Automatic 3-D Displays with the PACE® TR-48/DES-30 Desk-Top Hybrid Computer System

INTRODUCTION

These Notes describe the programming of the PACE TR-48/DES-30 Hybrid Computer System to produce three-dimensional effects in X-Y plots. The particular application of interest here is the automatic plotting of "surfaces" of temperature, as a function of time and distance, in a slab of glass which is being air-cooled subsequent to heat treatment. The display of such surfaces aids in locating possibly dangerous temperature gradients which might develop in the slab during the cooling process.

The techniques described are applicable to a wide variety of situations where functions of two variables are produced. Such situations, for example, include the voltage (or current) distribution along a transmission line, the displacement along a vibrating cantilever beam, the electric (or magnetic) field configurations in wave guides, etc.

BENEFITS

Several benefits are provided by the programming techniques described in these Notes. First, the visual, 3-dimensional displays obtained from the TR-48 Computer under the direction of the DES-30 Digital Logic System convey much more information more quickly than tables of values or even standard 2-dimensional plots can offer.

Second, these plots are produced *automatically* with the minimum of operator intervention or manipulation required, so that the operator is left free to observe the display critically while it is being drawn.

Third, the high-speed repetitive solutions produced by the TR-48 Analog Computer are displayed on the oscilloscope for continuous monitoring even as the logic-directed slow plotting (for extra-dimensional axis rotation and shifting) on the X-Y Plotter is taking place. In this way, the problem can be observed in depth; any distortions occurring over the space or time domains can be noted or appropriate action taken.

Finally, significant economies can be effected in the analog equipment complement required through time sharing under control of the DES-30 control logic.

PROBLEM DISCUSSION

Recent significant advances in computer hardware and organization now enable the modern electronic computing system to produce problem solutions at rates which far exceed the ability of the human operator to absorb and interpret them efficiently. Consequently, much effort has been directed at improving the so-called "man-machine interface" in high-speed systems. One important aspect of this problem is that of presenting the results of a computation in more meaningful, easier-to-interpret form.

Hybrid analog-digital computer systems are capable of providing significantly-improved visual displays of complex phenomena. First, such hybrid systems can call upon the ability of the analog computer to produce solutions in the form of continuous curves which can be put directly on X-Y plotters without interpolation or smoothing. Second, the ability of the analog computer to provide such continuous solutions at very high repetition rates permits their display on oscilloscope screens where the effects of changes in parameter values on the nature of the solution can be established quickly and effortlessly.

Finally, the patchable, digital logic portion of the hybrid system provides the necessary "brainwork" in directing the operation of the analog computer and in manipulating its results to provide more meaningful visual displays.

PHYSICAL SYSTEM

Figure 1 illustrates the geometry of the glass slab considered in this application.

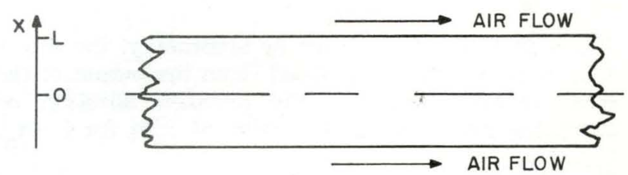

Figure 1: Air Cooling of Glass Slab Following Heat Treatment

The equation describing the cooling process is

$$\frac{\partial^2 T}{\partial X^2} = \frac{\rho c}{k}\frac{\partial T}{\partial t} \qquad (1)$$

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with the boundary conditions $T(X, O) = T_o$ and $\left.\frac{\partial T}{\partial X}\right]_{X=O} = O$; this last condition is due to the symmetry of the system. The equation can be simplified by normalizing, i.e., by letting $Z = X/L$ and $\theta = \alpha t/L^2$. Thus

$$\frac{\partial^2 T}{\partial Z^2} = \frac{\partial T}{\partial \theta} \quad (2)$$

METHOD OF SOLUTION

The analog computer is programmed to solve the normalized heat diffusion equation, Equation (2), in two different ways. The first solution is by finite differencing the space (Z) dimension from which a set of equations for the "parallel" solution result:

$$\frac{T_{j+1} - 2T_j + T_{j-1}}{(\Delta Z)^2} = \frac{dT_j}{d\theta}, \; j = O, 1, \ldots m \quad (3)$$

This set of equations produces a number of simultaneous solutions, $T_j(t)$, representing temperature as a function of time at *j* points in space.

