

May 12, 1936.

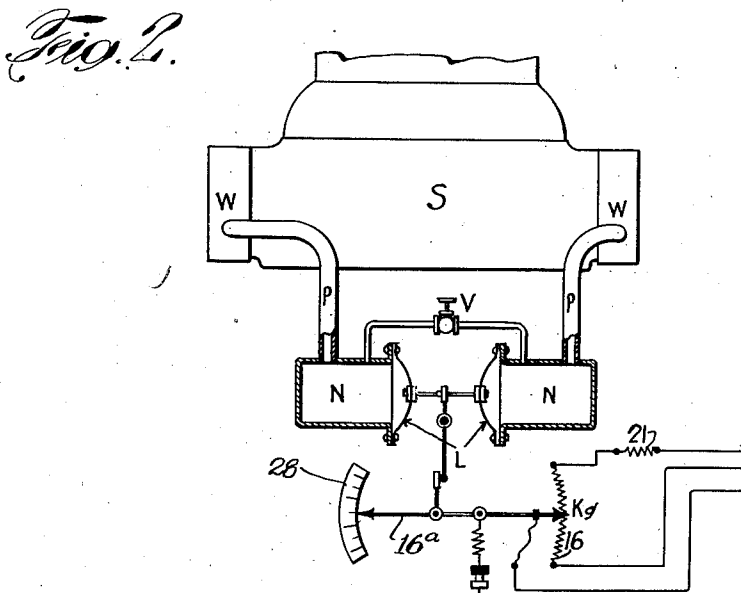
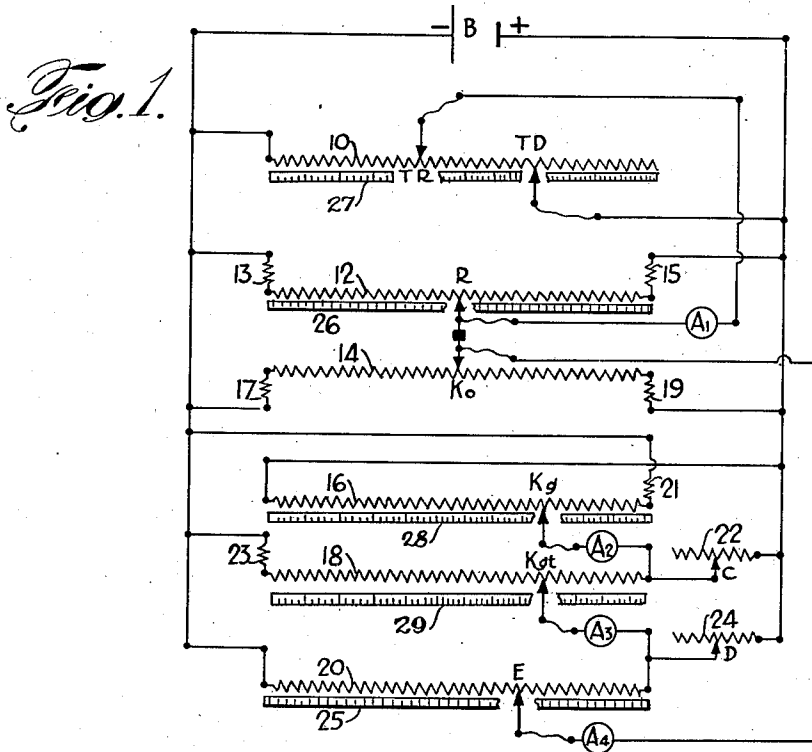
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2,040,086

CONDENSER EFFICIENCY CALCULATOR

Filed Oct. 29, 1930

2 Sheets-Sheet 1



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2 Sheets-Sheet 2

Fig. 3.

