A FULLY INTEGRATED FOCUS MECHANISM FOR A HIGH RESOLUTION CAMERA

Nigel Phillips [(1)], **Alizee Malavart** [(2)], **Mark Ferris** [(3)]

(1) SSTL, 20 Stephenson Road, Surrey Research Park, Guildford GU2 7YE, UK, Email:n.phillips@sstl.co.uk

(2) SSTL, 20 Stephenson Road, Surrey Research Park, Guildford GU2 7YE, UK, Email:a.malavart@sstl.co.uk

(3) SSTL, 20 Stephenson Road, Surrey Research Park, Guildford GU2 7YE, UK, Email:m.ferris@sstl.co.uk

ABSTRACT

In 2014, SSTL had a launch opportunity for a small LEO spacecraft. This SSTL funded mission intended to use a COTS telescope to provide images of Earth. However this proved to be too optimistic and it proved necessary to develop a new imager and a mechanism to focus it. This paper describes the design and test of the focus mechanism that was required to achieve the focussing needs of the program.

INTRODUCTION

Surrey Satellite Technology Ltd (SSTL) is a unique supplier of low cost, small satellites to international customers. SSTL operates uniquely compared to traditional space companies: by making use of commercial off the shelf (COTS) components and keeping the full satellite development and manufacturing in house, SSTL is capable of designing and delivering hardware within extremely tight schedules. However, SSTL reactiveness was pushed even further when July 2014, the development of a small satellite carrying a high resolution camera was kicked off for a launch opportunity in Q1 2015. As part of this challenging mission, SSTL had to design and manufacture a focus mechanism (FCM) for the camera.

The optics and detector from a COTS telescope have been used as the basis for a new imager. The new camera has been designed using a CFRP (carbon fibre reinforced plastic) structure which can survive launch loads and give the stability necessary to obtain clear images. Analysis showed that good performance could not be achieved unless a focus mechanism was integrated into the design.

The key part of the solution was to integrate the mechanism into the imager's structure to get a mass efficient design. In a traditional imager the detector is generally rigidly mounted and the focus mechanism is placed in the optical path and is used to move a lens. Depending on the exact location in the optical path, the optical gearing can help reduce the focal range but it does increase the positional accuracy required. In this case the chosen solution was to move the detector.

DESIGN DESCRIPTION

The imager for this mission is a Cassegrain design with a parabolic primary mirror which focuses on the secondary mirror, which then directs the light through the centre of the primary mirror onto the detector (see Fig. 1). The approach for this new imager has been to use the mechanism to move the detector directly. The location of the focus mechanism within the camera is shown in Fig. 2.

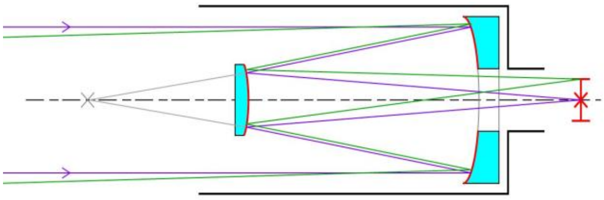

Figure 1. Layout of Cassegrain imager

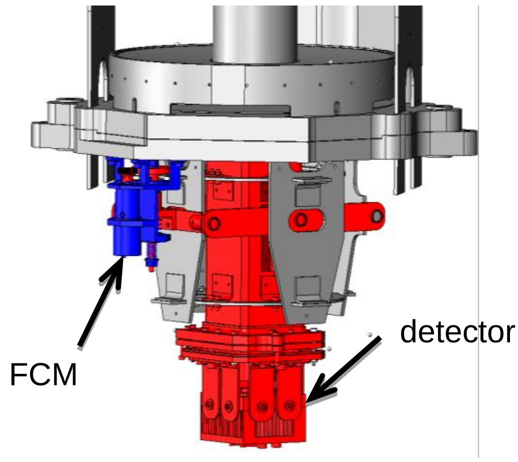

Figure 2. Focus mechanism location within camera.

The challenge was to design a mechanism using heritage parts wherever possible to minimise the development timescale, whilst also achieving a tight mass target.

The detector assembly is relatively heavy (about 1kg) and must be supported in a way that maintains good alignment whilst allowing for focus adjustment. The

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chosen solution was to attach the detector to a CFRP barrel supported on titanium flexures. These flexures are arranged in two sets of four flexures separated vertically. This gives good stiffness in all axes whilst still allowing the focus adjustment. The design challenge for the flexures was to find a geometry that was stiff enough to support the launch loads but would still allow the full range of motion. A compromise solution was found which has enabled a successful design: the nominal focus position is set by shimming the detector into place so that the FCM is then only required to compensate for in orbit changes due to thermal and moisture effects. The focus range for the detector can thus be restricted to a relatively small operational range (±1mm). This also means that there is no optical gearing and the positional accuracy needed is reduced (±15 microns).

