UCLA Astrophysics Program | **U.C. Berkeley** | **W.M.Keck Observatory**

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NIRSPEC Cryomechanics Design Note 18.02
Instrument support structure

1 Introduction

NIRSPEC has to be mounted on a stable support structure at the telescope, on either of the two Nasmyth platforms of Keck II. The instrument will not be permanently installed, nor will it have a unique location; instead it will sometimes have to move between the two Nasmyth platforms. To meet this requirement, the support structure will need the ability to run on tracks. To make the transfer, NIRSPEC will roll over to a temporary position on the Nasmyth deck (the "balcony" around the dome where the elevator comes up). The telescope will then be rotated so that NIRSPEC can be rolled onto the opposite Nasmyth platform.

On the right hand Nasmyth platform NIRSPEC will also have to move out of its observing position and into a standby position in the corner of the platform, to allow DEIMOS to get to the focal plane. The two instruments will probably be interchanged once or twice a month. On this platform the rail system will include a railroad style turntable to enable both NIRSPEC and DEIMOS to rotate and then move off into the corners of the platform.

After each move the instrument will have to be re-aligned to the optical axis, preferably with the minimum amount of work. To deal with this we need to ensure two things: the support structure must re-locate exactly each time it is moved back into one of its observing positions, and we need a reliable method of accurately and reproducibly re-aligning the instrument on the structure.

The support structure will also carry the instrument electronics, housed in two or more cabinets bolted together and placed under the instrument. The optical axis is 1.5 meters above the floor of the Nasmyth platforms, so there is quite a bit of space under the dewar. This layout avoids a floor space problem, which we would have if we placed the electronics cabinets beside or behind the instrument. Space would be a particular problem on the left platform, which has the AO bench. The electronic equipment should travel with the instrument when it moves around on the tracks, so that the minimum of dismantling is required when making a move. We need to complete the layout and design of the electronics housing as part of this design, since some of the space issues will be affected by things like the size of the racks after they have had thermal insulation added to limit their heat dissipation.

We also need to be able to move the instrument around independent of the tracks installed at the telescope, such as when it is in the lab, and any time it has to be moved to an instrument prep room at the observatory, so it will need a second set of wheels. These will be hard rubber castors rather than the steel rollers used on the tracks. The track rollers won't allow the instrument to turn corners, and are only meant to roll on a smooth straight steel rail.

This iteration of the design document should be close to the final one. The remaining effort should consist mostly of producing the final drawings, and tracking down all the components we won't actually build, such as motors, geaboxes and jacks.

2 Design goals

The main requirements for this design are listed below.

C The structure must support the weight of the instrument and its auxiliary equipment and be stable and rigid (i.e. not shift or vibrate when the telescope moves). This includes being secure during earthquakes.

C The instrument will move on wheels which run on the tracks provided at the telescope. All transport functions must be simple and convenient for the telescope support crew to use.

C There must be provision to attach additional wheels or castors for moving the instrument independent of the tracks, on any reasonably flat surface.

C The support structure must locate on kinematic mount points on the Nasmyth platforms, so that the instrument returns to exactly the same place each time it is moved and replaced.

C The structure must have provision for adjustment of the instrument alignment, so that NIRSPEC can be quickly re-aligned with the optical axis after a change of location. The adjustment mechanisms should be indexed so that any configuration can be recorded.

C The electronics equipment racks will be mounted underneath the instrument, but the equipment must still be easily accessible and the cabling not any longer or more complicated than absolutely necessary.

C Access to the underside of the dewar, which has the CCR heads and all the vacuum and electrical feedthroughs, should not be restricted by the electronics crates.

C The design must include convenient locations for connecting and disconnecting electrical supply, coolant, CCR hoses and fiber-optic data connections.

C NIRSPEC must be compatible with DEIMOS and the turntable arrangement on the right hand Nasmyth platform, so the instruments can be interchanged easily.

C NIRSPEC must also locate at the focus provided by the AO bench without mechanical interference.

