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Space environment (natural and artificial) — Procedure for obtaining worst case and confidence level of fluence using the quasi-dynamic model of earth's radiation belts

Environnement spatial (naturel et artificiel) — Mode opératoire pour obtenir le cas le plus défavorable et le niveau de confiance de la fluence en utilisant le modèle quasi-dynamique des ceintures de radiation terrestres

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Introduction

The space environment changes greatly due to solar activity, magnetic storms, etc. Therefore, the radiation fluence environment received by a satellite varies depending on its launch date, orbit, and operation period.

What is important for satellite design is the worst condition and confidence level of fluence. Optimum design can be done by knowing these conditions. Although the radiation belts model so far can be distinguished between the solar activity maximum and the minimum, it was difficult to deal with short-term and long-term fluctuations. The procedure for obtaining the worst condition and confidence level of fluence is defined using the quasi-dynamic model of Earth's radiation belts.

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1 Scope

This document, by using a model that reproduces the fluctuations of radiation belts, defines the calculation method (orbit, operation period) of the radiation fluence received by a satellite. The quasi-dynamic model of Earth's radiation belts adopts input parameters (index values) to predict variation. The input parameters are selected from those that are easy to obtain data and have high correlation with the variation in Earth's radiation belts.

NOTE This method is an engineering method used for satellite design and similar purposes.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at https://www.iso.org/obp
- IEC Electropedia: available at http://www.electropedia.org/

3.1
L-value
distance to a point where the magnetic lines of force intersect with the equatorial plane of the geomagnetic field from Earth's core, with Re (radius of Earth) used as the unit

3.2
B/B0
value normalized to the minimum value of the field line in the magnetic equator

3.3
Kp and ap
planetary indices that are based on 3-hour measurements from 13 ground stations

Note 1 to entry: Values of ap range from 0 to 400 and are expressed in units of 2 nT. *Kp* is essentially the logarithm of ap, with its scale of 0 to 9 being expressed in thirds of a unit (e.g., 5− = 4 2/3, 5o = 5, 5+ = 5 1/3). A daily index (*Ap*) is obtained by averaging the eight values of *ap* for each day and the index *Ap* can have values intermediate to those of *ap*

3.4
solar wind speed
outward flux of solar particles and magnetic fields from the Sun used in external magnetic field model computation

Note 1 to entry: Typically, solar wind velocities are around 350 km/s−1.

3.5
F10.7
F10
traditional solar energy proxy that is used on atmosphere models

Note 1 to entry: Measure of the solar radio flux at a wavelength of 10,7 cm at Earth's orbit, given in units of 10–22 W·m–2.

3.6
Sunspot number
R
Ri
Rz
daily index of sunspot activity, defined as R=k (10g + s) where s is the number of individual spots, g the number of sunspot groups, and k is an observatory factor

[SOURCE: ISO 16457:2014, modified — synonymous terms editorially revised for alignment with ISO/IEC Directives Part 2]

3.7
Dst
Disturbance storm time
geomagnetic index used in external magnetic field model computation that describes variations in the equatorial ring current and is derived from hourly scalings of low-latitude horizontal magnetic variation

Note 1 to entry: Dst is expressed in nT.

3.8
IMF
Interplanetary Magnetic Field
geomagnetic index used in external magnetic field model computation that corresponds to the part of the Sun's magnetic field that is carried into interplanetary space by solar wind

Note 1 to entry: The three orthogonal components of the IMF are Bx, By, and Bz. Bx and By are oriented parallel to the ecliptic.

Note 2 to entry: The IMF is a weak field, varying in strength near Earth from 1 to 37 nT, with an average of about 6 nT.

4 Radiation belts model

The magnetically trapped radiation around Earth is known as the Van Allen belts. The belts consist of energetic electrons from ~100 keV to 10 s of MeV and protons from ~100 keV up to around 1 GeV. The belts are organized into an inner zone and an outer zone separated by a slot region. Below 100 keV, a plasma population, known as the ring current, is also magnetically confined in this region.

