CUBESPACE

CubeTorquer Generation 2

Interface Control Document (ICD)

DOCUMENT NUMBER	CS-DEV.ICD.CR-01
VERSION	1.00
DATE	28/07/2023
PREPARED BY	C. LEIBBRANDT
REVIEWED BY	LH, JM
APPROVED BY	W. Morgan
DISTRIBUTION LIST	External

Revision History

VERSION	AUTHORS	DATE	DESCRIPTION
A	C. Leibbrandt	19/06/2023	First draft release
B	C. Leibbrandt	28/07/2023	Update after initial review
1.00	C. Leibbrandt	28/07/2023	First published version

Reference Documents

The following documents are referenced in this document.

[1] CS-DEV.PD.CR-01 CubeTorquer Product Description Ver.1.00 or later

[2] CS-DEV.UM.CR-01 CubeTorquer User Manual Ver.1.00 or later

[3] Molex 503763-0291 Datasheet (Available here)

List of Acronyms/Abbreviations

ACP	ADCS Control Program
ADCS	Attitude Determination and Control System
CAN	Controller Area Network
COM	Centre of Mass
COTS	Commercial Off The Shelf
CSS	Coarse Sun Sensor
CVCM	Collected Volatile Condensable Materials
DUT	Device Under Test
EDAC	Error Detection and Correction
EHS	Earth Horizon Sensor
EM	Engineering Model
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
ESD	Electrostatic Discharge
FDIR	Fault Detection, Isolation, and Recovery
FM	Flight Model
FSS	Fine Sun Sensor
GID	Global Identification
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GYR	Gyroscope
I2C	Inter-Integrated Circuit
ID	Identification
LTDN	Local Time of Descending Node
LEO	Low Earth Orbit
MCU	Microcontroller Unit
MEMS	Microelectromechanical System
MTM	Magnetometer
MTQ	Magnetorquer
NDA	Non-Disclosure Agreement
OBC	On-board Computer
PCB	Printed Circuit Board

RTC	Real-Time Clock
RWA	Reaction Wheel Assembly
RW	Reaction Wheel
SBC	Satellite Body Coordinate
SOFIA	Software Framework for Integrated ADCS
SPI	Serial Peripheral Interface
SRAM	Static Random-Access Memory
SSP	Sub-Satellite Point
STR	Star Tracker
TC	Telecommand
TCTLM	Telecommand and Telemetry (protocol)
TID	Total Ionizing Dose
TLM	Telemetry
TML	Total Mass Loss
UART	Universal Asynchronous Receiver/Transmitter

Table of Contents

Table of Tables

Table of Figures

1 Introduction

This document is written with the assumption that the reader is familiar with the CubeTorquer as described in [1]. The purpose of this document is to provide Interface Control Document (ICD) related information about the CubeTorquer.

This version of ICD applies to the CubeTorquer hardware versions as stated in Table 1 below.

Table 1: Document Applicability

CUBEPRODUCT	VERSION	NOTES
CubeTorquer	M2.0E1.0	All sizes

2 Electrical Interface

This chapter describes the electrical interfaces of the CubeTorquer. This includes:

1. Power interfaces and expected power levels, and
2. Harness details

2.1 CubeTorquer Power supply

Table 2 below summarizes the power supply voltage to be supplied by the client ADCS / OBC.

Table 2: CubeTorquer external power supply requirements

	CUBETORQUER VARIANTS							
	CR0002	CR0003	CR0004	CR0006	CR0008	CR0010	CR0012	CR0020
EXTERNAL POWER								
Max Voltage [V]	5							

2.1.1 Power Consumption: Magnetorquers (5V rail)

Magnetorquers such as CubeTorquers are active for significant durations during satellite detumbling (often driven at maximum on-time), whereas the magnetic control authority required to desaturate the reaction wheels during normal satellite operations is typically less than 10% on-time. Table 3 shows the peak current consumption and the power consumption scaled with on-time of the various CubeTorquer variants.

