# Mechanical features of the OzPoz fiber positioner for the VLT

Peter Gillingham*, Stan Miziarski, and Urs Klauser

(Anglo-Australian Observatory, PO Box 296, Epping NSW 1710, Australia)

## ABSTRACT

OzPoz is a multi-fiber positioner which will feed Nasmyth spectrographs on one of ESO's VLT unit telescopes. Its concept follows that of the positioner for the two degree field facility on the Anglo-Australian Telescope. Thus its fibers will be fed from prisms housed in buttons which attach magnetically to steel focal plates; a robotic system will position the buttons; and the plates will be interchanged so one can be re-configured while the other is gathering starlight. However, OzPoz has a number of novel features, most notably the use of a pneumatically operated gripper which relies for its accuracy and friction free rotation on air bearings. The robot motions also employ air bearings, with vacuum preloading.

The mechanism which exchanges focal plates has been carefully designed to ensure it will survive the maximum likely earthquake on Paranal without significant damage.

Keywords: Optical fibers, fiber feed, fiber positioner, air bearings, gripper, robotic positioning, linear motor

## 1. INTRODUCTION

The Anglo-Australian Observatory (AAO) has a contract with the European Southern Observatory (ESO) to design and build a multi-fiber positioner which will feed Nasmyth spectrographs on the second of the Very Large Telescope 8 metre unit telescopes. As in the AAO's two degree field (2dF) fiber positioner[1], the positioner for the VLT, which has become known as OzPoz, will configure magnetically attached buttons on one of a pair of steel focal plates while the other member of the pair is in the observing position collecting light. The single fiber buttons each carry a microlens and right angle prism through which the telescope pupil is imaged onto the core of an optical fiber. There are also to be integral field unit (IFU) buttons, each feeding a set of 21 fibers using a microlens array, and buttons for acquisition and guiding, referred to as FACB (for field acquisition coherent bundle) buttons. The single fiber and IFU buttons and their associated fibers are to be supplied by Paris Observatory, Meudon. Figure 1 shows the appearance of OzPoz on the Nasmyth platform and indicates its scale; figure 2 shows more detail.

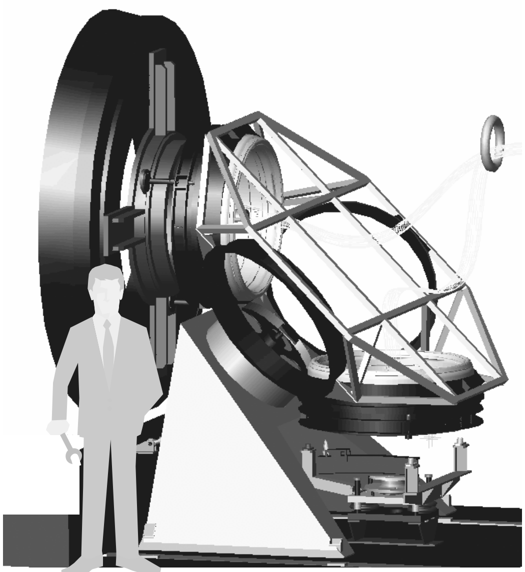

Figure 1. CAD model of OzPoz on Nasmyth platform with instrument rotator and corrector lens support at left (Ozpoz enclosure omitted).

To interchange the pair of focal plates, the robot is lowered through about 10 cm then the exchanger is translated a similar distance away from the Nasmyth rotator. This gives clearance to allow the assembly carrying the focal plates to rotate through 180° around an axis inclined at 45°. Then the focal plate ready for observing is engaged with the rotator (at 3 semi-kinematic locators) by driving the exchanger forward and the robot is raised so it engages with the plate about to be re-configured. During exposure, the focal plate is rotated by the VLT's instrument rotator to compensate for field rotation; for interchange, the rotator always returns to a home position.

