A scaleable pick-off technology for multi-object instruments

Peter Hastings[a], Suzanne Ramsay Howat[a], Peter Spanoudakis[b], Raymond van den Brink[c], Callum Norrie[a] , David Clarke[a], K.Laidlaw[a], S.McLay[a], Johann Pragt[c], Hermine Schnetler[a], L.Zago[b]

[a]UK Astronomy Technology Centre, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ.
[b]CSEM SA (Centre Suisse d'Electronique et de Microtechnique), Rue Jaquet-Droz 1, P.O. Box CH-2007 Neuchâtel, Switzerland.
[c]ASTRON, P.O. Box 2, 7990 AA Dwingeloo, The Netherlands.

ABSTRACT

Multi-object instruments provide an increasing challenge for pick-off technology (the means by which objects are selected in the focal plane and fed to sub-instruments such as integral field spectrographs). We have developed a technology demonstrator for a new pick-off system. The performance requirements for the demonstrator have been driven by the outline requirements for possible ELT instruments and the science requirements based on an ELT science case. The goals for the pick-off include that the system should capable of positioning upwards of one hundred pick-off mirrors to an accuracy better than 5 microns. Additionally, the system should be able to achieve this for a curved focal surface – in this instance with a radius of curvature of 2m.

This paper presents the first experimental results from one of the approaches adopted within the Smart Focal Plane project – that of a Planetary Positioning System. This pick-and place system is so called because it uniquely uses a combination of three rotation stages to place a magnetically mounted pick-off mirror at any position and orientation on the focal surface. A fixed angular offset between the two principal rotation stages ensures that the pick-off mirror is always placed precisely perpendicular to the curved focal plane. The pick-off mirror is gripped and released by a planar micromechanical mechanism which is lowered and raised by a coil-actuated linear stage.

Keywords: spectroscopy- multi-objects, spectroscopy - infrared, smart focal planes, pick-off mirrors, pick-and-place system, ELTs

1 INTRODUCTION

Consideration of the instrument designs for future extremely large optical and infrared ground-based telescopes (ELTs) is proceeding in parallel with the telescope conceptual designs, to try and ensure the provision of gravity stable platforms, large space envelopes and mass limits, and even sufficient budget, in the telescope programmes [1,2,3]. Funded by the EU under the Framework 6 Opticon programme, a Joint Research Activity* on 'Smart Focal Planes'† was set up to study the technology developments required to carry out the science case for the telescopes [4]. Under this programme, we have examined the design of a near-infrared multi-integral field spectrometer capable of meeting the science requirements of a 50-m to 100-m telescope (Smart-MOMSI [5]). Many of the scientific goals of an ELT are most efficiently met by using multi-object instrumentation. In this respect, ELTs are no different from existing telescopes for which multi-object instruments have become a mainstay of optical spectroscopy (e.g. GMOS [6], FORS [7], 2dF[8]) and are beginning to be developed for infrared spectroscopy (Flamingos [9], EMIR [10]). An extension to multiple integral-field spectroscopy will prove a powerful tool in the future (e.g. KMOS [11]). Examples of multi-field science cases include studies of the star-formation history of galaxies through observations of clusters of high redshift objects, observation of stellar populations in the nearest galaxies and of the black holes at the centres of the earliest galaxies.

---

* *The JRA is funded by OPTICON (www.opticon.org.uk).OPTICON has received research funding from the European Community's Sixth Framework Programme under contract number RII3-CT-001566.*
† *Smart Focal Planes are devices that enable the efficient sampling of a telescope's focal plane to feed spectroscopic and imaging instruments.*

From the developing ELT science cases, we assembled set set of science requirements that could meet some of these science cases. These are summarised in Table 1.

Table. 1. Science requirements for Smart-MOMSI.

Parameter	Requirement
Wavelength range	0.8-2.5µm (0.4-2.5µm goal)
Modes	imaging and IFU spectroscopy
Spatial sampling	2.5mas sampling on sky
Spectral resolution	R~4000
Pick-off field of view	100mas (goal 200mas)

We considered four pick-off technologies for development for use in Smart-MOMSI: pick-off arms as adopted for the KMOS; pupil steering mirrors plus static focal plane pick-off mirrors [12]; Starbugs [13] and a novel "pick and place" positioner - the planetary positioner. In the SFP programme, two technologies were developed – the Starbugs and the planetary positioner system (StarPicker). The former are described elsewhere in these proceedings. Here, we present results of the development of the StarPicker. This project has been realised as a collaboration between CSEM SA (the Centre Suisse d'Electronique et de Microtechnique), ASTRON and the UK Astronomy Technology Centre.

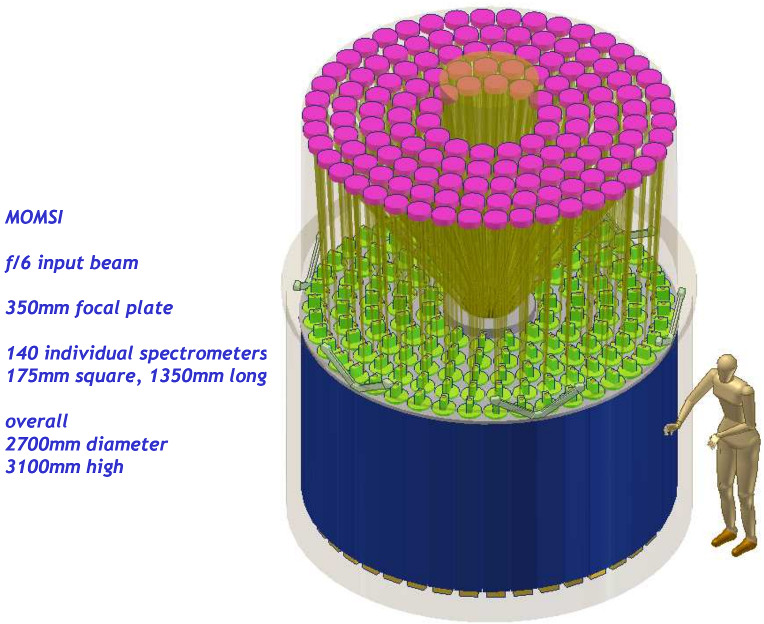

Figure 1: The overall instrument concept for Smart-MOMSI.

