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SOFTWARE PRODUCTS FOR TEMPERATURE DATA REDUCTION OF PLATINUM RESISTANCE THERMOMETERS (PRT)

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Introduction

The main objective of this project is to create user-friendly personal computer (PC) software for reduction/analysis of platinum resistance thermometer (PRT) data.

The Callendar-Van Dusen Equation

The Callendar-Van Dusen equation is the accepted method (International Temperature Scale - 1927, ITS-27, and International Practical Temperature Scale - 1948, IPTS-48) for calculating resistance, $R$, given a temperature, $t$, for PRTs.

The general expression for the Callendar-Van Dusen equation is:

(Rosemount Report 68023F)

$$ R_t = R_0 \left[ 1 + \alpha \left( t - \frac{t}{100} \right) \left( \frac{t}{100} - 1 \right) - \beta \left( \frac{t}{100} - 1 \right)^3 \right] $$  \hspace{1cm} (1)

where:

- $R_t$ = resistance at temperature $t$ (ohms)
- $R_0$ = resistance at 0°C
- $t$ = temperature, °C
- $\alpha$, $\delta$, and $\beta$ are calibration constants

For temperatures above 0°C, $\beta = 0$, and equation (1) becomes

$$ R_t = R_0 \left[ 1 + \alpha \left( t - \frac{t}{100} \right) \left( \frac{t}{100} - 1 \right) \right] $$  \hspace{1cm} (2)

and this equation is known as the Callendar Equation.

When $t_r = 100°C$ then, from equation (2)

$$ \alpha = \frac{R_{100} - R_0}{100R_0} $$  \hspace{1cm} (3)

where $\alpha$ is the temperature coefficient over the range 0°C to 100°C.
Knowing the value of \( \alpha \), \( \delta \) can be calculated from a third calibration point, \( t_2 \) as follows:

\[
\delta = \frac{t_2 - \left( \frac{R_{t_2}}{R_0} - 1 \right)}{(t_2 - 100)\left( \frac{t_2}{100} - 1 \right)} / \alpha
\]  

(4)

Finally, knowing the value of \( \alpha \) and \( \delta \), \( \beta \) can be calculated from a fourth calibration point, \( t_2 \), (below 0°C) as follows:

\[
\beta = \frac{R_0 \left(1 + \alpha t_3 \right) - R_{t_3}}{R_0 \alpha \left( \frac{t_3}{100} - 1 \right) \left( \frac{t_3}{100} \right)^3 - \left( \frac{t_3}{100} \right)^2} - \frac{\delta}{\left( \frac{t_3}{100} \right)^2}
\]  

(5)

For efficient computation, however, a method that relates \( \alpha \), \( \beta \), and \( \delta \) is desirable. For this reason, constants \( A \), \( B \), and \( C \) can be computed as follows:

\[
A = \alpha(1 + \delta/100)
\]  

(6)

\[
B = -\alpha\delta/10^4
\]  

(7)

\[
C = -\alpha\beta/10^8
\]  

(8)

or

\[
\alpha = A + 100B
\]  

(9)

\[
\delta = -10^4B/(A + 100B) = 10^4B/\alpha
\]  

(10)

\[
\beta = -10^8C/(A + 100B) = -10^8C/\alpha
\]  

(11)

With these constants, equation (1) may be computed with

\[
W = 1 + At + Bt^2 + Ct^3(t-100)
\]  

(12)

where \( W \) is the resistance ratio \( R_t/R_0 \) and \( C = 0 \) when \( t > 0°C \)
This approach allows the calibration to use three temperature points in addition to 0°C. One is a low temperature < 150°C, another is a high temperature > 250°C, and a third temperature ≤ 100°C. The constants A, B, and C may be computed by solution of the simultaneous equations:

\[ W_1 = 1 + A_{11} + B_{11}t^2 \quad \text{for } (T_1 > 0\,^\circ\text{C}) \]  
\[ W_2 = 1 + A_{22} + B_{22}t^2 \quad \text{for } (T_2 > 0\,^\circ\text{C}) \]  
\[ W_3 = 1 + A_{33} + B_{33}t^2 + C_{33}(t_3 - 100) \quad \text{for } (t_3 < 0\,^\circ\text{C}) \]

The solution set is as follows:

\[ A = \frac{(W_2 - 1)/t_2 - (W_1 - 1)/t_1}{t_1 - t_2} \]  
\[ B = \frac{(W_2 - 1)/t_2 - (W_1 - 1)/t_1}{t_2 - t_1} \]  
\[ C = \frac{W_3 - 1 - A_{33} - B_{33}t_3^2}{t_3(t_3 - 100)} \]

**Solving for Temperature**

Equation (12) must be solved for temperature, \( t \), to easily compute the temperature represented by a measured resistance. For temperatures above 0°C only, the solution is as follows:

\[ t = \frac{\sqrt{A^2 - 4B(1 - W)}}{2B} - A \]
For temperatures < 0°C, another method must be used. The first derivative of equation (12) is used to successively approximate t. This equation is

\[ \frac{dW}{dt} = A + 2Bt + 4Ct^2 (t - 75) \]  

(20)

where \( C = 0 \) for \( t > 0°C \)

Software Products for Using these Methods

Software products were designed and created to help users of PRT data with the tasks of using the Callendar-Van Dusen method. Sample runs are illustrated in this report. The products are available from Mr. Bill White, Bldg. 4487, EB-22, Marshall Space Flight Center, Alabama 35812.; telephone (205) 544-6417; email: William.B.White@msfc.nasa.gov.

Sample Output
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References