Table 3: CubeTorquer power consumption

SATELLITE SIZE	CUBETORQUER VARIANT	MAGNETIC DIPOLE @ 5 V (AM^2)	NOMINAL RESISTANCE [Ω]	CURRENT (MA) ON 5 V (*PEAK PER ROD*)	AVG. POWER OVER A 1HZ LOOP[B] (MW) ON 5 V RAIL (*TOTAL FOR 3X CUBETORQUERS*)	
					10% on-time	80% on-time
Up to 3U	CR0002	0.2	51.5	98[a]	123	981
	CR0003	0.3	67.5	74[a]		
Up to 6U	CR0004	0.4	40	125[a]	188	1500
Larger than 6U	CR0006	0.6	45	111	167	1334
	CR0008	0.8	44.5	113[a]	168	1349
	CR0010	1.0	37.5	134[a]	200	1600
	CR0012	1.2	36.5	137[a]	206	1644
	CR0020	2.0	32.5	154[a]	231	1847

[a] Measured at 20-25°C ambient temperature. Note that resistance (and therefore current) of the torque rods will slightly vary with temperature.

[b] Excluding local DC-DC regulation losses.

[c] Magnetic actuation is limited to 80% of the ADCS loop to allow undisturbed magnetometer measurements to be taken.

2.1.2 Power Protection

It is expected that the user follows the specifications provided for the CubeTorquer system as specified in this document. Whenever any input or interface is used out of specified ranges, CubeSpace cannot ensure that the CubeTorquer will function as intended.

2.1.3 Electrical Model

CubeTorquer can be modelled as a resistor and inductor connected in series. The full theoretical model of a magnetic torquer includes both an electric- and magnetic resistance and inductance, but for rods of the sizes in the CubeTorquer range, the simplified model is sufficiently accurate. The simplified model is illustrated in Figure 1.

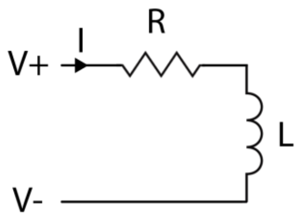

Figure 1: Electrical model of torquer rod

The R and L values for the various sizes rods are provided in Table 4. As expected for an R-L series combination, a torquer rod has a time constant (τ = L/R), also shown.

Table 4: CubeTorquer model characteristics

	CUBETORQUER VARIANTS							
	CR0002	CR0003	CR0004	CR0006	CR0008	CR0010	CR0012	CR0020
ELECTRICAL MODEL CHARACTERISTICS								
Nominal Resistance [Ω] ± 1.0	51.0	66.5	39.5	45.0	44.5	37.5	36.5	32.5
Inductance [H]	0.26	0.45	0.26	0.34	0.32	0.38	0.31	0.37
Time Constant [ms]	5	6.7	6.5	7.6	7.2	10.1	8.4	11.4

2.2 Harnesses

The CubeTorquer is designed to connect to the CubeComputer (or the client ADCS / OBC) via a dedicated harness with a Molex Micro-Lock plus housing crimped on the ADCS / OBC side and a Molex Pico-Lock on the CubeTorquer Interface.

The wire length between the housings can be specified from a selection of standard lengths. The client can specify the desired length when the order for the CubeTorquer is placed.

If the client needs a different connector between the CubeTorquer and the client ADCS / OBC, CubeSpace suggests that the standard CubeTorquer harness is supplied and the ADCS / OBC side connector be replaced by the client with his desired connector – CubeSpace tries to focus on mass production of harnesses with a limited number of connector housing supported to ensure reliability and repeatability. “Custom” / non-standard CubeSpace connectors are avoided if possible.

The wire used has a PTFE insulation which is low outgassing.

The CubeTorquer standard harness characteristics are described in Table 5 below. In Table 5, Housing 1 and terminal 1 mates with CubeComputer of Client ADCS / OBC, and Housing 2 and terminal 2 mates with the CubeTorquer itself.

Table 5: CubeTorquer Harness characteristics

Harness	Housing 1 mass (mg)	Terminal 1 mass (mg)	Wire Gauge (AWG)	Wire mass (kg/km)	Housing 2 mass (mg)	Terminal 2 mass (mg)	pins	Total[1] Mass
MTQ	138.021	35.434	28	1.4	16	7.04	6	

2.2.1 Magnetorquer Header on client ADCS / OBC

For the standard Magnetorquer harness to be used, the header as detailed in Table 6 is required on the client ADCS / OBC. This header allows for 3 CubeTorquers to be connected.

