# CALIBRATION OF HEAT FLUX GAUGES AND THE OSU APPARATUS

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ABSTRACT

The methods used to calibrate heat flux transducers and OSU heat flux will be explored. Evaluation of where we are now and proposals for future improvements will be made. Techniques for getting a consistent and accurate calibration will be revealed.

## HEAT FLUX GAUGE CALIBRATION

### NIST Procedure

Currently, NIST uses a VTBB (Variable Temperature Black Body) graphite tube furnace with graphite extensions as shown in figure 1.

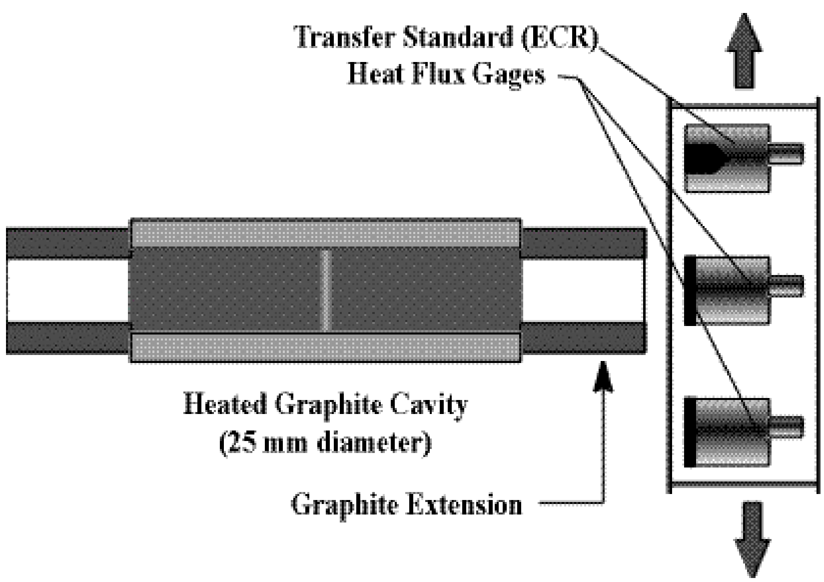


FIGURE 1. TRANSFER CALIBRATION USING THE VTBB[1]

The ECR (Electrically Calibrated Radiometer) is also known as a cavity radiometer. It has an open black cavity that absorbs thermal radiation. An inner black cone transfers its absorbed heat to the water cooled outer body through an insulative layer. The resulting temperature difference equilibrium is measured and the heat flux calculated. It is electrically calibrated by an internal electrically heated coil contacting the cone. A known wattage is applied to the cone that corresponds with an equivalent heat flux. The temperature difference is plotted for various watt inputs.

Even though the ECR is self calibrating, it is characterized against a QED (Quantum Efficiency Detector) using a laser as the irradiance source as shown in figure 2. This provides a more accurate and traceable calibration. The QED primary is a well characterized silicone detector. A portion of the beam is split off, attenuated by a filter and detected in an integrating spherical silicone detector. This can measure and compensate for energy differences when irradiating the QED primary standard and alternately the ECR transfer standard.

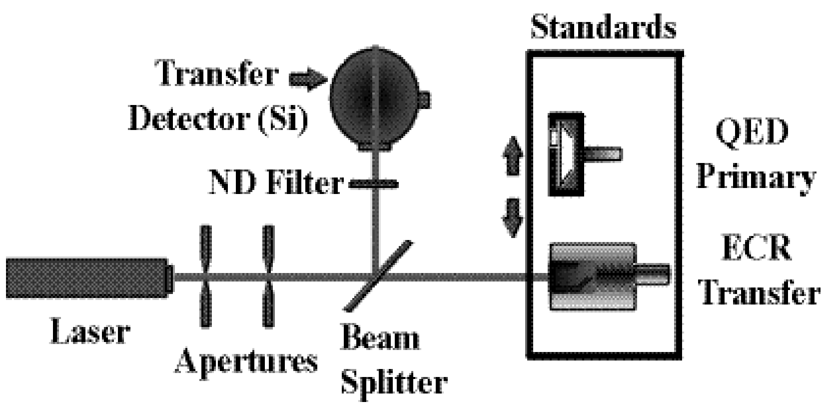


FIGURE 2. TRANSFER STANDARD CALIBRATION[1]

NIST also has a new absolute technique developed in Sweden. They plan to implement it once they have procedures developed. It is a spherical furnace shown in figure 3 with a water-cooled aperture and sensor housing assembly to minimize convection heat loss form the sensor surface.

