INTERNATIONAL STANDARD

ISO 21648

First edition
2008-12-01

Space systems — Flywheel module design and testing

Systèmes spatiaux — Conception et essai du module de volant moteur

Reference number
ISO 21648:2008(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. The ISO Central Secretariat accepts no liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies. In the unlikely event that a problem relating to it is found, please inform the Central Secretariat at the address given below.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 21648 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Flywheels are mechanical devices that store kinetic energy in a rotating mass. A simple example is the potter's wheel, which was widely used by people in ancient times. The first use of such devices dates from between 3500 and 3000 BC. According to archaeological evidence, these early flywheels were built from wood, stone and clay. One type of potter's wheel was a rim made from a unidirectional material (bamboo), wound in the hoop direction and embedded in a matrix (clay). This design option is clearly a foreshadowing of the later use of composites for their inherent strength and lightweight nature.

It is, however, only since the 1970s that the use of flywheels as energy storage systems has become the focus of serious attention from energy researchers due to the constant threat of a shortage of fossil fuel supplies. Today, a typical flywheel energy system consists of a flywheel rotor, a supporting device (magnetic bearing ball bearings, superconductor bearings or other types of bearings), a charge/discharge device (motor/generator) and a safety containment (housing). For space applications, due to weight constraints, the use of a bulky safety containment system is not necessarily a desirable design. Thus, from a safety point of view, the design of flywheel energy systems needs to concentrate on reliability and longevity.

Current flywheel energy storage technology is made possible by the use of high-strength, carbon-fibre-based composite materials in the rotor. Flywheel energy storage systems are designed to both control spacecraft attitude and to store energy — functions which have historically been performed by two separate systems. The stored energy is needed for the dark portions of the orbit when the Earth's shadow makes solar power unavailable for spacecraft. For many spacecraft, flywheels offer the potential to significantly reduce weight and extend service life. However, the use of composite materials, coupled with variations in design approaches and demanding operating conditions, combine to present certification challenges for the rotor assemblies.

This International Standard establishes the design, analysis, material selection and characterization, fabrication, test and inspection of the flywheel module in a flywheel. Many requirements set forth in this International Standard can also be adapted by similar types of rotating machineries, but for different usage. The momentum wheels and momentum gyroscopes are typical examples. The implementation of these requirements will ensure a high level of confidence in achieving safe operation and mission success for these critical hardware items.

Space systems — Flywheel module design and testing

1 Scope

This International Standard establishes the design, analysis, material selection and characterization, fabrication, test and inspection of the flywheel module (FM) in a flywheel used for energy storage in space systems. These requirements, when implemented on a flywheel module, will ensure a high level of confidence in achieving safe operation and mission success. With appropriate modifications, this International Standard can also be applied to similar devices, such as momentum and reaction wheels and control-moment gyroscopes.

The requirements set forth in this International Standard are the minimum requirements for flywheel modules in flywheels used in space flight applications. They are specifically applicable to the parts in the flywheel rotor assembly (FRA), including rim, hub and/or shaft and other associated rotating parts, such as the bearings and the motor generator rotor. The requirements are also relevant to the non-rotating parts, such as module housing, main suspension assembly (magnetic or rolling element bearings, superconductor bearings, etc.), motor stator, caging mechanism and sensors within the module housing, and backup bearings, if applicable. However, control and interface electronics are not covered in this International Standard.

2 Terms, definitions, symbols and abbreviated terms

2.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

2.1.1
A-basis allowable
mechanical strength value above which at least 99 % of the population of values is expected to fall, with a confidence level of 95 %

NOTE See also **B-basis allowable** (2.1.4).

2.1.2
acceptance tests
required formal tests conducted on hardware items to ascertain that the materials, manufacturing processes and workmanship meet specifications

2.1.3
allowable load
allowable stress
allowable strain
maximum load that can be accommodated by a structure/material without rupture, collapse or detrimental deformation in a given environment

NOTE Allowable loads commonly correspond to the statistically-based minimum ultimate strength, buckling strength and yield strength, as applicable.

