Acquisition and Actuation Modelling of RVSAT-1

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Abstract: The prerequisite that the Attitude Control Subsystem (ACS) of any satellite should satisfy lies in efficient actuation. There has always been a dilemma over choosing a method that would control the orientation of the satellite in the best possible manner. Considering the case of nanosatellites, the best possible way of attitude control would be using magnetorquers which render stabilization to the otherwise intemperate satellite.

RVSAT-1 uses magnetorquers in combination with 3-axis magnetometer to acquire the desired orientation. This paper gives an insight on various possible methods for actuation and guides our way through the conundrum that control algorithms are.

Keywords: Actuation, B-Dot Control Algorithm, Magnetorquers, Stability.

I. INTRODUCTION

Attitude determination and control system is a very crucial aspect to be considered while building a satellite. The number of methods that can be employed for attitude control along with deploying mechanisms are constrained by mass, volume and power, unique to every satellite. For tackling attitude stabilization in a cost effective manner, magnetic actuation and acquisition is customarily used. Diverse publications cover the domain which relates to magnetic actuation. Wertz and J. Larson have given several established tools for exploration of methods for attitude control [1]. Lovera and Silani have put forth linear design methods in [2], along with derivation of H_∞ control law. Satellite system references include NPSAT1[3] and CUBESAT[4]. Quite a few papers have witnessed pairing between momentum exchange devices (traditional method) and magnetic actuators. For an increment in stability, a combination of flywheel with actuator has been introspected in some papers.

II. GENERAL ACS CONFIGURATION

Various methods of actuation and acquisition of attitude can be employed, broadly classified into two categories- Passive Attitude Control and Active Attitude Control.

- Passive Attitude Control

Passive control techniques for actuation of a satellite exploit the fundamental physical principles and/or indigenously occurring forces by engineering the spacecraft such that the effects of one force are pronounced and those of other forces are subdued. Passive stabilisation can be realised in 2 ways:

1. Spin Stabilisation: Stabilisation of a spacecraft by means of spin about a single axis is known as spin stabilisation. It has been superseded by three-axis stabilisation. It helps with inertial orientation though requirement of torquers for precession control (spin axis drift) persists. A stable inertia ratio is essential too, given by-

$$I_z > I_y = I_x$$

Spin stabilisation can be harnessed by spinning the exterior of the satellite on its axis at a fixed rate.

Lastly, nutation damping is desirable when considering passive stabilisation through eddy current, ball-in-tube, viscous ring and active damping. Precession, which is the change in orientation of rotational axis of a body, is also calculated for passively controlled satellites to avoid periodic deflection.

2. Gravity Gradient - Gravity gradient passive control provides earth orientation but no stability with respect to yaw. Liberation damper is required for management of eddy current and hysteresis. Momentum wheel can be employed for conceiving gravity gradient stabilisation with yaw control. Torquers have no role to play in this kind of stabilisation and inertia condition to be fulfilled is:

$$I_z << I_{x,} I_y$$

Passive stabilization surely is the best in the way that it consumes no power, lags from active stabilization since using passive stabilization means no impromptu control over the satellite in case of emergency conditions. Moreover, in case of permanent magnets, satellite shifts by 180^o at the poles of the Earth. Thus, RVSAT-1 uses active attitude control.

- Active Attitude Control

Active Attitude control monitors spacecraft attitude and implicates mechanisms to alter and yield a control torque as per requirements which also forms the elemental theory for feedback control.

Several actuators can be used for active attitude control, reaction wheels being the conventional choice. It encloses a dynamic system, i.e., moving parts which help provide fast and sustained feedback control. Momentum dumping cannot be executed by active control since it can generate only internal torques. Also, active control adds to weight of the spacecraft along with power and cost. Control is lucid for independent axes.

A number of methods exist for actuation of attitude of a spacecraft but magnetorquers gain preference over methods like reaction wheels, jets/thrusters, etc. when considering nanosatellites due to the following characteristics:

- Suitable for low earth orbit (LEO)
- Useful for initial acquisition manoeuvres and also for desaturation of momentum.
- Torque rods help generate magnetic field which aligns with the geomagnetic field to create torque and may also be employed for attitude sensing and manipulating orbital location.