2 THE MOMSI CONCEPTUAL DESIGN

Details of the Smart-MOMSI design are given elsewhere [5]. This summary is intended only to place the StarPicker in context. In the basic instrument concept, small optics on a magnetic base ('pick-off mirrors' or 'poms') are placed in the focal plane and relay a collimated optical beam from the object to steerable mirrors located around the periphery of the focal plane. The steering mirrors relay the light into the heart of the instrument – in this case, a number of integral-field spectrographs, but it could equally be an imager or a long-slit spectrograph – and also compensate for optical path differences as the poms are placed at different points on the focal surface. Since most telescope focal surfaces are curved, a requirement on the MOMSI design is that any instrument concept should either incorporate a pick-off system capable of operating on a curved surface or the design should include fore-optics to correct the field curvature. Given the limitations of material availability and wide-field image quality in such fore-optics, the ability of the StarPicker to place poms to great accuracy on a curved surface opens up new possibilities for very large focal planes.

3 THE STARPICKER DESIGN

3.1 Requirements on placing the poms

One of the most challenging aspects of designing the StarPicker arises from the requirement on positional accuracy. It is expected that observations with Smart-MOMSI will be co-added over a number of nights to reach the desired signal/noise ratio on the object. To maintain the image quality and signal/noise in this co-addition, the object frames must be registered to ±1 of a spatial sample (±2.5mas) which is ±7.3μm at the f/6 focal plane of the 100-m OWL telescope (chosen as the starting interface for Smart-MOMSI). To achieve this, our operational model is to place the target within the field of view of the pom optics, measure the position of the pom on the focal plane using a metrology system and then use the measured offset in post-processing to register the objects.

In this case, a separation of the requirements is made as follows. Acquisition of the object onto the pick-off should be to ±10% of the field size i.e. ±10mas (±30μm) at the telescope focal plane and the offset of the achieved position from the target should be achieved to ±0.5 spatial samples i.e. ±3.5μm at the telescope focal plane. The total budget of ±7.3μm is distributed equally amongst the contributing modules (e.g. metrology of the PPS system, the beam steering mirrors, the IFU module and the spectrograph module). Each module is allocated a budget of ±3.5 μm. To meet the requirements of positioning the object wthin ±10% of the field size, we then have the comparatively relaxed tolerance of ±17 μm for the StarPicker as built (two rotary stages and the gripper), with the remainder of the budget used up in non-repeatable errors within the full MOMSI system (e.g. flexure). Inherent in our approach is the idea that repeatable errors will be calibrated. Errors which can be corrected in this way include the calibration of motor drive steps to position on the focal plate and astrometric mapping of the focal plate to the sky.

3.2 The StarPicker 'pick and place' mechanism

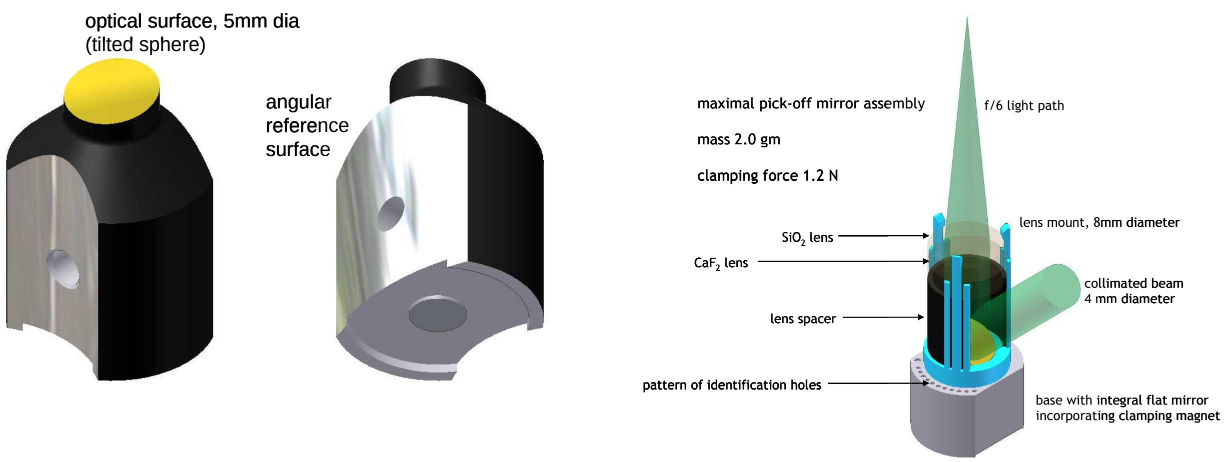

Figure 2: Two of the options for the focal plane pick-off or 'pom'.

