Electrical Specification for Thermal Compression Fit Mirror Heater Driver

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T2000289-v6

1. Overview

Adaptive optics are required for active mode matching to minimize loss by mode-mismatch in O4 and A+ upgrade, both in the SRC-OMC path and SQZ-FC-IFO path. The thermal-driven compression fit mirror (CFM) is one of the candidates for the suspended active matching stages (SAMS). The tentative plan for CFM heating uses four 25 Ω resistors, connected in series. This document discusses the requirement on electrical driver for these heaters.

2. Resistors

Parameters	**Values**
Resistor maker and model*	Barry Industry RA2000-20-8X
Nominal resistance*	25Ω ± 5%
Max rated voltage*	400 VDC
Rated power*	20 W
Operating temperature limit*	-50-150°C
Maximum actuating temperature	60°C

(*)http://www.barryind.com/pdf/Resistors/Power_Flange/RAXXXX-20-8X.pdf

Wire specification (http://www.coonerwire.com/cooner_catalog_rev9-8.pdf):

Parameters	**Values**
Vendor	Cooner wire and cable
Part #	CZ 1105 ***
Gauge	28 AWG
Current limit	280 mA (**)
Nominal overall diameter	0.024 inch (0.670 mm)
Nominal conductor diameter	0.0138 inch (0.3505 mm)
Coating	Teflon FEP
Teflon emissivity	0.9 (conservative)
Resistance	0.0649 Ω/ft (0.2129 Ω/m)

(**) The current limit is imposed by the increase in temperature of wire, which results in excess outgassing. The temperature change in wires under the nominal maximum operation is discussed in the next section.

(***): Per D2000283, the wire to provide power to the heater has been changed to CZ 2205 PFA, which is a 22AWG wire. This gives us a comfortable safety margin.

3. Electrical layout

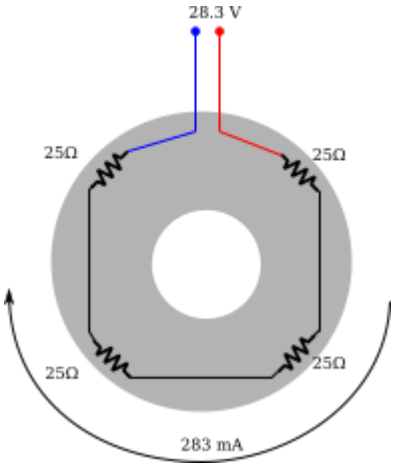


Figure 1 Layout of the resistors.

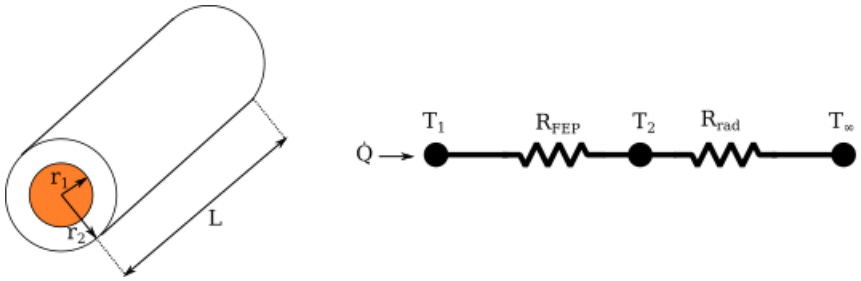
- Maximum current = 280 mA
- Power supply maximum voltage: 30 V
- Maximum power = 8 W
- Maximum radiative heat loss = 5.7W, assuming
    - maximum operating temperature = 65ºC
    - radiative cooling to 25ºC surroundings
    - emissivity = 0.75 (100-micron-thick flame-sprayed aluminum oxide)

Fig.1 shows conceptual wiring of the CFM heater under the nominal maximum operation configuration. To compute the temperature change in the current supply wire, considering the followings:

Maximum operating current $I = 0.283\ ADC$

Assumed wire length: 12 inches (1 ft)

Power dissipated due to wire resistance $\dot{Q} = I^2 \rho L = 5.2\ mW$, where ρ is the wire resistance per ft.



