Minutes of the BSM Progress Review

15 March 2000

UK ATC, Edinburgh

Colin Cunningham/ David Henry   14 May, 2000

Present

Colin Cunningham	ATC	Gillian Wright	ATC
Walter Gear	Cardiff	David Henry	ATC
Didier Ferand	LAS	Martin Fisher	ATC
Patrick Lavacher	LAS	Richard Bennett	ATC
Louis Rodriguez	CEA-SAp	Peter Hastings	ATC
Oliver Krause	MPIA Heidelberg	Bruce Swinyard	RAL
Ulrich Gröezinger	MPIA Heidelberg	Matt Griffin	QMW

Introduction   Colin Cunningham

The meeting began with an introduction by Colin Cunningham. He outlined the aims of the meeting - an informal review of the design of the Beam Steering Mirror, prior to the formal PDR.

Some key issues to be resolved were outlined as:

- Analogue or digital controller
- Free-running - no synchronisation required
- Crosstalk specification
- Power dissipation
- Flex pivot choice
- Who does what (especially WE build)
- Open loop performance (if position sensors fail)
- Functionality of the DRCU

BSM Requirements   Gillian Wright

Gillian Wright gave an overview of the scientific requirements of the BSM.

The BSM is required to perform three functions; chopping, jiggle-mapping/microstepping and fine pointing correction, because the Telescope has 3.7” maximum Absolute Pointing Error (APE).

On the top level requirements, the following points were made:

The photometric performance of the system should not to be determined by the BSM (to 1% TBC).

The BSM is also necessary for the FTS in order for it to do jiggle spectroscopy. BMS pointed out that if the FTS arrays are rotated by 14.5° then motion is only required in one dimension.

The fail safe position should be at the centre of the range of travel. The criterion for this is that we lose at most one row of pixels - gives 9” on the sky. CRC stated that if the flexures fail, the mirror could get stuck anywhere. An end stop should be considered. WKG asked if there was a spec on stability if the mirror fails.

The requirements in chop mode were then discussed.

Error in the signal due to random motion of the mirror should be less than the photometric accuracy requirement for the worst case pointing (source “on edge” of beam for smallest pixel, eg at 6” offset). This corresponds to a 1.7% rms error in the signal for 0.2 arcsec rms pointing error. The stability requirement is therefore 0.2 arcsec rms in 0.1-25Hz band, with a goal of 0.1 arcsec rms in same band.

The (static) stability requirement is 0.2” RMS, 0.1-25Hz with goal of 0.1”, This is equivalent to the resolution. As a goal, this specification should be met even under the fail-safe condition.

The chop frequency is 2 Hz (reduced from 5 Hz) operable up to 5 Hz with increased dissipation and/or reduced efficiency. The chop direction is along the long axis of the array (the spacecraft y-axis).

The jiggle frequency requirement is 1 Hz (again, can go faster with reduced performance)

The minimum chop throw required is 18 arcsec. However, the resolution is the important factor. The required maximum chop throw is ±2 arcmin; the goal is ±2.5 arcmin.

The absolute accuracy for a chop step should be ±2” (e.g. for a requested 18 arcsec step, the actual motion should be in the range 16 - 20 arcsec). This error should be calibratable.

The requirement on settling time comes from the required 90% duty cycle at 2 Hz. This specification requires careful definition. It should be ~1% of full scale (125” chop) i.e. ±1” for any chop amplitude.

The required repeatability is 0.2” RMS. This is set by the same science requirement as the stability.

The required stability during a half-cycle or a jiggle step is a residual mirror movement of < 1” RMS.

DF pointed out that external disturbances are what affect the stability most severely - the control system itself will easily be able to hold it. CRC stated that the FTS mechanism turning round could introduce disturbance.

The jiggle mode requirements were then discussed:

The required jiggle pattern is a hexagon. Movement in X and Y simultaneously is more efficient. The alternative is to do X then Y. Simultaneous X and Y motion should be treated as a goal - as long as the settling time requirement is met, it doesn’t really matter.

UG asked whether crosstalk between the axes makes any difference here? MF replied no, as long as the crosstalk has died away within the 25 msec settling time.

The jiggle frequency requirement is 1Hz - this gives ~1 minute for a 64 pt jiggle. The typical step size is 1/2 beam width. Drizzling means down to 1/10 beam. The step size range is from 2 - 30”

The synchronisation of the jiggling is the responsibility of the control system.