Draft FAA Requirement

The FAA has proposed a specification for radiometer construction and calibration. The FAA spec. radiometer is a one inch diameter Gardon gauge with a calibration range of 0 -5 Watts/cm$^2$. It has a .25 inch diameter center foil and is coated with high emmisivity “Black Velvet” paint.

The radiometer is calibrated against a NIST calibrated radiometer of the same construction. They are placed equidistant on opposite sides of an electrically heated graphite plate at 1/16 in. to 3/8 in. and compared.

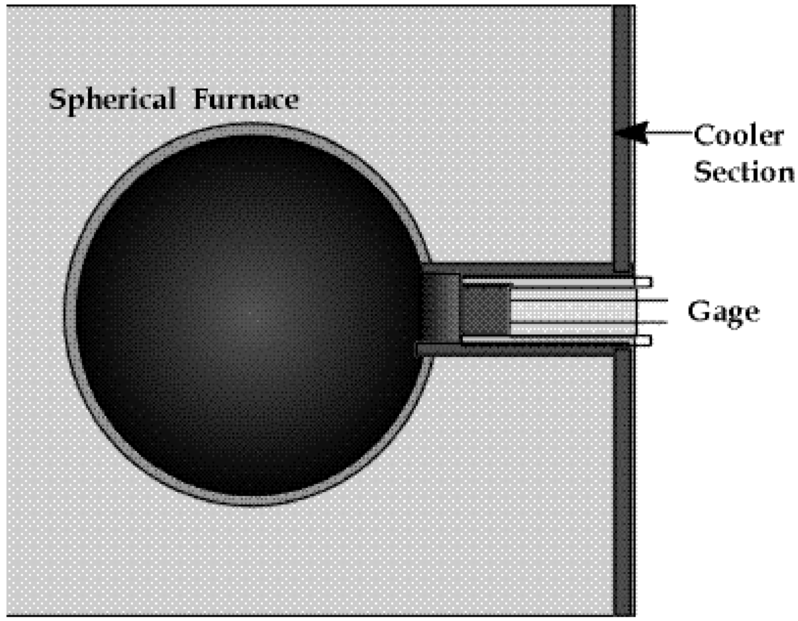


FIGURE 3. ABSOLUTE CALIBRATION USING A BLACK BODY CAVITY[1]

This draft requirement is intended to standardize heat flux measurements. Up until that time, the three manufacturers of Gardon gauges used three different procedures and all had different interpretation of such things as incident vs. absorbed radiation.

## RESULTS AND DISCUSSION OF THE DRAFT REQUIREMENT

The first set of FAA specification radiometers our lab purchased in July 1997 both had the same calibration of 5.03 mv at 3.5 w/cm$^2$. Our lab purchased another set in June of 1998. This time the calibrations were 6.49 and 6.31 mv at 3.5 w/cm$^2$. This latest calibration caused us to raise the heat flux in our OSU.

From our latest round robin comparison of OSU's, we plotted the spread in 2 minute totals in figure 4. The labs reporting that they used the FAA spec radiometers are shown as solid black bars.

One might now be tempted to conclude that the FAA spec. radiometers produce just as much variation as we had before. However, 2 OSU's in this study were calibrated using the same radiometer and they had significant variation (see figure 5). The radiometer cannot be blamed in this case.