Table 6: Magnetorquer header specification

MAGNETORQUER HEADER DETAILS	
Header Type:	Molex Micro-lock plus, single row 5055680671 or 5055670671 (On client side)
Number of pins	6
Number of Headers:	1
Mating Housing	Molex Micro-Lock plus Receptacle Crimp Housing 5055650601 (on Magnetorquer harness)
Housing Terminal	Molex Micro-Lock Female crimp Terminal, Gold, 26-30 AWG, 5054311100 (used in Magnetorquer mating housing)

MAGNETORQUER HEADER ON CLIENT ADCS / OBC				
Pin #	**Pin Name**	**Pin Description**	**IO Type**	**Voltage range [V]**
1	T1+	CubeTorquer 1 pin 1 (V+)	Output, PWM driven H-Bridge	GND-5$V_{Supplied}$
2	T1-	CubeTorquer 1 pin 2 (V-)	Output, PWM driven H-Bridge	GND-5$V_{Supplied}$
3	T2+	CubeTorquer 2 pin 1 (V+)	Output, PWM driven H-Bridge	GND-5$V_{Supplied}$
4	T2-	CubeTorquer 2 pin 2 (V-)	Output, PWM driven H-Bridge	GND-5$V_{Supplied}$
5	T3+	CubeTorquer 3 pin 1 (V+)	Output, PWM driven H-Bridge	GND-5$V_{Supplied}$
6	T3-	CubeTorquer 3 Pin 2 (V-)	Output, PWM driven H-Bridge	GND-5$V_{Supplied}$

2.2.2 Electrical Interface

All CubeTorquer sizes use a 2-way Molex Picolock connector (Mfr Part: 503763-0291). Figure 2 shows an image of CubeTorquer CR0002 with the connector. Refer to [3] for more information on the Molex Picolock series connectors, and all resources available for it.

[1] Total mass of the harness depends on the harness length. The total mass can thus be self-calculated using the wire mass (in kg/km) for the specified / selected harness lengths.

Figure 2: CubeTorquer Molex connector

The connectors have a triangular marker at pin 1, as illustrated in Figure 3.

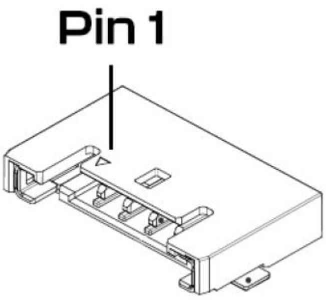

Figure 3: Pin 1 marker on Picolock connector

The electrical interface utilised by a CubeTorquer is detailed in Table 7 below.

Table 7: CubeTorquer Electrical interface

MAGNETORQUER HEADER DETAILS				
Header Type:	Molex Pico-Lock, single row, 5037630291			
Number of pins	2			
Number of Headers:	1			
Mating Housing	Molex Pico-lock, 1mm, single row crimp housing			
Housing Terminal	Molex 1mm, Pico-Lock Female crimp Terminal, 28-30 AWG, Gold 5037650098			
CUBECONNECT MAGNETORQUER HEADER PIN DEFINITIONS				
Pin #	Pin Name	Pin Description	IO Type	Voltage range [V]
1	T+	CubeTorquer 1 pin 1 (V+)	Output, PWM driven H-Bridge	GND-5$V_{regulated}$/5$V_{Supplied}$
2	T-	CubeTorquer 1 pin 2 (V-)	Output, PWM driven H-Bridge	GND-5$V_{regulated}$/5$V_{Supplied}$

3 Mechanical Interface

This chapter describes the mechanical interface of the CubeTorquer. This includes:

1. The outer dimensions of the CubeTorquer,
2. The mounting definition and specifics (hole pattern and if the mounting of the component affects its performance),
3. Mass, Centre of Mass, and Inertia,
4. Coordinate System.

<u>PLEASE NOTE</u>: The dimensions given in this section are **indicative only**. The mechanical CAD files received from CubeSpace should be treated as the source of truth.

3.1 CubeTorquer

All CubeTorquers have the same basic layout as shown in Figure 4. The torquers are composed of two aluminium mounting brackets, treated with a chromate conversion coating (Alodine), on either end of the magnetic core over which the windings are added. Each torquer is equipped with a 2-pin Molex Pico-Lock connector for interfacing.

CubeTorquers can be mounted on three of the four sides of the square mounting brackets. Please note that each mounting bracket contains a potted screw that holds the bracket onto the core. This screw should never be removed.

