

Section 10: Appendix 4

Mechanical Failure Modes Effect and Criticality Analysis

EQUIPMENT INSTRUMENT:		SPIRE		Subsystem / System:		BSM		Doc. Number:	Design Description appendix 4
Operating Mode:		CHOP & JIGGLE MODE		Operating / Mission Phase:		Observing		Issue:	1
Functional Diagram / Drawings:								date	24.JUN.01
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ID	Item and Function	Assumed Failure Mode	Resulting Performance of and Effects on Equipment / Subsystem / System	Observable Symptoms (Housekeeping, Test)	Criticality	Prevention or Compensation Methods (back-up, redundancy)	Recommendations	Remarks	
RBD-1	1	BSM STRUCT	Failure to cool down	degraded detector	high background	2R	redundant thermal path		should complete a thermal path fmea?
	2		Fails on launch	probable damage to SPIRE	lack of signal	2R	three fasteners.(2/3 redundant)	sizing calc on structural fasteners	MSSL responsible for fastener sizing
	3		Failure during operation (SCC OR FATIGUE CRACK)	erratic resonance effects	changes natural frequencies	2	back-up mode - drift map	perform FEA, use SCC OK material	
	4		Degraded operation (RESONATES)	longer settling time	longer settling time	3	reduce speed operation		

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RBD-2b	1	Jiggle axis flex pivot protection sleeve	Failure during operation - icing	increase in friction (or stuck) after cooldown	motors & sensors working OK but no motion results	2			
	2		Failure during operation - debris ingress	increase in friction & power usage		2			
	3		friction or end-stop caused by small clearance	increase in friction & power usage		2		flex pivot mounting is critical. End stops to be well characterised.	
	4		vacuum welds during launch rubbing contact	no jiggle mode. Fixed stare mode, not (0,0)	motors & sensors working OK but no motion results	2	dissimilar metals (aluminium, inconel)	tribology investigation if funds permit	
	5	redundant journal bearing function	fretting failure, possibly vacuum welding	increase in friction & power usage	erratic torque-position plot	2	dissimilar metals (aluminium, inconel)	tribology investigation if funds permit	consider tests of this mode.
RBD3	1	Jiggle frame structure (includes fasteners)	Failure to cool down quickly	Flex pivot differential thermal stresses	nil	3	thermal end-stop. Controlled cooldown rate for instrument		

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	2	Fails on launch: structure cracks	loss of chop axis position definition	erratic torque-position plot	2		perform FEA, use SCC OK material		
	3	Fails on launch: fastener loosens	loss of chop axis position definition	erratic torque-position plot	2R	redundant fasteners (4/8)		locking fasteners, torque control	
	4	Failure during operation (SCC OR FATIGUE CRACK)	erratic resonance effects	changes natural frequencies	2	back-up mode - drift map	perform FEA, use SCC OK material		
	5	Degraded operation (RESONATES)	longer settling time	longer settling time	3	reduce speed operation		unlikely	
RBD4	1 Chop demand	no chop requested (eg due to error in ODF, telemetry, operator error)	delay to troubleshoot problem	no chopping	3	nil in BSM	ODF software needs to be robust handling chop requests	higher level system needs to provide protection	
	2	excessive chop angle or frequency requested	flex pivot overload or excess power dissipation	as RBD2a	2	nil in BSM	MCU needs voltage limiter, software needs sanity check	higher level system needs to provide protection	
	3	chop demand short circuits	excess power dissipation	excess power dissipation, fixed offset	2	reset higher level system			
RBD5	1 Chop Structure	Failure to cool down quickly	Flex pivot differential thermal stresses	nil	3	thermal end-stop. Controlled cooldown rate for instrument			

