Weston
ENGINEERING NOTES

VOLUME 3 APRIL 1948 NUMBER 2

In This Issue

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HISTORICAL BACKGROUND OF THE PHOTOELECTRIC CELL

THE PHOTOELECTRIC effect was known to science more than a century ago. Becquerel, in France, wrote of it in 1839 in connection with his work on glass-enclosed primary batteries. While studying primary voltaic cells he discovered that the voltage of one of his cells increased when a beam of sunlight fell on the platinum electrode. His curiosity was aroused to the extent that he experimented with various brightness values and colors of light to determine their effect. He discovered that the voltage increased with increased illumination and that green light produced the highest voltage. Unfortunately, Becquerel was so absorbed with his work on the wet battery that he contented himself with merely recording his unusual findings regarding the photoelectric effect.

The Photovoltaic Cell

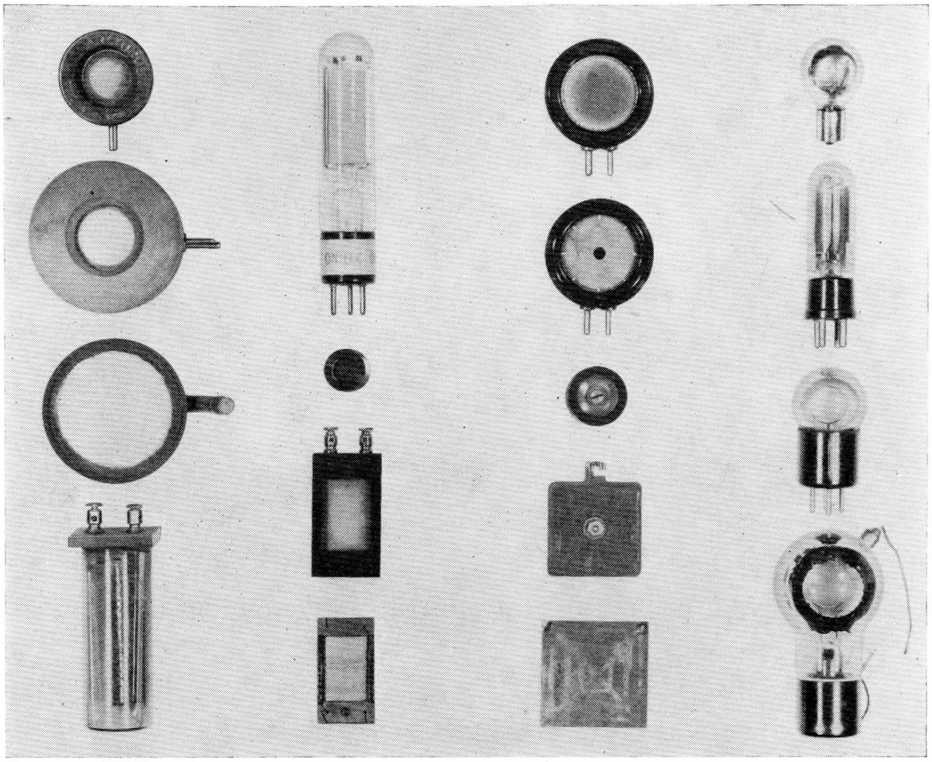
Liquid type photocells were then lost to the world for some 90 years when in 1929 the Wein and the Arcturus cells were introduced commercially and enjoyed a short but interesting life. These photoelectric cells were simply miniature voltaic wet cells arranged so that illumination impinging on one side of the front plate generated a considerable amount of electrical energy, easily enough to operate milliammeters and certain relays. These photovoltaic cells were simple, inexpensive, and very sensitive to light but unfortunately they were self-destroying. If used in cold places or outdoors in the winter, the electrolyte froze, expanded and cracked the case. If illuminated or heated for more than a very brief period, they generated gas which several times caused explosions. In use they soon became unstable and worthless, sometimes after a few months, occasionally in a few days.

The Selenium Resistor Cell

Fritts, an American, in 1883, developed and demonstrated the first self-generating dry disc barrier layer photocells which, incidentally, were made with selenium as was the resistor type photoconductive cell discovered by Willoughby Smith in 1873.

Smith apparently first discovered the photoconductive effect. While working as a telegrapher in the Azores he was puzzled by sudden changes in selenium resistors used in checking his lines. Investigating further, he found that moving a sun shade up and down had caused the sun to fall on his resistors and that the ohmic resistance of the selenium decreased when illuminated and increased when dark.

In 1930 the selenium resistor type of cell enjoyed a brief popularity and many versions reached the production stage. The cell is merely a resistor and conducts electricity which is supplied by a battery or generator. The ohmic resistance of the selenium cell varies with the intensity of light to which it is exposed and, by the resulting variation in current flow, its use as a light sensitive device is made possible. This cell has a high temperature coefficient and is rather unstable and subject to continuous drifting. It has a large dark current causing continuous drain on the battery and any circuit in which it is used must be readjusted continuously. To compensate for these



Various types of photoelectric cells in order of their development. Left to right—First Column, Photovoltaic; Second Column, Selenium Resistor; Third Column, Barrier Layer; Fourth Column, Photoemissive. The latest cell is shown at the top of each column.

undesirable characteristics, it offers a larger current change for a given change in illumination than any other type of photocell and it is suitable for use where it can be under constant observation.