Currently, many of the models used in satellite design are what we call a static model to predict the average particle distribution. However, the actual environment from various observation data fluctuates much more complexly than the static environment described by their models. In particular, spatial and especially temporal variations in satellite design are becoming more important than previously believed. When designing a satellite, the uncertainty of these models is dealt with by taking a design margin. Currently, physics-based models that enable an understanding and prediction of the dynamics of Earth's radiation belts are now available, but are complicated models that require a lot of parameter data. However, there is also a simple quasi-dynamic model of Earth's belts that predicts variations in the radiation belts with several input parameters (highly available, long-term accumulated index). This document specifies the worst case and confidence level calculation method using the latter model.

5 Principles of the method

5.1 Cumulative fluence

See ISO 12208:2015, 4.1.

5.2 Confidence level

See ISO 12208:2015, 4.2.

5.3 Quasi-dynamic model of Earth's radiation belts

5.3.1 Overview

The variations in radiation belt particles greatly depending on the solar cycle effect, secular changes in the geomagnetic field, the anisotropy of trapping, and the geomagnetic state. The variations of the radiation belts can be predicted quasi-empirically by using the activity level of the Sun and disturbance of the geomagnetic field. Most activity indices are given for short periods and as long duration averages. By statistically analysing the variations of these indices and radiation belts, it is possible to predict variations of radiation belts quasi-empirically. The input parameters are selected from those that are easy to obtain data and have high correlation with Earth's radiation belt variations.

The solar activity indices include Sunspot number (R), F10.7, solar wind speed, and so on. Also, Kp and ap, Dst and IMF are examples of geomagnetic activity indices.

Annex A shows the procedure for calculating the worst case and reliability level using the quasi-dynamic model.

5.3.2 Available models

a) CRRESSELE model in Annex B.

b) MDS-1 Radiation belt model in Annex C.

5.4 Remarks

a) The worst case and confidence level of fluence can be easily obtained by using the radiation belts variation parameter SW, AP, and F10.7 index.

b) This technique is applicable when there are at least ten years' worth of parameters used to predict radiation belt fluctuation.

c) Although the design margin has thus far been left to the judgment of the satellite designer, it is possible to set the margin accurately from the worst environment.

Annex A
(informative)

A.1 Procedure for obtaining worst case and confidence level of fluence using the quasi-dynamic model of Earth's radiation belts

Select the dynamic model of Earth's radiation belts. The probability distribution of one-day radiation fluence operation is calculated by assuming that the satellite was launched on one day in the past and started its operation. The radiation fluence is calculated by changing the day of the launch and a histogram is created to obtain the probability of the radiation fluence. The detailed calculation method is described as follows. Estimate cumulative fluence by using the method in 5.1 Cumulative fluence.

1) Calculation of the orbital position (B/B0-L)

   The number of days longer than the recurrence period, here 30 days is used as an example, is used for a low-orbit satellite to minimize the effect of the orbital position on the variation of radiation. The orbital positions during 30 days after the predetermined day of the launch are calculated and converted to *B/B0-L*.

2) Calculation of daily average particle fluence

   The particle fluence is calculated for each 30-day period by changing the date one day at a time from the past to the present (during this period, the driving parameters are known) using B/B0-L obtained in 1). The daily average particle fluence is calculated from the particle fluence over 30 days.

3) Calculation of fluence during operation

   The fluence during operation is calculated by assuming that the daily average particle fluence obtained in 2) is the one-day particle fluence and accumulating the one-day particle fluences for an arbitrary operation period by delaying the operation start date one day at a time from the past to the present.

4) Calculation of the maximum, minimum, and average fluences during operation

   The maximum and minimum fluence are determined from the results obtained in 3), and the average fluence is calculated.

5) Creation of a histogram

   A histogram of the fluence during operation is created using the results obtained in 4).

6) Probability distribution

   The probability of occurrence of fluence during operation is calculated using histogram obtained in 5).

Then, a reliability curve is obtained in the form of a probability distribution.

Table A.1 summarizes the calculation conditions used in the example. In this example, a reliability curve for the fluence of a day during operation is obtained by the calculation of fluence between 1984 and 2010. Figure A.1 shows the one-day particle fluence for different days of launch. In this example, the maximum fluence was on 1 November 2003. This may be because many large magnetic storms were