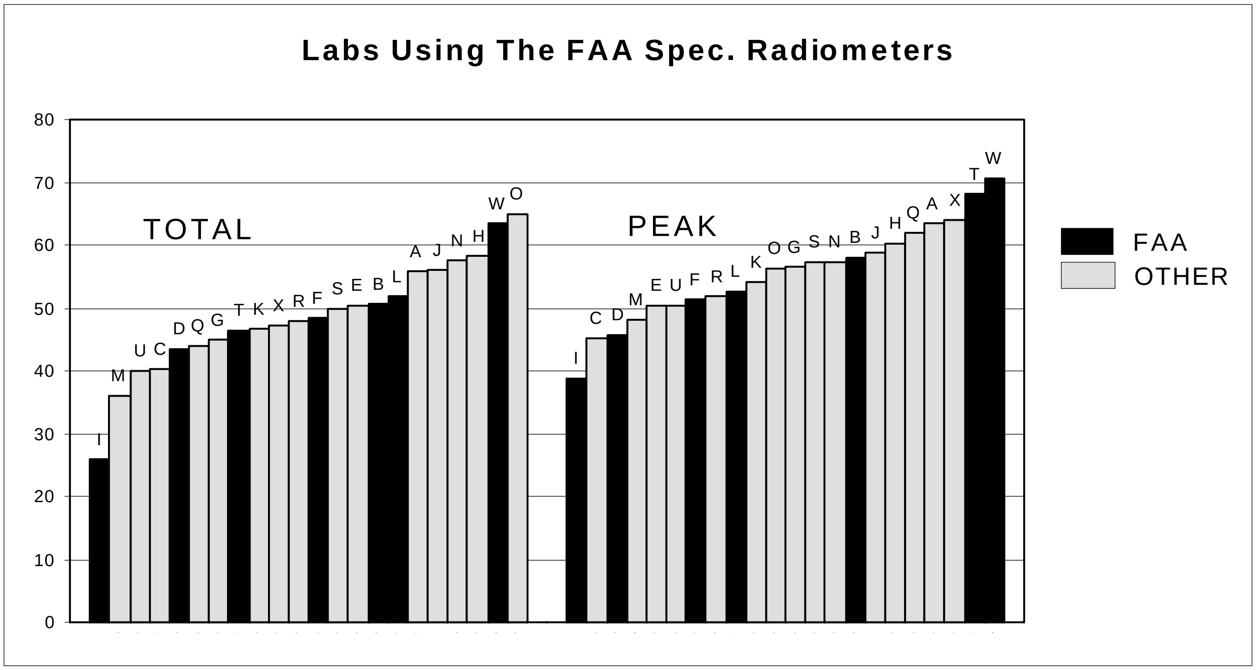


FIGURE 4. RADIOMETER COMPARISON

Interpreting the Manufacturers Calibration Report

There is a possibility some labs could have misinterpreted the calibration report they received from the manufacturer. For instance, the report I received was marked as absorbed heat flux with units of BTU/ft$^2$S vs. mV and a sensor emissivity of 0.98. Of course what we really want is incident heat flux in units of W/cm$^2$ and emissivity doesn't enter the calculation. I know of one lab that initially had very high values in a round robin because of confusion over BTU's and Watts. If the FAA calibration procedure is followed, the result is incident flux unless the result is adjusted for emissivity of the coating. I didn't suspect the manufacturer did that so I verified with them that the report was indeed incident heat flux and that it had simply been mismarked.

Also, if the report you receive is in BTU/ft$^2$S vs. mV, make sure the conversion to W/cm$^2$ is correct. For example, if the calibration report is 0.473 BTU/ft$^2$/sec per millivolt, the target mV output at 3.5 W/cm$^2$ is calculated as follows:

$$(1) \qquad \frac{\mathbf{3.5}\ \text{W/cm}^2}{(\mathbf{0.473}\ \text{BTU/ft}^2\text{S/mV})\ (\mathbf{1.141}\ (\text{W/cm}^2)/(\text{BTU/ft}^2\text{S}))} = \mathbf{6.485}\ \text{mV @ } 3.5\ \text{W/cm}^2$$

I have been assured that all future reports would be clarified to avoid confusion.