Chronologically so far we have Becquerel as the discoverer of the wet photovoltaic cell in 1839, Willoughby Smith as the discoverer of the photoconductive or selenium resistor cell of 1873, and Fritts as the inventor of the first dry disk cell in 1883, about which more will be said later.

The Photoemissive Cell

In 1887 Hertz discovered that sparks across a spark gap increased in the presence of ultraviolet light and Hallwachs found that charged zinc plates lost their charges when exposed to ultraviolet light. In 1889 Elster and Geitel investigated the light sensitive characteristics of the alkali metals and discovered that sodium and potassium were quite sensitive to ordinary visible light. Later they conducted further experiments in evacuated and gas-filled atmospheres and found still greater photoelectric sensitivity.

The Elster and Geitel phototubes or photoemissive cells and their later day counterparts are simply bulbs either evacuated or partially filled-in glass or quartz walls and containing the cathode usually sensitized with one of the alkali metals such as sodium, potassium, or caesium. The other electrode consists of a collector ring or post insulated from the rest of the cell. A window or transparent area in the tube permits light to impinge upon the light sensitive material, causing it to emit electrons. These electrons are attracted to the collecting electrode which is maintained at a positive potential by a battery.

These phototubes have a low current output usually of the order of 10 to 20 microamperes and rarely exceeding 100 microamperes. They require considerable voltage and some means of amplification for their operation. They are practically instantaneous in operation, that is, their frequency response is very high and therefore they are admirably suited to sound picture work, television, and similar applications requiring high frequency response. Due to the need for an amplifier circuit, their application is somewhat more complicated and delicate than other forms of photocells and it is difficult to apply them, except as a unit, by one not having special training.

The Dry Disc Cell

Getting back to the self-generating dry disc cell as made by Fritts, the *Electrical World* of April 25, 1885, contained an article entitled *Dr. Werner Siemens on the Production of Electricity From Light,* in which the cell was described as follows: ". . . consisting of a thin, homogeneous sheet of selenium, which is spread upon a metal plate and, after subsequent heatings—for the conversion of amorphous into crystalline selenium—is covered over with a fine gold leaf. The light passes through the gold and acts upon its junction with the selenium, developing an electromotive force which results in a current when the circuit is completed. The current thus produced is radiant energy converted into electrical energy directly and without chemical action."

Fritts not only produced usable cells but he actually applied them to various uses and demonstrated some of the possible applications. In the same article Fritts reported having obtained the following data in checking the intensity of the sky with one of his cells.

TIME OF OBSERVATION	DEFLECTIONS OF THE GALVANOMETER
9:37 A.M.	190
10:30 A.M.	209
11:35 A.M.	250
12:30 P.M.	250
1:30 P.M.	249
2:30 P.M.	188
3:30 P.M.	172

Later in the *Scientific American Supplement* of June 6, 1885, Fritts wrote: " . . . hundreds of cells were made, finished, and tested . . . ." Other interesting excerpts of the report follow:

"The current produced is radiant energy converted into electrical energy directly and without chemical action and flowing in the same direction as the original radiant energy which thus continues its course but through a new conductory medium suited to its present form. The current is continuous, constant, and of considerable electromotive force. A number of cells can be arranged in series, like any other battery.

" . . . Experiments show that the cell will sing or speak, without the use of external current if suitably varied light is thrown upon it while in closed circuit.

" . . . The application or uses for these cells are almost innumerable, embracing every branch of electrical science especially telegraphy, telephony, and electric lighting. Only two will be mentioned. The first is my Photometer. The light to be measured is caused to shine upon a cell and the current thus produced flows through a galvanometric coil in circuit whose index indicates upon its scale the intensity of light. The scale may be calibrated by means of standard candles, and the deflections of the index will then give absolute readings showing the candle power of the light being tested.

" . . . Photoelectric Regulator—My regulator consists of a cell arranged in front of a light, say an electric lamp, whose light represents the varying strength of the current which supports it. The current produced in the cell by this light flows through an electromagnetic apparatus by means of which mechanical movement is produced, and this motion is utilized for changing resistances, actuating a valve, rotating brushes, moving switches, levers, or other devices. This has been constructed on a small scale, and operates well--

" . . . However great the scientific importance of these cells may be, the practical value will be no less obvious when we repeat that the supply of solar energy is both without limit and without cost, and that it will continue to pour own upon us for countless ages after all the coal deposits of the earth have been exhausted and forgotten.

" . . . In conclusion, I would say that the investigation of the properties of selenium still offers a rare opportunity for making very important discoveries. But candor compels me to add that whoever undertakes the work will find it neither an easy nor a short one."

