MEMORANDUM
To: Dan Fabricant
From: Warren Brown
Date: 23 May 2002
Subject: Binospec Thermal Analysis VII: Design Recommendations

1. INTRODUCTION

This is the final memo in series on the Binospec thermal analysis. In the previous memos I described the thermal modeling and found no thermal gradient show-stoppers for Binospec. However, a number of design changes can be made that would improve the thermal characteristics of Binospec.

In this memo I describe our design recommendations. I note that this is not an exclusive list. Other design changes may achieve the same goal of smaller temperature gradients, but these are the design changes we've looked into.

2. DESIGN RECOMMENDATIONS

Recommendation
INSULATION
3 inch thick insulation covering the exterior
Entrance window
Low conductivity, or thermally isolated, support struts to the mounting flange
CONVECTION
2-3 inch air gap between optical bench and insulation
~1 inch holes in the camera barrel
MOTORS
If possible, do not mount heat sources to the optic mounts and optical bench
Mount motors with thermal stand-offs
Paint motors with high emmitance paint
Use radiation shields around motors to prevent optics from seeing motors
GENERAL
Don't attach anything within ~3 inches of the edge of the optical bench

2.1. INSULATION

3 inch thick insulation covering the exterior

The key to minimizing temperature changes and temperature gradients inside Binospec is to insulate the spectrograph as much as practical. The baseline thermal model assumed 3 inch urethane foam ($k_{urethane} = 0.026$ W m^{-1} K^{-1}) insulation over Binospec's 21 m^2 surface area, which resulted in a 36 hr thermal time constant for the optical bench. 2 inch thick insulation, which may be easier to purchase, will result in ~10% greater temperature gradients in the optics than 3 inch foam.

Trade-offs of insulation include the weight (100 kg assuming a rather dense $\rho_{urethane} = 70$ kg m^{-3}), the structure to support the insulation, and hatches needed to access the slit masks, filters, and gratings.

Entrance Window

An entrance window is more important than increasing insulation thickness from 2 to 3 inches. Without an entrance window, temperature gradients in the optics would be ~0.25° C (67% greater) and the optical bench time constant would be 26 hours (30% faster). This would cause a 0.1 pix/hr shift rate on the detector just due to thermal deflection of the grating. In addition, without an entrance window the inner support plate that holds the fold mirrors would experience 2.5° C (5× greater) temperature fluctuations. The thermal issues strongly support having an entrance window.

The trade-off of an entrance window is light lost due to air/glass reflections. On the plus side, an entrance window will help keep dust out of the spectrograph.

Low conductivity, or thermally isolated, support struts from the mounting flange

To complete the insulation issue, the graphite epoxy support struts should have low conductivity or be thermally isolated from the mounting flange. The support struts (I assume $k_{graphite\ epoxy} = 36$ W m^{-1} K^{-1}) account for ~1/3 of the peak heat flow (8 W) into the spectrograph from the environment, and directly connect the mounting flange (at the telescope temperature) to the optical bench. Because the optical bench is a thermally sensitive structure, the conduction path to the mounting flange should be minimized. I ran a thermal model assuming 1/2 inch delrin spacers between the mounting flange and struts, and found that the peak heat flow is reduced 4× (to 2 W) and the temperature gradients in the optics are reduced by 10% (to ~0.1° C).

The trade-off of thermally isolating the struts from the mounting flange may be a structural stiffness issue.

2.2. CONVECTION

2-3 inch air gap between optical bench and insulation

The axial temperature gradient in the optical bench, which causes significant thermal deflection of the optical bench, is primarily due to different air temperatures above and below the optical bench. An air gap around the edge of the optical bench will allow air exchange; natural convection will occur when Binospec is pointing away from zenith. Fans are not a good solution here. Fans would be a significant part of the total heat flux in the spectrograph, and would introduce more heat than help with convection. If the air above and below the optical bench were the same temperature, the optical bench would have a 50% smaller (~0.05° C) axial temperature gradient, and the collimator lens groups would have 25% smaller (~0.45° C) temperature differences. In addition, moving the insulation away from the optical bench will reduce the radial temperature gradient in the optical bench by 10% (to ~0.36° C).

Trade-offs of an air gap between the optical bench and insulation include additional structure to mount the insulation off the optical bench and a slightly larger instrument diameter.

$\sim$1 inch holes in the camera barrel

The primary reason the camera and collimator lens groups differ in temperature (up to $\sim$0.6° C) is the large difference in thermal capacitance mC of the lens groups. The secondary reason the lens groups differ in temperature is that center lens group is protected from radiative and convective heat transfer by the camera/collimator structure. Placing large holes > 1 inch across in the camera barrel around the front and back of lens group 2 will allow convection on those lens surfaces and help equilibrate the lens groups. The thermal model predicts that convection on lens group 2 will result in a 0.4° C (20% smaller) lens group temperature difference.

Trade-offs include scattered light and dust protection of lens group 2, and possible stiffness issues with the camera barrel.

2.3. MOTORS

If possible, do not mount heat sources to sensitive structures

Sensitive structures include the optical bench and all the optics mounts. A hot spot on the optical bench next to the grating turret, for example, will cause as much image shift on the detector as the from the overall deflection of the optical bench itself (see memo V). If motors must be mounted to the optical bench or to the optics mounts, use thermal stand-offs.

Mount motors with thermal stand-offs

Because motors in Binospec will not heat by more than a few degrees Celsius in forseeable operation, it is prudent to dump the heat around the entire spectrograph rather than directly into the structure. A thin ($\sim$1/4 inch) slice of low-conductive material (i.e. delrin or nylon) will suffice to insulate the structure from the motor.

The trade-off of using thermal stand-offs is that motors may get up to 3$\times$ hotter (up to 4.5° C) than without thermal stand-offs.

Paint motors with high emmitance paint

Any color paint is fine. On the other hand, an anodized surface has low emmitance and is bad. High emmitance helps keep the radiative heat exchange low ($\epsilon_1 T_1^4 - \epsilon_2 T_2^4$).

Use radiation shields around motors to prevent optics from seeing motors

All lines-of-sight from an optical surface to a motor should be blocked by radiation shield around the motor. This will help minimize any temperature gradient in an optic caused by radiative heat flow from a motor.

2.4. GENERAL

Don't attach anything within $\sim$3 inches of the edge of the optical bench

Due to the unconstrained nature of the optical bench, the greatest thermal deflections occur at the edge of the optical bench. In memo V, Henry Bergner's plots show that the tilt caused by a radial or diametral temperature gradient is $\sim 5\times$ greater at the edge than anywhere else along the optical bench. These calculations assumed a 6 inch honeycomb-core optical bench.