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Electromechanical batteries for low earth orbit satellites

Master thesis

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Approval sheet

For the thesis

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The thesis:

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Symbol and Nomenclature

GEO	geosynchronous Earth orbit,
MEO	mid Earth orbit
LEO	low Earth orbit
PV	photovoltaic systems
PM	permanent magnet
SAD	solar array drive
PRU	power regulator unit
PDU	power distribution unit
EMB	Electromechanical battery
E	the kinetic energy stored
I	the moment of inertia
ω	the angular velocity of the flywheel
h	the length of the cylinder
r	the radius
ρ	the density of the cylinder's material.
r_o	the outer radius
r_i	the inner radius
e_v	the kinetic energy per unit volume
e_m	per unit mass

K	the shape factor
σ	The maximum stress in the flywheel
ρ	The mass density
PMSM	Permanent magnet synchronous machine
BDCM	Brushless Dc machine
SRMs	Switched reluctance machines
SPM	Surface mounted permanent magnet
p	The number of pole pair
α_p	PM arc to pole pitch ratio
B_r	Magnet remance flux
μ_m	Magnet remnant and permeability
N	Coil number of turns
Z	Axial length
B_{air}	The PM air gap flux density (T)
J	the linear specific electric loading (Aturns/m)
K_w	The winding factor, which include the zone factor,Kws, and the chording factor , kchs
p_s	The number of rotor poles
P_n	Rated electromagnetic power
λ_c	Ration between core lengths to pole pitch
N_n	Rated speed (rps)
B_{sy}, B_{ry}	the yoke flux density for level of magnetic saturation
Kα	first harmonic coefficient of magnet field
Kcu	Necessary cupper area for flow one ampere of current
ff	Filling factor

ω_2	The final speed of flywheel
ω_1	The initial speed of flywheel
Ipm	Moment of inertia of permanent magnet
Ife	Moment of inertia of ferromagnetic material
Icom	Moment of inertia of carbon epoxy material
M_t	Total mass of the system
M_s	Mass of stator
M_c	Mass of copper
M_m	Mass of permanent magnet
M_r	Mass of rotor
M_f	Mass of Flywheel
b_{r0}	The slot opening .

Abstract

In this thesis, a surface-mounted permanent magnet synchronous machine and flywheel are designed and optimized analytically. The machine and flywheel are supposed to be used in low earth orbit satellite as electromechanical battery. Due to the application, there is a limited amount of space for the system which set constraints on the design.

The low earth orbit satellites usually include nano and micro satellites which rotate around the earth is a period of 90 minutes. the most critical part of these satellites are their batteries which supply power to a load of about 100 w during 30 minutes eclipse period .

The electromechanical battery is a motor generator mode device with flywheel which is used to store kinetic energy during motor mode through the flywheel during sunlight and supply electrical power from the stored kinetic energy by the generator mode at eclipse period.

Among several types of machine, the permanent magnet synchronous machine is chosen to be used in this battery with outer rotor to be suitable for the flywheel system for space applications.

An analytical design method for surface mounted permanent magnet machine is described. Special attention is given to the mechanical properties of the machine to withstand high speed which has maximum of a 60000 rpm. A selection of material for the each component of the machine is considered.

The development of flywheel to be a hollow cylindrical body which is composed of two parts to minimize the weight of the system and to optimize its volume and guarantee the storage and supply of enough kinetic energy.

Chapter 1

Introduction

A brief overview of satellite systems, earth orbit classification, energy storage and topologies and current State-of-the-Art in relation to the scope of the work is presented.

1. 1 Scope of the work [1]

Energy storage and conversion have been and will continue to be the key elements in developing satellite project. Most satellites to date utilizes photovoltaic technology for energy conversion during period of existence in sun light and electrochemical technology for energy storage to supply the satellite with power during the eclipse time such a satellite is shown in fig 1. This is the main driving force for the present study and the design of a flywheel for possible application in a satellite.

Flywheel is a mechanical battery; the stored energy can be converted into electricity using an electromagnetic machine in the generating mode.

Recharging (spinning the wheel) is done using the same machine in the motoring mode.

It typically consists of a high speed inertial composite rotor to store kinetic energy, a magnetic bearing support and control system, an electrical machine that can run either as a motor or a generator to undertake the energy transfer to and from the flywheel, a vacuum support housing and containment, compact heat removal and exchangers, Instrumentation for monitoring, control, and power electronics for electrical conversion.

Figure 1.1. The satellite system.

1.2 Satellite Systems [1]

The typical communications satellite consists of the following systems .

A. **Communications and Data Handling**
B. **Attitude and Orbit Control System**
C. **Tracking, Telemetry, and Command System**
D. **Electrical Power System**

The electrical power system generates, stores, conditions, controls, and distributes power within the specified voltage band to all bus and payload equipment .The protection of the power system components in case of all credible faults is also included. The basic components of the power system are the solar array, solar array drive, battery, battery charge and discharge regulators, bus voltage regulator, load switching, fuses, and the distribution system.

1.3. Earth Orbit satellite Classification [1]

Satellites are usually sent to rotate around the earth in three levels of orbits

GEO: geosynchronous Earth orbit, circular very distant from earth orbit at 35,786-km altitude

MEO: mid Earth orbit, circular at 2000 to 20,000-km altitude

LEO: low Earth orbit, generally circular at 200 to 2000-km altitude

1.3.1 Low Earth Orbit

This is approximately a circular orbit at low altitude. The International Space Station (ISS) and NASA's space shuttle orbiter operate in low Earth orbit.

Most communications satellites operate in GEO, but some newer constellations are placed in LEO between 500 and 2000-km altitudes.

Being closer to the Earth, smaller and simpler satellites can be used in this orbit. So using low earth orbit satellite must be small as possible as we can, one of the most important components of satellite is battery and battery charge and discharge system.