Charles Fritts was apparently something of a prophet. Two generations passed and much time and money was spent by scores of scientists and research laboratories before the selenium barrier layer cell came into practical and widespread use.

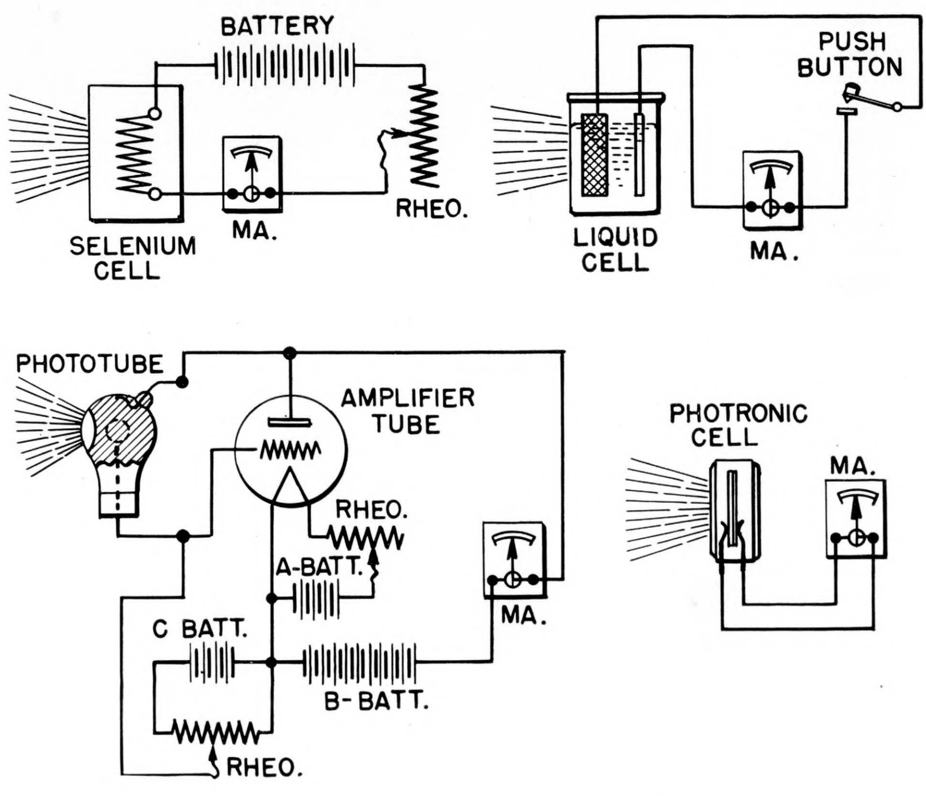
Fritts described methods of manufacturing barrier layer self-generating cells, he described and made candle power meters and photoelectric relays basically similar to our foot-candle meters and photoelectric control relays of today.

It seems surprising that, after Fritts' developments, writings, and lectures, the cells were not used at least to the extent of being handed down to us in some form or another. However, Fritts seems to have been more of a scientist than a business man; he gave sample cells freely to other scientists but he would not offer them for sale, and no one else seemed interested, or able to equal his results. Apparently the fact that the cell could not be made sufficiently efficient to generate large amounts of power from sunlight help to cool everyone's ardor.

At any rate, the cell seems to have died with Fritts to be reborn in improved form some four decades later. In 1928, various scientists noticed in their work on cuprous oxide rectifier plates that plates connected to a galvanometer generated a slight voltage when exposed to light. During 1929 and 1930 large scale research projects were being diligently conducted abroad and in this country.

The Weston Photoelectric Cell

At first the copper oxide cell pushed to the fore, but further experiments conducted with tellurium, selenium, and other materials soon indicated that a selenium alloy would offer the best possibilities. However, the going was not easy as Fritts had predicted. The 1928-29-30 cells lacked sensitivity, or stability, or both, or were



Simple circuits used with the various types of Photoelectric cells.

not reproducible commercially. Somewhat before this period, the Weston Company started an investigation of photoelectric cells including the liquid type, the dry-disc copper oxide and selenium type and others, but it was not until May 1931 that the first satisfactory progress was achieved. Regarding this accomplishment, a booklet published by Weston in 1935 states, "Lamb and Bartlett, two Weston engineers, were first to produce barrier layer cells with apparently permanent characteristics. Their cell is known as the PHOTRONIC Photoelectric Cell."

In the past fifteen years definite improvements in fundamental cell characteristics particularly in the direction of providing increased current output without sacrificing stability have been achieved. Knowledge of the photoelectric effects involved in cell design and manufacture has now reached a point permitting the creation of cells "tailor-made" to the requirements where conditions limit the usefulness of the regular types. The entire operation from processing of the raw materials to the sensitization of the finished cell is performed under close technical control in the Weston plant. The material, skills and experience are available to move forward with new strides of progress in which even greater commercial utilization can be expected for the barrier layer cell.