3.1.1 Outer Dimensions

The physical size and mounting points for the various CubeTorquers are given in Table 8. The dimensions provided in Table 8 are in reference to Figure 4.

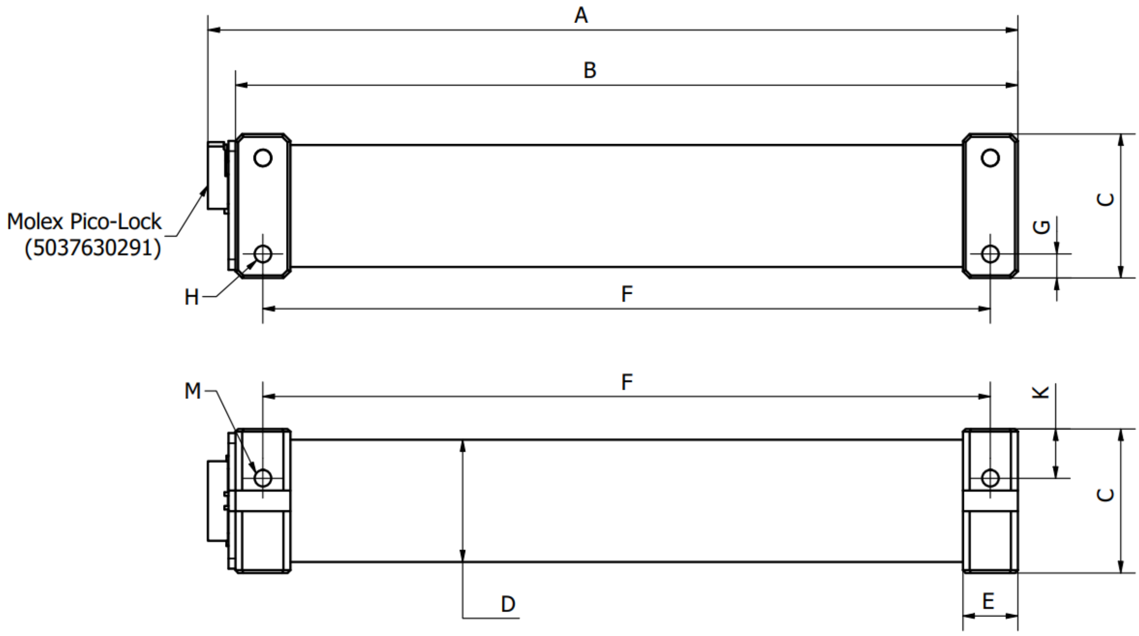

Figure 4: Indicative dimensions of CubeTorquer

Table 8: CubeTorquer dimensions for each variant

MODEL	MAGNETIC MOMENT (AM²)	A (MM)	B (MM)	C (MM)	D (MM)	E (MM)	F (MM)	G (MM)	H	K (MM)	M
CR0002	0.2	47.0	45.0±0.2	10.5±0.1	9.3	4.0	41.0±0.1	1.75 ± 0.05	M1.6 X 0.35 THRU	3.60±0.05	M1.6X0.35 3.2 DEEP
CR0003	0.3	59.0	57.0±0.2		9.3		53.0±0.1				
CR0004	0.4	59.0	57.0±0.2		9		53.0±0.1				
CR0006	0.6	77.0	75.0±0.2		9.1		71.0±0.1				
CR0008	0.8	92.0	90±0.2		8.4		86.0±0.15				
CR0010	1.0	92.0	90±0.2		8.4		86.0±0.15				
CR0012	1.2	122.0	120.0±0.3	13.0±0.1	8.3	5.0	115.0±0.2			4.8±0.05	
CR0020	2.0	152.0	150.0±0.3		8.0		145.0±0.2				

3.1.2 *Mounting definition*

A CubeTorquer can be mounted on one of three faces using a pair of mounting holes. Two mounting faces that are parallel to one another share a M1.6x0.35 mm tapped hole (see dimension H in Table 8) that pass through the full length of the bracket. The third mounting face that can be used has a M1.6 x 0.35 mm tapped hole (see dimension M in Table 8) of finite depth.

A CubeTorquer should always be mounted to a rigid and flat surface far from any magnetometers or other components overly sensitive to the magnetic field produced by a CubeTorquer.

Magnetic torquer rods must be placed carefully inside the satellite to ensure that neighbouring rods do not cause crosstalk on each other.

