

BigBOSS

R-θ Fiber Positioner for the BigBOSS Instrument

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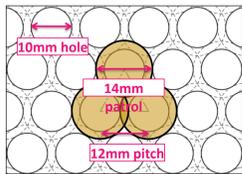
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GOALS

The BigBOSS instrument is a multi-object spectrograph for a massively parallel survey of deep sky objects. It will rely on 5000 miniature robotic fiber positioners to dynamically target thousands of unique galaxies on every observation, with reconfiguration of the field to new targets every 20 minutes.

Can we build robotic positioners that are sufficiently...

1. Small 12mm pitch
2. Precise < 5 μm
3. Fast < 45 sec repositioning
4. Well-aligned < 0.15° tilt error
5. Well-located < 5 μm axial error
6. Straight-moving < 20 μm defocus error
7. Low cost < \$1k each
8. Long-lived > 40k repositions



DEVELOPMENT APPROACH

The development schedule was:

1. Concept map: Sketch options, back-of-envelope calcs
2. Select kinematics: Flexural R-θ chosen
3. Structural analysis: Flexure and housing design geometries
4. Rough prototyping: Early flexure concept built for feel / feasibility
5. Materials selection: Chose a precipitation-hardened steel (17-7PH)
6. Structural analysis: Re-analyze with final mat'ls, geometry
7. CAD model: Full positioner modeled
8. Sub prototypes: Careful build / test of key sub-assemblies
9. Full prototype 1: Whole positioner built for fits, feel, assembly, electronics integration
10. Cost estimate: Whole positioner cost @ 5000x qty
11. Full prototype 2: Immediate revision of CAD, then 2nd round of full prototypes
12. Testing 1: In-depth testing of full positioner
13. Full prototype 3: Commit revisions necessary from Testing 1
14. Testing 2: (In-progress)

Key kinematics get analyzed; everything gets prototyped!

Concept sketch, Dec 2010

Early CAD model, March 2011

Flexure final materials selection, July 2011

Final analysis, Aug 2011

17-7PH Stainless @ 75um (selected)

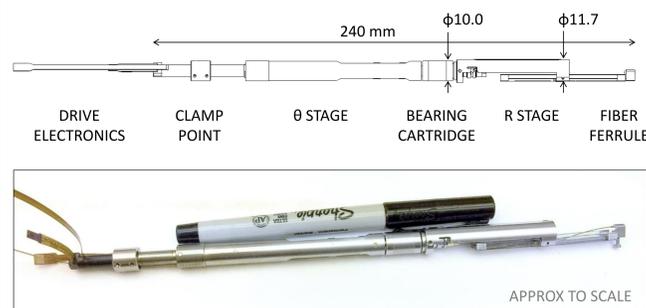
1st 3x protos, Dec 2011

Bearing prototypes, Sept 2011

On test stand, Jun 2012

Cord kinematics, April 2012

DESIGN



R STAGE (radial kinematics)

Upper housing + flexure

Flexure acts as:

- 1) extensible linear bearing
- 2) anti-backlash spring
- 3) fiber radius control

Multiple flexures are laminated in parallel on one tool.

Bearing + spool

HDPE gel-spun cord for actuation

Cord/spool tie-off

Batch of flexure leaves

θ STAGE (angular kinematics)

θ stage transmits rotation around R drive components, then thru bearing to upper housing

R-θ vs θ-θ kinematics

Bearing cartridge is the key datum, setting 5 DOF with respect to focal plane:

- X, Y, Z position
- XZ, YZ tilts

Clamp fixes XY rot.

Bearing constraint

Preloaded bearing cartridge

θ rotational constraint (clamp)

MOTOR ASSEMBLY (drives R, θ)

Drive assembly inserts into R+θ unit

Fiber runs along motors, then thru center

Fiber + service bypasses via transfer gears

Drive assy before fiber routing and insertion

2x 6mm DC brushless servos with 1024:1 gear heads

Planetary transfer gears pre-bonded to make one unit

FIXED PLANETS

FIBER CHANNEL

TESTING

Full positioner accuracy, precision, repeatability (in progress)

Video coordinate measuring machine is primary tool for measuring positioner performance.

Originally, manual point taking. Recently, we've fully automated, with feedback to positioner; allows thousands of points and strong statistics.

Also in development is an automated system centroids light of a backlit fiber: even faster, allows parallel measurement of multiple positioners; replicates the actual feedback loop that will be on the BigBOSS corrector.

Parasitic motion of flexure, defocus direction

Shim stack

Flexure ("short reinforcement")

Cord guide (Bore brass)

Cord (100% fused polyethylene)

Optical target (Invar-steel)

Defocus Z (μm) vs Travel R (mm)

Cord guide Z displacement (mm)

Transverse error (μm) vs Deflection (mm)

Optical target (Photo-top of fiber ass)

Parasitic motion of flexure, transverse direction

Transverse error (μm) vs Deflection (mm)

Loop 1

Loop 2

Loop 3

More sub-component testing

Bearing Cartridge Testing

	Min	Max	Average	Unit	Notes
Axial Displacement	0.0	1.0	0.462	μm	0.5, 3.5 axial load
Fit of nominal shaft axis	0.007	0.082	0.0310	deg	roundness of sleeve included
Fit due to radial run-out of shaft	0.006	0.018	0.0130	deg	roundness of shaft included
Torque resistance	4.6E-05	5.8E-05	0.00050	deg/Newton	40, 120 Newton load
Radial stiffness				N/μm	-4, +4 N radial load
Radial stiffness					measurements ongoing

Geartrain+Bearing Repeatability

Fiber Transfer / Safe Passage

Frequency vs Theta Deviation / μm

THE BIGGER PICTURE

Mayall 4m Telescope Kitt Peak, Arizona

Corrector (optics)

4X Lens

2X ADC

Focal Plane

Fibers

Hexapod / V/F Ring

End cap (distributes optical fibers, control signals, power, cooling)

Focal plate (5000 holes for 5000 positioners)

Fiber positioner (targets individual fibers on individual galaxies)

CONCLUSIONS / CURRENT STATUS

A complete mechanical design for the BigBOSS fiber positioner is ~90% complete, and 100% operational for test purposes.

The feasibility is proven (by good results from sub-component testing).

The expertise gained through the prototyping process has helped drive interfaces and specifications for the larger engineering effort.

Cost estimate is currently rough (due to scaling of small batches), but looks reasonable at this point.

Testing of full positioner is in progress, completion in July.



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