E. N.—No. 46 —*A. H. Lamb*

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THERMAL PROBLEMS RELATING TO MEASURING AND CONTROL DEVICES—PART II

The preceding article (E.N.—No. 40, Vol. 2, No. 6) in this series discussed the fundamental laws of heating and cooling of simple bodies. Some applications were made, and consideration was given to time constants in general.

This article will continue with this subject by considering the lag in temperature and intermittent heating and cooling of simple bodies.

8. Lag in Temperature at Any Time of a Simple Body Immersed in a Medium Changing in Temperature at a Constant Rate

When a body is immersed in a cooling medium, such as air or water, both being initially at the same temperature, and the medium suddenly starts to increase or decrease in temperature at a constant rate, then the temperature of the body tends to follow the change in the ambient temperature but lags behind it. The object of this analysis is to determine the lag at any time.

One example of this problem in practice is when a thermometer is used to measure air temperature from aircraft where the temperature changes with altitude. It must be stated, however, that thermometers usually employed for this purpose cannot be considered strictly as simple bodies, as they are usually mounted in protecting cases. This general problem was considered in a paper by the author published elsewhere[1]. However, a good quality of mercury-in-glass chemical thermometer, or equally good bimetal or resistance thermometer, when used in direct contact with the air, the temperature of which is to be measured, can be considered for most practical purposes approximately as a simple body. Other examples are: (a) The temperature lag at any time of a simple body mounted in a calorimeter changing in temperature at a constant rate; (b) The lag in temperature of the movable coil of an instrument, mounted in a case changing in temperature at a constant rate; and other similar examples.

Let θ_o = the initial temperature of both medium and body, at which time $t=0$.

θ_1 = temperature of medium at any time t.

θ_2 = temperature of body at any time t.

r = the rate of change in the temperature of the medium. It is positive for increasing, and negative for decreasing temperatures; degrees per second.

t_o = time constant of the body $= Ms/h$; seconds.

Then the lag in the temperature of the body behind that of the medium, after any elapsed time t is

$$L=(\theta_1-\theta_2)=rt_o\left(1-\epsilon^{-\frac{t}{t_o}}\right) \quad (14)$$

This equation will be proved later in this series of articles as a special case of the thermal lag of a more complicated system of bodies.

After a relatively short time, the exponential term in Equation 14 becomes negligibly small, and then the final maximum value of the lag becomes

$$L_m=rt_o \quad (15)$$

That is, the maximum lag is simply the rate of change in temperature multiplied by the time constant in seconds. This result was obtained by Harper[2] for thermometers, which he considered as simple bodies as defined in these articles.

Equation 14 may now be written in terms of the final lag as

$$\frac{L}{L_m}=\left(1-\epsilon^{-\frac{t}{t_o}}\right) \quad (16)$$

Figure 3 is a graph of this equation from which the lag at any time can be determined in terms of the final lag and the time constant. It will be noted that this curve is the same as the ascending curve shown in Figure 1 for Equation 5.

For example, Equation 16, or the curve in Figure 3, shows that the lag in temperature of a body reaches to within five per cent of its final value; that is, when $L/L_m = 0.95$, in a time equal to three times the time constant of the body; that is, when $t/t_o=3$.

PROBLEM 1. As an example, assume that a thermometer having a time constant $t_o = 120$ seconds is used to measure the temperature of the air in a chamber, which is increasing at the rate of 5 deg. Cent. per minute or 1/12 deg. Cent. per second. Then the maximum amount that the thermometer can read low is, from Equation 15,

$$L_m = rt_o = 1/12 \times 120 = 10 \text{ deg. Cent.}$$

The actual lag after, say, three minutes, would be from Equation 14,

$$L = 1/12 \times 120 \times \left(1 - \epsilon^{-\frac{3\times 60}{120}}\right)$$

$$= 10 \times (1 - 0.223) = 7.77 \text{ deg. Cent.}$$

That is, the thermometer after three minutes would indicate 7.77 deg. Cent. too low, which can be determined also from the curve in Figure 3.

This indicates that, for such measurements, it would be necessary to correct the indications or to use a thermometer having a much smaller time constant.

PROBLEM 2. To compute the time constant of the movable coil of an instrument from which, in turn, its lag in temperature behind that of the case which is changing in temperature at a constant rate can be computed.

In addition to lag, this problem also considers the time constant of a non-homogeneous simple body.

Assume a movable coil in a permanent magnet instrument, having a nominal diameter of one inch, e.g. a Weston Model 1 Voltmeter coil, in which the constituent parts have the following values of mass:

Copper (wire, etc.)	$M_1 = 0.352$ gram.
Aluminum (frame, etc.)	$M_2 = 0.450$ gram.
Insulation	$M_3 = 0.100$ gram.

The heat capacities in joules per gram per 1 deg. C. for these materials, as computed from tables of specific heat, are as follows:

Copper	$s_1 = 0.385$
Aluminum	$s_2 = 0.896$
Varnish	$s_3 = 1.680$

The time constant, from Equation 1, is $t_o = Ms/h$.