The StarPicker is illustrated in Figure 3. It places the pick-off mirrors (Figure 2) in locations which match those of the astronomical target fields. Each mirror has a magnet in its base which holds it to the curved focal plate from which it is lifted by a gripper mechanism. This has two jaws which are actuated electro-magnetically through a parallel-action linkage. A second electro-magnet is used to lift the jaws and mirror away from the plate along the Z-axis.

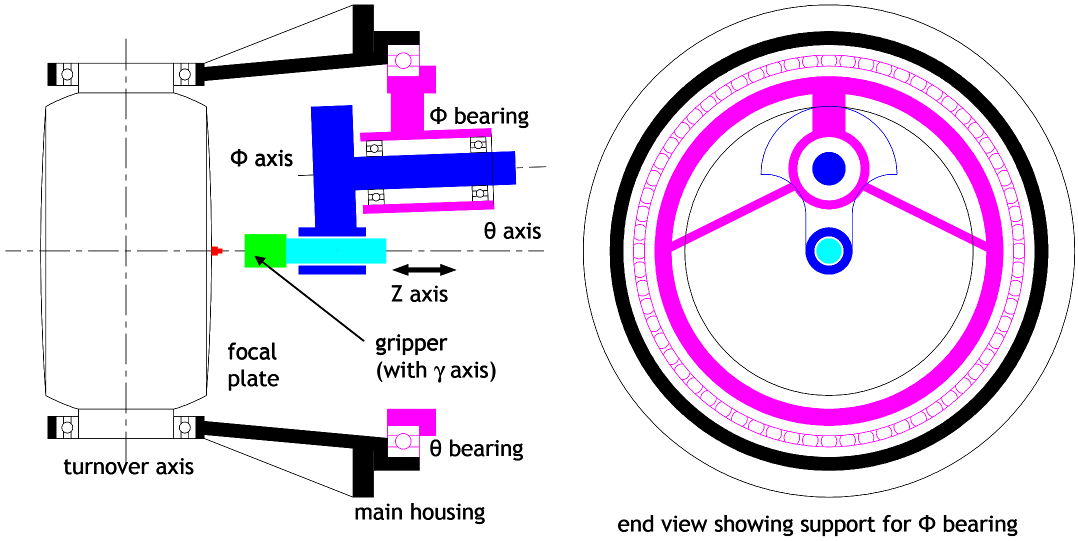

Figure 3: The PPS rotary mechanisms in cross-section.

The gripper can be rotated about the γ-axis to align the output beam from the mirror with its appropriate beam-steering mirror.The gripper can be positioned anywhere across the surface of the focal plate by a combination of two rotations. Rotation of the gripper about the phi-axis moves it in an arc from the centre of the plate to the edge. Rotation of the whole unit about the theta-axis sweeps the arc around the whole of the plate – giving complete coverage. The phi-axis is not parallel to the theta-axis but passes through the centre of curvature of the focal plate. This ensures that, irrespective of the location of the gripper, movements along the z-axis are normal to the plate's surface. The geometry of the mechanism is analogous to that of the swing-arm profilometer used in optical metrology. Positioning a large number of mirrors will take some time and so two focal plates are provided and positioned back-to-back. As one is illuminated and taking an observation, the other is being re-configured for the next observation. At the end of an observation the gripper is swung completely clear of the focal plate and the plates are turned over, allowing a new observation and re-configuration sequence to start.

3.3 Design of the rotary mechanisms

The layout of the rotary mechanisms is one that has been used many times in cryogenic instruments designed and built at the UK Astronomy Technology Centre. A stepper motor drives a Vespel worm which engages with an aluminium gear wheel which is mounted on ball bearings. The stepper motors used are Oriental Motors five-phase motors that are de-powered when not in operation. The motors are prepared for cryogenic operation by thorough cleaning and replacing the normal bearings with ones made from 440C stainless steel prepared with a suitable dry-film lubricant. The datum position is set by the closing of a NC contact in a commercial microswitch, a technique which has long been employed at the UKATC and gives a repeatability of less than one micron (see the results report below).

A new feature of the PPS that will be tested in the next stage of the project is that the motors will be run nearly continuously throughout an observing night. Previous instruments have been set to their observational configuration and then the motors remain stationary and de-powered for the observation time (typically of order one hour). As a result, the thermal management of motor dissipation will need to be studied in more than usual detail and the motor currents themselves will need to be minimised – without slowing the re-configuration process unacceptably. A side-benefit is that the motors need not be run only in full-step mode and the use of multi-stepping brings advantages in terms of operating smoothness and positional resolution.

Using rotary rather than linear mechanisms brings a number of advantages. First, it is straightforward to balance the mechanisms so that they are unaffected by changes in gravity vector. Second, it is easy to obtain cryogenically-prepared ball-bearings. Third, the design of cable wraps for electrical signals and thermal links is relatively simple. Fourth, the resulting positioner is compact and can thus be designed to combine modest weight with high stiffness.

3.4 Design of the gripper

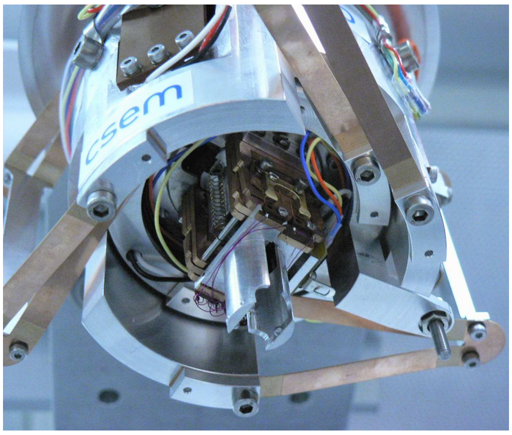

Figure 4: Detail of the Gripper module

The gripper development was based on the use of similar technology at CSEM adapted for the requirements of grasping objects under cryogenic conditions. The gripper itself (Figure 4) was inspired by a design that uses flexures for the pinching or gripping action driven by a voice-coil actuator. The gripper design uses two voice-coil actuators, one to grip an object and a second one for the linear displacement of the jaws (Figure 5).