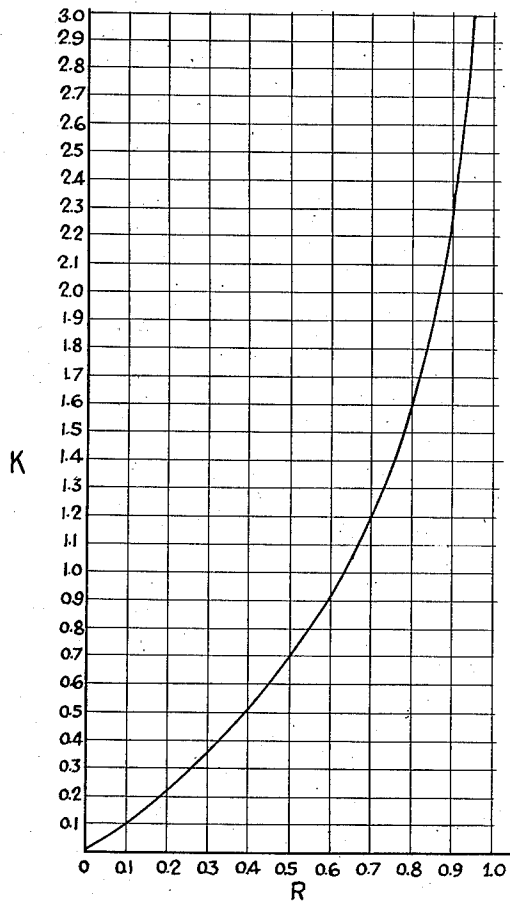
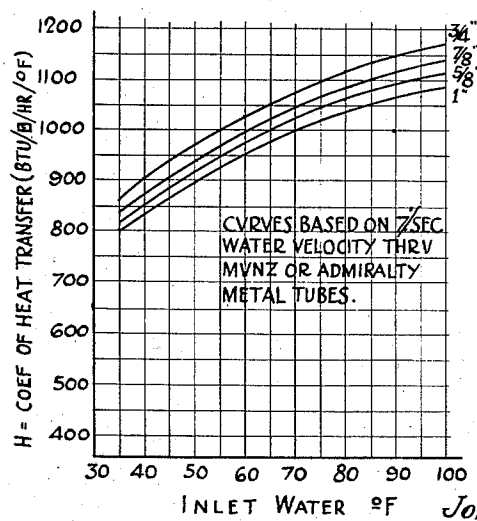


Fig. 4.



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CONDENSER EFFICIENCY CALCULATOR

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Application October 29, 1930, Serial No. 491,915

3 Claims. (Cl. 235—61)

This invention relates to apparatus for the interchange of heat and, in its broader and more general aspects, deals with methods and devices for determining changes during operation in the operating characteristics of apparatus arranged to occasion an interchange of heat between two or more fluids. More specifically, the invention concerns methods and devices for determining the operating characteristics of steam surface condensers, and is of particular adaptability in the intermittent or continuous determination of performance or operating efficiency of such apparatus.

For a proper analysis and operation control of heat exchanging equipment in general, and steam surface condensers in particular, consideration must be given to certain variable factors entering into the operation of such equipment. A steam surface condenser in its usual form, comprises essentially a tubular shell having disposed therein a plurality of tubes so arranged as to allow for an unrestricted flow therethrough of a cooling medium, usually water, and affording means for the introduction to the free space within the shell of water vapor or steam. The steam coming into contact with the outer surface of the water tubes condenses thereon, and flows away as condensate or liquid water, due to a sufficient flow of heat from the vapor body outside the tubes to the cooler liquid flowing within the tubes. In the ordinary operation of steam surface condensers in conjunction with other power plant equipment, such as the steam engine or steam turbine, the heat taken up by the cooling water is essentially the latent heat given up by the steam in condensing and no attempt is made, nor is it usually desired, to cool the condensate. Air and other non-condensable gases are usually present in the steam to a small extent and also enter the condenser by reason of partially ineffective packing at connections and other sources of leakage. Such non-condensable gases as do find their way into the condenser shell, are removed by a vacuum pump provided for the purpose. A condensate pump is also provided for the purpose of removing from the condenser shell, the condensed steam. Although the general purpose of the condenser and its auxiliary apparatus is twofold, namely, to recover the condensate and to maintain the lowest possible back pressure on the prime mover to which it is connected, the second object mentioned is usually by far the most important.

In order that the condenser shall always fulfil adequately its function of maintaining the high-

est possible vacuum or, in other words, the lowest possible back pressure on the prime mover, it is essential that some means be available for at least a periodic thermal analysis of the apparatus in order that a careful check may be made upon its performance. Under the present practice, this necessary thermal analysis entails long and involved engineering calculation by a competent technical man and the results are not always to be completely relied upon. Hence, the continuous check, which should be made upon condenser performance, is all too frequently foregone altogether, with a resultant loss in general plant efficiency and a consequent increase in operating costs.

The transfer of heat, from one body of matter to another through a dividing wall separating the two masses, is quantitatively expressed by the familiar form of Newton's law which assembles, in general relationship, the several variable factors involved:

$$\frac{Q}{\theta} = HA \Delta t$$

where

$$\frac{Q}{\theta} =$$

Heat transferred from the mass of higher temperature to the mass of lower temperature, in unit time, and expressed as B. t. u. per hour (British thermal units).

θ = Time of operation expressed as hours.

H = Overall coefficient of heat transfer for the particular device concerned, expressed as B. t. u. per hour per square foot of effective surface per degree Fahrenheit temperature difference.

A = Effective area of heat transfer surface, expressed as square feet.

Δt = Effective temperature driving force or mean temperature difference in the direction of heat flow. Sometimes referred to as "heat head", and expressed as degrees Fahrenheit.