The quantity Ms is simply the heat capacity per degree of the entire coil considered as a simple body, which may be asssumed to a close approximation in this problem. Ms, then, is the sum of the heat capacities of the several parts, which, in joules per deg. Cent. are as follows:

Copper	$M_1 s_1 = 0.352 \times 0.385 = 0.136$
Aluminum	$M_2 s_2 = 0.450 \times 0.896 = 0.403$
Varnish	$M_3 s_3 = 0.100 \times 1.680 = 0.168$
Total	$Ms = 0.707$

Actual tests have shown that the rate at which heat is dissipated from such a coil to the magnet and surrounding air and other parts is $h = 0.1278$ watt per degree Cent. Then the time constant is

$$t_o = \frac{Ms}{h} = \frac{0.707}{0.1278} = 5.5 \text{ seconds.}$$

A rough check on this result was made by measuring, by means of a stop watch, the time constant of the coil from which the above data were taken, connected in a bridge circuit, and was found to be about six seconds.

The value of the lag in the movable coil temperature can now be computed by using the time constant for any rate of increase in temperature of the case. Let the case and magnet system increase in temperature, for example, at the rate of 5 deg. Cent. per minute, or 1/12 deg. Cent. per second. Then, by Equation 15, the maximum lag in the movable coil temperature would be

$$L_m = rt_o = 1/12 \times 5.5 = 0.46 \text{ deg. Cent.}$$

9. Intermittent Heating and Cooling of a Simple Body

When a simple body, immersed in a cooling medium, is alternately heated at a constant rate and then allowed to cool, the heating and cooling being carried out during definite periods of time respectively, the cyclic changes in temperature soon reach a steady state condition in which the temperature varies from a definite low value to a definite high value.

The problem is to determine the maximum temperature for given periods of heating and cooling, and rates of heating.

An example of this problem is where the movable coil of an instrument is subjected to periodic overloads of current or voltage, and it is desired to compute the maximum temperature of the coil under given conditions.

Let θ_2 = maximum temperature above ambient reached during heating period.
θ_1 = minimum temperature above ambient during cooling period.
t_1 = heating time; seconds.
t_2 = cooling time; seconds.
t_o = time constant of body; seconds.
θ_m = temperature elevation the body would reach if the heating period were continuous $= W/h$.
W = rate at which heat is applied; watts.
h = heat dissipated from the body to surrounding medium per 1 deg. Cent.

Then the ratio of the maximum

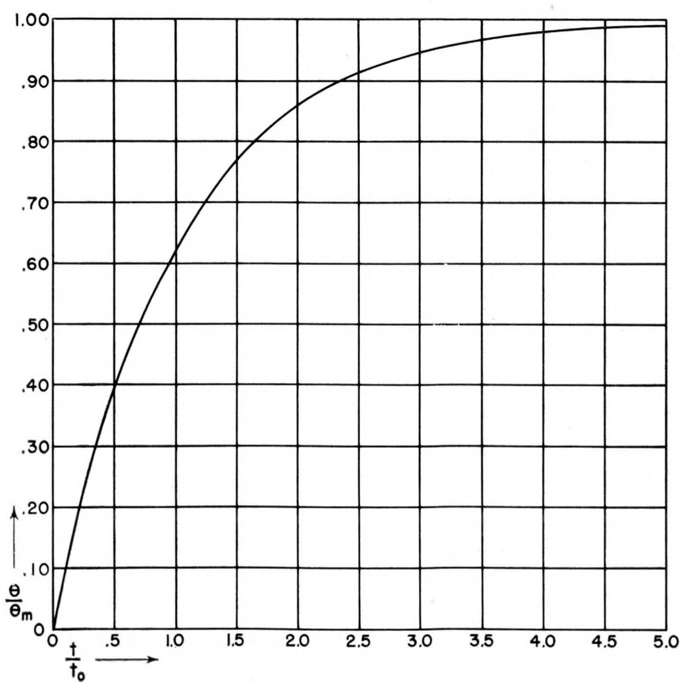

Figure 3—The lag in temperature at any time of a simple body behind that of a medium in which it is immersed, between which heat is exchanged, when the medium is changing in temperature at a constant rate.