The wire outer temperature T_2 is given by:

$$T_2 = \dot{Q} R_{rad} + T_\infty = \dot{Q}\left(\frac{1}{h_r A}\right) + T_\infty = I^2 \rho L \left(\frac{1}{h_r 2\pi r_2 L}\right) + T_\infty \quad (1)$$

, where h_r is given by:

$$h_r = \epsilon\sigma(T_2^2 + T_\infty^2)(T_2 + T_\infty) \quad (2)$$

, where ϵ and σ are Teflon emissivity and Stefan-Boltzmann constant respectively. Rearranging Equation (1) to give an expression for T_2, assuming T_∞ = 298 K:

$$T_2 = \sqrt[4]{\frac{I^2 \rho}{\epsilon\sigma 2\pi r_2} + T_\infty^4} \quad (3)$$

Temperature of at the conductor T_1 is given by:

$$T_1 = \dot{Q}(R_{FEP} + R_{rad}) + T_\infty$$
$$= I^2\rho\left(\frac{\ln[r_2/r_1]}{2\pi k} + \frac{1}{h_r 2\pi r_2}\right) + T_\infty \quad (4)$$

Using T_2 computed from (3) and substitute into (2) to calculate h_r , then substitute h_r into (4) , assuming the thermal conductivity of Teflon is 0.25 $W/(m \cdot K)$. The temperature change calculated for 283 mA, 28.3 V operation is:

$$\Delta T_1 = 0.824\ K, \qquad \Delta T_1 = 0.821\ K$$

Running 283 mA with CZ 1105 in vacuum is therefore not a concern in term of outgassing.

4. Optical actuation

- Measured optical-power gain: $G_{opt} = 6.06$ mD/K
- Maximum actuation = 242 mD

5. Electrical power noise requirement

The maximum allowable AWC curvature/defocus noise, S_{defocus}, (T1800480), is plotted in Fig. 2. The OM2 requirement is the most stringent.

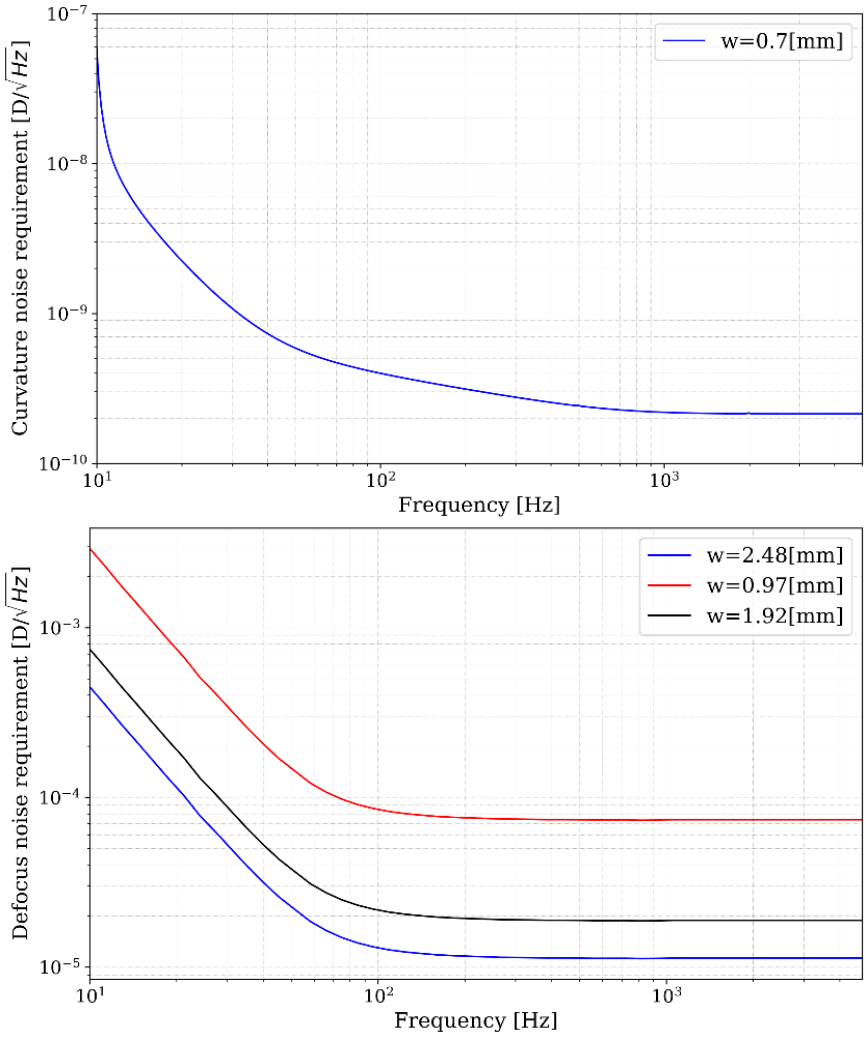


Figure 2. Defocus noise requirement for OM2 (top panel) and ZM2, ZM4, ZM5 (bottom panels)

The thermal response of the optical power to small changes in the electrical power can be described by a single-pole low-pass filter with (1/e) time constant τ :

$$H(s) = G_{th}\frac{1}{(1+\tau s)} \text{ K/W.}$$

The DC gain, G_{th}, and time constant were determined using a Comsol FEM, and are plotted as a function of the operating temperature in Fig. 3. As expected, the thermal time constant is shorter at higher operating temperature. The thermal gain G_{th} is also reduced at higher power due to greater radiative heat loss.