3 Summary of design

3.1 Overview

There are six main elements to the design:

- the basic support structure or framework supporting the instrument and electronics
- the transport shuttles (carts) for use on the rails or on regular floors
- the kinematic mounts to the Nasmyth platforms
- the kinematic adjustment of the instrument itself on the support structure
- the mounting and placement of the electronics racks and their thermal insulation
- the mounting of the calibration/guider unit

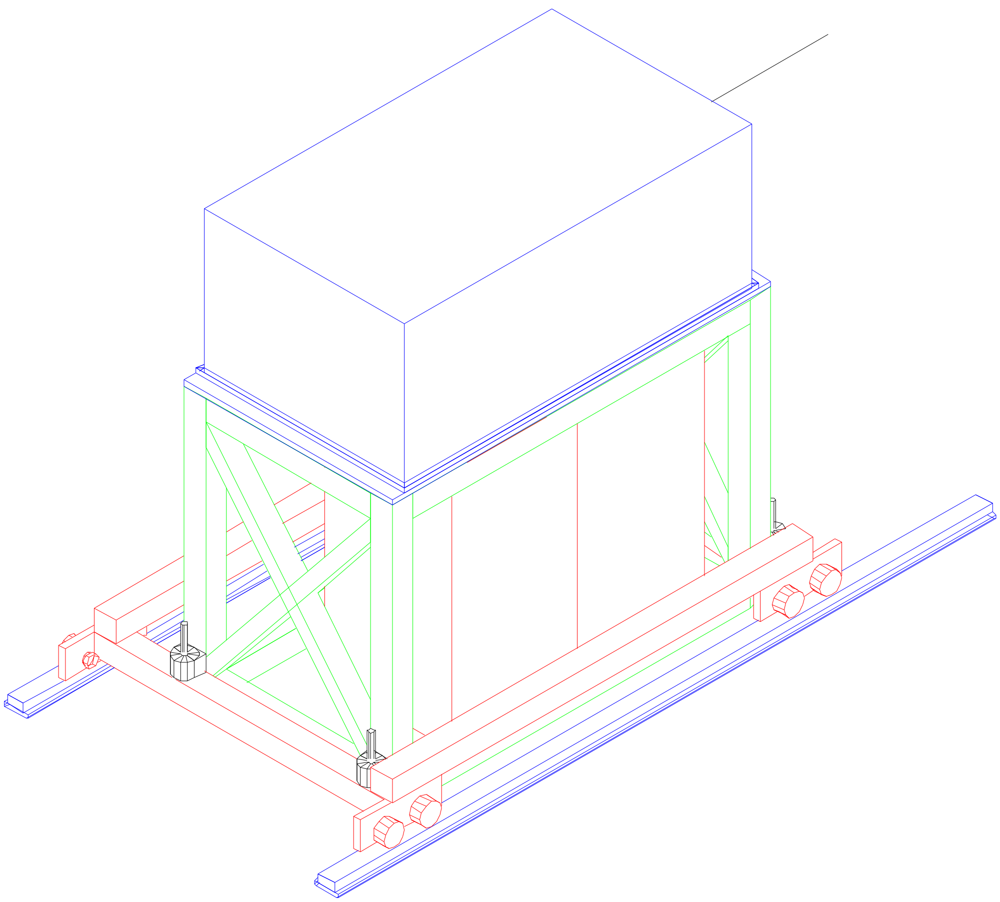

Figure 1: The support structure on the rails at the telescope

The weight of the instrument rests on the support frame (see section 3.2) via three kinematic adjusters (section 3.5). Three kinematic mounts support the frame, instrument and electronics on hard points on the Nasmyth platform floor (section 3.4).

There will be two transport carts (section 3.3), one which runs on the rails on the Nasmyth platforms and Nasmyth deck at the telescope, and one with castors to run on regular floors.

The electronics racks (section 3.6) are placed so that their front and rear doors face to the right and left of the instrument (where instrument “front” means the face with the input window and “right” is the longer face showing in the picture).

On the front of the instrument is the box holding the calibration/guider unit (section3.7).

3.2 Support framework

The support framework should be very simple. Figure 2 above illustrates the basic idea, with the dewar on its support structure rolling on the rails at the telescope. We will build the frame mostly of 4" × 4" steel tube, with some 4" × 2". The frame consists of four legs with horizontal frames around the top and bottom. There will be gussets at the corners to provide additional stiffness.