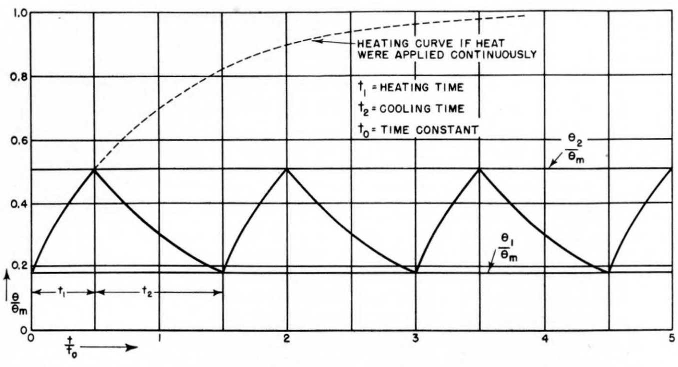

Figure 4 — Periodic Heating and Cooling: The temperature at any time of a simple body alternately heated and then allowed to cool in the surrounding medium, periodically. The curves show the steady state condition for the particular case where the heating time is equal to half the time constant, and the cooling time is equal to the time constant. Temperatures are relative to the maximum which would be reached if the heating were continuous and time is given relative to the time constant.

temperature elevation reached to that which would result if the heat were applied continuously is, as will be proved later,

$$\frac{\theta_2}{\theta_m}=\frac{1-\epsilon^{-\frac{t_1}{t_o}}}{1-\epsilon^{-\left(\frac{t_1+t_2}{t_o}\right)}} \qquad (17)$$

Figure 4 shows graphically the cyclic variation in temperature of a body at any time, for the particular case, where the heating time is one-half the time constant and the cooling time is equal to the time constant. That is, $t_1/t_o=0.5$ and $t_2/t_o=1$. The dotted line shows what the temperature would be at any time if the heat were applied continuously.

Example:

Assume that θ_m and t_o are known or can be computed. Find the maximum temperature elevation θ_2 relative to the maximum temperature θ_m which would result if the heat were applied continuously, when both the heating and cooling periods are equal to the time constant t_o. That is,

$$\frac{t_1}{t_o}=\frac{t_2}{t_o}=1$$

Substitute these values in Equation 17 and we have

$$\frac{\theta_2}{\theta_m}=\frac{1-\epsilon^{-1}}{1-\epsilon^{-2}}=\frac{0.632}{0.865}=0.73$$

That is, under the conditions given, the maximum temperature elevation reached would be 73 per cent of the maximum temperature elevation which would result if the heat were applied continuously.

6(*a*) *Given the Desired Maximum Temperature, Find Heating and Cooling Periods.*

If a body is to be subjected to periodic heating, for example, overloads, alternating with no load cooling periods, and it is desired that the maximum temperature elevation reached shall not exceed a given value θ_2, then the cooling time t_2 can be computed for a given heating time t_1, or vice versa, as follows:

Let it be assumed that the maximum temperature elevation θ_m, which would result if the heating load were applied continuously, is known or can be computed. Then from Equation 17, by separating the variables,

$$1-\epsilon^{-\frac{t_1}{t_o}}=\frac{\theta_2}{\theta_m}-\frac{\theta_2}{\theta_m}\left[\epsilon^{-\frac{t_1}{t_o}}\times\epsilon^{-\frac{t_2}{t_o}}\right]$$

from which

$$\epsilon^{-\frac{t_2}{t_o}}=\frac{1}{\frac{\theta_2}{\theta_m}}\left[1-\frac{1-\frac{\theta_2}{\theta_m}}{\epsilon^{-\frac{t_1}{t_o}}}\right] \qquad (18)$$

which gives the cooling period t_2 desired, in terms of the heating period t_1, both relative to the time constant t_o.

Example:

Assume that the temperature elevation of the movable coil in an instrument, resulting when normal current is applied continuously, is 20° C. Assume further that the time constant t_o is known or can be computed and is 10 seconds. Let the current be doubled; that is, heat is added at four times the normal rate for a definite time, and then the circuit opened allowing the coil to cool also for a definite time, and then again heated; the cycle being continued periodically. Find the cooling time required, if the heat is applied for 1 second per temperature cycle, so that the maximum temperature elevation θ_2 reached will not exceed the normal temperature change of 20° C.

The temperature change θ_m which would result if heat were added continuously at four times the normal rate would be $4\times20=80°$ Cent.

Then,

$$\frac{\theta_2}{\theta_m}=20/80=1/4$$

Substitute the known values in Equation (18) and we have

$$\epsilon^{-\frac{t_2}{t_o}}=4\left(1-\frac{1-0.25}{\epsilon^{-\frac{1}{10}}}\right)$$

which, when solved by the use of a table of exponential functions, gives

$$\frac{t_2}{t_o}=0.374$$

That is, the cooling period necsary to prevent an increase in coil temperature greater than 20° C. under the given conditions of intermittent heating, is $t_2=0.374\times10=3.74$ seconds.

