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TESTS OF A COMMERCIAL VERSION OF THE LLL MODEL LC-13 LASER BEAM CALORIMETER

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April 1, 1977

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Prepared for U.S. Energy Research & Development Administration under contract No. W-7405-Eng-48.

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TESTS OF A COMMERCIAL VERSION OF THE LLL MODEL
LC-13 LASER BEAM CALORIMETER

Abstract

Two specimens of a commercial version of the LLL model LC-13 laser calorimeter have been tested. A comparison of peak-reading and corrected-temperature-rise methods of treating the calorimeter response has also been performed.

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Introduction

A line of laser beam calorimeters patterned upon the LLL model LC-13¹ is being manufactured commercially.² Two of these, with apertures of 25- and 100-mm diameter, have been inspected and tested. These will be designated C-25 and C-100; a third model, of 50-mm aperture, is also manufactured. An operating procedure utilizing the value of the peak output following a laser pulse, recommended by the manufacturer, has been compared with a conventional calculation of the corrected temperature rise.

Visual Inspection and Comments

Comments apply to both calorimeters except as noted.

1. The absorbing glass on both is apparently Schott BG-18, which is suitable only near 1.06 μm . The manufacturer's literature specifies an operating range of 0.3 to 1.2 μm , which implies use of NG-1 glass,^{3,4} although it is questionable if NG-1 is satisfactory below 0.45 μm .
2. The jackets are smaller and less massive than those of LC-13; outer diameters for the C-25 and C-100 are respectively 2.5 and 5.5 inches, and lengths are 5.0 and 11.0 inches. This is more convenient for mounting, but means that the output will respond more sensitively to changes in room temperature. Use of an entry tube will reduce the effect of air currents and variations in background radiation, as for the LC-13.⁵
3. The thermoelectric modules are apparently from Borg-Warner: one model 930-1/ for C-25 and four model 930-35 for C-100. They are apparently attached with a thermal-conducting, electrical-insulating epoxy, as suggested elsewhere.¹ An excessive amount of this epoxy is smeared about the module, which will contribute to undesirable thermal lags and a high thermal leakage modulus.
4. The thermoelectric modules are mounted with the leads adjacent to the copper receiver and dummy discs; it is preferable that they be adjacent to the center plate, whose temperature is nearly constant and therefore gives smaller thermoelectric volatages at the lead junctions.

5. The heater resistances are 9.67 and 11.50 ohms for the C-25 and C-100, respectively. These undesirably low values mean that the error contributed by heat generated in the leads is relatively large and that a relatively high-current, low-voltage power supply is required for calibration. The current leads are not cemented into contact with the copper disc for a distance but are simply attached to the edge of the disc with a large lump of cement where they are soldered to the heater resistance wire.
6. The heater current leads have undesirable heavy plastic insulation, which contributes a thermal lag.
7. The heater current leads pass loosely through a hole in the center plate, and the potential leads are attached near the rear of the calorimeter. The current leads should be thermally anchored to the center plate with the potential leads attached midway between the center plate and receiver disc. The resistance of the heater leads would have to be measured to estimate the probable error due to heat generated in these leads between the potential leads and the heater discs.

Operating Procedures

Two methods of treating the time-temperature data from the calorimeters were employed. The first was a conventional calculation⁶ of the corrected temperature rise involving the usual assumptions for an isoperibol calorimeter; the second was a peak-reading procedure recommended by Apollo.

1. CTR Method. The calorimeter output was amplified by a Keithley model 140⁷ amplifier set at 0.5-second rise time and measured by an integrating-type digital voltmeter set at a 1-second integration period and taking readings at 3-second intervals. The data were treated by the integration method;⁶ the foreperiod duration was 27 seconds; the main period was varied between 9 and 33 seconds and the final period was correspondingly varied between 66 and 42 seconds.
2. PK Method. The manufacturer recommends a procedure in which the peak value reached by the calorimeter output voltage following an input of electrical-heating or laser energy is used as the measure of that energy. They manufacture a readout unit which has a peak-holding capability. One of these was available for the C-100 only and was used for some electrical-heating calibrations. For the rest of the work by the

PK method the calorimeter output was amplified by the same Keithley-140 used for the CTR method, still set at 0.5 second rise time, and measured by the same integrating DVM, now set at 0.1-second integration period and the maximum repetition rate, which gave 2.9 readings per second; this is about the reading rate of the manufacturer's readout unit.

