COMPASS-1 PICOSATELLITE: MAGNETIC COILS FOR ATTITUDE CONTROL

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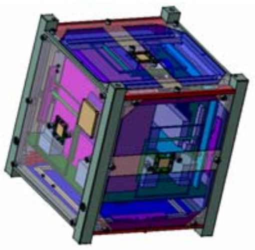
ABSTRACT

The COMPASS-1 Cubesat is an active controlled picosatellite by using magnetic coils as means of attitude control. The Attitude Control System (ADCS) is featured with a three-axis stabilizing capability. The ADCS was developed to stabilize the spacecraft against disturbances. Magnetic coils are mounted to generate control torque in the roll and yaw axes. The attitude sensors use magnetometer for measurements of the local magnetic field vector, GPS System for determine the position and sun sensors. The paper describes the required hardware components and the design and development of the electromagnetic torquers.

INTRODUCTION

COMPASS-1 is the name of the first picosatellite being developed at the University of Applied Sciences Aachen, Germany [1]. Since the projects' initiation in September 2003 it is being managed and carried out by students of different engineering departments, with a majority being undergraduate students from the Astronautical Department. Currently the team counts fourteen students with an increasing number of new participants. The project focuses on a number of goals. Mainly the students will gain essential practical experience in realizing a research and development project from start to end. Moreover, an adequate infrastructure shall be created that enables more space engineering activities to take place at our university in the future. And definitively not least, a fully functional picosatellite is going to be built and finally launched into orbit!



The satellite is being built according to the CubeSat specification documents [2] published by Stanford and Calpoly University, which define a cubical structure with 10cm edges and a mass of not more than 1kg. Powered by solar cells, such a satellite will have an average of 1.5W for operation. Attempting to develop a spacecraft within the stringent constraints mentioned above becomes reasonable when considering the satellite being stored inside a container (P-POD) for simultaneous launch with other CubeSats, which in turn helps decreasing launch costs significantly.

The launch date of COMPASS-1 is not yet determined. Nevertheless it is planned to conclude the development and have the spacecraft ready for launch acceptance testing by end 2005.

OVERVIEW

ADCS System Overview

The Attitude Determination and Control System (ADCS) is to stabilize the spacecraft against attitude disturbing influences resulting from the environment in the earth orbit in order to orients it in the desired fixed nadir pointing.

For the design layout of the ADCS, firstly a mathematical concept had to be established. Then, the hardware is being built around the mathematical equations. In no other subsystem design it becomes more obvious than in dynamics related spacecraft systems like the ADCS: the hardware is the carrier of the software, which is the theoretical concepts translated into a numerical solution.

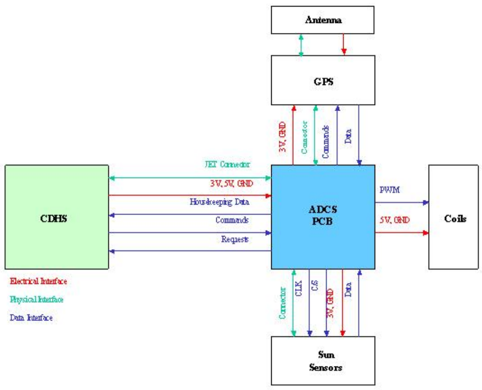


Fig. 1: ADCS Hardware Interfaces

Figure 1 summarizes the interfaces between the ADCS Printed Circuit Board (PCB) and the adjacent components and subsystems and aids in obtaining an overall perspective on the ADCS hardware configuration.

The ADCS subsystem board is mounted perpendicular at the Command and Data Handling System (CDHS) board as indicated in figure 2. It is exchanges information with the CDHS (shaded green) and receives the commands to switch modes. The communication is done via I²C system bus. There are two voltage levels available for the ADCS via the connectors; those are 3.3V and the unregulated battery voltage (around 3.7V).

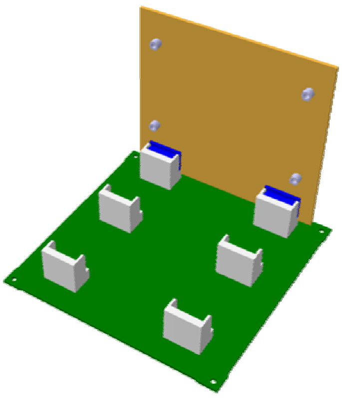


Fig. 2: The ADCS placed on the CDHS board

ADCS Hardware Components

The ADCS Hardware is separated into two units:
- one unit determines the spacecrafts attitude and position and
- the other unit stabilizes the spacecraft.

The determination unit comprises the SunSensors, the magnetometers and the GPS system.

The stabilizing unit consists of magnetic coils (also referred to as magnetic torquer) as the only devices for actuation on board the satellite.