The kinematic mounts are on the cross-members at each end: one set on the centerline of the rails at the window end and two near the corners at the other end. The bottom kinematic mounts are directly below the upper ones, as nearly as possible. This should make it easier to use the different adjustments in concert (for instance when backing out the coarse adjustment to bring the fine adjustment in range). To allow room for the kinematic mounts top and bottom, the cross-members at the ends are offset a few inches in height. The longitudinal members are placed as high or low as possible to give as big an aperture as we can make for the electronics.

3.2.1 Compatibility with turntable concept

On the right hand Nasmyth platform NIRSPEC has to share the observing position with DEIMOS. This is accomplished by a railroad style switching system with two sidings and a turntable. The turntable was originally conceived as quite large, so that NIRSPEC would have rolled onto it and rotated standing as normal on the rails. This idea has now been dropped (I’m not sure why) in favor of a smaller turntable about 3' in diameter. This turntable will lift each instrument *off the rails* by pushing under the center of gravity.

In our original concept there were no cross-members underneath the instrument, so the smaller turntable would push up in the middle and crush our electronics cabinets! Obviously that’s no good so we need to incorporate cross-members that can bear the weight of the instrument. We also need a way of lifting the cart along with the support structure. Our original idea was that the instrument would only rest on the cart and not be firmly attached, since the instrument isn’t putting its weight on the cart when it’s on its kinematic mounts on the floor. When the instrument lowers itself into position it needs to be able to move slightly side to side in order to slip into the kinematic mounts. It shouldn’t be difficult to come up with some simple bracket arrangement to take care of this problem.

3.3 Transport mechanisms

3.3.1 Introduction

Any large heavy component which has to move around at Keck mounts on its own shuttle assembly. These shuttles run on a series of tracks installed on the Nasmyth deck and Nasmyth platforms. The track system consists of three tracks, as shown in Figure 2. The two outer rails bear the load, while the middle one is used for driving via a rack and pinion mechanism, and also keeps the moving shuttle in line on the outer tracks. The standard gauge of the outer tracks is 1.5 meters (59") center-to-center. This is a good bit wider than the NIRSPEC dewar, which will be 40.5" wide. To match the gauge of the tracks we will have to place the wheels outboard of the simple support structure, as shown above. The wheels will stick out to the sides and occupy a bit more floor space than the footprint of the dewar alone, but this shouldn't pose a problem.

The outer tracks rest in a 6" channel set into the floor, and have the profile shown below. The wheels are mounted in pairs so that one of them can take the load whenever the other crosses a break in the tracks, such as between the edge of the Nasmyth platform and the Nasmyth deck. These wheels have no flanges to keep them on the raised profile of the track, so something has to keep them in line. This is accomplished by the middle track. The middle track has a rack which is used to drive the equipment along the tracks, and a steel angle which acts as a guide rail. Cam followers on plates mounted at either end of the moving trolley run inside the angle to give the trolley lateral guiding and vertical restraint. The trolley is driven by a pair of gears which mesh with the rack mounted along the middle track.

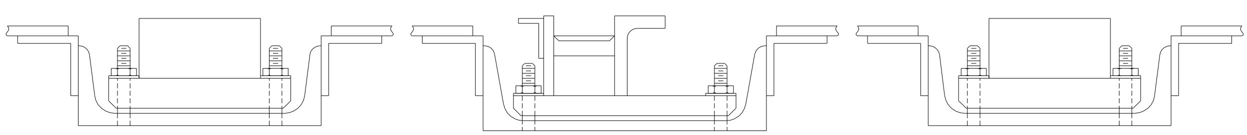

Figure 2: End view of the track system

Since we are going to fill up the space under our instrument with electronics, there isn't room under there for the motor and gearbox and the drive gears which run on the central rack. As the DEIMOS group are proposing with their shuttle, we will move the drive system gears to the rear of the instrument. One consequence could be a great big motor sticking out horizontally, about a foot or so off the floor. To avoid the possible tripping hazard and make the whole setup more self-contained, I propose to rotate the motor so it is vertical. **I need to follow up with the gearbox manufacturer in case this has some unforeseen consequence.** We might have to change the lubricant fill point but otherwise I don't anticipate any problem. I talked to an engineer at Utec Metals, the company that built the original carts, and he concurred.

