Experiments in Thermal Conductivity and Mean Free Path

Notes on the Required Equipment

Steve Hansen

These notes relate to the use of model engine glow plugs as sensors to conduct experiments related to molecular mean free path and thermal conductivity of gases in a vacuum. The approach was developed by Dr. Bruce Kendall of Pennsylvania State University [1]. With his permission, his material was adapted as an accessory for the VPAL-A, manufactured by The Science Source of Waldoboro, ME.

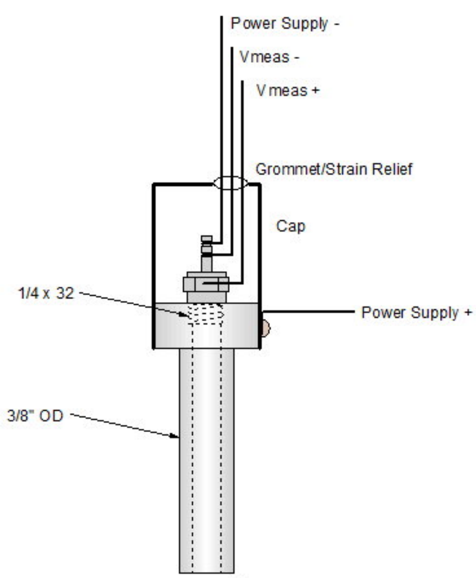
These notes were developed to assist the manufacturer in the design of the final product. Additional detail and updates are included. Refer to the related documents covering the theory and experimental procedures for more information.

Glow Plugs

Kendall recommended a 2 volt glow plug. 2 volt plugs are designed to be used with lead-acid batteries, as opposed to dry cell or Ni-Cd batteries as the elements have a higher resistance. This provides a greater sensitivity. The production version used a Fox 2 volt short plug. It appears that 2 volt plugs are now obsolete although they can be found on ebay. Some tests will be run with the OS #6 1.5 volt plug. However, I do have a limited number of Fox plugs. Write for more information. Glow plugs have a ¼-32 thread. Suitable taps can be found at hobby shops.

Glow Plug to Vacuum Chamber Interface

Three vacuum chamber adapters will be described in this section. In the first, the glow plug is mounted in a short length of 3/8-inch diameter aluminum. This implementation is designed for insertion in a #11 Ace-Thred bushing, as is standard on the VTS-1B and VPAL-A vacuum training systems. This is depicted in the figure below.



The starting material is rod stock, about 3 inches long. Using a small lathe, drill through the axis and tap one end deep enough for the glow plug's threads.

There are two power connections and two voltage sense connections. This arrangement is rrequired to eliminate any potential drop across the power carrying wires. Two of the connections are made to the center pin (there are two grooves in this pin, attach one wire to each). One wire (sense) is soldered to a flat on the plug's hexagonal body. The remaining wire (power) can be attached to the body of the plug or to the bushing on the rod. The bushing (a shaft collar) is required to prevent the possibility of the assembly from slipping through the Ace-Thred bushing when under vacuum.

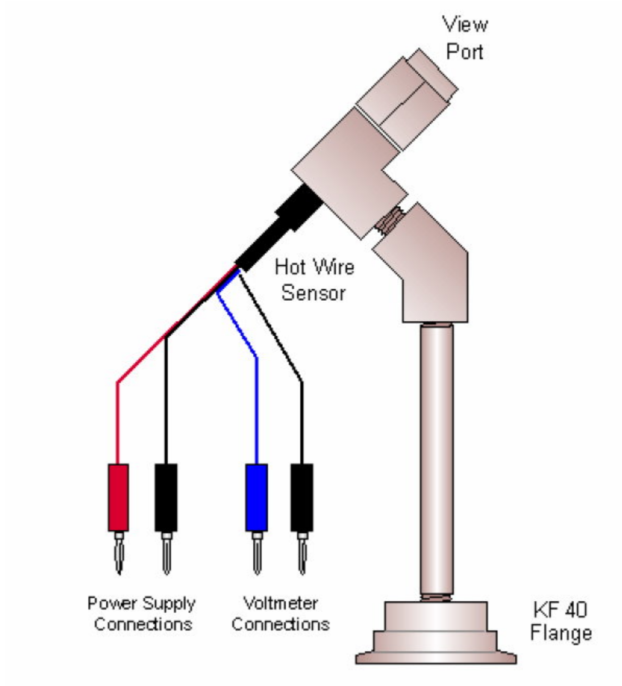
The plug may be sealed to the rod using epoxy cement. Remove the supplied copper gasket before installation.

Another approach is to simply drill and tap a KF blank flange.

Both of the above approaches are shown in the photograph below.

The above glow plug assemblies have the disadvantage of not rendering the filament visible. At low pressures, as the thermal conductivity of the residual gas reaches a minimum, the filament will glow. This is a useful visual aid.

The arrangement depicted on the next page makes it easy to see the filament.



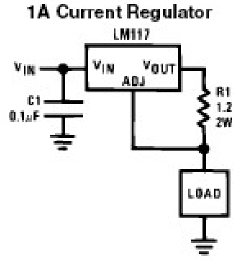
The fixutre is made from ¼-inch brass pipe fittings. The right angle fitting is a pipe thread to compression (tubing) adapter. The tubing end is fitted with a small lens or other clear plastic or glass disk. It may be affixed and sealed with an o-ring or with epoxy. The position of the glow plug permits the filament to be seen through the window. Other permutations are, of course, possible.