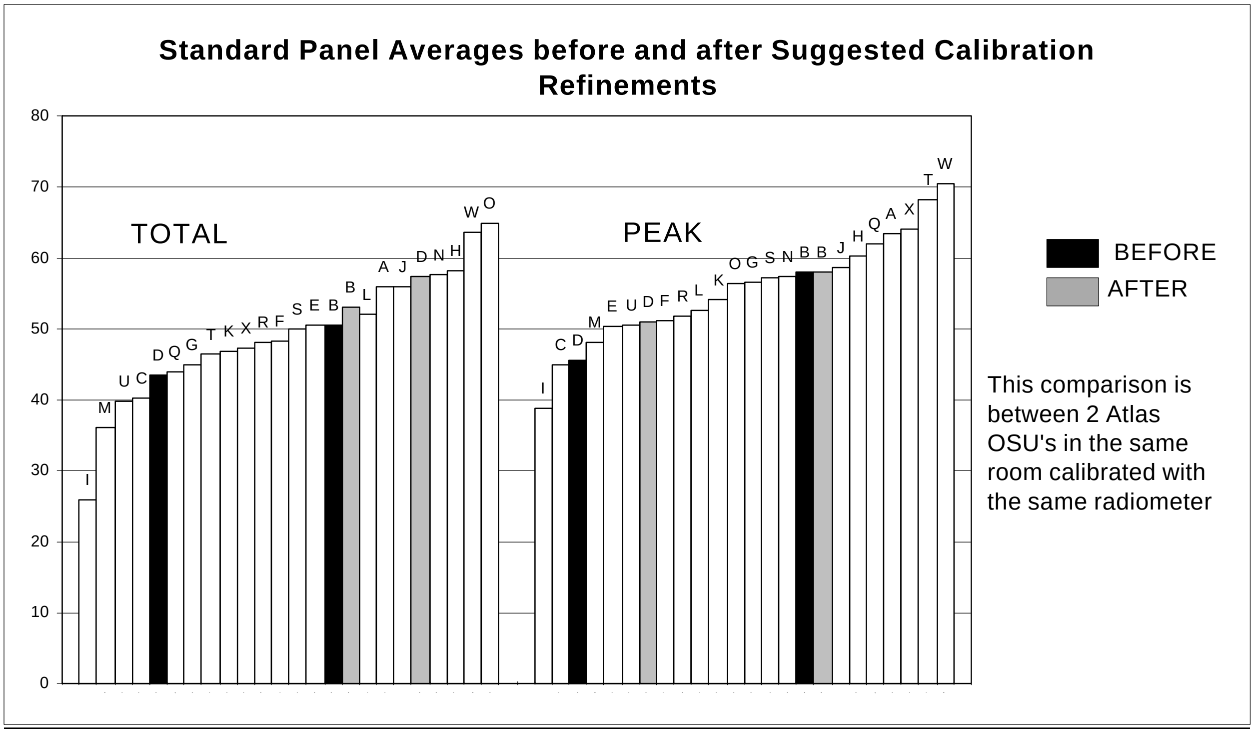


FIGURE 5. CALIBRATION REFINEMENTS

IMPROVING THE ACCURACY OF THE OSU CALIBRATION

Setting Heat Flux

Our lab has focused on refinements to the calibration procedure. The current rule has you set the center to 3.5 w/cm$^2$ and then verify that the corners are within 5% of the center. That leaves some room for variation, especially since the corners represent a larger portion of the face area than the center does. A set of three different standard panels were tested with the corner average adjusted to -3%, 0%, and +3% of the center. The results are shown in figure 6. The 2 minute total can vary by more than 10%.

Our lab has made a procedure change to tighten up on this variation. Instead of starting out with the center, we average the four corners and adjust our heat to get 3.5 w/cm$^2$ at the corners. Then we adjust the mask position to bring the center to 3.5 w/cm$^2$. We have mounted our mask on a rod that we can adjust from outside the chamber. The mask position affects the center reading with almost no effect on the corners. A very good way to take your readings is with a chart recorder. For each reading, insert the gage holder for 15 to 20 seconds and pencil in an average line for the last 5 seconds.