3.3.2 Lift mechanism

When it is in its observing positions the support structure has to rest on fixed mount points, but it will have to lift out of those a few inches before moving. There will be a set of screw jacks at the corners of the support structure, which will push down on the trolley and so lift the instrument and support frame up. An electrical interlock will ensure that the motor can not drive the instrument along the tracks until it is lifted clear of the mounting points.

3.3.3 Off-track transport

The trolley used on the rails will be detachable, so that the instrument on its support frame can be lifted off, leaving the trolley on the tracks. For rolling on normal floors the instrument will be placed on a similar trolley equipped with castors, as shown below. As with the rail system, we need a way to set the instrument down in a stable position once it has been moved. To achieve this we can put adjustable feet on the ends of the legs, and lower the instrument with the screw jacks until they rest on the floor. For alignment in the lab we could even re-create the mount points on the Nasmyth platform so that the instrument can always be re-located in the same place relative to our optical bench.

3.3.4 Electrical

Both the driving of the cart and the lift mechanism will be powered, so there are some electrical things to be defined. I am not sure what happens about a hand control for the motion of the existing shuttle, for instance whether each shuttle has one or there is one which plugs in to the cart that needs to be moved. **I should check this with Kyle**. It is also likely we will have to motorize one of the kinematic mounts because of a space constraint. That adjuster (focus direction) sticks out from the front of the support structure and might clash with the AO bench. If it does, we need to rotate the whole adjuster 180°, which would make it hard to reach. In that case making it motorized might make the setup much easier.

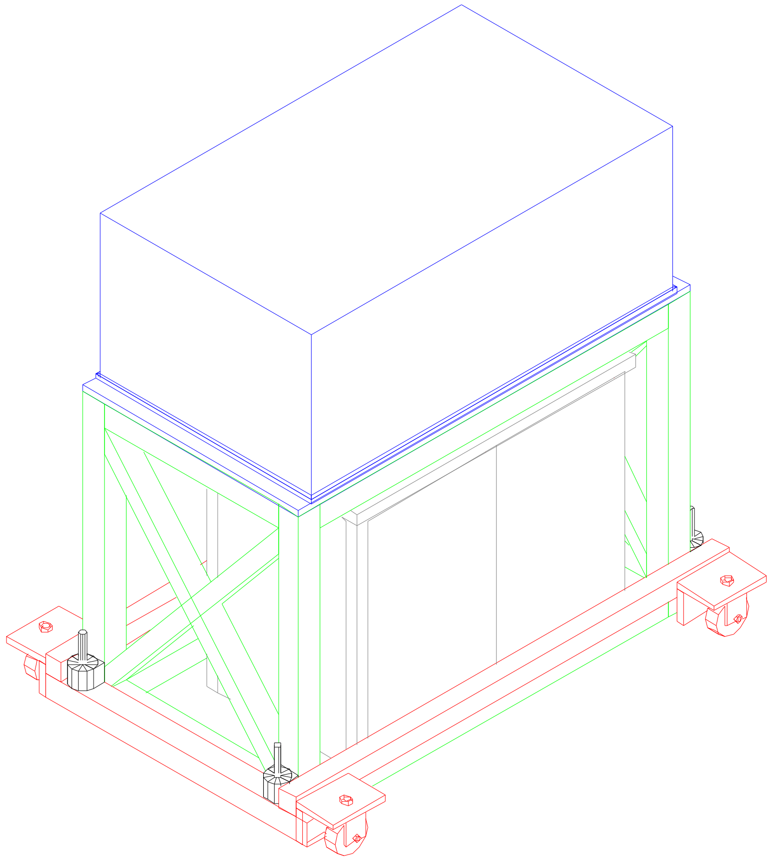

Figure 3: NIRSPEC on its lab cart

3.4 Kinematic mount to platform

The instrument has to rest on fixed static mount points once it is in place on the platform (and have safety bolts dropped into place to restrain it in the event of an earthquake). It will roll along the tracks until it is close to the right place, then the instrument lowered so that it drops into its locating points. We need to have three points for our mount so that the support is kinematic. The location of the mount points will have to be discussed further with Dave Cowley and his group at Lick, who are designing the mounting for DEIMOS. There is a problem in that there are no load-bearing points close up to the elevation bearing, where the front of both NIRSPEC and DEIMOS would have to rest in their observing positions. However Kyle Kinoshita at CARA will be looking into adding something to the Nasmyth platform structure to take care of this. I think from what I saw during my April 1996 visit that there should be no problem having the front locating point on an additional cross-member and the rear two on or near an existing cross-member. **I need to check this on the drawings.**