While the factor A is usually a constant for any given device or piece of equipment, the factors H and Δt are variables whose value, at any time θ , is dependent upon the thermal and physical characteristics of the two bodies of matter involved, and, to a lesser extent, also dependent upon the physical and thermal characteristics of the dividing wall. It is therefore necessary, before any thermal analysis of a condenser can be made, to determine the functional relationships existing between the factors H and Δt and their respective independent variables. The two sets of variables, expressed as their respective func-

tions, must then be reduced to the proper dimensional units, after which the performance of the condenser may be calculated.

My invention is predicated upon a simplified system which I have devised for the calculation of the operating characteristics of heat interchangers from operating data; and may be considered to comprise this system in conjunction with its adaptation to thermal, electrical, and mechanical devices, in proper combination for the integration of the several variables involved, to indicate a measure of the progressive performance of the condenser. Due to the simplicity of the new functional relationships, which I have derived from a consideration of well-known thermodynamic principles, the accuracy of the results, whether such results be attained by ordinary computation or be indicated by mechanical or electrical integration of the variables, is considerably enhanced.

I will now present the derivation of my system of calculation in the thermal analysis of equipment, designed to effect interchange of heat between two or more bodies of matter, using, for the purpose of arriving at a clear visualization of the system, a steam surface condenser as an illustrative and typical heat transfer apparatus. It is to be clearly understood, however, that the system, in its mechanical interpretation as well as in its essential features, is equally applicable to other forms of heat transfer apparatus and I do not hereby limit the scope of my invention to the particular type of apparatus mentioned.

As outlined above, the functional inter-relationship of the variables involved may be expressed in the general form of Newton's law:

$$\frac{Q}{\theta} = HA\Delta t$$

Using one operating hour as a basis, the general expression becomes $Q = HA\Delta t$ where Q is now the amount of heat transferred per unit of time.

In a steam surface condenser there are three measurable temperatures directly affecting the proper evaluation of the factor Δt . These are (1) the temperature of the steam (t_s), (2) the inlet temperature of the cooling water (t_i), and (3) the outlet temperature of the cooling water (t_o). According to well established thermodynamic principles, the mean temperature difference over a period of operation is a functional relation of the temperatures involved expressed as

$$\Delta t = \frac{(t_s - t_i) - (t_s - t_o)}{\log_e \frac{(t_s - t_i)}{(t_s - t_o)}} = \frac{(t_o - t_i)}{\log_e \frac{(t_s - t_i)}{(t_s - t_o)}}$$

where $\log_e$ indicates the natural logarithm. Defining TR (temperature rise of the cooling water) as $(t_o - t_i)$ and, TD (temperature difference—between steam and inlet cooling water) as $(t_s - t_i)$ then

$$(TD - TR) = (t_s - t_i) - (t_o - t_i) = (t_s - t_o)$$

Replacing the original expressions with their equivalents, the mean effective temperature difference becomes:

$$\Delta t = \frac{TR}{\log_e (TD - TR)}$$

Calling the gallons of cooling water flowing per minute G , the heat transferred from the steam to the cooling water in the unit operation time (one hour) will be:

$Q = (G)(500)(TR)$ where the factor 500 is the conversion factor necessary to express Q as B. t. u. per hour.

The original general form of Newton's law may now be expressed, in terms of the new variables, as

$$(G)(500)(TR) = \frac{(H)(A)(TR)}{\log_e \frac{TD}{(TD - TR)}}$$

or,

$$\frac{(H)(A)}{(500)(G)} = \log_e \frac{TD}{(TD - TR)}$$

Setting the expression

$$\log_e \frac{TD}{(TD - TR)}$$

equal to a variable calculation factor K , the performance of the condenser is then indicated by:

$$\frac{(H)(A)}{(500)(G)} = K$$

The performance for any heat interchanger under any given conditions of operation will be dependent not only upon the factors arising out of the physical and thermal characteristics of the materials involved but will also be influenced by factors arising from the accuracy of the original designing and from the cleanliness of the heat transfer surface at any particular time. A laboratory perfect condenser may be defined as one in which the loss of useful work during the operation of the apparatus is reduced to an absolute minimum. Such a condenser is designed in strict accordance with fundamental thermodynamic principles, and is so constructed as to preclude the possibility of any loss of useful work due to a variance during the operation of all factors indirectly affecting the thermal operating characteristics of the condenser as well as the variance in operating conditions directly affecting the performance. Such a condenser, for example, would comprise the usual shell but contain a single water tube in place of the multiplicity of tubes usually present, in order to properly allow for the effect of steam pressure drop through the shell upon the heat transfer mechanism. With respect to operating conditions, such a condenser will always be maintained under ideal conditions of cleanliness, and thus will serve as a criterion by which to judge the overall effectiveness of performance of any condenser in industrial use. The comparison of performance under identical operating conditions with respect to water temperature and water rate may be expressed as the overall efficiency of the industrial condenser. Expressed in terms of effective overall coefficient of heat transfer, the efficiency of a particular condenser in operation may be regarded as the ratio of the operating heat transfer coefficient (H) to the heat transfer coefficient which would be attained by a laboratory condenser under identical operation conditions. As previously pointed out, the ratio of the calculation factor (K) of the condenser in operation to the K for a laboratory perfect condenser can be shown mathematically to be identical with the ratio of the respective values of H . I prefer, however, to express the efficiency of a condenser as the ratio of the calculation factor (K) of the condenser in operation to the K for a laboratory perfect condenser. It will be seen, as the exposition of my invention proceeds, that this affords