2.1.4
B-basis allowable
mechanical strength value above which at least 90 % of the population of values is expected to fall, with a confidence level of 95 %

NOTE See also **A-basis allowable** (2.1.1).

2.1.5
catastrophic failure
structural failure event due to the rotor separation, or the rupture or collapse, of other flywheel rotor assembly components or assembly

2.1.6
composite material
combination of materials which differ in composition or form on a macro-scale

NOTE The constituents retain their identities in the composite, i.e. they do not dissolve or otherwise merge completely into each other, although they act in concert. Normally, the composites can be physically identified and exhibit an interface between one another.

2.1.7
damage tolerance
ability of structure/material to resist failure due to the presence of flaws for a specified period of unrepaired usage

2.1.8
damage tolerance life
required period during which a part of a flywheel module, even containing a large undetected crack, is shown by analysis or testing not to fail catastrophically in the expected service load and environment

2.1.9
damage tolerance analysis
damage tolerance testing
analysis/testing that is used to demonstrate damage tolerance life

NOTE For metallic parts, this type of analysis is also referred to as safe-life analysis.

2.1.10
design safety factor
multiplying factor to be applied to the limit load and/or maximum expected operating speed

2.1.11
fatigue life
number of load cycles experienced in service that a defect-free part in a flywheel module can sustain before failure of a specified nature could occur

NOTE The number of load cycles experienced in service can be flight loads, ground test loads and charge/discharge cycles.

2.1.12
flaw
local discontinuity in a structural material

EXAMPLE Crack, delamination, void.

2.1.13
flight-like test article
test article that is built in accordance with a fabrication process identical to the flight hardware

2.1.14
flywheel module
FM
assembly of mechanical parts which support and spin the flywheel rotor assembly and which house the appropriate sensors, rotor support systems and motor, which with the appropriate avionics suite and software can act as a stand-alone functional flywheel unit

NOTE A flywheel module typically includes the housing, main suspension system (magnetic or rolling element bearing, superconductor bearings), motor stator, caging mechanism, sensors and backup bearings, if applicable.

2.1.15
flywheel rotor assembly
FRA
assembly in a flywheel which consists of rim, shaft and/or hub, bearings, motor generator rotor and other associated parts that rotate under normal operation

2.1.16
fracture critical part
classification of a part for manned space systems, which assumes that fracture or failure of that part resulting from occurrence of a crack-like defect would create a catastrophic hazard

NOTE Such classification is required on components unless it can be shown otherwise, i.e. if the part (and subsequent parts it could fail) can be shown to be contained, or in the case of low released energy, or if the part is failsafe, or if there is only a remote possibility of significant crack growth on the part to begin with.

2.1.17
fracture control

application of design philosophy, analysis method, manufacturing technology, quality assurance and operating procedures to prevent premature structural failure caused by the propagation of cracks or crack-like flaws during fabrication, assembly, testing, transportation and ground-handling and service

2.1.18
fracture mechanics
engineering discipline that describes the behaviour of cracks or crack-like flaws in materials under stress

2.1.19
fracture toughness
generic term for measurements of resistance to extension of a crack

2.1.20
impact damage
damage in a non-metallic part within the flywheel module that is caused by an object striking the part or by the part striking an object

2.1.21
impact damage tolerance
ability of the fracture critical non-metallic parts in the flywheel module to resist strength degradation due to the impact damage event

2.1.22
initial flaw size
maximum flaw size, as defined by non-destructive evaluation, that is assumed to exist for the purpose of performing a damage tolerance (safe-life) analysis or testing

2.1.23
key process parameter
KPP
critical process parameter that affects design and product characteristics

2.1.24
life factor
factor by which the service life is multiplied to obtain total fatigue life or damage tolerance life

NOTE Life factor is often referred to as a scatter factor that is normally used to account for the scatter of a material's fatigue or crack growth rate data. It can also account for the dispersion of loading spectra parameters and other uncertainties, when appropriate.