III. RVSAT -1 SPECIFICATIONS

- Dimensions: 2U (10cm X 10cm X 22.7 cm)
- Altitude: 580 km
- Inclination: 98^o
- Orbit type: Polar Sun Synchronous

IV. ACQUISITION of RVSAT -1

Despite the austere precedence that magnetic control gives over other methods, some problems are encountered if it is singularly used. Critical diminutions are imposed on control torques due to small magnitude of geomagnetic field. Thus, to avoid underactuation, RVSAT-1 has used reconfigurable magnetorquer coil which interacts with the Earth's magnetic field and provides torque to the satellite. Each layer in magnetorquer coil is attached through switches and treated as an individual coil which gives the benefit of arrangement and hence gives freedom to generate required amount of dipole moment and control power dissipation. The control laws that govern the principle behind working of the actuating system of RVSAT-1 in particular use the following principles:

- Angular velocity can be obtained as a reflection of change in Magnetic Field **b**. Three factors may lead to changing magnetic field – change in magnitude of Magnetic Field **b**, change in its direction as the satellite moves and rotation of the body with certain angular velocity. The orbit of RVSAT-1 is Polar Sun synchronous with an altitude of 580 km, where the former case is dominant and the latter two can be considered imperceptible.
- Developing a system for detumbling in cases of change of angular velocity will cease possibility for magnetic field component, if parallel, fails to generate torque and component of angular momentum in that direction can not to damped.

Detumbling of most of the nanosatellites uses a standard algorithm called B-Dot controller which relies on magnetometers as sensors and magnetorquers as actuators. RVSAT-1 is an Earth pointing (in field of view) satellite actuated by use of magnetorquers in the form of 2 torque rods and 1 coil, which encompasses B-Dot control law. This takes into account the rate of change of body-fixed magnetometer signals measured on-board. Using torque rods and coils along with data from magnetometer, despinning the spacecraft relative to Earth's magnetic field vector is achieved. Magnetometers are body-fixed sensors integrated with IMU (with respect to RVSAT-1, independent magnetometer systems can also be realised) which help in acquiring rate of change of magnetic field vector components. Denotation of geomagnetic field is given by '**b**' and corresponding rate of change d**b**/dt, is ordinarily inscribed as $\dot{b}$. External torques generated by interaction of geomagnetic field with that of torque rods provide attitude stabilisation, estimation of which is done using the expression

$$\mathbf{T} = \mathbf{m} \, \mathrm{X} \, \mathbf{b} \tag{1}$$

where, $$\mathbf{m} = -\boldsymbol{K_r}\,\dot{b} \tag{2}$$

Quantities enveloped in the equations (1) and (2), when measured in SI units, reveal the value of **T** in N-m which equals cross product of magnetic moment, **m**, in Amp-m^2 with magnetic field, **b**, measured in Tesla. Equation (2) is popularly known as the B-Dot control law. K$_r$ is the static positive control gain which is indicative of the strength of the actuating system. Its value is a function of inclination, mean motion and inertia of the body about the principle axes and can be realised by using (3). Torque applied perpendicular to the magnetic field in the direction opposite to **b** brings down the rotational kinetic energy of the satellite as depicted by the negative sign in (2).