The focus mechanism (shown in Fig. 3) consists of an actuator and two CFRP lever arms. These levers are used to span the imager, with the actuator on one side and the detector barrel in the middle. This pivot arrangement gives a mechanical advantage that reduces the loading imposed on the mechanism and consequently enables the use of a leadscrew with a smaller load capacity and helps keep the overall mass of the mechanism low. Flex-pivots with very low hysteresis are used for all pivot points and hence help to achieve good positional performance. The flex pivots are bonded into end fittings that in turn are bonded to the levers and to the imager structure. Consequently, the mechanism assembly into the imager required great care because no adjustment was possible once was all the components were bonded together. The actuator consists of a leadscrew and spur gear transmission which is actuated by a stepper motor gearbox. The stepper motor gearbox was supplied by Phytron GmbH and is grease lubricated. This motor gearbox has heritage on many other SSTL LEO missions so has well proven performance. The stepper motor gearbox drives a spur gear pass which in turn drives the leadscrew. The leadscrew is supported by two bearings in a titanium housing. The housing incorporates flexures so that thermal stress into the imager structure is minimised. The leadscrew is also grease lubricated. The actuator has two micro-switches which are set to limit the travel within the safe operational range of the main flexures.

Another key element of the mechanism is the electronics. The timescale for this program was very short so the approach taken was to re-use existing hardware. The electronics from another SSTL product, the antenna pointing mechanism, was reprogrammed for the FCM. This uses a CAN bus to communicate with the spacecraft. The electronics is mounted in a nanotray and is located within the main structure of the spacecraft.

Despite its simple design, the mechanism performances surpassed what was expected: the detector carriage can be moved by measurable steps of less than 2µm and the overall behaviour over the +/-1mm range of interest is linear within +/-2µm. The backlash measured is 4µm and is fully repeatable. Despite the loads imposed by the flexures at the two extremes of travel, the mechanism was cable of holding the position unpowered.

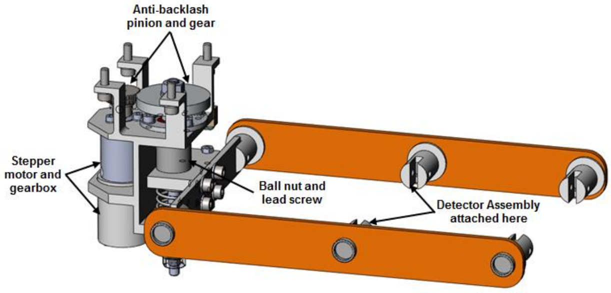

Figure 3. Focus mechanism.

The complete mechanism integrated to the imager is shown in Fig. 4. The imager is shown in Fig. 5

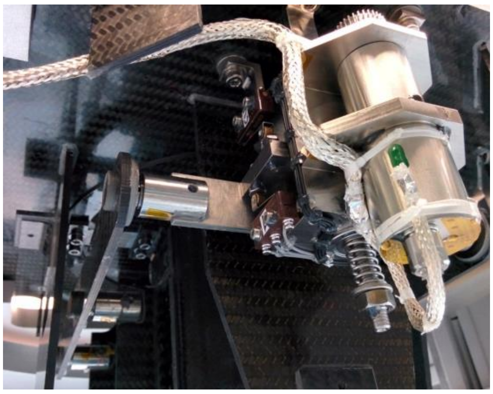

Figure 4. Focus mechanism integrated to camera.

TEST PHILIOSOPHY

The test philosophy used for this development is consistent with the SSTL philosophy for its LEO satellites which is an integrated approach with limited functional testing at unit level. The full performance of the FCM is verified by combining test results from unit level with those at imager level and at spacecraft level.

At mechanism level the following functionality was verified:

- Ambient functional
- Thermal test
- Flight preparation
- Calibration of the two end stops (micro-switches)
- Recovery from contact with the hard stops
- Multiple sweeps through the complete operational range

At imager level the parameters measured were:

– Operational range
– Positional performance
– Repeatability
– Unpowered holding of position for the full range of motion

At spacecraft level

– Vibration test
– Thermal test
– Focus accuracy
– Final focus adjustment prior to launch

TEST RESULTS

The mechanism level performance is summarised in tab. 1.