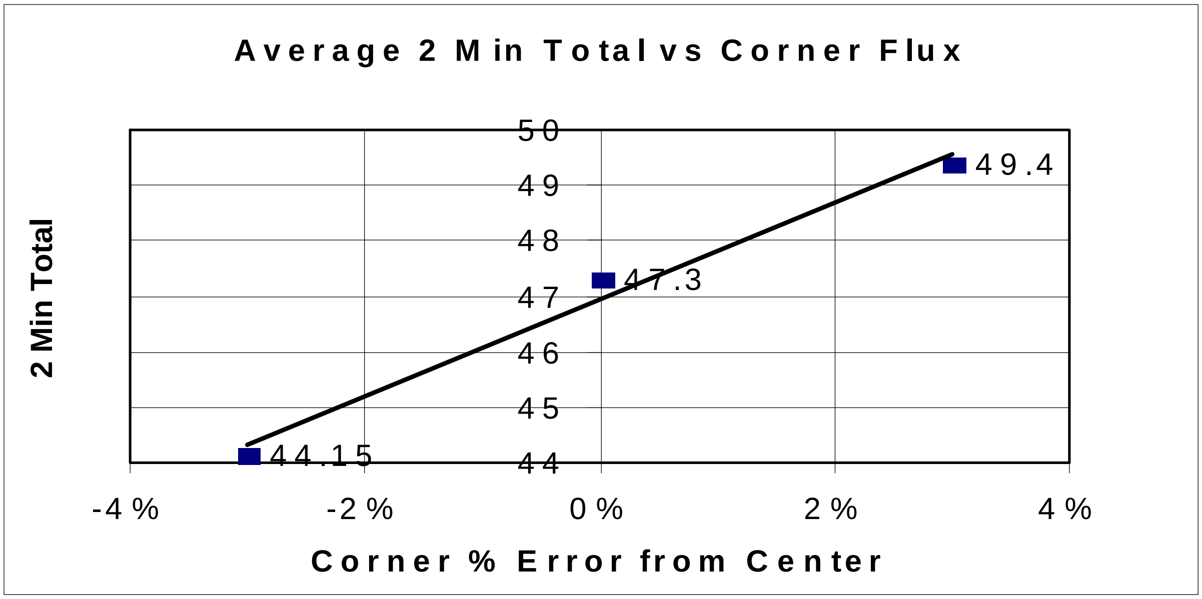


FIGURE 6. EFFECT OF CORNER HEAT FLUX

Another source of error is random variation, for heat flux and the calibration factor. There is some random variation in every measurement. You can actually introduce variation into a process by adjusting it to often. It can be better to use a running average of measurements. This will produce smaller incremental adjustments to the process.

Instead of trying to tweak the machine in at 3.5 w/cm$^2$, I recommend initially making a 5 point calibration curve of heat flux vs. dial setting (see figure 7).

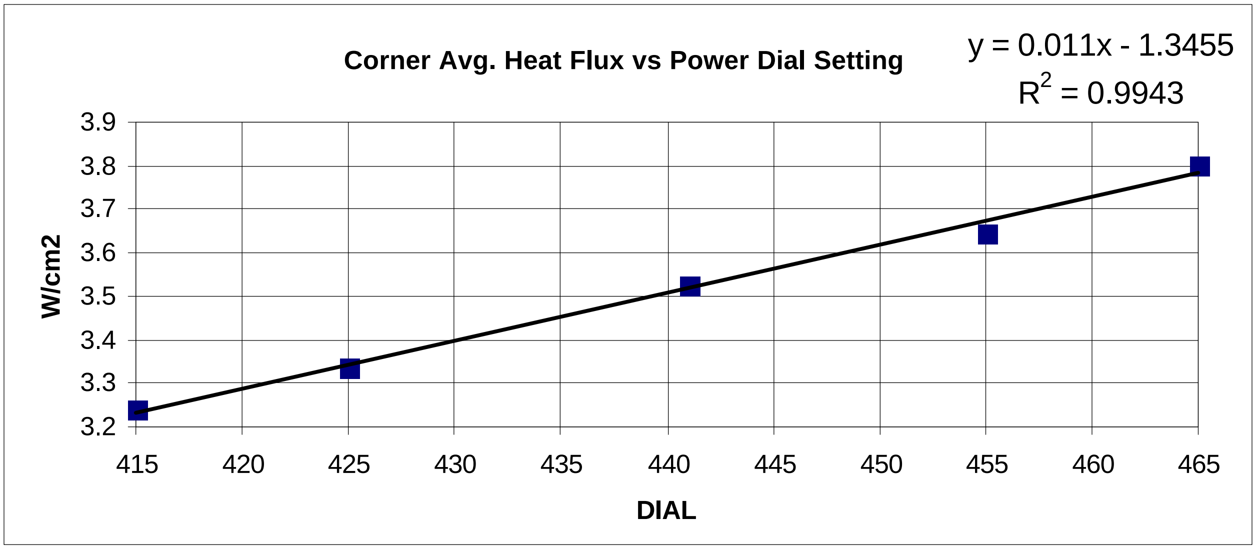


FIGURE 7. 5 POINT HEAT FLUX CALIBRATION CURVE

Each time the heat is checked after that, just set it at one of the points and replace that point on the curve. Then you use the curve to pick the right dial setting. This way you are using a 5 point running average and you don't have to converge on the right setting. Try to target your curve to +/- 10% (i.e. about 3.15, 3.33, 3.50, 3.67, and 3.85 w/cm$^2$)

Setting the Calibration Factor Kh

Another source of variation is error in the calibration factor Kh. Figure 8 is a plot of peak vs. Kh taken from the round robin at the end of 1997. The plot shows a trend of increasing peak values with increasing Kh values. If Kh were only compensating for differences in each machine, there would be no trend in the data.