ESO are providing a corrector lens which will give telecentric performance; ie. the exit pupil will be at the centre of curvature of the focal surface, which has a radius of about 4 metre. The field over which

* Correspondence: Email pg@aaoepp.aao.gov.au; WWW http://www.aao.gov.au; telephone: 612 9372 4845;
Fax: 612 9372 4860

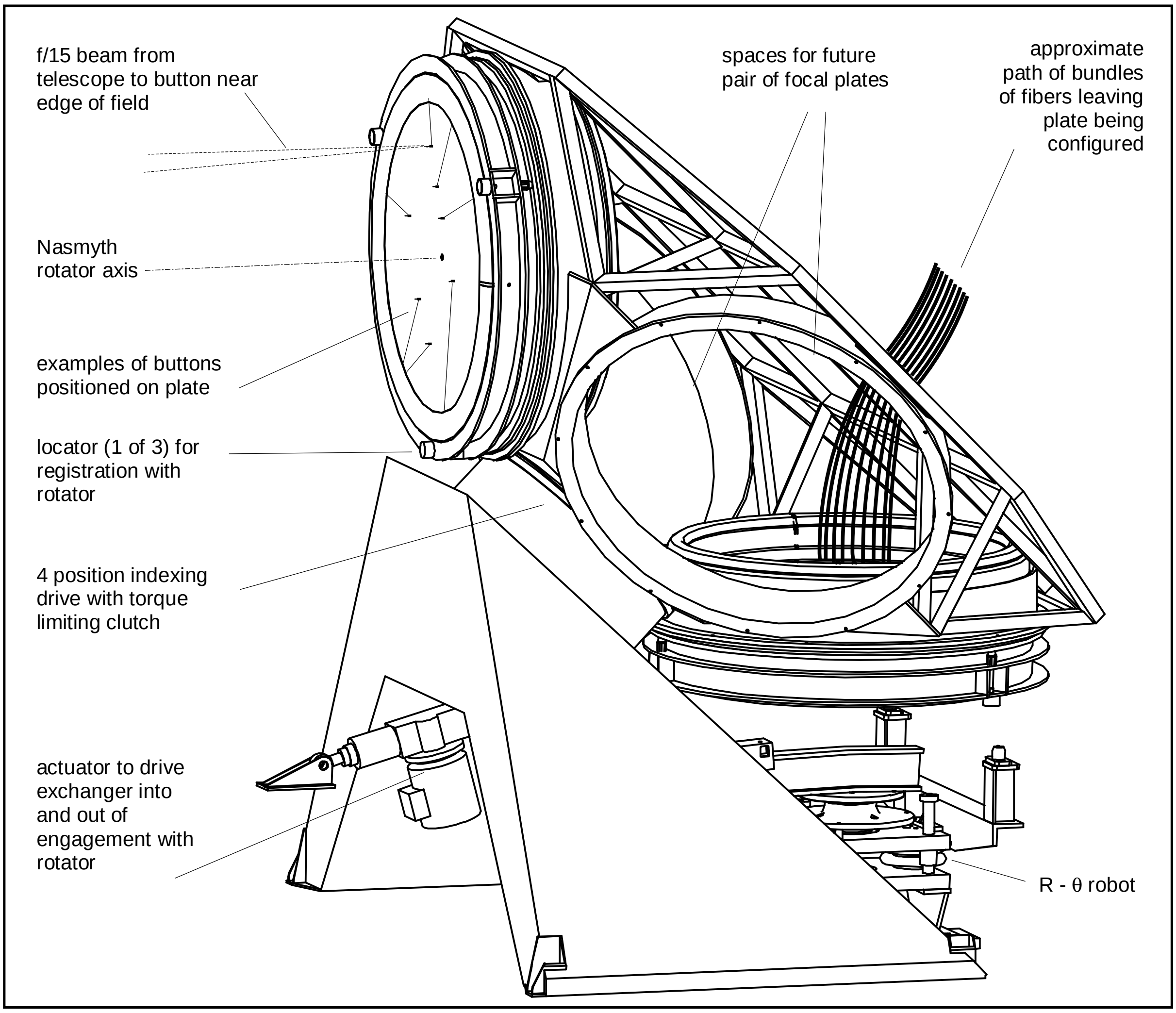


Figure 2. View of OzPoz showing the front of the focal plate in observing position.

buttons will be placed has a diameter of 870 mm, equivalent to 25 arcmin.

While the initial installation will provide for only 132 single fiber buttons/field, space is provided for an adding another pair of focal plates in the future. With the initial complement of buttons, an average of 10 seconds to re-position each button is satisfactory but the aim is to achieve a much shorter cycle time to allow for placing many more fibers in the future.