Jiggle settling time is 50 msec. This means that some efficiency is lost, but this is still OK for a 1 second half-cycle.

WKG pointed out that there is no specification that chopping and jiggling have to be synchronised - this is a requirement

Action BSM 1: MJG/BMS spec jiggle/chop synchronisation in the OMD June 1st

The accuracy and repeatability requirements are as for chop mode.

It was felt that fine pointing correction doesn’t require to be specified as a separate mode; it can be treated as a subset of chopping and pointing modes. This does have implications for the software and the control system.

Mechanical Design Richard Bennett

Richard Bennett then gave an overview of the mechanical design. The following points were made:

A simple FEA model shows that inertia is high. The moment of inertia of the jiggle stage is not quantified yet.

The required size of mirror is 32 mm not 30 mm. The ATC will take on the manufacture of the mirror. A 2 mm hole for the calibrator gives 0.4% loss of area; 1 mm gives 0.1% loss of area.

It was questioned whether it was possible to have the chop axis through face of mirror. This should be possible.

OK/UG pointed out that there is a large temperature gradient during cooldown (up to 120 K). This depends on the flex pivots.

It should be possible to determine the likely failure modes.

The position of the sensors near the motors was queried - this may need shielding. Consultation with PACS on this issue was recommended.

Oliver Kraus showed some viewgraphs on the position sensors.

The forces due to the position sensors need to be taken into account. PACS design eliminates them and provided good shielding. The performance is better than ISO-PHOT design (only one air gap between magnet and field plate). Strong magnetic field reduces current needed and power dissipation.

- Power: 0.5mW
- Angular range: ±15°
- Accuracy: 0.4'

The PACS prototype has been built and will be tested in a few weeks. They need to look at power dissipation by eddy currents. This is being simulated with EM code.

Using high-purity Al for coils, with anodised support structure.

It was pointed out that PACS need 10 Hz at ±4.5° degrees. This is more stringent than the SPIRE requirements.

Control System Design Martin Fisher

Martin Fisher then outlined the work that has been carried out on the control system.

To date, a rigid body model of the chop stage has been looked at.

This shows that the resonant frequency is 19 Hz (up from 13). This will increase if stiffer flexures are used to cope with launch loads.

MSSL have stated for structural parts have to be designed to cope with 50g loads. BMS stated that MSSL can probably provide information on vibration loads in the 20-Hz range. The system will have sine-sweep testing at 15g, 0-50Hz.

Extra damping (in the form of velocity feedback) is needed from controller. The velocity must be derived from position measurement

The chop stage inertia has been reduced by 2 - factor of 4 in dissipation. This is OK. In ISO-PHOT, the damping is dominated by induction losses. This makes settling easier.

There are three possible controller types. These are:

- PID controller (as used in ISO-PHOT)
- Notch filter to damp resonance
- State controller (must be digital)

The PID option gives 20 msec to 1% full scale or +/- 1.2 arcsec. (even ignoring eddy current damping). There is a need for sensor noise model to assess set point stability. The gain margin is 8 dB, while the phase margin is 80°.

This is a very simple implementation. DF asked if this can be implemented without DSP? MF replied that he believes it can be done. However, the DSP gives more flexibility and more options for recovery in the event of a failure.

The options for the electronic design are to follow the ISO-PHOT architecture or use digital controller.

The ISOPHOT controller is all analogue, with 12-bit DACs for command and position compensation and relays for mode switching. We will need to design different coil drivers for redundancy.

A digital controller will still need driver and sensor electronics. 12-bit DACs can be used for command and position compensation. The sample rate needs to be ~1.2 kHz. This option gives better control of failure modes, better robustness and better flexibility.

For the position sensors, we need two for each axis with only one powered at a time. A failure mode analysis on the mechanism is required. The power-up of the position sensors is computer controlled. The interfacing depends on controller option.

It is intended to use ISO-PHOT equivalent position sensors. A question was asked as to what extent do they need to be selected? UG replied that they are selected for qualification. Linearity was coped with by means of a look-up table.

UG pointed out that we could do procurement and selection in collaboration with PACS is we can have same type of position sensors, and CRC agreed to bear this in mind.

The position sensors are now mounted on the jiggle stage. This will require flexible wires leading to them.