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2		Fails on launch: structure cracks	loss of chop axis position definition	erratic torque-position plot	2		perform FEA, use SCC OK material	unlikely		
3		Fails on launch: fastener loosens	loss of chop axis position definition	erratic torque-position plot	2R	flex pivots would act as journal bearing.		locking fasteners, torque control		
4		Fails on launch: magnet loosens	chop axis jams anywhere in range of travel	chop jams or high friction load	2	try cycling prime and redundant motor coils and restore to zero position. Scan map.	good process control on magnet adhesive required			
5		Failure during operation (SCC OR FATIGUE CRACK)	erratic resonance effects	changes natural frequencies	2	back-up mode - drift map	perform FEA, use SCC OK material	unlikely		
6		Degraded operation (RESONATES)	longer settling time	longer settling time	3	reduce speed operation		unlikely		
7	chop mirror	print throug of lightweighting on mirror surface	image degradation	waffle pattern	2		test mirror surface for print through			
8		contamination on mirror	image degradation	loss of signal, spectrographic signature	2	clean room assembly		unlikely		

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RBD-6A	1	Chop axis flex pivot	Fails on launch	loss of definition of pointing Loss of restoring torque. Increased friction to drive. Chop mode probably unusable	-unstable pointing. - Increase in drive currents. -Random noise on sensors	2R	-prevention by flex pivot protection sleeve. -redundant bearing surface (RBD-2B) - degraded operation. -Coarse control with motors to central position. -use of jiggle for 1/f deconvolution -Scan-map back-up mode	increase test programme to cover failure modes if funds permit.	most likely to lose both flex pivots if one goes.
	2		Failure during operation - icing	increase in friction & power usage (or stuck) after cooldown	thermal history . Cured by warm up	2	prevented by clean room procedures		only during AIV - not possible during on-orbit operations
	3		Failure during operation - fatigue	as fails-on launch	deterioration in performance as crack progresses	2	prevented by design selection and by careful alignment	flex pivot alignment procedure is critical	
	4		Failure during operation - debris ingress	increase in friction & power usage	random sticking. Power consumption high	2	prevented by clean room procedures		unlikely

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RBD-6b	1	Chop axis flex pivot protection sleeve	Failure during operation - icing	increase in friction (or stuck) after cooldown	motors & sensors working OK but no motion results	2R	-scan map -use of jiggle for 1/f deconvolution				
	2		Failure during operation - debris ingress	increase in friction & power usage		2R	-scan map -use of jiggle for 1/f deconvolution				
	3		friction or end-stop caused by small clearance	increase in friction & power usage		2R		flex pivot mounting is critical. End stops to be well characterised.			
	4		vacuum welds during launch rubbing contact	no jiggle mode. Fixed stare mode, not (0,0)	motors & sensors working OK but no motion results	2R	dissimilar metals (aluminium, inconel)	tribology investigation if funds permit			
	5	redundant journal bearing function	fretting failure, possibly vacuum welding	increase in friction & power usage	erratic torque-position plot	2	dissimilar metals (aluminium, inconel)	tribology investigation if funds permit	consider tests of this mode.		
RDB 7A, 8A, 9A	1	DRCU - MAC - BSMe Primary boards	Premature operation	chop before unlatch or power surge? Could damage motors or pivots	unknown	2	nil in BSM	DRCU to perform FMECA			

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2		Failure to operate	no chop or jiggle mode. No unlatch command?	no chopping, jiggling. Latch and damping remain in place	2R	scan map				
3		Failure to cease operation	excess power dissipation	excess power dissipation, fixed offset	2R	reset higher level system or switch to redundant unit				
4		Failure during operation	motors fail in on condition	excess power dissipation, fixed offset	2R	reset higher level system or switch to redundant unit				
5		Failure during operation	loss of BSM control	no chopping, jiggling. Latch indeterminate?	2R	scan map or switch to redundant unit		indeterminat latch state should be avoided.		
6		Degraded operation	degraded BSM function	degraded BSM function	2R	scan map or switch to redundant unit				
7		short circuit				nil in BSM				
8		open circuit				nil in BSM				
9		incorrect function				nil in BSM				
10		Incorrect commands				nil in BSM				
11		Incorrect software functions				nil in BSM				