The second solution is by finite differencing the time (θ) dimension from which a set of equations for the "serial" (actually, semi-serial) solution result:

$$\frac{T_i - T_{i-1}}{\Delta \theta} = \frac{d^2 T_i}{dZ^2}, \; i = O, 1, \ldots m \quad (4)$$

This set of equations also produces a number of simultaneous solutions, $T_i(Z)$, representing temperature as a function of normalized distance *z* for a number of instances, *i*, in time.

The serial solution requires two initial conditions for each *i* block, viz:

$\left.\frac{\partial T_i}{\partial Z}\right]_{Z=O}$ and $\left.T_i\right]_{Z=O}$. The former condition is known to be zero by symmetry; the latter I.C. values can be obtained from the output of the first block (j = O) of the parallel solution by sampling and storing the value of $T_j(t)$ for $t = t_o, t_1, \ldots t_m$.

For this reason, the parallel and serial solutions are operated in complementary fashion: the serial program is in I.C. (reset) while the parallel program operates to provide the needed I.C., then, the parallel program resets while the serial program goes into Operate.

Both programs are operated in the high-speed repetitive operation mode in which solutions are produced at rates fast enough for display on an oscilloscope. At the same time, however, the timing and control functions of the DES-30 Digital logic system direct a slow plot of the functions $T_j(t)$ and $T_i(Z)$ with appropriate axes rotations and shifts to produce a 3-dimensional effect. The sketch of Figure 2 shows the type of three-dimensional temperature vs time vs distance plot that can be obtained with this program.

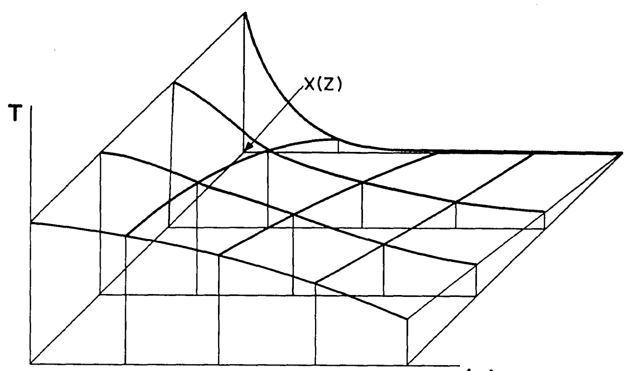

Figure 2: Sketch of Typical 3-D Plot Obtained of Temperature "Surfaces" in a Glass Slab

Figure 3 shows a block diagram of the program used in this application.

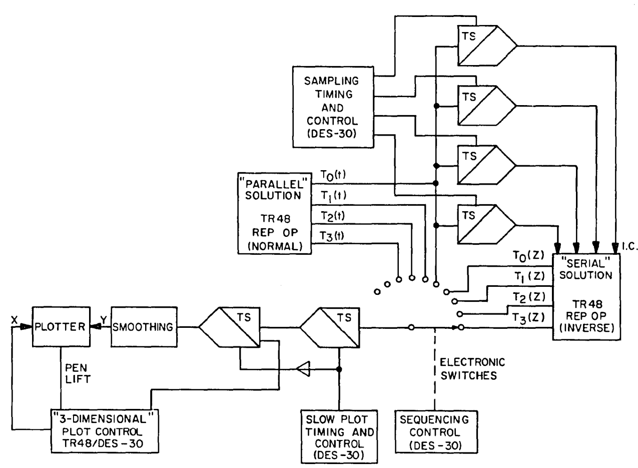

Figure 3: Block Diagram of 3-D Program

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