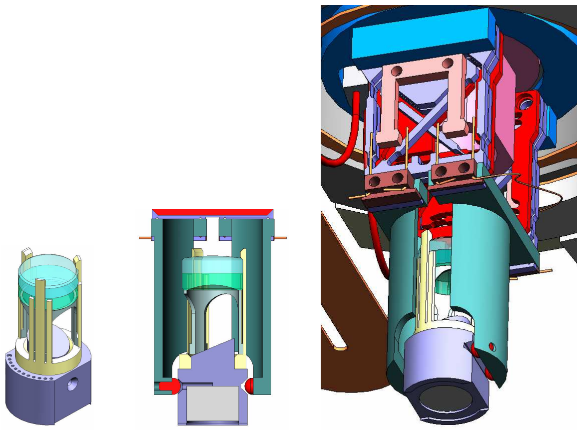

Figure 5: Pick-off Mirror (left), POM gripped by jaws (right)

3.4.1 Gripper Module

The gripper module uses a flexure plate design that transforms the axial motion from a voice-coil actuator to an orthogonal gripping motion. Two series of flexure plates on either side of the actuator create a “cage” around the pick-off mirror that is to be captured. A passive “power-off” grip force of 2 N assures that the pom can be pulled off the focal plate surface.

The jaws have a gripping stroke of 3 mm and have been designed to maintain a parallel and repeatable motion when closing on and releasing a pick-off mirror. An integrated return spring maintains the jaws closed with the power off.

When the gripper module actuator is activated, it opens the jaws and the pom is released. This minimizes the heat load of the actuator when operating at cryogenic temperatures.

3.4.2 Linear stage

The linear stage provides (Figure 6) the vertical motion to pull a pom off the focal plate surface or to put it down. The motion is provided by a commercial voice coil actuator guided by CuBe flexure blades. The linear stage has a stroke of 21mm in order to clear the height of the poms on the surface. In the power off or neutral position, the linear stage is retracted away from the focal plane by a central return spring. When the linear stage is activated it descends toward the focal plate where it grips or releases an object. When the gripper places an object on the focal plate, the membranes are in their neutral, non-deformed position. This provides higher lateral stiffness and stability during pom placement. The linear stage is operated in closed loop using a LVDT position sensor for feedback.

Figure 6: Gripper Linear Stage

3.5 Cabling the StarPicker

To get the required signal and power from and towards the gripper, actuators and other parts of the system through the three rotational axes, flexible printed circuits were used (Figure 7). Unlike slipring constructions these parts aren’t sensitive to wear and tear due to friction, since they just roll up. The main challenge for the design was making it suitable for use in vacuum at room temperature and for cryogenic use. Due to the relatively high currents (maximum 1.5A) required for the gripper and motors, the cross section of the tracks for the motor power had to be large while the flexible circuits had to be flat to maintain flexibility. To fit the flexible printed circuit into the available space it laminated from two parallel Kapton circuits of unequal length. Each end of the flexi-circuit is attached to a rigid PCB providing additional support where the micro-D connectors are mounted.

Figure 7: The flexible printed circuit used in StarPicker.

3.6 The Focal Plate

Figure 8: The curved steel focal plate.

The final opto-mechanical part of the StarPicker system is the focal plate (Figure 8). For the technology demonstrator, the focal plate consists of a spherical plate and its mount. In the final instrument concept, the eventual focal plate will be part of a tumbling mechanism, making it possible to place a configuration of pick-off-mirrors on one side, and perform observations at the same time on the other side. Since the pick-off-mirrors are held in place by magnets, the focal plate has been made from Stainless steel 430F because of its magnetic properties. Since the main construction of the instrument is made out of aluminium, the mount has been designed to compensate for the difference in shrinkage by an iso-static mounting.

3.7 Software control of the StarPicker

The software's principal aims are to support both the testing required during construction of the system and to control a rolling demonstrator of the final assembly.

The StarPicker software is broken down in to two main packages. One package is the Motion Control Software which handles the control of the mechanism themselves; the other is the Patterning Software which models the arrangements of POMs and transformations between them. This latter also provides the principal interface through which the system is driven. Engineering interfaces were also written to allow testing of the developing system at any level of granularity required.

Key to the rapid development of the software was the early definition of a clear and simple interface between the two packages, and the writing of a simulator of the motion control software which implemented this interface. This allowed parallel development of the two packages. Effectively the patterning software was developed against the simulator while the motion control software was developed against the hardware.

3.7.1 Motion Control Software

The electronics hardware controlling the StarPicker mechanism consists of two main components. A custom designed electronics box for controlling the gripper functions provided by CSEM and a commercially available stand alone motion controller with built in Ethernet connection. The StarPicker software runs on a standard PC and communicates through the Ethernet connection to the motion controller device. The motion controller has an extended digital I/O board for interfacing with the gripper electronics and drives two stepper motor axes configured for using micro-stepping.

The motion control device has its own processor and on-board memory for storing program applications that can be written to perform specific tasks. A set of applications were written to perform sequences of gripper and motor axis movements with built in hardware status tests to exit an application in the event of any unexpected behavior. These applications could be downloaded and stored in memory as updated versions became available.