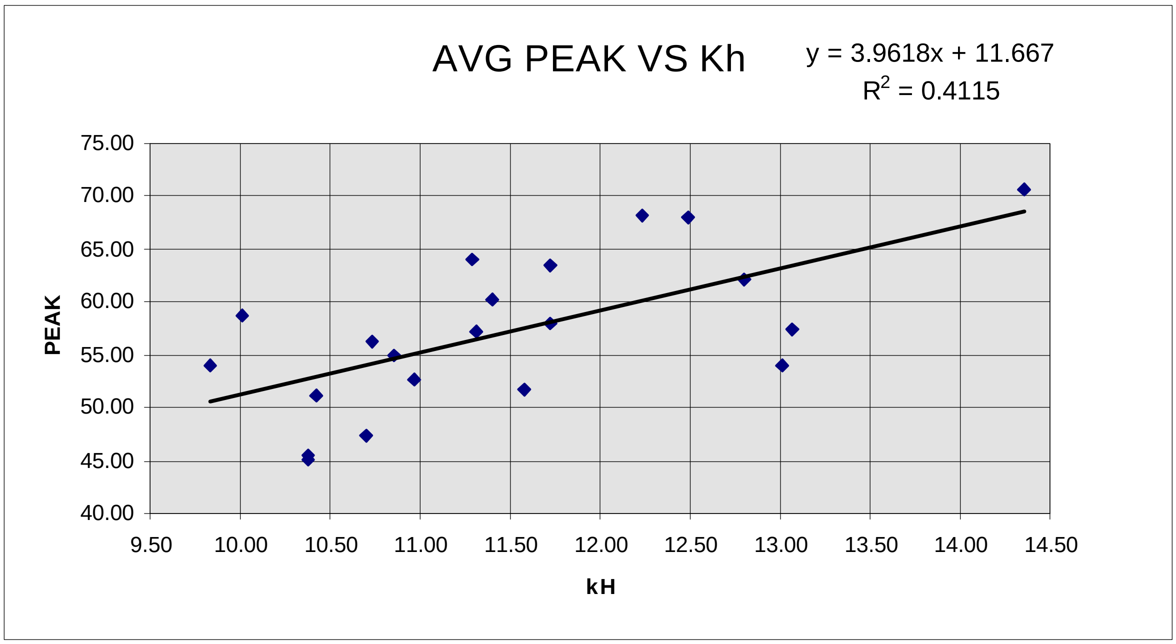


FIGURE 8. CORRELATION OF PEAK VALUES AND Kh

Some of the error may be reduced by using a running average of Kh factors. I suggest a running average of 5. That will reduce random fluctuation error.

Results of These Refinements to the Calibration Procedures

After making these refinements, 3 more sets of standard panels were run on both OSU's. Observe the gray bars in figure 5 representing the results after method refinement. They are closer than the black bars representing the same OSU's before refinement.

OTHER POINTS TO PONDER TO ENSURE GOOD RESULTS

There is some systematic error in calibration factors from one lab to the next. It is hard to determine possible causes without knowing details of how each lab calibrates the methane Kh factor. I plan to have more dialog between labs about that in the future.

At this point I can only make some suggestions. Review the handbook and make sure you are following it. The wet test meter must be the last thing in the gas line before the burner. Minimize any flow restrictions from the wet test meter to the burner. I was concerned that the quick connects from my CSI (Atlas) gas cabinet to my burner would cause back pressure. I replaced them with clamped Tygon tubing.

Make sure you keep the thermopile brushed. I have found this to be significant.

Some thermopiles have been supplied with spot welds rather than the bead of 0.050” +/- 0.010”. Figure 9 is a graph from a panel with a sharp peak