Strong emphasis has been placed on achieving high reliability and requiring a minimum of maintenance. With the high incidence of seismic shocks at the Paranal site, special consideration had to be given to earthquake survival. Considering that relatively heavy components have to be moved through large arcs and that compliance in the support of the focal plates is very desirable so they readily align with the rotator and robot, it was not feasible to attain such high natural frequencies (30 Hz or more) that simple stress analyses could be applied. So a detailed finite element analysis (FEA) model of the exchanger had to be built and its dynamic performance studied.

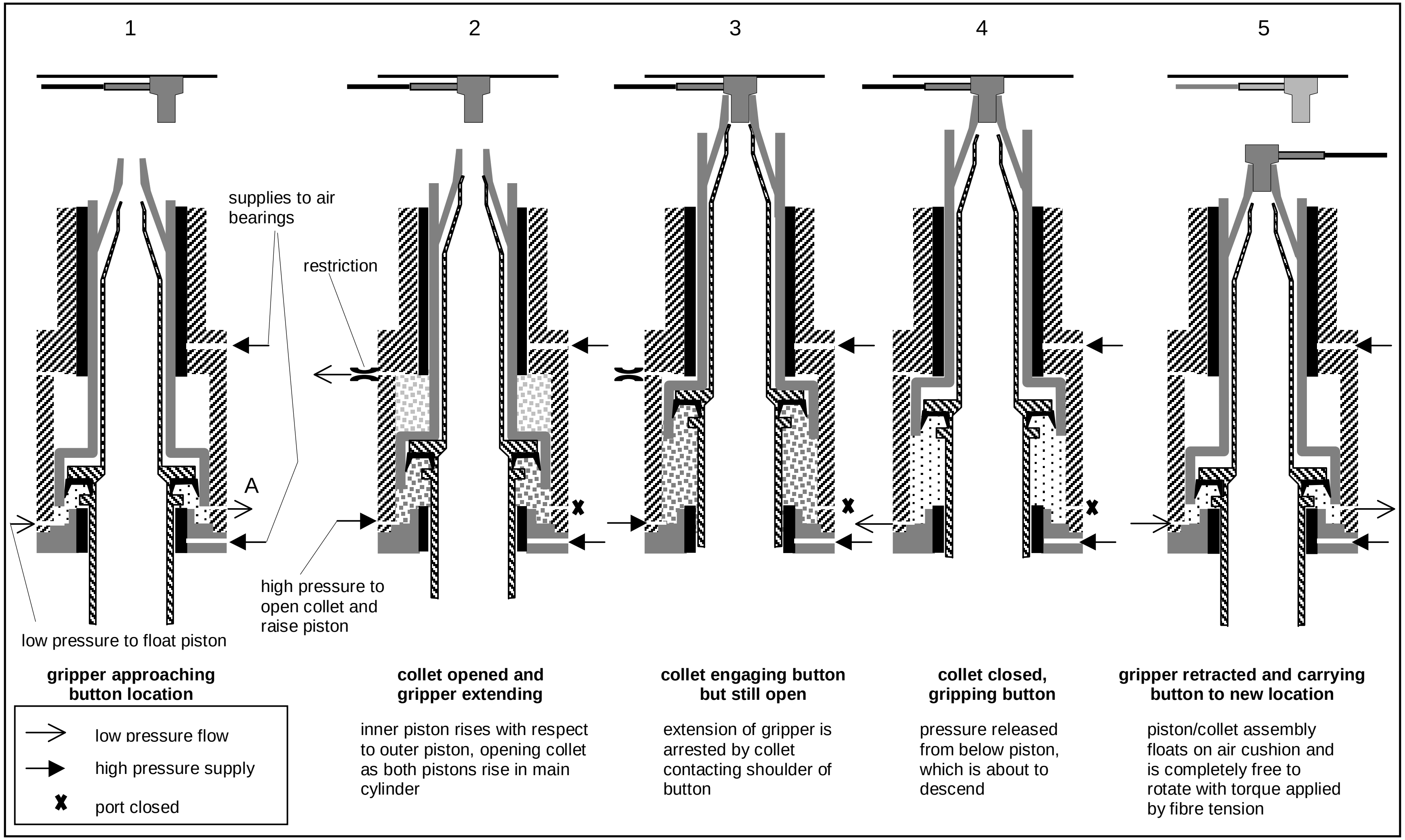


Figure 3. Illustration of way in which the gripper operates to pick a button from the focal plate. All motions are pneumatically driven with control by miniature solenoid valves. Cross sections are simplified and are not to scale. Relative movement of inner and outer pistons is greatly exaggerated.