The Constant Current Power Supply

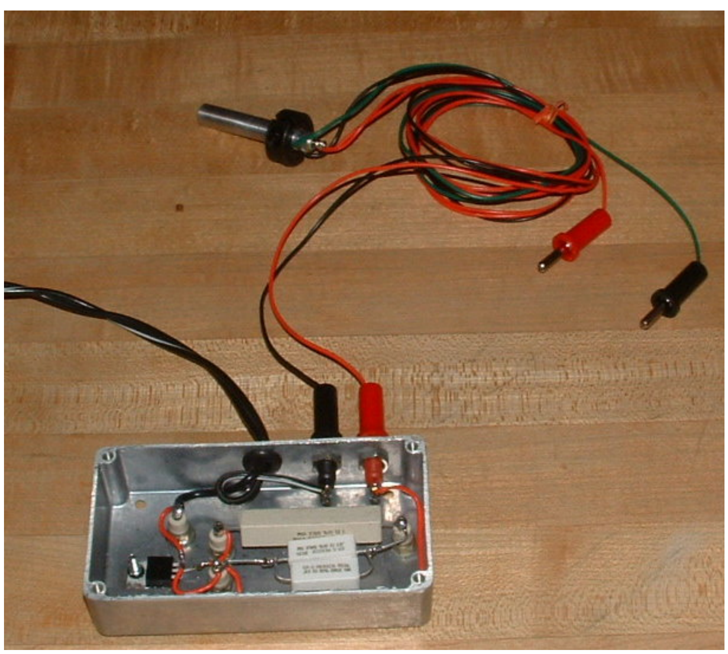
The power supply uses a LM317 variable voltage regulator as a constant current source. The voltage between the adjustment terminal and the output terminal is always 1.25 volts, so by connecting the adjustment terminal to the load and placing a resistor (R) between the load and the output terminal, a constant current of 1.25/R is established.

Thus we need a 1.2 ohm, 2 watt resistor for 1 amp of current. It is good but not necessary to use a high precision resistor but I'd recommend being within 5%. I used a 1 amp 12 volt (dc) wall wart to supply power to the circuit.

1A Current Regulator



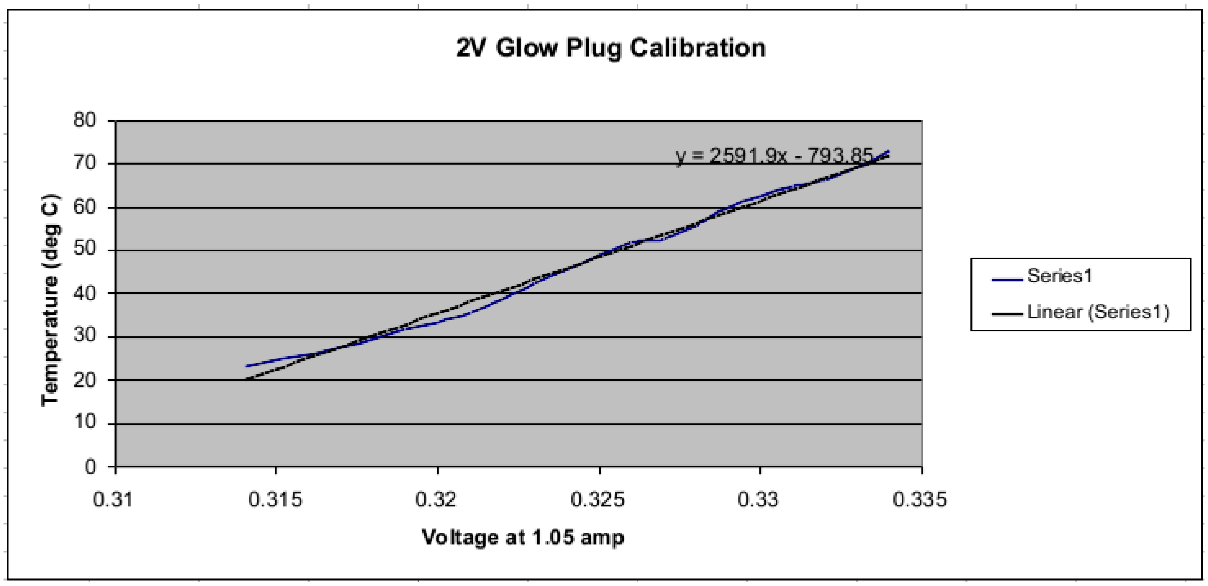
The prototype is shown in the picture below. Two leads (plug center pin and shank leak) are conected to the power supply via banana plugs/jacks. The other two leads (shown not connected) are either connected to a DVM or (better) to a Vernier voltage probe. I used resistors from a local supplier. Since they didn't have a 1.2 ohm resistor I used a 1 ohm in series with two 0.5 ohm in parallel. The resulting current was 1.001 ampere. Power is supplied by a 12 volt wall wart.



The Glow Plug as a RTD

The plug can serve as a resistive temperature device (RTD). In order to obtain quantitative measurements, the glow plug must be calibrated.

I used a water bath with a Vernier temperature sensor. Using Vernier Logger *Pro* I plotted temperature versus voltage as the bath cooled. Logger *Pro* then provided the equation for the curve. This is shown in the plot below.



Reference

1. Bruce R.F. Kendall in "Educational Outreach at the 42nd National Symposium of the American Vacuum Society," AVS Monograph Series M-16, 1996.