In the problem, a heating period of 10 seconds was assumed. It is obvious physically and from the equation that the permissible heating time is not unlimited, and the

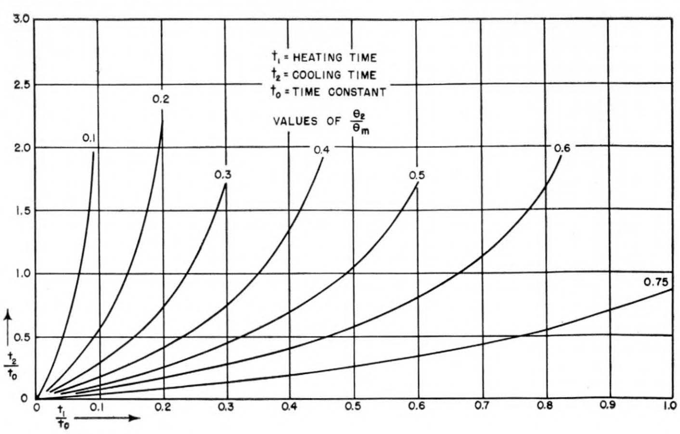

Figure 5 — Periodic Heating and Cooling: Relation of the periodic heating and cooling times of a simple body to produce a definite maximum termperature θ_2 relative to the maximum temperature θ_m which would result if the heating were continuous, in terms of the time constant t_o.

maximum value of the heating time t_2 which is permissible is that which makes $\epsilon^{-\frac{t_1}{t_o}}$ equal to $\left(1-\frac{\theta_2}{\theta_m}\right)$ for which $\epsilon^{-\frac{t_2}{t_o}}$ becomes zero; that is, the body is heated to θ_2 from $\theta_1=0$, and requires an infinite cooling time.

In the example, $\epsilon^{-\frac{t_1}{t_o}}$, therefore, must exceed $(1-0.25)=0.75$, from which $\frac{t_1}{t_o}$ must be less than 0.288; that is, t_1 cannot exceed 2.88 seconds. In Figure 5, the curves show values of t_1/t_o for various values of $\frac{\theta_2}{\theta_m}$.

Derivation of Equation 17 for Intermittent Heating

Heating Period:

Following the same reasoning used in deriving Equation 3, the rate at which heat is added to the body is equal to the rate of heat dissipation, plus the rate that heat is absorbed by the body, then, as in Equation 3

$$W=h\theta+Ms\left(\frac{d\theta}{dt}\right)$$

or

$$\frac{W}{h}=\theta+\frac{Ms}{h}\left(\frac{d\theta}{dt}\right) \qquad (19)$$

Where M = mass of body; grams
s = heat capacity per gram; joules per gram per deg. Cent.
$t_o=\frac{Ms}{h}$ = time constant, seconds.

But W/h is the maximum temperature increase θ_m which would result if the heat were added continuously. Then,

$$\theta_m-\theta=t_o\left(\frac{d\theta}{dt}\right)$$

from which,

$$dt=t_o\left(\frac{d\theta}{\theta_m-\theta}\right)$$

Integrating, we have

$$t=-t_o\log(\theta_m-\theta)+C$$

Now, when $t=0$, $\theta=\theta_1$

Then,

$$C=t_o\log(\theta_m-\theta_1)$$

and

$$t=t_o\log\left(\frac{\theta_m-\theta_1}{\theta_m-\theta}\right)$$

From which, if $t=t_1$ is the heating period, at the end of which, $\theta=\theta_2$,

$$\frac{t_1}{t_o}=\log\left(\frac{\theta_m-\theta_1}{\theta_m-\theta_2}\right)$$

or expressing this as an exponential,

$$\frac{\theta_m-\theta_2}{\theta_m-\theta_1}=\epsilon^{-\frac{t_1}{t_o}} \qquad (20)$$

which corresponds to the ascending curves in Figure 4.

Cooling Period:

Following the reasoning used in deriving Equation 7, the heat dissipated by the body to the medium during cooling is taken from the heat contained in the body material and is equal to the loss, from which

$$h\theta=-Ms\left(\frac{d\theta}{dt}\right) \qquad (21)$$

which, when integrated, yields

$$t=-\frac{Ms}{h}\log\theta+C$$

At the beginning of the cooling period, when the cooling time $t=0$, the initial value of the temperature is the maximum temperature θ_2 reached during the heating period; that is, at $t=0$, $\theta=\theta_2$ from which the constant C can be evaluated, then

$$t=\frac{Ms}{h}\log\left(\frac{\theta_2}{\theta}\right)=t_o\log\left(\frac{\theta_2}{\theta}\right)$$

from which

$$\frac{\theta}{\theta_2}=\epsilon^{-\frac{t}{t_o}} \qquad (22)$$

which corresponds to the descending curves in Figure 4. During the cooling time t_2, the temperature elevation has fallen to θ_1, therefore from Equation 22,

$$\frac{\theta_1}{\theta_2}=\epsilon^{-\frac{t_2}{t_o}} \qquad (23)$$

In Equation 20, substitute the value of θ_1 in terms of θ_2 as derived from Equation 23, and solve for θ_2/θ_m and we have

$$\frac{\theta_2}{\theta_m}=\frac{1-\epsilon^{-\frac{t_1}{t_o}}}{1-\epsilon^{-\left(\frac{t_1+t_2}{t_o}\right)}}$$

which is Equation 17.