# 2. GRIPPER

## 2.1 General features of gripper

The gripper – the mechanism which is to grasp the buttons to lift them off the focal plate and release them when in their new positions – is a key component of the robot. Extreme reliability is essential, especially in the sense that it must not cause damage, eg. by promoting breakage of fibers. It was considered that high reliability could most readily be achieved by cutting to a bare minimum the actuators and encoders involved in its operation. The implementation which was chosen employs all pneumatic actuation of the grip/release and extend/retract functions and dispenses with any drive in rotation and with any encoding.

Figure 3 illustrates several of the steps in a pick/place cycle and figure 4 shows a section through the gripper assembly. The button is gripped by its 4 mm diameter cylindrical shaft with a three jaw collet which has an unstressed diameter a little less than 4 mm. To release the button, the internal collet opener is pressed axially against a conical bore within the collet. The axial force to release the collet and the forces to extend the gripper and to retract it, pulling the button from the focal plate, are provided by applying air pressure to the top and bottom of the cylinder in the gripper main body.

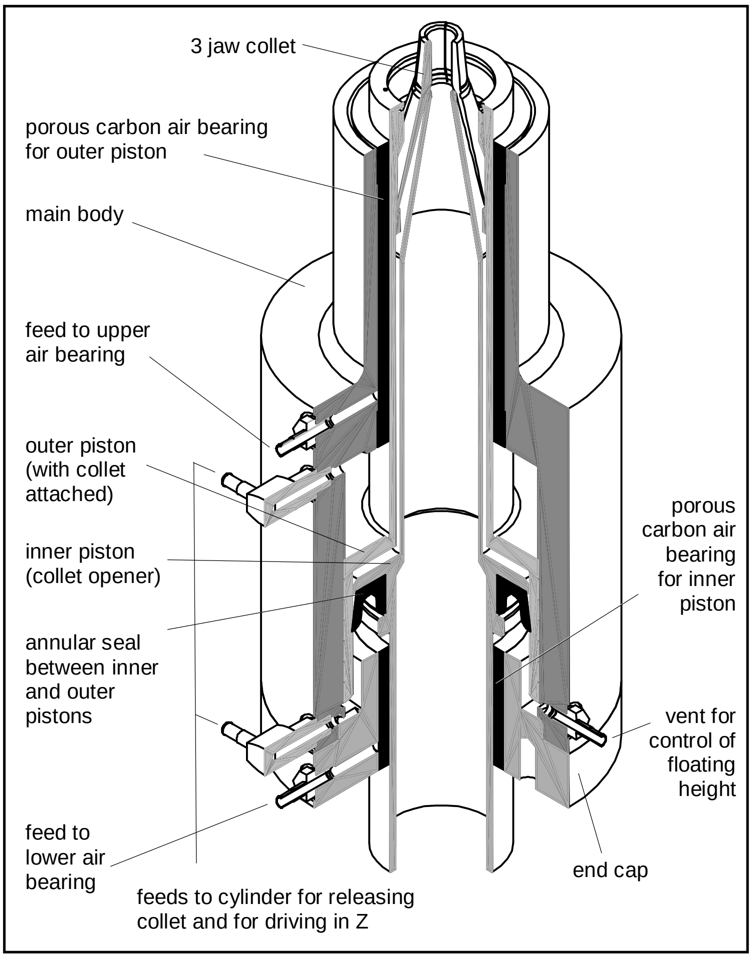


Figure 4. Sectioned view of gripper, showing details of its components.

Since rotation of the button with respect to the carriage carrying the gripper will generally occur while a button is being carried to a new position, the collet must rotate when carrying a button. Rather than drive this rotation, it was decided to make the rotation completely free of static friction so that the rotation would be a natural consequence of the tension on the fiber. To this end, the internal gripper components are radially located by air bearings and when a button is being carried, the piston/opener assembly floats axially on an air cushion with its height set by the vent A (indicated at step 1 of figure 3).

Pneumatic drive of the gripper in the Z coordinate (extension and retraction along its axis) has the attractive feature that it is easy to allow for the slight variations that occur in the Z travel from the retracted position to making contact with a button. The travel is simply stopped by the collet-button contact without applying undue force to either. Similarly, in the event that the gripper is so misaligned with a button that the collet does not pass onto the button handle, the gripper travel is stopped with no harm (though a software check using the CCD camera should prevent such an occurrence).