A generic device communication application was written in the python programming language. Python was chosen for its portability, speed of development and ease of use as a scripting language which is very advantageous for developing and testing new hardware. The application was designed to be highly configurable using XML configuration files that contain all the information necessary to communicate with an electronics device that uses a standard communications protocol such as Ethernet or RS232 serial connections where commands and replies are encoded in ASCII or binary formats. It was also written to be compatible with Jython compiler for building a Java JAR file for linking into the higher level patterning software which was written in Java.

3.7.2 Patterning Software

With a view to the tight timelines for the project, a layered architecture was chosen for the patterning software. Essentially, this breaks down the problem into a series of smaller, simpler problems each solved by one layer. Each resultant layer is quick to implement and easily testable – the problem it addresses being manageable and well defined. Additionally, the design is very flexible, allowing the software to evolve to match any future changes in the hardware.

Starting from the lowest, the following layers were identified

- **(θ, ϕ) Sequencing** This is the interface implemented by the motion control software (and hence also the simulator), supporting movement in planetary (i.e. (θ, ϕ)) coordinates as well as picking up and putting down a POM. It knows nothing about poms other than whether there is one currently held in the gripper or not.
- **(x, y) Sequencing** This performs the conversion of Cartesian coordinates to 'planetary' ones. It provides essentially the same interface as the (θ, ϕ) Sequencing layer, only using Cartesian coordinates instead. It also knows nothing about poms beyond whether there is one in the gripper.
- **(x, y) Positioning** This layer adds knowledge about the location of multiple poms on the focal plate. Given a desired configuration it will work out how to move to it from the current layout. To do this is uses a greedy algorithm to pick the best move to do at any given point. Also in this layer is knowledge of how closely together we can place poms, and it will check the separation. This is actually done in two places to be doubly sure – not only does the move generation algorithm avoid asking the system to place poms too closely together but also the move execution will refuse to so do. Finally, this layer was designed to be fault tolerant, remembering where the POMs are on the plate so that in the event of an unexpected shutdown the StarPicker can restart quickly. Indeed we had a power cut during development and this function worked perfectly in what was a more realistic than normal test of catastrophe tolerance.
- **Pattern Sequencing** This is the top level of the rolling test and demonstrator. It continuously cycles through each of a list of patterns. These patterns are defined in simple text files, each listing a set of (x, y) coordinates. The pattern sequencing does know whether it is being run for test or for demonstration purposes, moving the mechanism clear and activating the CCD camera if it is testing and pausing for applause if doing a public demonstration. This layer also handles loading and unloading procedures for getting poms onto and off from the focal plate in a controlled manner.
- **User Interface** A very thin user interface allows control of the system, providing all the facilities needed for test and for the rolling demonstration. This includes instigating loading or unloading of the system, selection of patterns through which to cycle, start and stop the rolling mode etc. The user interface also provides a monitor of where the hardware is by subscribing to the motion control software which publishes updates about its position.

4 THE PLANETARY POSITIONER PROTOTYPE TESTING

4.1 Gripper Test Results

The Gripper was tested independently of the rotary stages at CSEM before shipment to the UK ATC for integration with the rest of the system. The results of that programme of testing are summarised below.

The lateral deviation of pom placement in the X-direction and Y-direction was measured by picking up and releasing the pom 30 times (X) and 20 times (Y) and recording the pom position each time it was placed and left on the focal plane. The repeatability of pom placements in the X-direction is 7 μm and in the Y-direction is 1 μm.

Since the poms with their magnets must work in a field already crowded with the other poms, the influence of one pom on another was also tested by remeasuring the pom lateral deviation when placing it next to a second pom. This test was repeated for two separations of the poms. For the X-deviation, and with a separation of 16.6 mm and 14mm the measured offset was 0.5 μm and 4.0 μm respectively. For the Y-deviation, the measured offsets were 3.5 μm and 1.0 μm respectively.

An important observed characteristic of the system is the ability for the the gripper to re-centre an offset pom. This was evaluated by offsetting the pom in the X-direction from 25 μm to 500 μm. In all cases, the pom was re-centered to an average of 1.5 μm. The test with the 500 μm offset required a repeated sequence (gripping, lifting and replacing the pom) to re-centre the pom due to the large, initial offset.

