large rotating machinery generally have the competence and experience necessary to specify the requirements for such testing.

### Withstand externally applied loads

- A vital safety aspect is to understand the maximum permissible external load on critical structures for dimensioning purposes. Such critical structures can be bearings, the machine frame, and other load supporting structures. As an example, the possible effects of potential seismic loads on the structure and safety need to be understood.

### Protection against overspeed

- It is necessary to assure that the flywheel system has inherent features that will prevent the occurrence of abnormal and potentially dangerous overspeed. The control and safety system must be designed to prevent such overspeed events.

### System fault tolerance

- System design redundancy must be considered. Potential loss of coolant, bearing oil, and of the control system must be mitigated by redundant systems or other practical measures.

### Homology of test article with respect to product

- It is recommended that a set of controls is put in place to assure correspondence between the intended material performance and the equivalent actual characteristics.
- Emphasis should be placed on the use of proper material. Experience of the applied materials characteristics and related dimensioning – for forgings, for instance – is important from the viewpoint of safety. This experience involves homology between the characteristics of the material used in calculations and those of the actual material.
- There are benefits to be gained from utilizing the same type of qualified suppliers and same type of quality control as for conventional heavy rotating machines. Experience of supplier quality and of procedures for implementing adequate quality control is an important factor in the safety of the application.

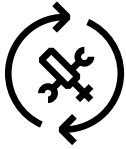
### Product acceptance safety testing

- Product acceptance safety testing should be conducted for each deployed flywheel unit. For suppliers of heavy rotating machinery, this is generally a standard process. It is recommended that every rotor unit is overspeed tested to an appropriate level according to the size of the flywheel.
- System fault testing should preferably be undertaken in such a way that system fault identification and mitigation are done as a Failure Mode Effect Analysis during the design stage.

### Assure restraint of loose rotor

- The flywheel system should have design features to assure that a loose rotor event is taken into consideration. It is recommended that this function is passive and does not rely on a detection system. Two practical alternatives are an integrated safety enclosure or an external safety enclosure such as a concrete structure.
- It is recommended that to qualify the design as safe, the adequacy of the rotor restraint be demonstrated by inducing a loose rotor event at the full rated speed of the rotor. However, as discussed above, such a demonstration may be unrealistic for a large flywheel. Equivalent advanced simulations (such as FEM) represent a practical alternative.

## Service and maintenance program



A detailed and application-specific service and maintenance program is recommended for ensuring high levels of safety

To maintain high levels of safety throughout the life of the flywheel, it is recommended that a detailed and application-specific service and maintenance program is followed.

In order to maintain safety, such a program should take into account the identified risks and hazards

and propose appropriate service and maintenance actions. It is recommended that the flywheel supplier, who also performed the risk assessment and implemented corresponding mitigation actions, should provide the service and maintenance program.

## Conclusion and proposed design



Safety must be a priority in the design and operation of large flywheels. General principles for risk assessment and safe design need to be taken into consideration, and recommended practices for safe design and operation must be applied.

Safe design is an iterating process between risk and design-related aspects. It involves several steps which need to be managed and controlled. Experience and competence in large rotating machinery, and in risk management, have vital parts to play in this process.

The Sandia National Laboratories report also recommends that safety requirements are satisfied during some abnormal events, including by containment of a loose but mainly intact flywheel rotor. Such containment can be arranged as a safety enclosure which is either integrated or

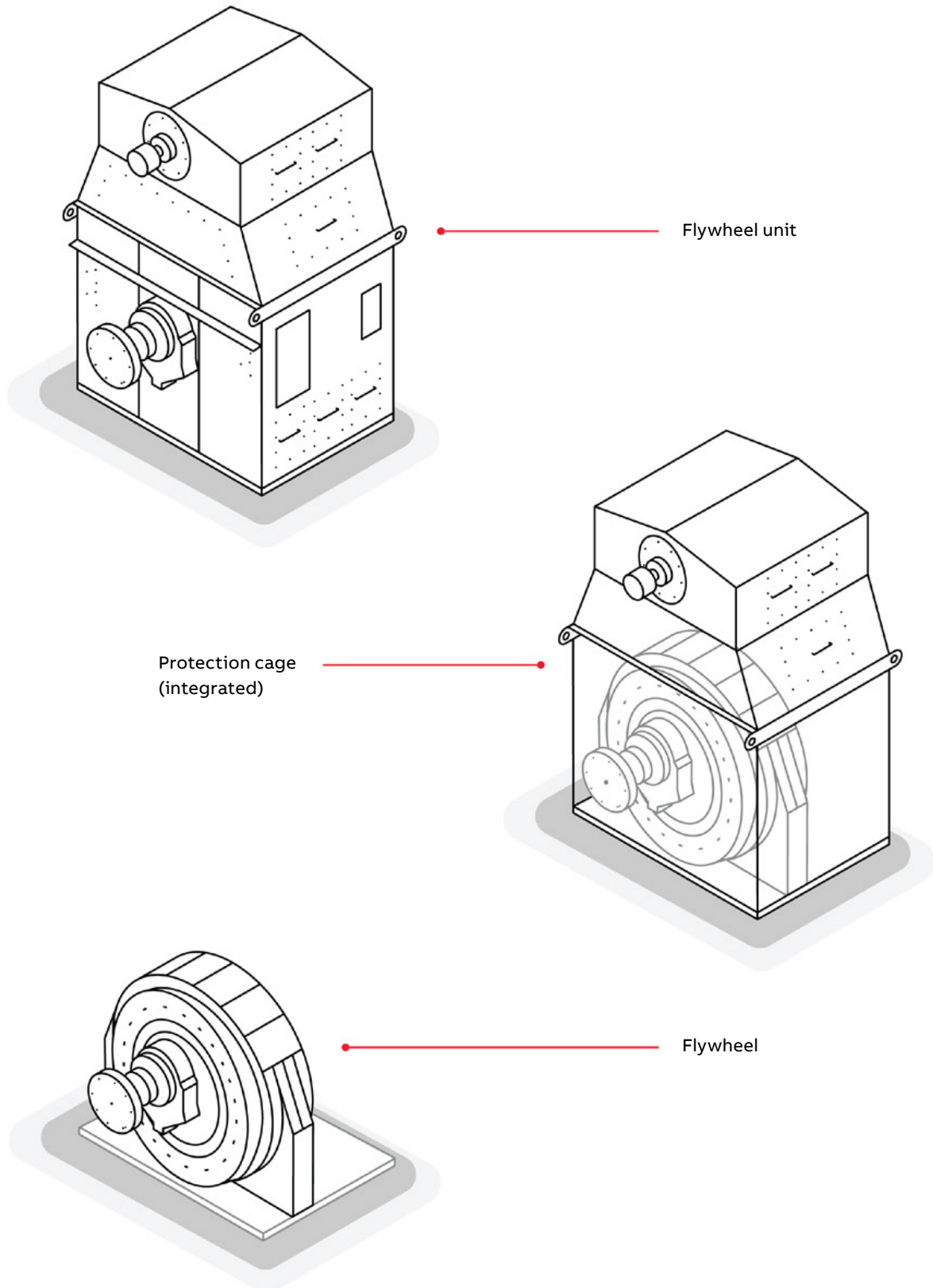
provided externally by means of a concrete or similar structure.

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**Flywheel designed for stabilization of electrical networks, with integrated safety enclosure designed in accordance with the concepts explored in this white paper**

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[new.abb.com/motors-generators](https://new.abb.com/motors-generators)