$$K_r = I_{min}\omega(1 + \sin \mathrm{i}) \tag{3}$$

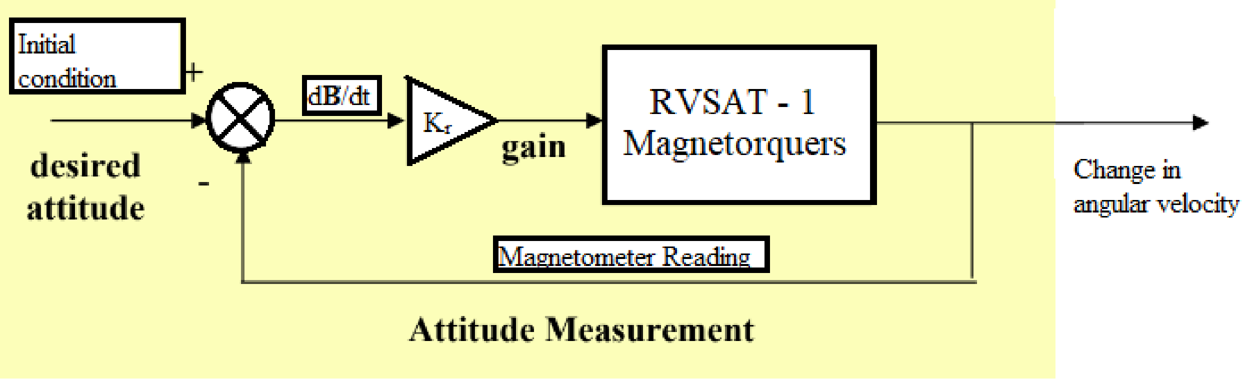

Figure 1. Block diagram of detumbling controller of RVSAT-1

Thus, current supplied to each coil can be calculated if the design of magnetorquer assembly is known by using (4)

$$\mathrm{Itot} = \sqrt{PAn/2r(a+b})} \tag{4}$$

Here a and b represent the height and width of the coil respectively, P is the power supplied, n is the number of turns, r is the resistance of coil.

Stability of the controller is vindicated by using mathematical tool of Lyapunov stability. Kinetic energy (E) is chosen as the Lyapunov function candidate. For a rotating object, its kinetic energy is given as

$$\mathrm{E} = \mathrm{I}\omega^2/2 \tag{5}$$

Derivative of kinetic energy can be then expressed as

$$\mathrm{dE/dt} = \mathrm{I}\omega(\mathrm{d}\omega/\mathrm{dt}) = \omega\mathbf{T} \tag{6}$$

Combining equations (1), (2) and (6), we get

$$\mathrm{dE/dt} = \omega((-\mathrm{Kr}\,\dot{b}\,)\ \mathrm{X}\ \mathbf{b}) = -K_r||\,\dot{b}\,||^2 \tag{7}$$

Negative value of time rate of change of kinetic energy is a proof that the system is stable when B-Dot control algorithm is used.

V. CONCLUSION

The Attitude Control System of RVSAT-1 has been emphasised upon in this paper. Passive and active control methods have been explored. It clearly explains the reason RVSAT -1 is choosing active magnetic actuation over passive. B-Dot controller has been put into action for detumbling. There are four other modes in RVSAT-1 based on mission requirements that ensure the satellite's desired orientation using magnetic control, i.e., only magnetorquers and magnetometer. Lyapunov stability is used as a tool to verify that the satellite achieves stability.

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REFERENCES

[1]. James Richard Wertz and Wiley J. Larson, *Space Mission Analysis and Design.* California; 1991.

[2]. Enrico Silani and Marco Lovera, *Magnetic Spacecraft Attitude Control: A Survey and Some New Results.* Italy; 2003.

[3]. Barry S. Leonard, *NPSAT1 Magnetic Attitude Control System*. Utah; 2002.

[4]. Junquan Li, Mark Post, Thomas Wright and Regina Lee, *Design of Attitude Control Systems for CubeSat-Class Nanosatellite*. UK; 2013.

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Rachna Dandwani is currently pursuing B.E. in Aerospace Engineering (2016-2020) from R.V. College of Engineering, Bengaluru, India. She is interested in the structure and designing of an Aircraft and seeks to becomes an Aircrash investigator. She is engaged in many cultural activities. She has been a part of CARV - the acting club of RVCE, and has been a part of many victories for the same. She has served as a College Representative for Mood Indigo 2017. As an active member of the Rotaract Club of RVCE and NSS - RVCE(National Service Scheme), she finds a way to serve the society. She has now been working for almost two years as an active member of the Attitude Determination and Control Subsystem of Team Antariksh, a student satellite team and has recently been appointed as the Mission Manager at Team Antariksh. She holds a certificate in Hacking as a part of the summer training program conducted by Internshala. This paper is her first attempt in the direction to expand her horizon of knowledge.