4.2 Test of the single rotary stages independently

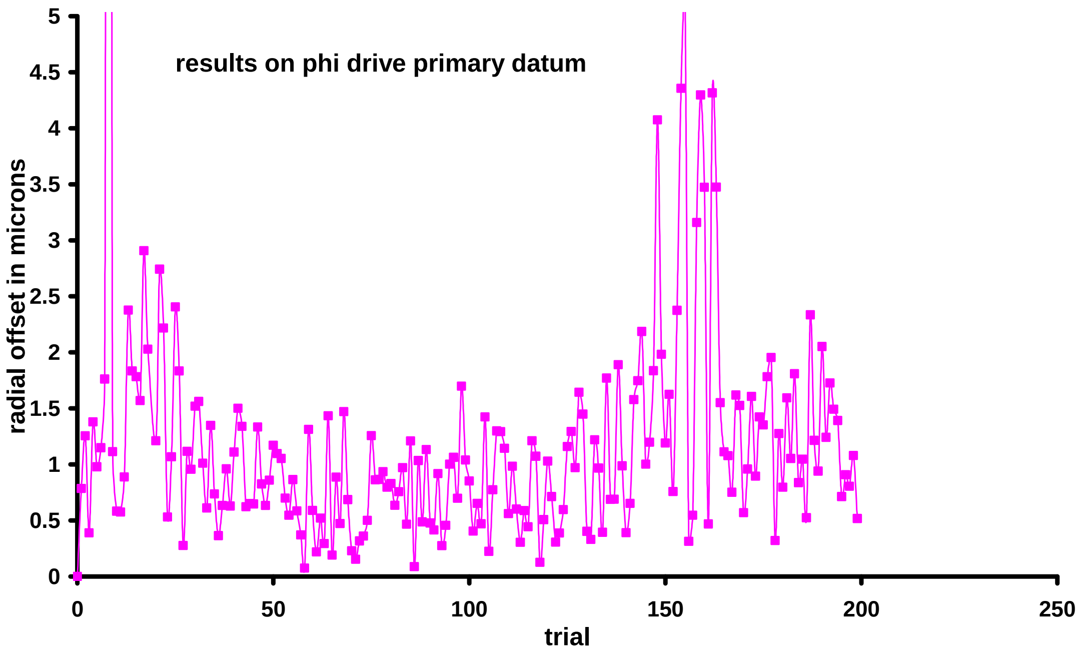

Figure 9: Tests of datuming on the phi rotary stage.

Our initial tests were to explore the repeatability of positioning the rotary stages independently and included a test on the achievable accuracy of initialising the mechanism on the microswitches. The tests were carried out by mounting a 'spot' target on the rotary stage which was positioned to be in the field of view of a CCD camera. The design of the test set-up was such that the plate scale was 30microns per pixel, sufficient to allow us to determine the repeatability to 1μm, given an estimated accuracy of centroiding of $1/30^{th}$ of a pixel. (In practice, we find a centroiding accuracy of $1/100^{th}$ of the pixel). The mechanism was then either simply offset to another step position or initialised and then returned to the target position. The tests of moving between two positions showed that the individual rotary mechanisms can be repeatably positioned at ~±1 micron. The results from the test of initiliasing the mechanism and the moving to a target position are shown in Figure 9. Variations in the datum behaviour were very small throughout this range of tests – 200 repeats of the datum and position cycle were carried out. With the mechanisms thus qualified, the assembly of the full set-up was carried out.

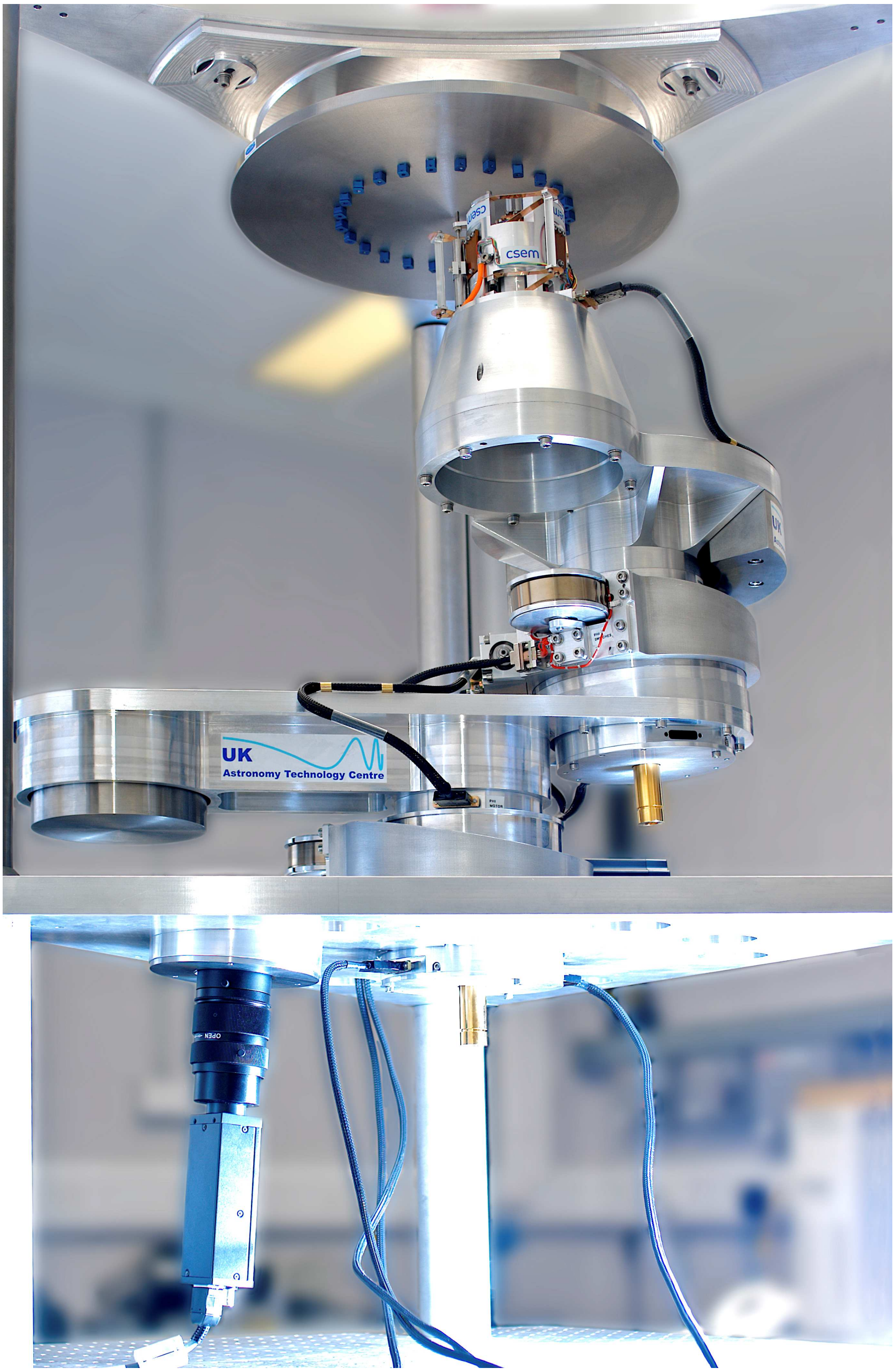

Figure 10: The complete ‘StarPicker’ in its test set-up.