The mounting points need to constrain the instrument to remain in the same place but will need to have some provision for thermal expansion and not over-constrain the structure. We need the classical type of mount where one point constrains in X, Y and Z, one in Y and Z and one in Z only. Our proposal is that we will have a ball-and-socket mount at the front under the focus position, a roller in a groove at one corner, and a roller on a plate at the remaining defining point. Coarse height adjustment will be built into these mounts, giving us a range of a 2 - 3 inches. **I need to check with Kyle/Mark how much this adjustment capability needs to be.**

The degree of reproducibility of these mounts needs to be investigated so that we know to what accuracy we can depend on the instrument being replaced in the same position and orientation when it has been moved.

3.5 Upper kinematic mounts

3.5.1 Introduction

The plan is that the mount points on the floor of each Nasmyth platform will ensure that the instrument can always be put back in exactly the same place when it has been moved. However these positions, although reproducible, will be different on each platform, so we need to have a way to tweak NIRSPEC into exactly the right alignment once the structure has been located on the floor. Ideally the settings for each Nasmyth platform should be indexed, so that NIRSPEC can be returned to the nominal position on each platform as soon as it has been moved. There might be a certain amount of slop in the fixed mounts, so that a final adjustment is still necessary even though the "right" settings for the kinematic mount are dialed into the mechanism.

3.5.2 Differential screw mechanisms

The basis of the design of the kinematic adjusters is the concept of using differential screws to give a fine adjustment rate. We picked up this concept from some notes given out by Dan Vukobratovich at an SPIE optics course. The idea is that rather than trying to make a very fine screw thread, the mechanism uses two different threads which are very close in pitch and work in opposition. The difference in pitch between the two threads then gives the effective pitch of the mechanism. Nick put together a simple demonstration of the idea and I wrote a simple program to generate a lookup table of the effective thread pitch generated by different combinations.

For example, suppose we use threads of 18 and 20 tpi working in opposition. The effective pitch is given by subtracting 1/20 (.05) from 1/18 (.0555), giving .00555" per turn or 180 tpi. The advantage of using this idea is that threads of 18 and 20 tpi are quite coarse, so they are able to support a large load without stripping, and are easy to fabricate with standard tooling. Trying to use a single thread of 180 tpi would give problems with both load-bearing and fabrication.

Another thing that needs to be figured out in using differential screws is the distance the coarser thread has to move in order to give the required adjustment range, which can have an impact on the space required for the mechanism. In this example the coarser thread would have to travel 2.5" to give just a ¼” adjustment range! (Meanwhile the other thread has moved the adjuster 2.25" the other way, giving the net move of one quarter of an inch.)

3.5.3 Vertical adjusters

For coarse adjustment of height, the floor-level kinematic mounts will have threaded pillars, giving us an inch or more of adjustment range. The upper adjuster, where the dewar base plate interfaces to the support structure will give us the final fine adjustment.

In the vertical adjusters (see Figure XX) the two opposing threads are cut on the inside and outside of a hollow pillar. The pillar threads into the moving component, in this case the base plate of the dewar, and a column from the fixed base (in this case the top of the horizontal adjuster) screws into the inside thread. As we rotate the adjusting knob clockwise, the outside thread moves the dewar up. Meanwhile the inner thread is moving the pillar downwards over the bottom column almost as far, for a very small net motion of the plate.

We use threads of 12 and 14 tpi, giving ¼” of adjustment range at 12 thousandths per turn of the knob (84 tpi). This gives a travel for the adjustment pillar of 1.75", which doesn’t extend the adjuster too far upwards in its extreme position.

When we move these adjusters the instrument will of course tilt, so there has to be provision for the dewar base plate to swivel slightly (maximum would be about ½° in the roll direction). To accommodate the tilt motion we will use pairs of spherical bearings between the flange at the bottom of the adjuster and the underside of the plate. The spherical bearings are quite large (almost 3" OD) so they will not be heavily loaded. If we take the weight of the dewar as 1600 pounds, and assume the weight is split 50/50 between the front one and the pair at the rear, the load on that one will be 800 pounds ÷ 4.5 square in. = 177 psi. Such a low pressure should mean there will be no difficulty with the spherical surfaces sticking as we try to tilt the dewar during alignment. We will also use some anti-seize lubricant between the surfaces.