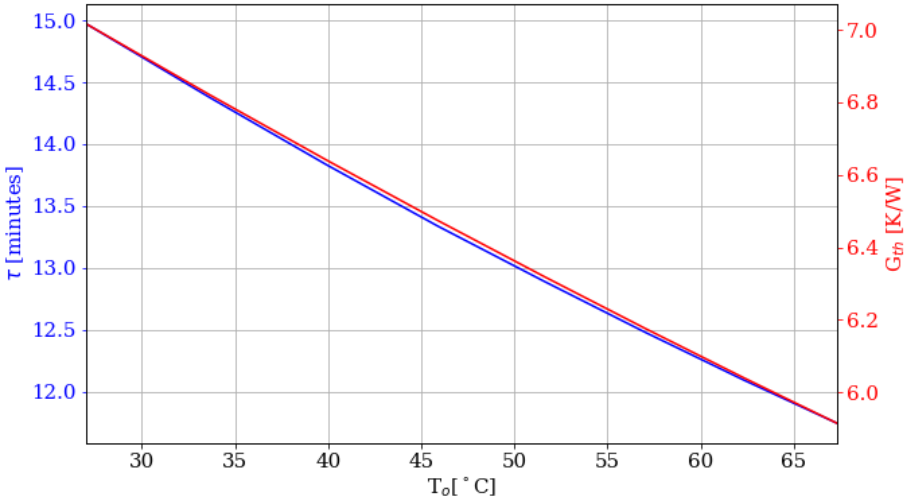


Figure 3 Dependence of thermal time constant (τ) and thermal gain (G_{th}) on operating temperature T_o.

The maximum allowable electrical-power noise is thus given by

$$S_{\text{power}}(\omega) = S_{\text{defocus}}(\omega)\,[1+(\omega\tau)^2]^{1/2}/G_{opt}G_{th}\,,$$

and is plotted in Fig. 4 for the two cases: 60°C (shorter τ, lower G_{th}) and 30°C (longer τ, higher G_{th}). The power noise limit is thus set by that at low temperature operation, with the most stringent requirement of $0.02\ \text{W}/\sqrt{\text{Hz}}$.

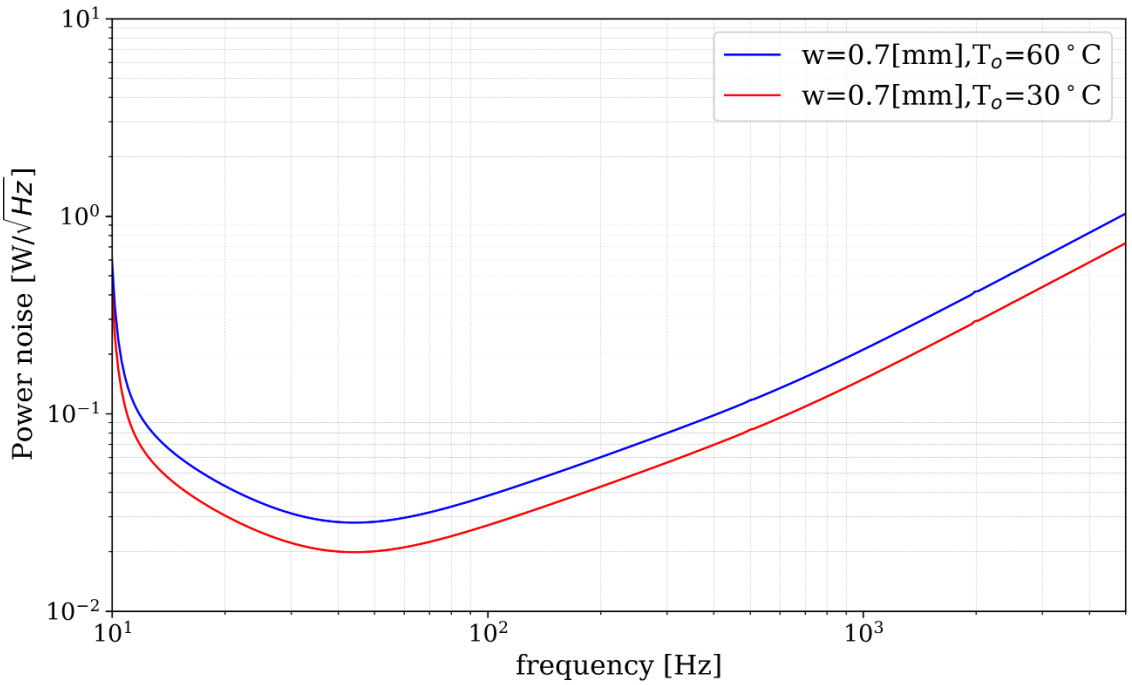


Figure 4 Power noise requirement for driver at 30°C and 60°C operating temperatures.