## 2.2 Performance specifications for gripper

Key performance specifications to be confirmed by tests on a prototype gripper include the following:

- force to withdraw a button with diameter at lower limit from collet in grip configuration: not less than 5.0 N

- force to withdraw a button with diameter at upper limit from collet in release configuration: not more than 0.5 N
- torque to rotate collet when in floating gripped configuration: not more than $4 \times 10^{-5}$ Nm.
- troublefree completion of 50 000 pick and place cycles.

The magnetic attractive force between the button and the focal plate is specified as $250 \pm 40$ gram ($2.45 \pm 0.39$ N). So the collet's grip and release forces have sufficient margins to ensure buttons are attached to and detached from the focal plate with complete reliability. With the fiber tension nominally 0.4 N, the specified friction torque would cause a mis-alignment of the fiber relative to a straight line between the button axis and the retractor of only 0.1 mm.

The first gripper to the final design is just reaching completion. In static tests it easily meets the first three specifications above and it is about to start its reliability tests. A prototype gripper built a year earlier demonstrated the basic feasibility of the design and gave very good reproducability in positioning (better than 1 μm rms) but did not provide sufficient margin between the grip and release forces for fully reliable operation.

### 2.3 Optical monitoring of gripper operation

A miniature CCD camera is mounted in line with the gripper axis, with a relay lens imaging the optical aperture of the button onto the CCD when the button's fiber is backlit. The camera is set so the button aperture is in sharp focus when the button is attached to the plate. Then a large de-focussed image is obtained when the button is held in the gripper and the gripper is retracted. Observing a small image when the gripper has deposited a button and retracted and a large image when the button has been gripped and retracted are used as checks for successfully placing and detaching a button, respectively.

Measurements of the centroid of the in focus image are used to confirm that the robot is adequately aligned with a button before extending the gripper to grasp it and to check that a button has been re-positioned within the required accuracy.

### 2.4 Gripper details

The air bearings are 20 mm diameter porous carbon bushes cemented into the gripper main body and the end cap by the bush manufacturers, New Way Machine Components Inc.[2] With a shaft diameter about 20 μm smaller than the bore of the bush, these bearings provide very precisely repeatable location of the collet axis. The collet bore is finish machined to its final size while the collet/piston assembly rotates on its air bearings, so the mechanical axis of the collet is coincident with its rotation axis to within about 1 μm.

## 3. POSITIONER ROBOT

To suit the spherically curved focal surface, the simplest geometry for the robot is one in which the gripper is carried along a curved radial arm which can be rotated around the axis of the focal plate. This avoids any need for a separate tilting mechanism to maintain the gripper Z axis perpendicular to the focal plate and makes the robot mechanism as compact as possible while covering a circular field. We refer to the robot as an R-θ mechanism.

### 3.1 R motion

The R carriage is kinematically guided against a flat surface and a cylindrically curved surface with vacuum pre-loaded air bearings and driven with an ironless linear motor (by Kollmorgen Corporation[3]). Figure 5 identifies components of the R drive. Using vacuum pre-loaded air bearings (by New Way Machine Components Inc.) eliminates the need for additional accurate surfaces for guiding the motion; this is especially beneficial in the case of the curved motion. With the required radius of curvature of the path being about 4 meter, it was possible to attach the permanent magnets for the linear motor around the required arc without exceeding the tolerance on width of the gap between adjacent magnets. The motor behaves exactly as if it was running on a straight path.

The R motion is encoded with an optical tape encoder (by Renishaw [4]). The self-adhesive gold coated stainless steel tape is attached to the cylindrical surface to one side of the area used by the air bearings. The encoder grating pitch is 20 μm and the reading head provides interpolation to 1 μm.