3.5.4 Horizontal adjusters

For the horizontal adjusters we will use simple slide mechanisms driven by the differential screw translation system. In this case though, we need a coarse adjustment range as well as the fine range. To accomplish this I came up with another variant on the differential screw concept, involving an extra component, a threaded collar in which the hollow pillar rotates. Suppose that as well as the hollow pillar rotating, we could also hold it stationary and rotate the outer collar with the coarser thread. The pillar would then move at the higher rate set by the coarser thread but without any offsetting counter-motion from the finer thread. This is the concept employed here. We can move the dewar horizontally over a range of 1¾” with ¼” of fine motion. We can use the fine range anywhere within the travel of the coarse adjustment by locking the outer collar and rotating the hollow pillar.

The slides will be simple v-blocks with a low-friction material called Glycodur between the sliding surfaces. Glycodur is a Teflon-impregnated material used in plain bearings. The front adjuster will have two axes of adjustment, focus and left-right. One rear adjuster will have one axis of adjustment left-right and slide freely in the focus direction, while the other will be just crossed slides free to slide in either direction.

3.6 Electronics racks

3.6.1 Placement and support

The electronics racks will be two 19" rackmount cabinets placed underneath the dewar. They will be at least 2' 8" square in the horizontal plane (allowing for insulation), and about 4 feet high. It looks like there is adequate room underneath the instrument to accommodate these racks, but there is the issue of placement. The underside of the dewar is the “working surface”, where all the feedthroughs, vacuum ports etc. are situated. The scheme for bringing wiring out of the inner cold shield/optical plate enclosure dictates that the wiring will all come though near the edges, so the main constraints on placing the racks are the CCR head and the liquid nitrogen fill tube.

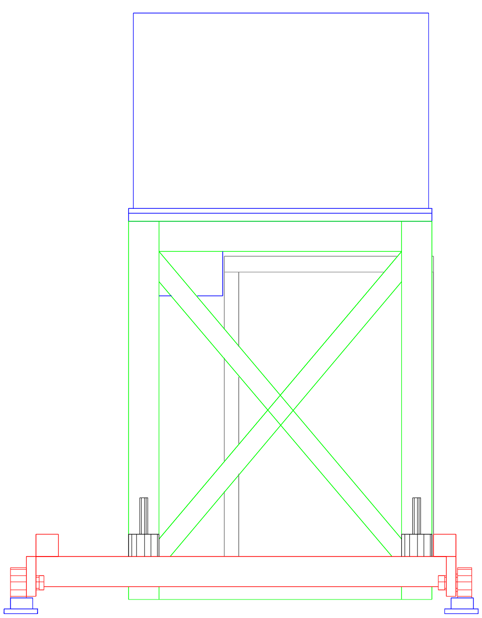

Figure 4

We have a problem with location in the left-right direction, since the racks must be off to one side to be clear of the CCR heads. That pushes them right over to the right hand side of the transport structure, but they are just able to fit in, as shown in Figure 4. Of course we have to figure out how to get access to the electronics when the instrument is installed at the telescope. One of the problems is the need to get the doors to open when the racks are installed underneath the support frame. The only way we have come up with to accommodate this necessity is to make the right hand longitudinal member of the transport cart detachable. Once the instrument is in place at the telescope the cart is merely sitting on the rails and not carrying any load, so the member could be detached and set aside if it was necessary to get access to the electronics. Another solution would be to keep that member as small as possible so that it doesn’t come up as high as the bottom of the door.

A more serious problem is accommodating the liquid nitrogen fill tube. The fill tube is approximately in the middle of the bottom surface, so it falls right between the two racks. I had hoped to make the two racks a single mechanical unit, but we have to move them apart by six inches or so to allow easy access to the fill tube. This doesn’t pose a space problem since there is enough room to move them towards the ends of the instrument, but we will have to provide some kind of cable duct between the two. It also increases the overall surface area of the whole enclosure, but the space in between could be completely filled with foam insulation below the level of the fill tube access, so that shouldn't be too much of a problem. Since the two racks are now separate we need to make sure they are adequately supported to maintain their relative position. The addition of a platform across the bottom of the support frame should take care of it (see also section 3.2.1).