The motors have two sets of 4 coils. These are of the same design as ISO-PHOT (with NdFeB). Cryoperm 10 (μ_r = 250,000 at low temp) - not easily acquired and not available with laminated cores OK stated that PACS are using Ultraperm. This is available in laminated form and its permeability (20,000) is good enough as the air gaps dominate in the magnetic circuit.

BMS asked about the FTS actuator? DF replied that it will be subconbtracted.

The motor coils are on the baseplate so the heat from the coils goes into the surrounding structure.

The controller will have a sinusoidal acceleration profile. The best estimate is of the power consumption is ~0.4mW per channel (both to maximum extent). More needs to be added for eddy-current losses. The sensor power is ~0.5mW. Therefore total stage dissipation ~1mW for each stage. The voltage requirements are a couple of volts.

The digital PID controller option was then discussed. Its advantages are:

- Better recovery from some kinds of failure
- Complexity is moved from the analogue to digital domain
- More versatile and robust

The disadvantages are:

- Higher cost
- Infrastructure support/cost (development software etc.) BMS: Should be able to find out from the Italians.
- Anti-aliasing requirements

Specifications

ATC to write an ‘Optical specification’ document. This will list the facts they need in order to complete BSM design.

Action BSM 2: DH write optical specification document June 1st

It was pointed out that the ATC needs to make BSM dummy for alignment. A specification is needed for it.

The vignetting at longer wavelengths was discussed. This could mean that the aperture stop needs to be opened up.

Action BSM 3: BMS to tell ATC whether TBD is OK in terms of vignetting at longest wavelengths May 17th

A self-induced vibration specification is required.

The temperature rise requirement needs to be re-cast and the need for baffling has to be examined.

There is a requirement that the BSM be testable warm, for health/functionality checks.

On the storage and handling environment, it was stated that the BSM must be compatible with 80° C bakeout.

BMS stated that there has to be a direct and visible translation from IRD to Subsystem Specification Document.

Critical components:

Richard Bennett led a discussion on the flexures.

It was stated that it is possible to have flex pivots manufactured with smaller radial clearance and maybe integral end-stops. This would reduce the degree of flop if it breaks. Inconel can be electron beam welded. These are available from Lucas with a ~ 6months lead time.

Alignment of the flexures is the most critical aspect. Thermal distortions could pose a problem. Clamping is recommended for installation.

BMS stated that they are a long lead time item, so must act soon. MJG said we should order some Lucas flex pivots now and use them for prototyping even if they're not identical to the ultimate flight design.

Position sensors and readout:

MF said that we need to look at requirements for the material for the cores. An analysis needs to be done to verify that proposed arrangement is adequate. The old position sensor design should be OK but not totally sure (it's commercially available). This is made by "Infineon" (ex Siemens)

DF asked if it was possible that they could use the same sensor for the FTS low resolution position sensor.

New or old sensor:

A question was asked whether it was possible to design the system so that the new device could be used if necessary, but use the old one first? This was thought to be possible. The plan is to get the old type of sensors and use them to build a prototype.

The ISO-PHOT circuit design is available.

Motors:

MF stated that we need to discuss options with MPIA on magnetic materials etc. Ultraperm should be OK. CRC stated that we need to look at modelling of magnetic circuit. UG replied that they can do this for SPIRE.

BMS stated that the development plan should involve a lot of attention to the quality programme. We should qualify at component level (actuator, flexures etc.) well in advance of system level.

Controller:

The main issue with the controller is whether a single DSP can serve the FTS mechanism and the BSM. This is the subject of a side meeting.

Failure modes and criticality Colin Cunningham

The BSM redundancy scheme is different to the FTS scheme (which has two totally parallel systems).

DF stated that in practice, the electronics are the most unreliable parts. Thermometers are still needed, especially for CQM.

The most important failure mode is sticking of mirror. This could lose FOV of the FTS. We could consider a launch lock that could put it back in place. It was felt that end stops are needed. We should drop requirement for 2.5 arcminutes travel goal.

Action BSM 4: BMS/MJG to check extent of loss of FTS field if BSM sticks at extreme position May 17th

Action BSM 5: BMS/MJG/WKG to propose solution which guarantees that BSM failure can't result in loss of the FTS May 17th

Requirements and Interfaces David Henry

David Henry discussed a number of issues relating to the system requirements and interfaces.

It was pointed out that there is no top level specification on the mirror axes position relative to surface.

The baffling requirements were briefly discussed. There may be a need for a cover between the edge of the mirror and the BSM structure.