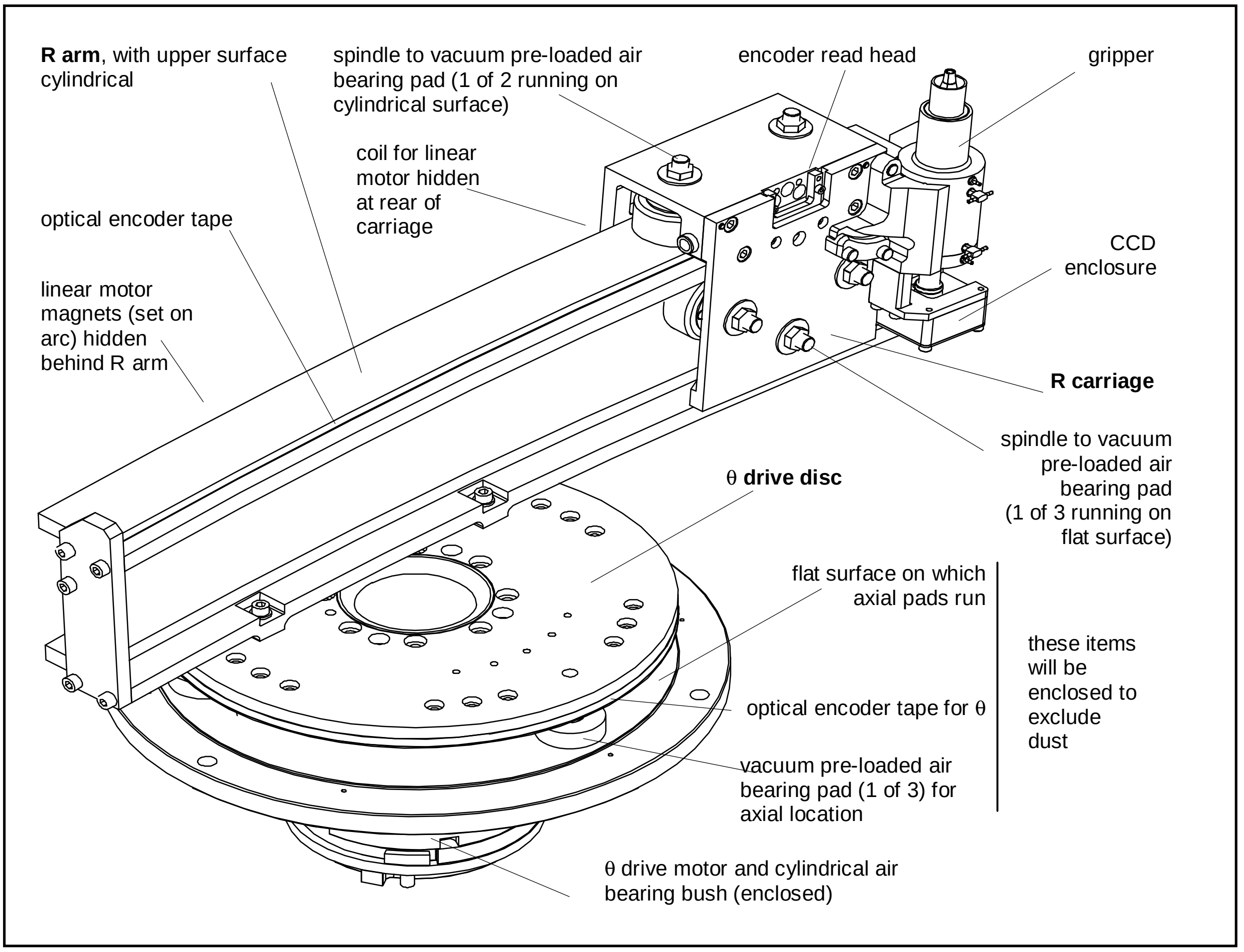


Figure 5. Details of R-θ robot.

## 3.2 θ motion

The θ axis is constrained radially by an 80 mm diameter porous carbon air bushing and in angle by three vacuum pre-loaded air pads running on an annular flat surface. The radial bearing has some compliance in tip and tilt, being supported in O rings which also seal its air supply, but is defined radially by a diaphragm. A brushless frameless torque motor (by Kollmorgen) provides the θ drive.

θ encoding is with the same encoder tape as used for R. In this case, the tape encircles a 300 mm diameter disc with the tape ends not more than 0.2 mm apart and epoxied to faces whose separation can be adjusted through > 20 µm, so a phase discontinuity across the gap can be avoided. Details of this phase adjustment follow a Renishaw recommendation. The reading head chosen for θ provides interpolation to 0.5 µm increments which correspond to resolution in the tangential direction at the outer edge of the field of about 1.5 µm.