2.1.25
limit load
maximum expected external load, or combination of loads, that a rotating part can experience during the performance of a specified mission in specified environments

NOTE When a statistical estimate is applicable, the limit load is that load not expected to be exceeded at 99 % probability with 90 % confidence.

2.1.26
margin of safety
MS

margin of safety expressed as $\left(\frac{\tau_{\text{allow}}}{\tau_{\text{limit}} \times k_{\text{safe}}}\right) - 1$

where

τ_{allow} is the allowable load;

τ_{limit} is the limit load;

k_{safe} is the design safety factor

NOTE Load can mean stress or strain (see 2.1.3).

2.1.27
maximum expected operating speed
MEOS
maximum spinning speed that a part in a flywheel module is expected to experience during its normal operation

NOTE Maximum expected operating speed is synonymous with limit speed.

2.1.28
maximum design speed
MDS
highest possible operating speed based on a combination of credible failures

NOTE Maximum design speed is required for some manned systems to accommodate any combination of two credible failures that will affect speed.

2.1.29
non-destructive evaluation
NDE
process or procedure for determining the quality or characteristics of a material, part or assembly without permanently altering the subject or its properties

NOTE In this International Standard, non-destructive evaluation is synonymous with non-destructive inspection (NDI) and non-destructive testing (NDT).

2.1.30
operating environments
all environments experienced during service life of the flywheel module

2.1.31
proof spin test
spin test run on a flight flywheel module at a pre-selected spinning speed that is higher than maximum expected operating speed

2.1.32
qualification tests
required formal tests used to demonstrate that the design, manufacturing and assembly have resulted in hardware conforming to specification requirements

NOTE Qualification test is synonymous with certification test.

2.1.33
service life
period of time (or cycles) starting with item inspection after the manufacturing and continuing through all testing, handling, storage, transportation, normal operation, refurbishment, re-testing and reuse that may be required or specified for that part

2.1.34
stress-rupture life
time during which the composite maintains structural integrity considering the combined effects of stress level(s), time at stress level(s) and associated environments

2.1.35
touchdown bearings
bearings required to act as the rotor suspension system in the non-operating mode and/or the backup suspension system in the operating mode during main suspension system failure

2.1.36
touchdown event
event that can occur with flywheel modules supported on magnetic bearings whereby the rotor is unexpectedly forced onto its touchdown bearings during normal operation due to malfunction of magnetic bearings, overload or other anomaly

2.1.37
ultimate load
product of the limit load and the design ultimate safety factor

NOTE The ultimate load is the load that the parts in a flywheel module need to withstand without catastrophic failure in the expected environment.

2.1.38
visual damage threshold
VDT
impact energy level shown by test(s) which creates an indication that is detectable by a trained inspector using an unaided visual technique

2.2 Symbols

a crack size

$\mathrm{d}a/\mathrm{d}N$ fatigue crack growth rate

I_p polar mass moment of inertia

I_t	transverse mass moment of inertia
K_{IC}	plane strain fracture toughness
K_{Iscc}	stress intensity threshold for stress-corrosion cracking
N	number of cycle
T_g	glass transition temperature

2.3 Abbreviated terms

ATP	Acceptance Test Programme
CT	Computer Tomography
FM	Flywheel Module
FMECA	Failure Mode, Effects and Criticality Analysis
FRA	Flywheel Rotor Assembly
KPP	Key Process Parameter
MDS	Maximum Design Speed
MEOS	Maximum Expected Operating Speed
MPE	Maximum Predicted Environment
MRB	Material Review Board
MS	Margin of Safety
NDE	Non-Destructive Evaluation
NDI	Non-Destructive Inspection
NDT	Non-Destructive Testing
SP	Specification Performance
S-N	Stress versus Life
ε-N	Strain versus Life
VDT	Visual Damage Threshold

3 Requirements

3.1 General requirements

This clause presents the general requirements for the parts in the FM for

— design,

— material selection and characterization,