Magnetic Torquer

The coils are mounted close to the panels of the satellite. In dependence of the current, sent through the turns, a magnetic field is established. An interaction, between these produced magnetic field vectors and the local geomagnetic field vector, is producing a control torque. This control torque will rotate the spacecraft to the desired position.

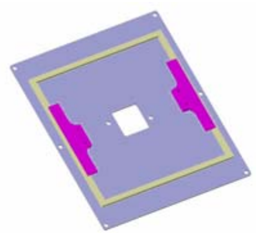


Fig. 3: One magnetic coil and its integration onto a panel

The components that define the interface between the Coils and the ADCS PCB are the coils driver, the H-Bridge, the low pass and the current sensor.

GPS System

For the computation of the reference vectors for attitude determination, the information of the current position of the spacecraft is important. In order to enable the autonomy of the system operation, a GPS will be incorporated. GPS system is made up by two prime components:

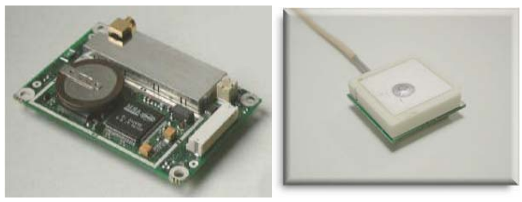


Fig. 4: The Phoenix GPS Receiver and the San Jose F-19 active patch antenna

The **antenna** receives the GPS signal and transmits it to the GPS receiver.

The GPS **receiver** is the device that receives a signal from the antenna, conditions and processes the signal into an location information, and sends the data, with a time stamp, to the ADCS unit. The GPS board contains two duplex serial ports that operate at high voltage levels.

Magnetometer

The measurement of the local magnetic field vector for attitude determination requires the implementation of magnetometers on the subsystem. The selected hardware is the HMC6352 digital compass developed and distributed by Honeywell.

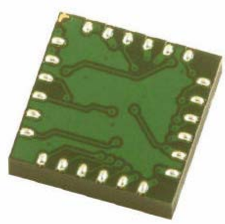


Fig. 5: The HMC6352 digital magnetometer

The magnetometer communicates via two-wire I²C bus system as a slave device.

Sun Sensor

The objective of the sun sensors is to measure the relative position of the sun in order to aid the attitude determination procedure. The sun sensors used on COMPASS-1 have been developed by the Micro Electronics Institute (MIC) of the Denmark Technical University (DTU) in MOEMS (Micro-Opto-Electro-Mechanical System) technology. They are extremely lightweight, small and power saving [3].

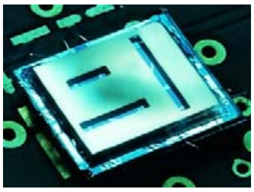


Fig. 6: MIC sun sensor chip mounted on the PCB

The interface between the sun sensor and the ADCS PBC are the analog-to-digital converter, the operation amplifier and the digital thermometer. Except of the SunSensors and the coils, the ADCS is purely built up with commercial off-the-shelf (COTS) products.

COIL DESIGN

Designing a coil for a satellite differs from commercial coils, because the coil operates in the vacuum of the space. It is therefore necessary to pay attention to a range of constraints and requirements explained in the following.

Coil Design

Due to the fact that the satellite should be a three axis stabilized satellite it will require a minimum of three torquers to dump momentum in every direction. The magnetic moment is given from the simulation with MATLAB. The torque requirement can be calculated from the definition as 1.0 E-06 Nm.

The power budget for the coils, are limited with 750mW. It is reasonable to design a torquers with a third up to a half of the given power consumption or less and still be able to produce the required moment. The coils are not used constantly; due to the limited available power.

The maximum weight for the coils was limited to around 20g for each coil.

The bigger the included surface of the coils is the better is their efficiency. We intend therefore to make square coils that follow the edges of the side plates and which will be mounted on them.

Design Parameter

Parameter	Symbol	Value	Unit
Maximum width	b	74	mm
Maximum height	h	83	mm
Maximum cross sectional breadth	d	2,1	mm
Maximum cross sectional height	sh	5	mm
Face of coil	A	6142	mm^2
Cross sectional area	Acmax	10,5	mm^2
average Amount	C	296	mm
Total Mass limit	Mges	60	g
Mass of coils each axes	Mc	20	g
Minimum temperature	T min	-20	°C
Nominal temperature	T Nominal	20	°C
Maximum temperature	T max	40	°C

HARDWARE DEVELOPMENT

The coils will require a significant fraction of the critical budgets (mass and power). Hence, sufficient analysis and optimization was spent on the coil design in the development phase. During this current definition phase an efficient tool has been developed which enables a fast design output for a given set of input parameters.