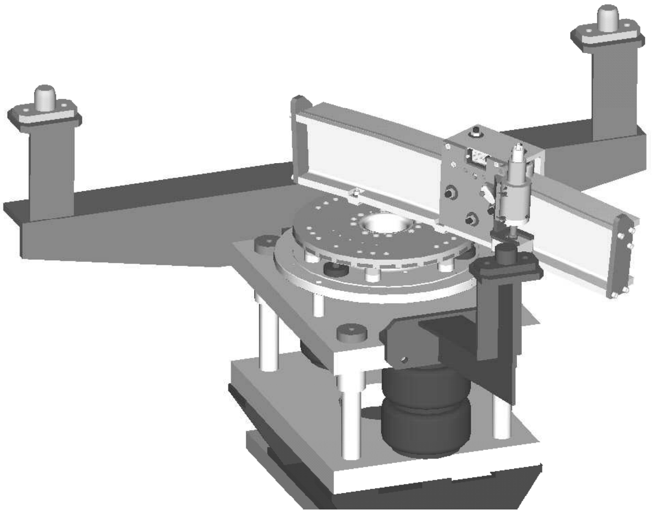

Figure 6. CAD model of R-θ robot raised on its lifter, showing locators to register with focal plate during reconfiguration.

3.3 Prototype R-θ robot

A prototype robot has been made (which will serve later as the fiber positioner for the 6dF project [5]). It differs from the robot for OzPoz in having a much smaller R travel but it does have a curved R path (with radius ~ 3 meter). The air bearings for R and the axial air pads for θ are pre-loaded with permanent magnets rather than using vacuum pre-loaded pads. Figure 7 shows this prototype.

Very good positional repeatability and servo performance have been demonstrated in R using the servo amplifier and the control software provided by Kollmorgen. A move of 150 mm is completed to within ± 1 μm in less than 0.3 second. θ drive and encoding has been demonstrated to function satisfactorily but has not yet been tested dynamically. The θ encoding has been confirmed to increment with no discontinuities across the tape gap.

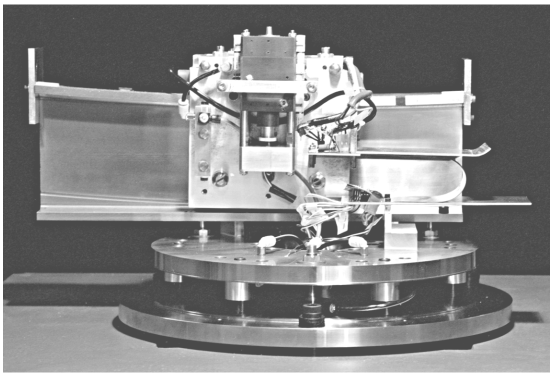

Figure 7. Picture of prototype R-θ robot

## 4. EXCHANGER

The exchanger refers to the mechanism which carries the focal plates and provides for their interchange between the observing location, with the plate registered against the VLT Nasmyth rotator, and the re-configuration location, with the plate registered in relation to the positioner robot. Its general functions were already outlined in the introduction.

In its translation towards and away from the telescope, the exchanger is guided by linear bearings on rails screwed to beams integral with the Nasmyth platform and it is driven by a standard industrial linear actuator. At its operational position and at its withdrawn position, the exchanger translation is locked by pneumatically operated lugs adjacent to the linear bearings (to minimize earthquake risks). The 180° rotation to interchange plates is provided by an electrically driven standard industrial indexing mechanism. It will have four indexing locations at 90° intervals to provide for an extra pair of plates in the future. The indexer has the useful feature of a torque limiting clutch which does not lose registration of the index angles if it slips.

To allow interchange, the robot must be withdrawn from its registration with the plate that has been re-configured. This is achieved by lowering the robot through several cm. The mechanism for this is a lifter, shown in figure 6, comprising a standard die set (in which the upper plate is guided by linear bearings constraining it to move vertically) actuated by a pair of air bellows.

To allow for slight misalignment between the focal plate locators and their matching components on the Nasmyth rotator, each focal plate is supported on three polyurethane bushes which will have appropriate lateral compliance. The bushes will also have axial compliance so that the focal plate locators can be pre-loaded into contact with the Nasmyth rotator with sufficient force to prevent their parting under earthquake induced vibration.

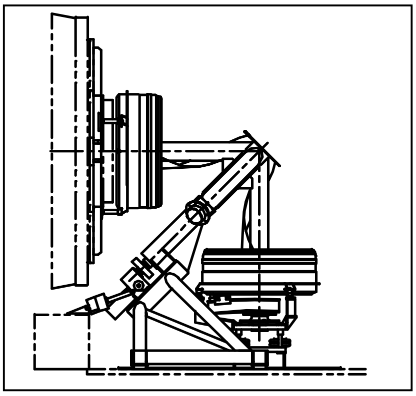

Figure 8. Early concept for structure of exchanger, abandoned in favor of form shown in figures 1 and 2.