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RBD 10A	1	Connectors and cryo-harness	short circuit	motor shorted	no motion	2R	switch to redundant harness and operate against a damped motor			
	2		short circuit	sensor shorted	invalid sensor value	2R	switch to redundant harness	set invalid sensor range flags in WE software	check - does de-power of WE primary open the circuit?	
	3		short circuit	PCAL shorted	nil in BSM	3	nil in BSM			
	4		short circuit	thermistor shorted	nil in BSM	3	switch to redundant harness			
	5		Degraded operation	intermittent short	as short, but more annoying	2R	switch to redundant harness		diagnose by extended telemetry?	
	6		open circuit	motor open	degraded motion	2R	switch to redundant harness			
	7		open circuit	sensor open	no position feedback	2R	switch to redundant harness or operate open-loop			
	8		open circuit	PCAL open	nil in BSM	3	nil in BSM			
	9		open circuit	thermistor open	nil in BSM	3	switch to redundant harness			
RBD 11A	1	Chop Axis sensor	Failure to operate	chop offset close to zero position	invalid sensor value	2R	switch to redundant WE or operate open-loop	set invalid sensor flags in WE software	problem may be in WE or harness	

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2		Failure to cease operation	chop offset at end of travel.	no position feedback, excessive power dissipation	2R	switch to redundant WE or operate open-loop			
3		Failure during operation	erratic pointing performance or drift	unknown	2R	switch to redundant WE			
4		Degraded operation	erratic pointing performance or drift	unknown	2R	switch to redundant WE			
5		short circuit	chop offset close to zero position	invalid sensor value	2R	switch to redundant WE			
6		open circuit	chop offset at end of travel.	no position feedback, excessive power dissipation	2R	switch to redundant WE or operate open-loop			
7		Incorrect software functions	unexpected behaviour, please contact your systems administrator	nil in BSM	2R	nil in BSM	test all modes in ground		
RBD 11B	1 Chop Axis control mode with no feedback	Failure to operate	undamped motion	undamped motion	3	switch to redundant harness or operate open-loop	test this mode on ground	this is a back-up degraded operation mode	

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	2		Incorrect software functions	unknown	nil in BSM	3	nil in BSM	ensure this operating mode included in software				
RBD 11c	1	Chop Axis control mode with current feedback	Failure to operate	undamped motion	undamped motion	3	switch to redundant harness or operate open-loop	test this mode on ground	this is a back-up degraded operation mode			
	2		Incorrect software functions	unknown	nil in BSM	3	nil in BSM	ensure this operating mode included in software				
RBD 12A	1	Chop Axis Motor	short circuit	no motion	no motion	2R	switch to redundant WE and operate against a damped motor	is the shorted condition detectable in WE by telemetry?				
	2		open circuit (broken wires)	no motion	no motion	2R	switch to redundant WE	housing damage can affect redundant motor so is SPF for chopping (but not SPIRE)				

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3		part-short circuit (motor windings reduced by short)	degraded motion	increased settling time, changed power dissipation	2R	switch to redundant WE and operate against a partly damped motor			
4		mechanical damage - housing	degraded motion or thermal hot spot	increase in friction & power usage (or stuck)	2	-switch to redundant WE -use jiggle for 1/f removal -revert to scanmap			
5		mechanical damage - fasteners loose	degraded motion or thermal hot spot	increase in friction & power usage (or stuck)	2	-switch to redundant WE -use jiggle for 1/f removal -revert to scanmap			
6		mechanical damage - shield	degraded motion or thermal hot spot	increase in friction & power usage (or stuck)	2	-switch to redundant WE -use jiggle for 1/f removal -revert to scanmap			
7		loss of electrical isolation	unknown	noise or erratic motion	2	-switch to redundant WE -use jiggle for 1/f removal -revert to scanmap	investigate		
RBD 12B	1 Chop Axis Motor (cold redundant)	short circuit (probably on launch)	damping of primary motor	damped motion, increase in power dissipation	2	operate against a damped motor	test this mode on ground. Test redundant circuits on establishing orbit	cold redundant component	