3.6.2 Insulation

We need to insulate and cool the racks so we don't dissipate too much heat into the atmosphere in the dome and cause convection which will affect the seeing. The total allowable dissipation is only 50W, so we will have to use quite a bit of insulation to meet this goal. If we don't use enough insulation we will have to run the electronics inside the racks very cold. I set as a goal an air temperature of 10°C inside, to give an adequate temperature differential between the cabinet air and the cooling water at around 0°C.

I did some calculations based on using PVC foam insulation, which comes in rigid sheets and does not support combustion. The total surface area of the racks is approximately 6¼ square meters (assuming 1m high by 0.6m square). The conductivity of the foam is 0.03 W/K.m.

The table below gives the results of the calculation. If we use 1" of insulation it is clearly not enough, and 2" is more than adequate. The question is whether we can get away with using just 1½". That thickness only just meets the goal of a 10 degree differential.

Insulation thickness	Dissipation for 10°C internal	Temperature for 50W dissipation
1"	75 W	6.7°C
1.5"	49 W	10.2°C
2"	37 W	13.4°C

3.6.3 Cooling

At the telescope there is recirculated cooling water available (actually it's a water/ethylene glycol mixture to prevent freezing) to remove up to 1500 W from each instrument. We have to make use of that coolant facility to cool our insulated racks. Obviously we need to use some kind of heat exchanger, but just a simple heat exchanger working open-loop might not be adequate. Ideally we would like the temperature to be held stable to minimize instrumental drift, and also we would like to have some warning if the temperature goes high for any reason such as a loss of coolant flow.

We looked at exchangers from various vendors, and the ones which look most attractive are from a company called Knurr (they are a German company but have a facility in Simi Valley, CA). Their heat exchangers are built in rack mount cabinets, and have a control mechanism which regulates coolant flow to provide cold air of a set temperature. There is also an over-temperature alarm output which we can use to drive a power cutoff relay, or monitor from the transputer system. That would give us better control over the shutdown of the system in the event the temperature goes too high.

In the previous section I calculated how much insulation is required to keep the thermal dissipation within the 50W limit for a 10°C air temperature inside. Does that give us enough temperature differential between the air and the cooling water to allow the heat exchangers to work efficiently? I looked at the data supplied by the manufacturer. They give performance data for two different flow rates, 50 and 100 liters/hour. For these two flow rates the performance graphs show a cooling power of 30W and 40W respectively per degree of differential between the cooling water and cabinet air. So the higher flow rate and our 10°C internal temperature would enable the exchangers to remove 400W from each cabinet, giving 800W total cooling power *vs* a load of about 750W. This is a little close; however the available flow rate is much higher, up to 2.7 gal/minute or almost 600 l/hr. Just to be sure we need to contact the vendor to see what power we would get at that kind of flow rate, but it can only be better.

3.6.4 Electrical connections to the dewar

The electrical connections need to be laid out carefully in order to get to the right compromise between accessibility and proper separation of different input and output signals.

3.7 Calibration/guider unit

The calibration/guider unit has to mount to the front of the instrument and maintain alignment with the instrument at all times, while being easy to remove and take out of the way if the dewar had to be opened.

There is also an issue of how big the calibration/guider unit will be, and how it will interface with the AO bench.

4 Further work required

This section should eventually disappear as all the design issues are settled and fabrication gets under way.

August 15, 1996

- Incorporate John’s diagram of the electrical connectors on the underside of the dewar.

- Complete ordering of components (motors, rollers etc.)

5 Drawing list

The following drawings are required for fabrication and assembly. Status is either “draft”, “complete” (i.e. ready for the shop), or “as built” (i.e. contains any last-minute changes added during the fabrication phase.