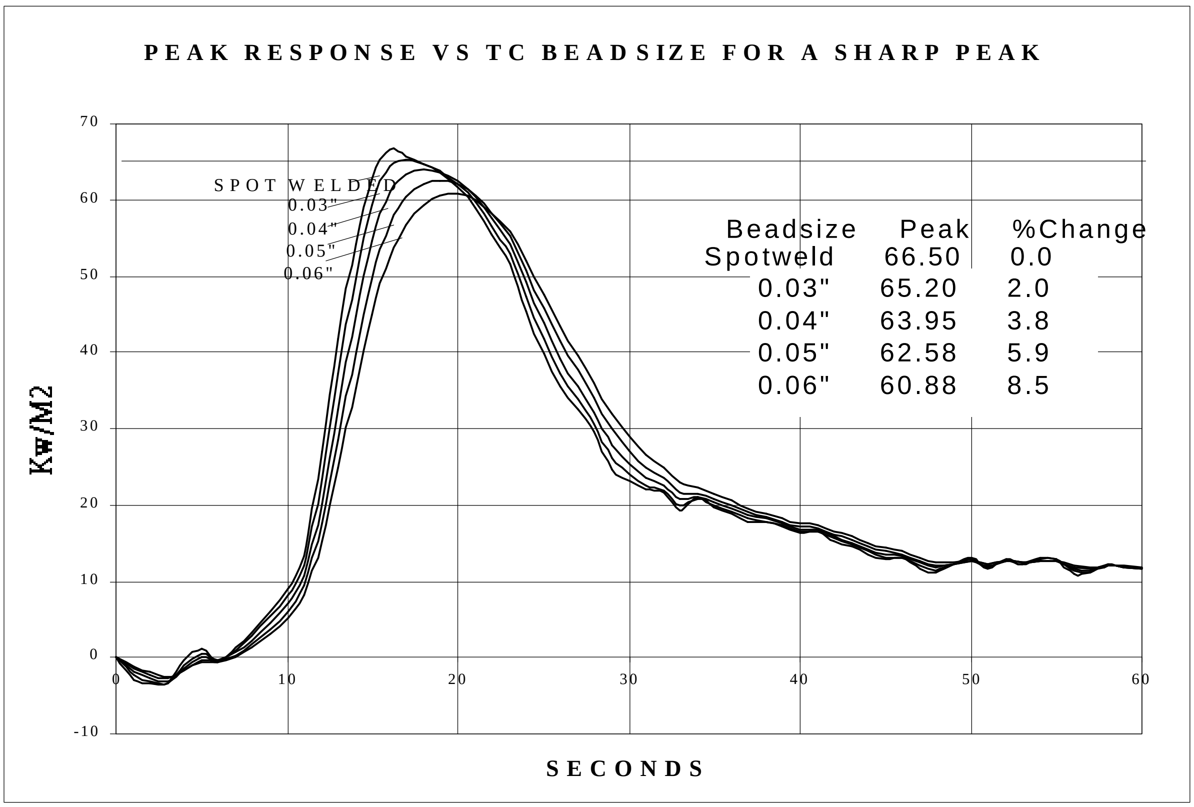


Figure 9

The spot weld curve is an actual data curve. The others are theoretical adjustments depending on bead size. In this case, the panel would fail with the spot welded thermopile but pass with a proper thermopile.

We use compressed air to supply air flow to the OSU. The flow was always fluctuating. We had to watch it every run. We added an automatic control to the valve as shown in figure 10 with the cover off. There are sensing wires sealed in the mercury manometer connected to a transistor circuit. The transistors control a +/- 12 volt reversible gear motor. The valve turns at 0.5 RPM. If anyone wants more details, please contact me.

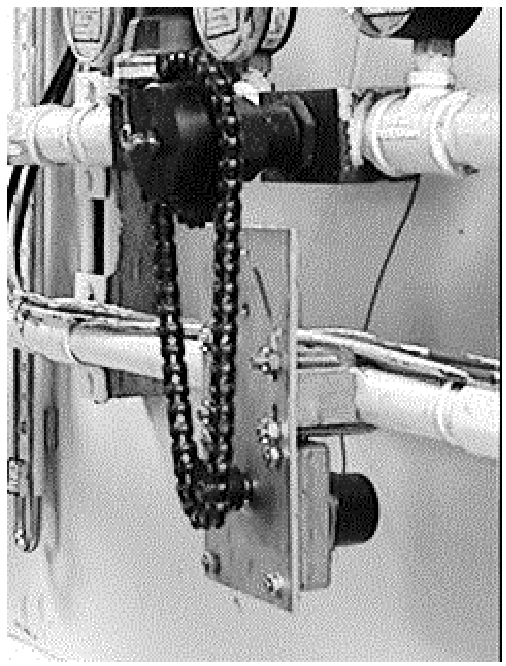

FIGURE 10. AUTOMATIC AIR CONTROL VALVE

ACKNOWLEDGMENTS

[1] The NIST calibration graphics were courtesy of the NIST High Heat Flux web page, http://physics.nist.gov/Divisions/Div844/facilities/hhf/hhf.html
Benjamin K. Tsai, a NIST engineer who is listed on the above web page was very helpful in clarifying the details of the NIST procedures to me.