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RBD 13	1 unlatch harness and connector	short circuit	latch shorted	no retract signal	2R	switch to redundant harness and operate against a damped solenoid coil		launch latch is on BSMs so is fed by cryo harness. Motor damping would just be in WE.	
	2	short circuit	sensor shorted	sensor indicates closed, but chop motion restricted	2R	switch to redundant harness			
	3	Degraded operation	intermittent short	as short, but more annoying	2R	switch to redundant harness		repeat unlatch command several times.	
	4	open circuit	latch unpowered	no retract signal	2R	switch to redundant harness			
	5	open circuit	sensor open	sensor indicates closed, but chop motion is OK	2R	switch to redundant harness or operate open-loop	incorporate in checklists	false negative sensor reading.	
RBD 14	1 unlatch demand	no unlatch requested (software error)	delay to troubleshoot problem	no retract signal	3	nil in BSM	MCU software to be robust		
	2	latch command set high	delay to troubleshoot problem	no retract signal	3	nil in BSM	MCU software to be robust		

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	3		latch demand short circuits	excess power dissipation	excess power dissipation, BSM pinned in chop	2R	reset higher level system, operate BSM in limited range of travel.	must be able to turn off power to launch latch solenoid with redundant function	solenoid left on would boil cryogen off if no provision to turn it off.
RBD 15 A,B,C	1	chop axis damping unlatch	Premature operation (during launch)	no damping of coil during launch. Possible damage to flex pivots	none	2R	redundant coils damped	test this mode on the ground	could incorporate feedback into MCU?
	2		Failure to operate	no damping of coil during launch. Possible damage to flex pivots	detectable in MCU?	3R	redundant coils damped	MCU feedback required on damping	
	3		Failure to cease operation	damping of primary motor	damped motion, increase in power dissipation	2R	serial redundant switches, possible to operate against damped coil		
	4		Failure during operation	indeterminate state	unknown	3R	serial redundant switches		
	5		short circuit	damping of primary motor	damped motion, increase in power dissipation	2R	serial redundant switches, possible to operate against damped coil		

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6		Incorrect commands	unlatch when not required	detectable in MCU?	2	nil in BSM	software protection against premature unlatch demand required		
7		Incorrect software functions	unlatch when not required	detectable in MCU?	2	nil in BSM	software protection against premature unlatch demand required		
RBD 16A	1 chop axis deployable end-stop unlatch	Premature retraction (during launch)	no limit of travel during launch. Possible damage to flex pivots	none	2R	motor coils damped, flex pivot sleeves, adequate reserve on pivots	could incorporate feedback into MCU?		
2		Overconstrains pivots	induced flex pivot failure	as RDB2, 4	2R	flex pivot sleeves, use of jiggle to address 1/f noise, scan map	test for this during vibration campaigns		
3		Failure to cease operation	locking of chop axis motion end stops at 1.5 degrees	no retract signal obtained, hard stops at end of travel	3R	redundant coil on solenoid, redundant harness			
4		Failure during operation	indeterminate state	unknown	3	unknown	test MCU / software for indeterminate state	unlikely as bi-stable magnet.	

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5		short circuit	damping of primary solenoid coil	no retract signal obtained, hard stops at end of travel	3R	redundant coil on solenoid, redundant harness				
6		Incorrect commands	unlatch when not required	detectable in MCU?	2	nil in BSM	software protection against premature unlatch demand required			
7		Incorrect software functions	unlatch when not required	detectable in MCU?	2	nil in BSM	software protection against premature unlatch demand required			