Figure 5 indicates some valid and invalid placement options of two rods with respect to one another. Each combination of two rods within the set of 3 rods must adhere to these placement rules.

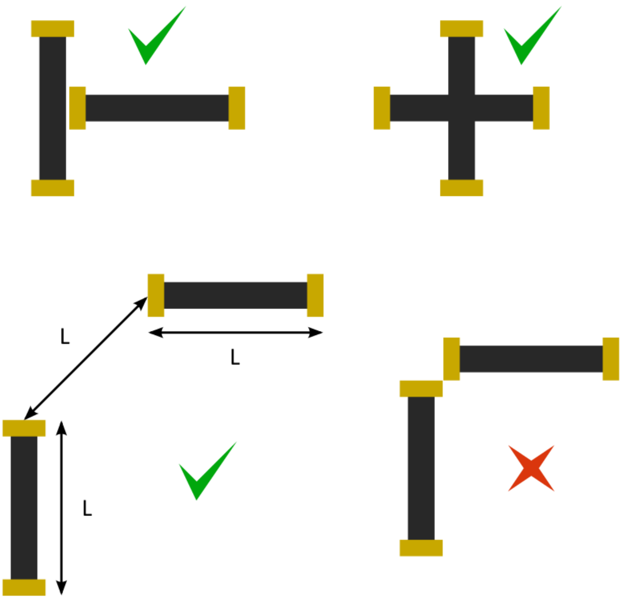

Figure 5: Placement of CubeTorquers with respect to each other

3.1.3 Mass, COM and Inertia

The position of the COM and its respective dimensions P, Q and R are shown in Figure 6 with their values detailed in Table 9. The inertial reference frame for all inertia's provided in is the same as the coordinate system definition shown in Figure 7.

Table 9: CubeTorquer mass, COM and inertia for each variant

MODEL	MASS [G]	COM (MM)			INERTIA AROUND COM (GMM²)		
		P	Q	R	I_{xx}	I_{yy}	I_{zz}
CR0002	16	22.96	5.31	5.26	2889± 10 %	2886± 10 %	170± 10 %
CR0003	24	28.89	5.29	5.26	6659± 10 %	6656± 10 %	246± 10 %
CR0004	23	28.92			6241± 10 %	6239± 10 %	215± 10 %
CR0006	31	37.89	5.28	5.25	14933± 10 %	14930± 10 %	301± 10 %
CR0008	30	45.49	5.28	5.25	21556± 10 %	21553± 10 %	242± 10 %
CR0010	37	45.39			25564± 10 %	25561± 10 %	321± 10 %
CR0012	45	60.43	6.53	6.52	60299± 10 %	60293± 10 %	415± 10 %
CR0020	54	75.45			111583± 10 %	111577± 10 %	462± 10 %

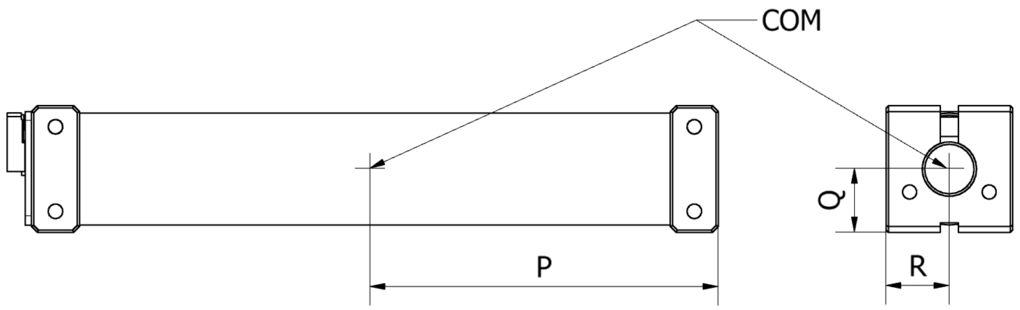

Figure 6: COM position of a CubeTorquer

3.1.4 Coordinate System Definition

The coordinates system definition used by the CubeTorquer is presented in Figure 7. This image also displays the magnetic moment direction generated when a positive voltage on Pin V+ relative to Pin V- is applied. The centre of mass of the rod can be assumed to be at the centre of volume, due to the symmetry of the heavy mechanical components, and the low mass of the connector and PCB. If a more accurate model is required, this can be requested from CubeSpace.