The manufacturer recommends heating the dummy receiver disc electrically to approximately null the output voltage before a measurement; their readout unit incorporates a circuit for doing this automatically. In the present work, except when the readout unit was used, it was done manually. In the following sections, t_p represents the time following the start of the rise at which the peak voltage, V_p , is reached. The voltage-time points were recorded for some time after heating the dummy (if needed); the voltage-time line in the interval $t = -t_p$ to $t=0$ was then extrapolated forward to obtain V_x at t_p , and ΔV , the corrected peak voltage, was taken as $V_p - V_x$. The curvature of the voltage-time line in the interval $t = -t_p$ to $t=0$ was in all cases negligible.

This procedure of nulling the output by heating the dummy is probably more useful for the PK method than for the CTR method. In the PK method, only a short forward extrapolation of the foredrift curve to the time of the peak is used. In the CTR method, the voltage-time curves for longer periods are used and, since the thermal characteristics of the receiver and dummy sides will not be identical, the curves will be perturbed from the ideal exponential shape.

Electrical Heating Calibrations

These calibrations were performed by passing current from a regulated power supply through the heater and a 10-ohm standard resistor in series with it, for an accurately measured two-second period. Two power supplies were used; the more stable, A, had a maximum current capability of only 0.200 amp. The second, B, had a capability of 1.5 amp. Using B, calibrations were performed with intervals of 0.2 seconds as well as 2 sec; results were consistent, thus showing that there was no significant error due to on-off transients. Both power supplies were also used in more precise calibrations of RC (see below) and gave consistent results.

Results are given in Table 1; each series consisted of 3 or 4 duplicate measurements. The sensitivity S is obtained from

$$S = .948 \Delta V/Q$$

where Q is the electrical energy, ΔV is voltage rise of the thermopile, and the factor .948 converts from electrical to radiation sensitivity, since 5.2% of incident 1.06- μm radiation energy is reflected or re-radiated.³

Three series were also performed using C-100 with the readout unit. This unit is supposed to be calibrated to match the particular C-100 used and to incorporate the 5.2% reflection-loss factor so that one joule of electrical energy input will give a reading of 1.0549, which is the number of joules of incident 1.06- μm radiation giving the same heating of the disc. The slow drift of the digital meter was recorded from 30 to 10 seconds before the electrical heating, extrapolated forward to the time of the peak reading (10 to 11 seconds after the start of the heating), and subtracted from the peak reading to find the value given in Table 2 as "reading."

The sensitivities indicated by the manufacturer on the calorimeter labels are 863 and 444 $\mu\text{V}/\text{J}$ for the C-25 and C-100, respectively. Presumably these were established by electrical heating and the PK method. Comparing these values with the results of series 2 and 5, it is tempting to think that they may have applied the reflected radiation correction backwards, dividing rather than multiplying $\Delta V/Q$ by .948.

Laser-Beam Calibrations

The setup shown in fig. 1 was used. The laser was adjusted to give a power of about 4 watts at the shutter. The ratio of energy in the first two transmitted beams to that in the first two reflected beams is about 4:1. The reference calorimeter, RC (model LC-13-2.0¹), and experimental calorimeter, EC, are interchanged in the through beam; the monitor calorimeter, MC (model LC-13-1.5¹), remains fixed in the other beam. RC and MC are operated only in the CTR mode. The sensitivity, S_{rc} , of RC is first determined by electrical heating, as described above. MC need not be calibrated.

All irradiations (shutter openings) were performed for a period of 2.0 seconds. Each series consisted of three separate measurements. RC was used first, and the ratio, R_{rc} , of the voltage rises of RC and MC, ΔV_{rc} and ΔV_{mc} , is measured:

$$R_{rc} = \Delta V_{rc} / \Delta V_{mc}$$

We may now define

$$F = R_{rc} / S_{rc},$$

Where S_{rc} is the sensitivity of RC, which represents the number of joules in the transmitted beams for a one-microvolt rise in MC. Then EC is put in place of RC and R_{ec} and

$$R_{ec} = \Delta V_{ec} / \Delta V_{mc},$$

is measured. The sensitivity of EC is then obtained from

$$S_{ec} = R_{ec} / F.$$

The beam diameter is quite small. Use of a stop (disc) of 13-mm diameter in front of RC reduced R_{rc} to about 0.2% of its value without the stop; most of the energy is in a spot of probably 2 or 3-mm diameter. The system could thus be used to map the response of C-100 to the same amount of energy received at different locations on the disc. The thermoelectric modules used in C-100 are rectangular, about 14×27 mm, centered about 25 mm from the center of the copper disc as shown in fig. 2. Irradiations of C-100 were performed with the beam at six positions, as shown in fig. 2: centered over three of the modules; centered at two places midway between these modules and 13-mm from the edge of the disc; and at the center of the disc. With C-25, irradiation was performed at the center only. Results are given in Table 3.