Coil Calculation

Considering the coil requirements an Excel program was developed for the calculation. The necessary parameters, the wire diameter and the number of turns are the outputs of the Excel program.

Parameter	Symbol	Value	Unit
Number of Turns	n	396	-
Bare wire diameter	d_w	0.15	mm
Mass of one coil	Mc	19,008	g
Current through coil	I (20°C)	38,703	mA
Magnetic dipole moment	Md	9,73E-02	A*m^2
Needed cross section area	Ac	9,508	mm^2
Power consumption	P	226,26	mW
Coil resistance @ -20°C	R_{-20}	106,07	Ω
Coil resistance @ 0°C	R_0	115,05	Ω
Coil resistance @ 20°C	R_{20}	124.02	Ω
Coil resistance @ 40°C	R_{40}	133,00	Ω

It should be noted that the design is not only dependent of the required mechanical torque but also of commercially available wire properties, i.e. diameters and material, as well as the selected number of turns. The production of coils has shown to be quite expensive, and for the convenience of producing multiple prototypes of coils, a coil winding machine is being designed and produced.

For the design of the coil mould and winding machine, CATIA V5 R13 was used. The software allows a full development of the winding tool including the drafting features.

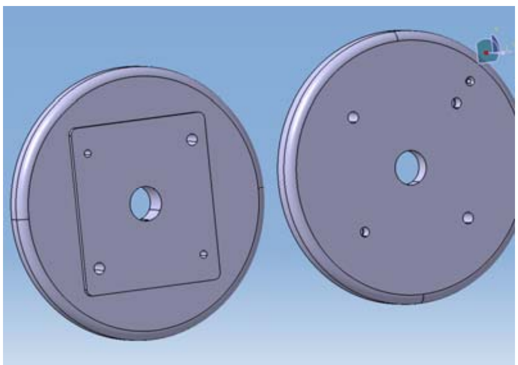


Fig. 7: The magnetic coil mould

Coil Winding Tool Design

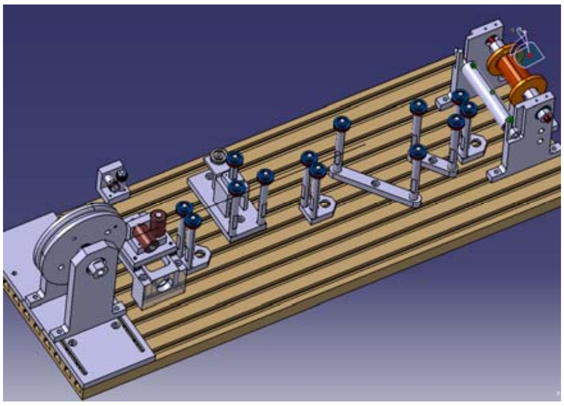


Fig. 8: Coil winding machine

The majority of the coil tool design is developed on commercial off-the-shelf (COTS) products. The winding tool is guaranties flexibility in the production of the coils itself and allows producing coils with different winding methods. This gives the liberty to produce coils with any input tension. The production of the hardware parts are produced in the workshop of our home university. The drive mechanism itself and the track sensible drive mechanism are solved with stepping motors. A force measuring unit was installed, which helps to secure the coils against a wire break.

Connection

The connection of the every wire string into an none detachably conductor is achieved with the method of "current bonding" [4].

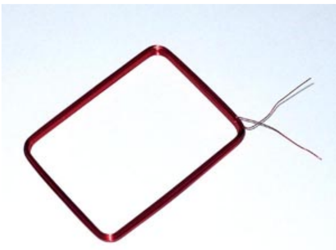


Fig. 9: Coil prototype

TESTING

Testing methods

The tests are the most important aspect at the design of magnetic torquer coils. The tests will approve the design calculations. The goal of the test will have a term which describes the real dependency between the current, sent through the coils, and the resulting magnetic dipole moment.

Test Hardware

To measure the magnetic dipole moment different test hardware are subsist. The first variety consists of using 3 axis magnetometer witch are already a hardware component of the mostly ADCS subsystem for pico - satellites.
The second variety is to measure with different available magnetometer in the industry, witch is not so easy to find.

SUMMARY

COMPASS ONE uses only magnetic torquer coils for orient the spacecraft along nadir with an accuracy of 8°.
The paper shows the design and development aspects of the Coils based on the calculation.
For the generation of a magnetic moment vector m, simple vector arithmetic's have been used, i.e. each coil produces one component of the vector m.
possibly the case is more complex.
So far the coils are produced perform the requirements and builds the basis for the tests.

REFERENCES

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[3] Pederson, M. et al., Linear Two-Axis MOEMS Sun Sensor and the need for MEMS in space, International Astronautical Congress, Bremen, Germany, 2003

[4] Bonding methods (Verbackungsmethoden) www.electrisola.com