Drawing number	Subject	Status
609000	Overall master drawing for the whole structure	draft
609001	Vertical adjuster	complete
609002	Vertical adjuster collar	complete
609003	Vertical adjuster outer pillar	complete
609004	Vertical adjuster inner pillar	complete
609005	Exploded view of vertical adjuster	complete
609006	X-Y adjuster	complete
609007	X-Y adjuster bottom V-block	complete
609008	X-Y adjuster top V-block	complete
609009	X-Y adjuster center slider	complete
609010	X-Y adjuster threaded collar	complete
609011	X-Y adjuster outer pillar	complete
609012	X-Y adjuster inner pillar	complete
609013	Exploded view of X-Y adjuster	complete
609014	1-axis adjuster	complete
609015	1-axis adjuster bottom V-block	complete
609016	1-axis adjuster top V-block	complete
609017	1-axis adjuster center slider	complete
609018	Exploded view of 1-axis adjuster	complete
609019	X-Y slider	complete
609020	X-Y slider bottom V-block	complete

Drawing number	Subject	Status
609021	X-Y slider top V-block	complete
609022	X-Y slider center slider	complete
609023	Exploded view of X-Y slider	complete
609024	Support frame	complete
609025		
609026		
609027	Kinematic mounts (floor level)	
609028	Front (ball-and-cone) kinematic mount	complete
609029		
609030		
609031	Left rear (v-block) kinematic mount	
609032		
609033		
609034		
609035	Right rear (slider) kinematic mount	
609036		
609037		
609038		
609039		
609040	Jacking system	
609041	Jacking system - angles	
609042	Jacking system - channels	
609043	Jacking system - angle-to-channel joiners	
609044	Transport cart for Keck rails	
609045		

609046		

Drawing number	Subject	Status
609047		
609048	Lab transport cart	
609049		
609050		
609051		
609052		
609053	Electronics cabinet joiner	
609054		
609055		
609056		
609057		
609058		
609059	Electronics cabinet modifications	
609060		
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6 Components list

This section lists all the components which have to be either fabricated or purchased. In the case of the drive system for the cart, a lot of the items have to duplicate the components of the existing handling carts. Prices don’t include tax or shipping.

Item	Mfg	Vendor	Price	Status
Cam followers (wheels of cart)	Osborn	Motion Industries	$910	Delivered
Gears for rack drive	Boston	Motion Industries	$205	Delivered
Cam followers (center guides)	McGill	Motion Industries	$111	Delivered
Motor, speed controller for cart	Dynamatic	Mfg	$1543	Ordered
Switches, starter etc. for motor	Various	Sierra Crane	WFQ	Spec’d
Magnetic brake for cart	Reuland	Foreman Ind.	$232	Ordered
Speed reducer for cart, 30:1	Boston Gear	Motion Industries	$327	Ordered
Jacks	Joyce/Dayton	Mfg	$1,195	Ordered
Miter gear boxes for jacks	Boston Gear	Motion Industries	$502	Ordered
Motor for jacks		McMaster-Carr?	? $126	Spec’d
Speed reducer for jacks		McMaster-Carr?	? $188	Spec’d
Shafts for jack system				Spec’d
Universal couplers for jacks(2)		Motion Industries	----	Ordered
Universal couplers for jacks(8)		McMaster-Carr	$203	Delivered
Spherical bearing for k-mount	SKF	Bearings, Inc.	$150	Delivered
Steel tube for frame and carts		Industrial metals	$441	Spec’d
Plate & angle for frame & cart				Unspec’d
Shafts for drive system				Spec’d
Bearings for drive system	Boston Gear	Motion Industries	$48	Ordered
Horizontal adjusters	Nick			In fab

Item	Mfg	Vendor	Price	Status
Vertical adjusters	Nick			In fab
Threaded parts for X-Y adjusters	Nelson grinding		$650	In fab

Item	Mfg.	Vendor	Price	Status
Threaded parts for Z adjusters	Nelson grinding		$750	In fab
Spherical washers & SS rods		McMaster-Carr	$126	Delivered
Glycodur®for adjusters				Delivered
Total so far (parts only)			$7707	

7 Post fabrication testing

Once we have fabricated the support system we need to test its stability and its ease of use. This procedure needs to be worked out, but will probably require we build a mockup of the Nasmyth platform rail system.

8 Installation at the telescope

This section (really part of the application note rather than the design note) should comprise an outline of the installation procedure for the kinematic mounts, and how to adjust the instrument for alignment to the optical axis.