References:

1. RESPONSE TIME AND LAG OF A THERMOMETER ELEMENT MOUNTED IN A PROTECTING CASE—W. N. Goodwin, Jr.—*Trans. A.I.E.E.*, Vol. 64, Page 665, 1945.
2. THERMOMETRIC LAG—D. R. Harper, 3rd—*Bulletin of the Bureau of Standards, Volume 8, Page 659, 1912.*

Note: As equations and figures in this and the preceding article in this series will be referred to in succeeding articles, it is desirable to save the articles for such references.—EDITOR.

E. N.—No.47 —*W. N. Goodwin, Jr.*

STANDARDIZED TEST BENCHES USED IN THE WESTON ENGINEERING LABORATORIES

IN the February, 1948 issue of ENGINEERING NOTES the article on the wall chase described how the electrical services, air, gas and water were distributed throughout the building. It stated that the light duty electrical services terminated at the utility outlets on the wall chase with all services available in every six-foot module. Air likewise terminates at every module and is available by removing a small cover plate.

Figure 1 shows a view of the engineering work bench which was developed at the time the New Engineering Building was on the drafting boards. It came into being not as an afterthought to the building proper, but rather in unison with it since it is an integral part of the planned distribution of the services required by the engineers for research, development and everyday testing.

The engineering bench was designed to afford an extension of these services in a manner which would make them readily available and at the same time afford a maximum of usefulness.

The bench proper consists of

Figure 1 — Standardized Test Bench as used in the Engineering Laboratories.

three major sections; the base section containing ten drawers 13⅞″ x 4¼″ x 24″, one double drawer 13⅞″ x 10″ x 24″ and a large center compartment; the flat working top and the vertical back shelf section. This construction not only affords ample means for modifying the sections when required for specialized purposes, but also made it possible to move them through doorways with ease, something which would have been difficult otherwise since the tops are over three feet deep.

The bench was developed with these thoughts primarily in mind.

1. It should have a reasonably large flat working area.

2. It should have provision for electrical service outlets and air and, when necessary, should accommodate a sink with hot and cold water.

3. When more than one bench is side by side a means shall be provided for extending all services to the adjacent and additional benches.

4. If possible, storage space shall be provided so as to make unnecessary additional cabinets insofar as possible.

5. The bench should be capable of being altered without affecting its basic structure.

That these conditions have been met to a large degree is evident from the picture.

First, the working area per bench is 30″ x 62″ which is ample for most all purposes intended.

Second, a trough is provided for bringing the services to an electrical outlet box system containing the various electrical services.

Third, by keeping the base section dimensions inside of the working area dimensions and by extending the electrical trough from one side of the bench to the other, benches do not interfere with each other and can be placed side by side with all services available at every bench.

Fourth, the storage space is about equal to that provided by the customary steel cabinet. The actual storage space is 25½ cubic feet and the surface area 41 square feet (working surface of 12.9 square feet not included).

Additional features of design include the following:

All drawers are interchangeable, in fact as well as in theory. Credit should be given here to the Weston Carpenter Shop for the excellence of workmanship built into these benches.

The center door affords access to the large center compartment which is provided with six standard size Weston trays 15″ x 5″ x 19½″ which can be slid in or out or removed entirely as desired.

The electrical outlet box system is energized by extra heavy service cords run from the wall chase outlets to the bench box, a photo of which is shown in Figure 2. Note that the first box which would be in the bench nearest to the wall chase contains circuit breakers which protect not only its own outlets from overloads, but also any others that are connected in series with it. This is so purposely. It is accomplished by connecting all boxes in series. All outlets have pilot lights for which different color caps are available. Red caps are to be used for lines to be on during the day only, yellow caps for circuits which may be on at all times. Other colors are used for special purposes.

The upper shelves are intended for holding small instruments and devices which are frequently used as well as decade resistance boxes, etc., which may be connected into the circuit under test, but which are more convenient when raised above the flat working surface.

Air is piped along the back of the bench and brought forward along the side with pressure reducers installed as necessary. Usually the reducer is located on the bench nearest the wall chase so that all benches receive air at the reduced pressure which can be varied at will by simply turning a wing nut.

A three-inch overhang is provided on the front to allow toe and knee room; a similar overhang is provided on each side to allow for bringing the air line and other piped services forward as necessary. A nine-inch overhang is provided at the rear to accommodate lateral runs of piping.

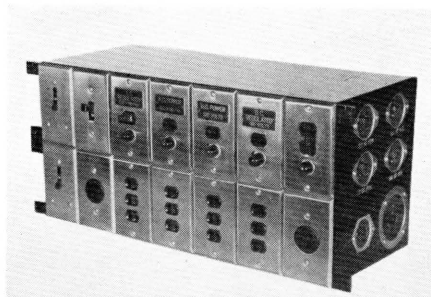

Figure 2—The electrical outlet bench box contains various electrical services.

Linoleum was selected for the working surface for a number of reasons, but primarily because of satisfactory experience with it for this purpose both in the laboratories as well as in the shop where it has given excellent service over the past many years. The benches are finished with several coats of orange shellac to give a presentable appearance.

E. N.—No. 48 —*F. X. Lamb*

Printed in U. S. A