4.3 Tests of the complete system

We have carried out room temperature tests on a system assembled from two rotary stages and the gripper. The tumbler mechanism and γ-rotary stage (for orientation of the gripper head) were not included in these preliminary tests. The test set-up is shown in Figure 10. A CCD camera views the focal plane through a hole in the StarPicker mounting plate. A single pom with a target spot located on the upper surface is fixed to the focal plate. This is the 'reference pom'. A second 'target' pom is moved using the StarPicker to four, randomly selected, positions on the focal plate and then returned to the target position. At the target position, both the reference and target poms are within the field of view of the camera. Analysis of an image of the field produces centroids of the two poms targets, from which any changes in the separation can be determined. This differential measurement is used so that the tests are insentive to any drifts in the test set-up (for example in the position of the camera) and so the high precision required in these tests can be met. The primary aim of these tests was to determine the repeatability of positioning the pom in a manner close to the expected operational conditions, though the test is necessarily somewhat accelerated. The requirement on positioning, as outlined in Section 3.1, is ±17µm. The motor axes were driven using micro-stepping at a velocity commensurate with the performance requirement that a full field of 100 poms should be positioned within one hour (20,000 microsteps per second, where one microstep is 0.1steps). The mechanisms are initialised using the datum switch before the run of tests, but not between placing the poms.

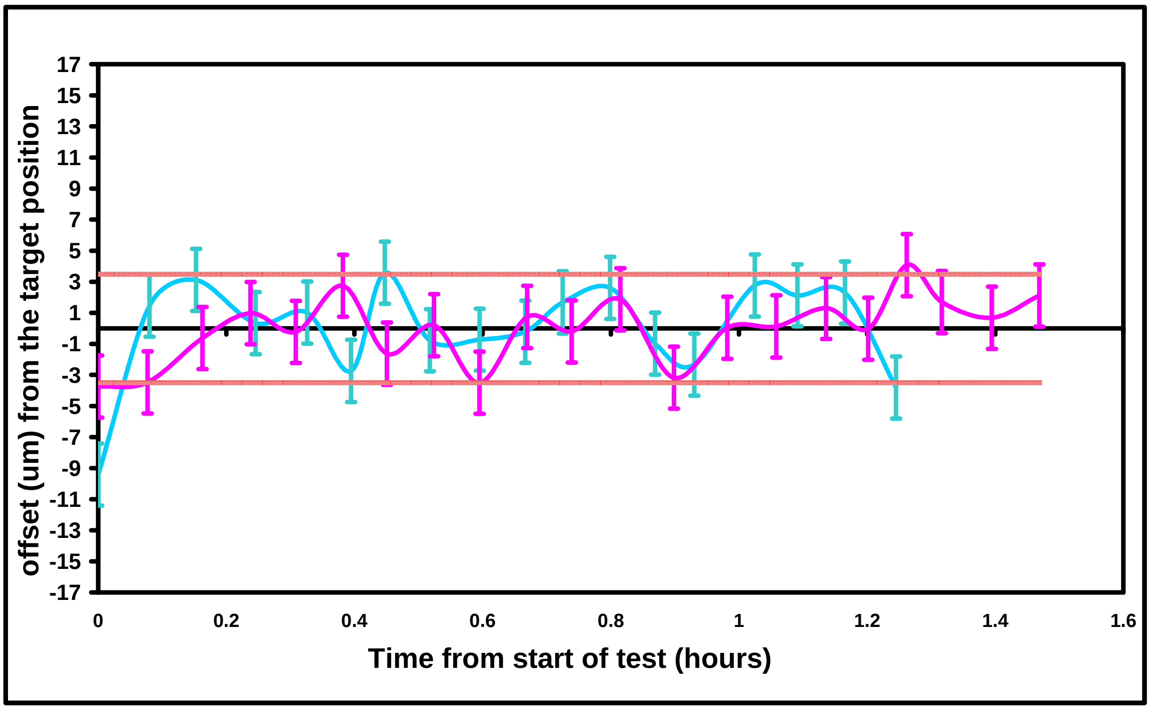

Figure 11: The measured repeatability of placing a pom. The red lines inidicate the tolerance on positioning without using a metrology system.

The offset in the pom position on repeat positioning is shown in FIgure 11. The results are from two tests carried out on the same day. Between the two tests, the motors have been initialised. The estimate errors (±2µm) are from the observed variance on the position on the reference pom. The centroids are measured in pixels and then converted to microns using a measured plate scale for the observations of 30microns/pixel. Figure 11 shows the radial offset from the mean position of the pom during the tests. The system performance comfortably exceeds the ±17µm requirement (which is the total x-axis extent in Figure 11). The horizontal lines shown on the diagram are the tighter tolerance – that for positoning without use of a metrology system. The repeatability of positioning the pom using the gripper and rotary mechanisms is accurate to ±3µm. The tests reported here are the first and only two sets of such tests carried out to date.