Discussion

Comparing values of S in tables 1 and 3, it may be seen that for C-100 with the CTR method the laser-beam values at all six spots agree with the

electrical-heating value within 2%, but with the PK method discrepancies range up to 30%. The reasons for this are illustrated qualitatively in figure 3. When the irradiation spot is directly over a module, that region of the copper plate becomes briefly very much hotter than if the whole copper disc had been heated uniformly; the result is an "overshoot" of the output voltage which then rapidly decreases for a time. But when the spot is near the edge and between the modules, it is some time before the copper plate adjacent to the modules is warmed. After 20 or 30 seconds, however, the heat is nearly uniformly distributed throughout the disc and the curves are nearly coincident; it is this part of the curve that largely establishes the CTR value.

These small-spot irradiation calibrations are of course worst cases. Better results are obtained if the beam is distributed uniformly over the whole disc; this is pointed out in the manufacturer's manual. However, it is never possible to achieve completely uniform distribution. And even if it were, there would still be a systematic error.

This error is due to the fact that in electrical-heating calibrations, the heat is applied to the rim of the copper disc but in laser radiation measurements it is applied to the front of the absorbing glass. The thermal conductivity of the glass is low, and it is the temperature of the copper which is measured by the thermoelectric modules. Thus for electrical heatings the curve is much like the upper in fig. 3: a peak followed by rapid cooling as the temperature of the glass equilibrates with that of the copper. But for radiation measurements, the heat gradually flows from the front of the glass through the glass and into the copper, giving a curve similar to the lower in fig. 3. This may be seen by comparison of series 2 and 10. For a disk of small diameter, the lateral distribution of heat in the copper is rapid compared with transfer through the glass; t_p is 3 seconds for electrical heating but 8 seconds for irradiation, and there is a 4% discrepancy in the peak-height sensitivities.

Detailed tests of the variation of the response of a five-inch LC-13, with three thermoelectric modules, have been reported elsewhere.¹ Discrepancies for irradiations with a small spot at various positions were less than 1%, by the CTR method; the PK method was not investigated.

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Table 1. Electrical-Heating Calibrations

<u>Series</u>	<u>Calorimeter</u>	<u>Power Supply</u>	<u>Mode</u>	<u>t_p (sec)</u>	<u>Q Joules</u>	<u>S (μV/J)</u>
1	C-25	B	CTR	--	6.629	794
2	C-25	B	PK	3	6.629	793
3	C-100	A	CTR	--	0.782	422
4	C-100	B	CTR	--	7.289	423
5	C-100	B	PK	10	7.289	407

Table 2. Electrical Heating, C-100 with Readout Unit

<u>Series</u>	<u>Range</u> (joules)	<u>1.0549 0</u> (joules)	<u>Reading</u> (joules)	<u>Error</u>
6	2.000	1.678	1.602	- 4.6%
7	20.00	18.312	17.73	- 3.2%
8	200.0	54.64	52.7	- 3.5%

Table 3. Laser-Beam Calibrations

<u>Series</u>	<u>Calorimeter</u>	<u>Spot</u>	<u>Mode</u>	<u>t_p</u> <u>(sec)</u>	<u>S</u> <u>(μV/J)</u>
9	C-25	6	CTR	---	796
10	"	6	PK	8	759
11	C-100	1	CTR	---	432
12	"	1	PK	4	528
13	"	2	CTR	---	427
14	"	2	PK	4	496
15	"	3	CTR	---	430
16	"	3	PK	4	496
17	"	4	CTR	---	427
18	"	4	PK	12	410
19	"	5	CTR	---	423
20	"	5	PK	17	395
21	"	6	CTR	---	430
22	"	6	PK	6	480

Fig. 1

D

Fig. 2

Fig. 3

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