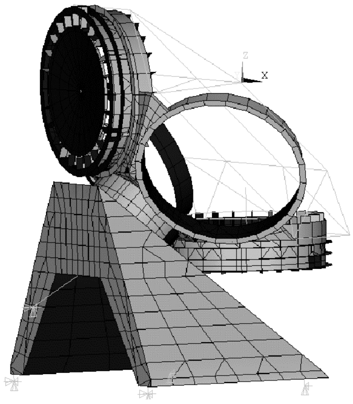

Figure 9. FEA model

The original concept for the exchanger structure had each focal plate supported with a relatively small diameter bearing at the end of a cantilevered tube, as indicated in figure 8. However, with this structure it would have been hard to attain high enough natural frequencies of vibration to ensure earthquake survival. Also, the routing of fibers with accommodation for rotation of individual focal plates during observing and for the interchange of focal plates was difficult. So a quite different structure, as indicated in figures 1 and 2, was adopted near the end of the design phase. This structure was modeled in detail for

FEA, as indicated in figure 9. After several detailed changes to the structure suggested by the preliminary FEA results, the lowest natural frequency was raised to above 13 Hz.

## 5. ACCURACY OF POSITIONING BUTTONS

A detailed analysis has been made of the contributions to positioning error. In predicting the accuracy with which button positions could be measured with the gripper camera, it considered:

- image centroid measurement on the CCD
- encoding intervals
- calibration of scale non-linearities
- effect of temperature change on scales
- stability of R path and θ axis

and gave a quadratic summation equivalent to an rms radial error of 2.5 µm.

Additional errors are involved in positioning buttons if no iteration is made after optically measuring the new button position. The contributing effects considered were:

- error in correction for eccentricity of optical center of each button from its mechanical axis
- eccentricity of gripper collet
- button tilt due to focal plate irregularity
- tilt of button due to foreign particles.

Quadratically summing these errors gave a prediction of an rms radial error of 2.3 µm. Compounding this error with the measuring error predicted above, the error in placement of a button in relation to all the other buttons in the configuration, without iteration, is expected to be 3.4 µm rms.

There will also be errors in the location of the full set of buttons in relation to the optical and mechanical axes of the Nasmyth focus. The set of three kinematic locators for the plates on the robot and on the Nasmyth rotator are nominally identical so, once it is first calibrated, the relationship between the R-θ coordinate system of the robot and the Nasmyth rotation axis should be very stable. A variability in this relationship of up to 50 µm rms is predicted. This error, corresponding to less than 0.1 arcsec, will be corrected simply as part of adjusting the initial pointing of the telescope, with the FACB buttons set on bright reference stars for feedback. The optical distortion at the focus behind the Nasmyth correcting lens is small enough that the differential distortion induced by 50 µm lateral shift is negligible.

## 6. CONCLUSIONS

The design of this new multi-fiber positioner relies heavily on the AAO's experience designing, commissioning and operating 2dF but also incorporates a number of novel features aimed at giving high reliability and accuracy and very fast re-positioning of buttons. The validity of the most critical new features has been proven by building prototypes.

## ACKNOWLEDGMENTS

Brian Hingley is responsible for the electronic design and manufacture associated with OzPoz while Dan Popovic has developed the software. Our associates at ESO, Luca Pasquini, Gerardo Avila, Franz Koch, and Heinz Kotzlowski have been helpful and understanding when difficulties have arisen. We have enjoyed collaborating with people at Paris Observatory, Meudon, where the spectrograph and fiber systems are being made and where Laurent Jocou has been our main contact.

## REFERENCES

1. G. Smith, A. Lankshear, "2dF mechanical engineering", *Optical Astronomical Instrumentation,* Sandro D'Odorico, Editor, Proc. SPIE 3355, 905-917 (1998)
2. http://www.newwaybearings.com/
3. http://www.kollmorgen.com/
4. http://www.renishaw.co.uk/
5. F.G. Watson et al, "Progress with 6dF: a multi-object spectroscopy system for all-sky surveys", *Optical and IR Telescope Instrumentation,* Proc. SPIE 4008 (paper 35, this conference)