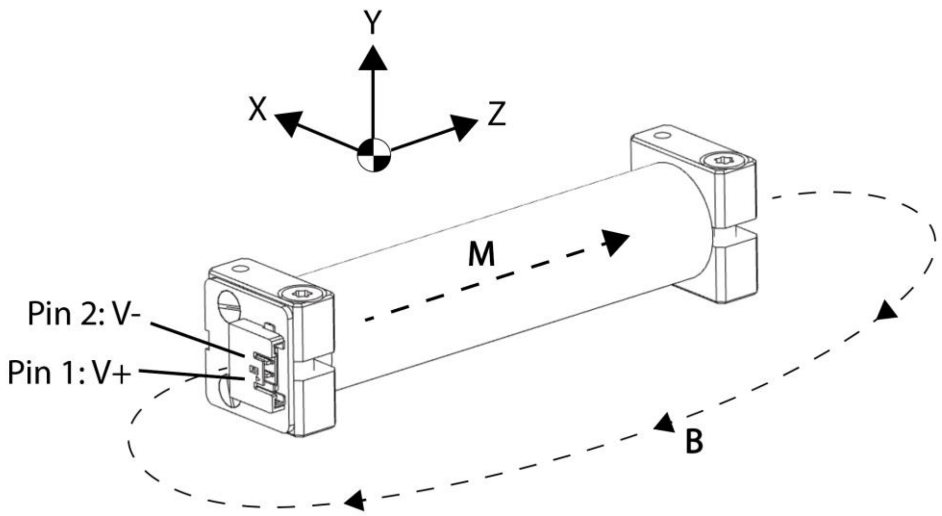

Figure 7: CubeTorquer coordinate system and magnetic polarity definition.

4 CubeTorquer Mass

Table 10 details the mass of the CubeTorquer.

Table 10: CubeTorquer mass

CUBETORQUER	VARIANT/MODEL	MASS (G)[2]	NOTES
CubeTorquer	CR0002	16	Measured
	CR0003	24	Measured
	CR0004	23	Measured
	CR0006	31	Measured
	CR0008	30	Measured
	CR0010	37	Measured
	CR0012	45	Measured
	CR0020	54	Measured

[2] This is the mass of the CubeProduct only and does not include any harnessing as these lengths can vary. Allow margin for the harness mass (refer section 2.1.3).

5 Environmental Qualification

CubeSpace has recently completed a so-called “re-spin” of all generation 2 CubeProducts, including the CubeTorquer. The re-spin effort entails minor design improvements across the board to improve lessons learnt during EMI/EMC characterisation sessions, to address minor layout optimisations that were identified and to address issues found on power regulation devices used on the CubeComputer whilst exposed to high TID radiation levels.

CubeSpace is currently in process of a full environmental re-qualification campaign of the re-spun versions of the generation 2 CubeProducts as they come of the production line. A completion date of mid 2023 is targeted. This chapter will then be updated accordingly documenting the formal qualification status of the CubeTorquer.

5.1 Test approach outline

Environmental testing is done according to a “CubeSpace generation 2 Environmental Qualification plan”.

The mentioned qualification plan contains detailed information and steps to be taken by the typical test engineer when qualifying the CubeTorquer, together with the applicable qualification test levels. In addition, derived from “CubeSpace generation 2 Environmental Qualification plan”, a detailed Environmental Test Procedure and Results document was created for the CubeTorquer. The CubeTorquer Environmental Test Procedure and Results document further detailed the exact procedure steps to be taken during a particular environmental test as well as the expected results that must be achieved to claim a qualification level “PASS” against a test.

The detailed test sequences are outside the scope of this document. Only the applicable qualification test levels are indicated in sub-sections below.

5.2 Thermal (Cold Start and Hot start) qualification testing.

The CubeTorquer, while not powered, is subjected to a cold start temperature of -35 degC. Once the soak period of minimum 30minutes have passed, the CubeTorquer is powered up and its start-up sequence is monitored for correct operation and if successful, a brief health check is done. The CubeTorquer is then powered down and temperature raised to +70 degC and the power up sequence and brief heath check is repeated. The CubeTorquer is again powered down and brought back to ambient temperature. A complete ATP is then conducted and if all tests pass, the CubeTorquer is deemed to have passed its Thermal (Hot and Cold start) qualification test.

