REFERENCE

AUTOMATIC NEUTRONICS CALIBRATION

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AUTOMATIC NEUTRONICS CALIBRATION

Summary

A need exists for a more precise measurement of reactor power level than that which is now possible using neutron detectors. This need becomes particularly evident when one considers that the trip settings of power level cutbacks and scrams must be adjusted to be greater than the maximum normal power by at least the expected measurement error in order to avoid false scrams. This report describes some present practices in regard to power calibration techniques and goes on to propose an automatic calibrator based on thermal power.

Nuclear Instrumentation Calibration

Present NI calibration consists of running the reactor up to a power level around 0.1% of full power (KIWI-B series) and noting the instrument readings. After the run, Oralloys wires are removed from the core and given a radio-chemical analysis. In addition to the Oralloys wires, a "rabbit", containing sample pellets, is run to a point near the reactor during the time that the calibration power is maintained. Subsequent analysis, either by the count method at the Site or by radio-chemical analysis at Los Alamos, is used to compute the neutron flux level.

From this analysis, and with the data from the run profile and the power distribution curves obtained during the Kiva test, the power level can be computed. An instrument calibration factor can now be applied based on the computed versus the indicated power level.

Power level is also computed after a full power run by the use of an IBM program which accepts a variety of test result inputs. This is an after-the-fact calculation and does not help in the instrumentation calibration.

Typically, on the KIWI-A3 test the following power levels were obtained:

Nuclear Instruments*	81.9% of F. P.
Post-Mortem Gamma Survey and Radio-Chemical Analysis	88.0% to 100.4% of F. P.
Computed Power by IBM 704	100% of F. P.

There are several factors which limit the accuracy of a nuclear instrumentation system at full power when the system is calibrated by the above methods. Considering only the instrument error, i.e., the conversion error due to changing a linearly varying ion chamber current to a logarithmic voltage, is on the order of $\pm 6\%$ per decade. For a five decade instrument, this means that a -50% to +100% error can exist at full power under adverse environmental operating conditions. A more realistic figure for a controlled environment, is approximately $\pm 20\%$. The second major source of error arises due to the fact that the initial calibration is performed three to four decades down from full power at a time when there is no hydrogen in the reactor.

These errors are due to two factors which are in opposition to each other. First, the introduction of hydrogen into the core, reflector, and piping changes the flux distribution within the core and also captures more of the neutrons radiating from the center of the core. A comparison of radial fluxes in the outer portion of the Be reflector as obtained from calculations on the one-dimensional transport theory code, DSN, show the fast flux to decrease about 20% upon the addition of hydrogen coolant.** Second, the detectors used for the KIWI tests are exposed to an unusually high gamma flux field. Incomplete gamma compensation can cause the detectors to read high by about 30%. In general, the neutronics used in the

* The nuclear instruments had been previously calibrated at about 1% power.

** Preliminary Estimates of the Effect of Temperature and Coolant on Instrumentation Calibration, RA-131, October 30, 1962.

KIWI tests have indicated power levels 10% to 30% higher than the actual power.

Thus, it can be seen that considerable errors can and do exist in measuring reactor power by nuclear instruments. However, power can also be computed from measured thermal parameters. Although this method is potentially capable of yielding a much higher degree of accuracy, it also has some serious shortcomings. Principally, the system time constants are so long that a power level scram would be ineffective. And secondly, since both propellant flow and temperature must be measured, the operation of such a system is restricted to the upper two decades of power, or when coolant flow is present. The latter is not a great disadvantage when it is used as an input to a high power level scram system or a power level control system. The long time constant disadvantage can be overcome by combining a thermal power computer with a neutron derived power signal. Such a system is described below.

Power Calibrator

Thermal power can be computed by several different methods using any two of three parameters, such as weight flow rate, exit gas temperature, or chamber temperature.

$$Q = K_1 W_c T_c \quad (1)$$

$$Q = K_2 P_c \sqrt{T_c} \quad (2)$$

$$Q = K_3 \frac{P_c^2}{W_c} \quad (3)$$

Equation 1 is the simplest computation to implement because it involves only a single multiplier to perform the arithmetic function. If we assume that the computed thermal power, Q , is the standard to which we want to correct the nuclear power indication, N , we can derive the necessary system equations.

Assume that initially Q and N are equal and that at time $t = 0$ we introduce a step

change in N . The thermal power will not change immediately, being delayed by the reactor thermodynamics. However, we do want to sense the sudden increase in reactivity in order to initiate control action as fast as possible. We therefore need a quick response to sudden changes in N . On the other hand, if N changes slowly, due to calibration errors, then we want to ignore this change and let the output of the calibrator be Q , the thermal power. This means that the corrected power, P , must contain a term equal to Q plus a function of Q , N , and t which goes to zero when t becomes very large or when the difference between Q and N goes to zero.

Stated mathematically, for a step change in $(Q - N)$,

$$P = Q - (Q - N) e^{-t/k} \quad (4)$$

Equation 4 satisfies all of our requirements since,

$$P = N \text{ at } t = 0$$

$$P = Q \text{ at } t = \infty$$

$$P = Q \text{ when } N = Q$$

A close approximation to Equation 4 can be obtained by using an operational amplifier to produce a simple lag of the difference between Q and N . The transfer function of such an amplifier is:

$$E_o(S) = - \frac{E_i(S)}{1 + K_s}$$

Let $e_i(t) = (Q - N) u(t)$

then for the step change in $e_i(t)$

$$E_i(S) = \frac{Q - N}{S}$$

and $E_o(S) = - (Q - N) \left(\frac{1}{S} - \frac{1}{1 + sK} \right)$ $e_o(t) = - \left((Q - N) - (Q - N)e^{-t/k} \right)$ (5)

if we now subtract N from Equation 5 and invert, we have the desired function.

$$P = e_o(t) = Q - (Q - N) e^{-t/k} \quad \text{Q. E. D.}$$

A system performing the above function was constructed using analog computer components. Figure 1 is the schematic for the experimental system. It was used in conjunction with the reactor and reactor control system simulation to produce the curves at the end of this report. Step changes were introduced in the measured nuclear power to correspond to instrumentation errors, i.e., not changes in true power. The capacitor, C, in the lag circuit was adjusted for optimum control system response. No significant change in any of the reactor parameters could be noted when the control system was operated with the computed LnP signal rather than the normal LnN signal.

Conclusions

A workable power calibrator has been constructed which is capable of producing a signal proportional to true power. The accuracy of such a system is limited primarily by the accuracy of the chamber temperature and the mass flow rate signals. The total system error, however, should be considerably less than $\pm 10\%$ of full power. This is at least three times better than conventional nuclear instruments. It is recommended that this calibrator be used for the E engine tests to supply the input to the high power level scram. It is not needed as an input to the control system since the controller can accept considerable errors in measured neutron level and still maintain the desired exit gas temperature. In that case, a slightly simplified version of the circuit shown in Figure 1 is possible. The Ln function generator can be eliminated and a linear N, instead of the LnN, can be used, if the calibrator is used only as an input to the scram or cutback system.

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