It was stated that the photometer calibration unit was now the responsibility of QMW, not GSFC. Peter Hargrave is the responsible person.

It was stated that LAM may become the point of contact for the warm electronics.

Alignment requirements are the same as for the other mirrors mounted in the structure.

Test plan Colin Cunningham

Colin Cunningham then outlined some aspects of the test plan.

The development model will be used for room temperature tests, to determine the following;

- Mass, stiffness, CoG etc.
- Dynamics, stability
- Vibration testing (resonant frequencies by sine sweep)

Microphonic export was discussed. It was agreed that some work is needed to get a specification on this.

Action BSM 6: MJG raise issue of spec. for vibration sensitivity with JPL June 1st

It was felt that radiation tolerance could be dealt with by analysis and/or heritage of design. The feeling was that this shouldn't be a problem.

The development model will be used for the following 4-K tests

- Dynamics
- Stability
- Power dissipation

- Lifetime
- Vibration testing (at RAL; 3-axis random + sine sweep; takes about a week)
- Thermal and vacuum cycles (BMS: about 30 should be OK)
- Thermal isolation

BMS stated that a specification is needed for the cool-down rate

Some initial thoughts on the test set-up were presented. For static deflection, an autocollimator and rotary table can be used. A laser and detector (quadrant photodiode) can be used to measure dynamic deflection

A Shutter in the N2 can could be used to allow life testing with same set-up. MPIA plan to have a similar setup. Zeiss did the same as for ISOPHOT- this is similar to the tests above.

Power consumption vs. rise time, chop and jiggle frequency, angular offset will be measured, both at room temperature and 4K.

Thermal isolation will be measured by mounting on an interface of known thermal conductivity.

BMS stated that he is concerned about the relationship between the Development Model and CQM. It is unclear how the "learning process" is catered for - there are a lot of new developments needed. The mechanism has moved so far from ISO that it should be regarded as a new development.

For the lifetime tests, it is necessary to test jiggle axis also. The BSM will jiggle at 1 Hz during the life test. It should be assumed that the BSM is chopping for 2/3 of photometer time. The BSM can operate at resonant frequency of around 20 Hz.

The warm vibration test will be a sine sweep only. Cold vibration (4K) will be carried out at RAL

For the microphonics, we should simplify the concept presented in the viewgraph. Measure the BSM exported vibration on some plate whose compliance is quantified.

For EMC testing, conducted noise down wires to position sensors was discussed. RF filters (200 MHz) should have no effect. Magnetic field generation shouldn't be a problem, though it must be specified internally though.

On the testing of the simulation and control system electronics, it was suggested that we could use a simulation of control system and drive electronics for DM (e.g. Simulink, Matlab, PC card). Meanwhile, the prototype flight electronics can be tested using a BSM simulator. We then verify flight prototype electronics.

For the CQM testing it was suggested that this be similar to the DM, but with a limited range of tests. This will depend on how similar it is to the brassboard.

For the PFM and FS testing, a development schedule and detailed project plan for period between now and end 2001 is now needed. This has to accommodate PDR in June. A realistic development plan needs to be formulated at the ATC over the next couple of weeks.

OK and UG are to be invited to comment on the BSM design and development programme when these minutes are written up.

The following general comments were made while summing up (BMS and MJG):

1. The mechanical design is very rudimentary at present. A lot of thought is needed on the electro-mechanical optimisation. It would be very useful to maintain consultation with the Heidelberg group. The possibilities for PACS collaboration need to be examined.
2. Even if FTS and BSM are to be used simultaneously could we consider using the same DSP?

3. The ATC programme needs a full time project manager and full time project engineer now. It can't continue to work in "campaign" mode. Someone full time is also needed at least to cover the mechanical design and control.
4. The ATC should have a brassboard model in October (like LAS and MPIA). This poses a problem in getting the essential effort.
5. Experience with space mechanisms shows that early prototyping is vital and Qualification at component level (sensor, pivot, actuator, structure, etc.) makes the overall qualification plan much more credible. Late development of BSM could pose high schedule and cost risk.

   The reviewers are worried that there are so many developments needed that a brassboard is vital. They recommend strongly that this be considered. A direct path to the CQM is considered to be too high risk.
6. Management/engineering effort is a critical issue starting from now.
7. KJK perspective: need to be reporting against a plan.

Action Items:

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