A potentially extremely powerful result from these tests is that the accuracy of positioning is sufficiently high to allow the metrology system to be removed from the instrument concept altogether. This would represent a significant simplification as the metrology system is a major sub-module of the instrument. Moreover, the need to have 'sight' of the focal plane has influenced the mechanism and gripper design (there is a sight-line down the centre of the gripper) and further simplifications may be possible in these areas. Further tests, include the cryogenic tests, will of course be required to ensure that removing a metrology system would incur no major risks. One aspect that would have to be addressed would be the re-location of the poms in the event of a failure of the hardware or software systems. At present, the location of the poms is stored in an ASCII file as soon as they are placed, and this would be a sufficient safeguard if the poms truly reach their destination. Should the mechanism misplace a pom, then an alternative method of locating it would be needed before the metrology cameras would no longer be required.

5 CONCLUSIONS

We have designed and developed a technology demonstrator of a novel pick-off system for cryogenic use. The StarPicker takes, as a starting point, the requirements of multi-field spectrometer on a diffraction limited ELT. We have demonstrated the ability of the system to meet the stringent requirements on repeatedly placing optics on a focal plate, with room temperature test results showing repeatabilities of ±3μm. Cryogenic tests will follow in the next project phase.

REFERENCES

1. D'Odorico, S. 2006, "An overview of the OWL instrumentation concept studies" in Proceedings of the workshop 'Instrumentation for Extremely Large Telescopes', MPIA Special Publication 0106, 59.
2. Crampton, D. & Ellerbroek, B. 2006, "The TMT Instrumentation Program" in Proceedings of the workshop 'Instrumentation for Extremely Large Telescopes', MPIA Special Publication 0106, 65.
3. Russell, A.P. G., Hawarden, T. G., Atad-Ettedgui, E., Ramsay Howat, S. K. Quirrenbach, A., Bacon, R., Redfern, R. M. 2004, 'Instrumentation studies for a European extremely large telescope: a strawman instrument suite and implications for telescope design' in Proc. of the SPIE, Volume 5382, 'The Second Backaskog Workshop on Extremely Large Telescopes', Arne L. Ardeberg, Torben Andersen, Editors, pp. 684-698.
4. Cunnigham, C.R., Ramsay Howat, S.K., Garzon, F., Parry, I.S., Prieto, E., Robertson, D. & Zamkotsian, F., 'Smart focal plane technologies for ELT instruments' in Proc. of the SPIE, Volume 5382, 'The Second Backaskog Workshop on Extremely Large Telescopes', Arne L. Ardeberg, Torben Andersen, Editors, pp. 718-726.
5. Norrie et al. 'Smart-MOMSI instrument concept and technology development' in *these proceedings*.
6. Crampton, D., Fletcher, J. M., Jean, I., Murowinski, R. G., Szeto, K., Dickson, C. G., Hook, I., Laidlaw, K., Purkins, T., Allington-Smith, J. R., Davies, R.L., 2000, 'Gemini multi-object spectrograph GMOS: integration and tests' in Proc. SPIE Vol. 4008, 'Optical and IR Telescope Instrumentation and Detectors', Masanori Iye; Alan F. Moorwood, p. 114-122.
7. Seifert, W.,Appenzeller, I., Fuertig, W., Stahl, O., Sutorius, E., Xu, W., Gaessler, W.,Haefner, R.,Hess, H.-J., Hummel, W., Mantel, K.-H., Meisl, W., Muschielok, B., Tarantik, K., Nicklas, H. E.; Rupprecht, G.,Cumani, C., Szeifert, Th., Spyromilio, J. 2000, 'Commissioning of the FORS instruments at the ESO VLT' in Proc. SPIE Vol. 4008, p. 96-103,'Optical and IR Telescope Instrumentation and Detectors, Masanori Iye'; Alan F. Moorwood; Eds., 96-103.
8. Colless, M., Dalton, G., Maddox, S., Sutherland, W., Norberg, P., Cole, S., Bland-Hawthorn, J., Bridges, T., Cannon, R., Collins, C., Couch, W., Cross, N., Deeley, K., De Propris, R., Driver, S. P., Efstathiou, G.,Ellis, R. S., Frenk, C. S., Glazebrook, K., Jackson, C., Lahav, O., Lewis, I., Lumsden, S., Madgwick, D., Peacock, J. A., Peterson, B. A., Price, I., Seaborne, M.,Taylor, K., 2001, MNRAS, 328, 1039.
9. Elston, R., Raines, S. N., Hanna, K.T., Hon, D.B., Julian, J., Horrobin, M., Harmer, C.F.W. & Epps, H.W. 2003, 'Performance of the FLAMINGOS near-IR multi-object spectrometer and imager and plans for FLAMINGOS-2: a fully cryogenic near-IR MOS for Gemini South' in Proc. SPIE 4841, 'Instrument Design and Performance for Optical/Infrared Ground-based Telescopes, Masanori Iye, Alan F. M. Moorwood, Eds., 1611-1624
10. Teuwen et al., 'Development of configurable slit unit for GTC-EMIR' *in these proceedings*
11. Sharples, R. et al., 'Design of the KMOS multi-object integral field spectrograph', *these proceedings.*
12. Madec et al. 'New beam steering mirror concept and metrology system for multi-IFU', in *these proceedings.*
13. Haynes, R. & McGrath, A. 2006, "Starbug – a smart focal plane technology for ELT instruments" in Proceedings of the workshop 'Instrumentation for Extremely Large Telescopes', MPIA Special Publication 0106, 237.