5.3 Thermal / Vacuum (TVAC) qualification testing

The components used in all CubeProducts are non-outgassing and are specifically chosen to fall within the CVCM < 0.1%, TML < 1% limits.

For every TVAC cycles (for both hot and cold extremes – see tables below) the CubeTorquer is subjected to a full health check test procedure. Once all cycles have been completed, the CubeTorquer is subjected to a full Acceptance Test Procedure. If the CubeTorquer passes all tests, it is deemed to have passed TVAC testing at qualification levels.

Table 11: TVAC Hot cycle qualification levels

TVAC PARAMETER	TEST LEVEL
Chamber Pressure	1e-3 Pa or 1e-5 mBar

TVAC PARAMETER	TEST LEVEL
Number of Cycles	4
Dwell time after thermal stabilisation	1h
Temperature Tolerance	±2 ºC
Temperature ramp rate	1 ºC/min
Maximum Temperature (Qualification)	+80±2ºC

Table 12: TVAC Cold cycle qualification levels

TVAC PARAMETER	TEST LEVEL
Chamber Pressure	1e-3 Pa or 1e-5 mBar
Number of Cycles	4
Dwell time after thermal stabilisation	1h
Temperature Tolerance	±2 ºC
Temperature ramp rate	1 ºC/min
Minimum Temperature (qualification)	-20±2ºC

5.4 Vibration qualification testing

For each of the three axes of the CubeTorquer, once a particular vibration type of test is done (see tables below), it is physically inspected for any damage and then subjected to a full health check test procedure. Once all vibration type tests have been completed the CubeTorquer is subjected to a full Acceptance Test Procedure. If the CubeTorquer passes all tests, it is deemed to have passed Vibration testing at qualification levels.

Table 13: Low level sine resonance search levels

FREQUENCY (HZ)	AMPLITUDE (G) [0-PK]
5	1
2000	1
Sweep rate	2 Oct/min

The **success criteria** for the resonance search are:

- Less than 5% change in the average frequency of peaks displayed by the accelerometer placed on the DUT.
- Less than 20% in amplitude shift

Table 14: Qualification sine plus quasi-static levels

FREQUENCY (HZ)	AMPLITUDE (G) [0-PK]
5	1
10	2.5
21	2.5
25	15
30	15
35	3
110	3

FREQUENCY (HZ)	AMPLITUDE (G) [O-PK]
125	0.25
Sweep rate	2 Oct/min

Table 15: -3dB random vibration qualification levels

FREQUENCY (HZ)	AMPLITUDE (G^2/HZ)
20	0.0282
50	0.0802
800	0.0802
2000	0.0130
Duration	60 seconds
Grms	10.02

Table 16: Random vibration qualification levels

FREQUENCY (HZ)	AMPLITUDE (G^2/HZ)
20	0.0563
50	0.1600
800	0.1600
2000	0.0260
Duration	120 seconds
Grms	14.16

5.5 Shock qualification testing

For each of the three axes of the CubeTorquer, once a particular shock test is done (see table below), it is physically inspected for any damage and then subjected to a full health check test procedure. Once tests in all axes have been completed the CubeTorquer is subjected to a full Acceptance Test Procedure. If the CubeTorquer passes all tests, it is deemed to have passed Shock testing at qualification levels.

Table 17: Qualification shock test levels

FREQUENCY [HZ]	SHOCK SPECTRUM VALUES [G] - 3DB (LOWER-LEVEL THRESHOLD)	SHOCK SPECTRUM VALUES [G] (NOMINAL QUALIFICATION LEVELS)	SHOCK SPECTRUM VALUES [G] +6DB (UPPER-LEVEL THRESHOLD)
30	2	5	20
1000	750	1500	6000
10000	750	1500	6000

5.6 Radiation

For the CubeSpace generation 2 product line, the minimum successful TID level is defined as 24 kRad at a 95% confidence level. (This is calculated for 3 units tested as: Rating = Mean – 3*STD)

5.7 EMI / EMC

As mentioned in this chapter's introduction only EMI / EMC characterisation sessions have taken place to date. No formal EMI / EMC testing has been done to date.

6 Materials used.

A Declared Materials List document is available for the CubeTorquer and is optionally available from CubeSpace and should be specifically requested during order placement.