Parameter	Value
Operational range	>±1mm
Positional resolution	<2µm
Positional linearity	<±25µm
Conversion coefficient	-0.4119
Backlash	4µm
Unpowered holding of position	PASS
Temperature range	+50˚C/-20˚C
Thermal cycles	10
Mechanism sweeps	293

Table1 FCM performance summary

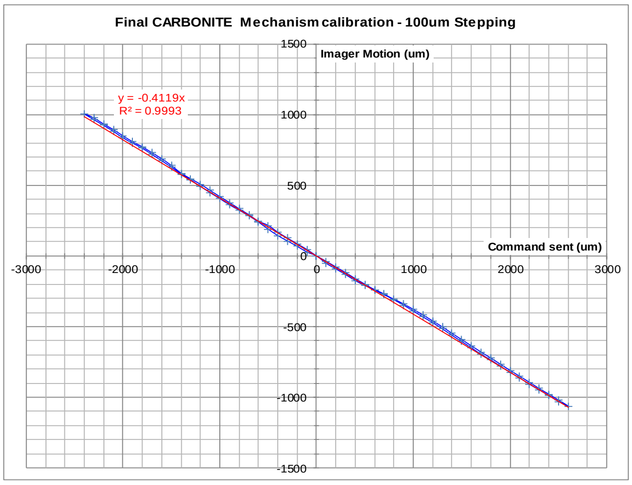

Figure 5. Focus mechanism linearity

Focus accuracy is a key parameter which was verified at imager and spacecraft level. Initially it was confirmed how much focus adjustment could be achieved across the range of motion of the mechanism. This was done using a calibration target. This calibration target was then used to verify the ability of the mechanism to hold position through the spacecraft test campaign. An example of a focussed image is shown in Fig. 6. This measurement was made by mounting a focussing target in a separate telescope focussed at infinity. The image at the detector was then adjusted into focus.

The integrated mechanism was environmentally tested at spacecraft level. Vibration test consisted of sine and random testing.

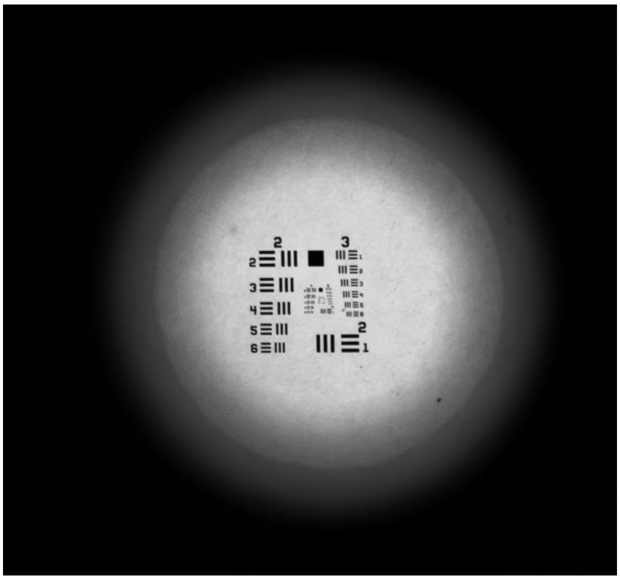

Figure 6. Focus measurement

The dominant load case for the mechanism is Z-axis testing. The spacecraft was subjected to 6.76grms random input and the response measured at the detector was 4.87grms (see Fig. 7).

The focus mechanism was instrumented and some test results are shown in Fig. 8. This graph presents the in-plane response at the FCM interface. The measured values are: 1.18grms(x), 1.01grms(y), 3.43grms(z). It is clear from these responses that the imager isolation has been particularly successful at protecting the imager and its components.

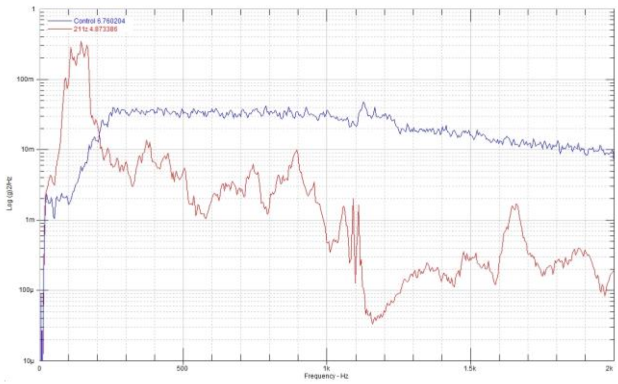

Figure 7. Z-axis sine response at detector

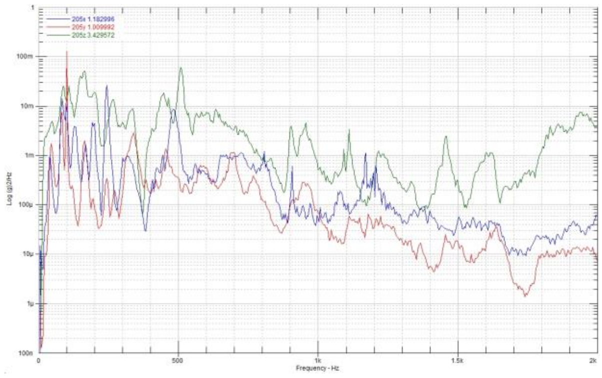

Figure 8. X,Y,Z response at FCM interface

Thermal testing was conducted a spacecraft level in the SSTL thermal chamber.

CONCLUSION

The FM FCM has been built, tested and integrated into the imager and the spacecraft has been environmentally tested and launched. The timescale was demanding but SSTL were able to meet the challenge.