a much more satisfactory measure of the efficiency in that the ratio of the respective calculation factors is more adaptable to mechanical interpretation.

For convenience in evaluating K, either mechanically or otherwise, a new relationship may be set up, involving the factors TR and TD aforementioned and K, the practical significance of which will be more fully apparent later.

Let the ratio of the temperature rise TR to the temperature difference TD be called R, which I prefer to term the condenser ratio. Then

$$\frac{TR}{TD} = R$$

By definition the calculation factor K is functionally related to the condenser ratio R, which relationship can be shown, by simple substitution of equivalent terms in the proper equations, to be

$$K = \log_e \frac{1}{(1-R)}$$

Having thus derived a relationship between K and R there is available therefore a means of determining K, the product of a multiplicity of operating variables often difficult to accurately determine, from R, the ratio of but two operating variables, the determination of which is simple and accurate.

Considering again the relation previously set up;

$$\frac{(H)(A)}{(500)(G)} = K$$

it will be seen that the group of variables comprising the left side of the equation will, when determined, occasion an evaluation of K for any conditions of operation. Inasmuch as A is fixed for a given condenser, the factor 500 is constant, and H is dependent upon the cleanliness of the tubes, the water temperature, and the water rate, with which it varies within the range of values met in industrial operation directly as the square root of G, the above expression may be rewritten as

$$\frac{H_o E}{\sqrt{G}} = K$$

where, H_o is an arbitrarily defined coefficient characteristic of a given condenser and varying only with the water temperature and, E is the overall efficiency of the condenser at any given time in its period of operation and is dependent upon the cleanliness of the tubes and imperfections in design.

From an inspection of this relationship it follows that the ratio of the value of K, for a condenser in operation at any given time, to the value of K, for a laboratory perfect condenser operating under identical conditions of water rate and water temperature, will give the overall efficiency of the condenser in operation. It is then only necessary to provide thermal, mechanical, and electrical means for indicating this ratio in order to accurately determine and continuously indicate the overall efficiency of a condenser.

As above indicated the overall efficiency of the condenser being observed under actual working conditions is determined by obtaining the ratio of the value of K for the condenser in operation at a given time, to the value of K for a laboratory perfect condenser operating under identical conditions of water rate and water temperature.

This ratio may be expressed in the form of an equation as follows:

$$E = \frac{\log_e \frac{1}{(1-R)}}{\frac{(H)(A)}{(500)(G)}}$$

Since the value of (H) for the laboratory evaluation of the condenser performance can be written as:

$$H = (\sqrt{G})(\text{function of } t_o)$$

and since the area (A) and the constant (500) do not vary for a particular installation, the efficiency equation can be written:

$$E = \frac{\log_e \frac{1}{(1-R)}}{\frac{(\text{function } t_o)}{(\sqrt{G})}}$$

The derivation of the values of the various factors in the above equation will be described in further detail hereinafter.

Before presenting a description of a preferred form of device by which I achieve the ultimate object of my invention, it should be pointed out that the overall efficiency of a condenser thus obtained is the product of two conditions occasioning loss of useful work in the unit. These may be expressed in terms of efficiency and are conveniently referred to as the design efficiency and the operating efficiency of the condenser respectively. The design efficiency is a measure of the useful work lost due to imperfections in design which may be due either to faulty engineering or to sacrifice of efficiency in the interest of economical construction. With the engineering talent available today, the first factor seldom enters the case and any loss of efficiency due to design imperfection is usually a matter of plant economics. Whatever the cause, the loss, though not constant, is one beyond the control of the operator and thus is of less real interest than the operating efficiency. The loss of useful work due to this factor is dependent largely upon the cleanliness of the tubes, and to a certain extent upon air leakage during operation, as affecting the rate of heat transfer from the steam to the cooling water and is within the power of the operator to control. The combined effect of the two efficiencies determine the overall performance of the condenser at any given time.

In the attached drawings,

Figure 1 is a wiring diagram depicting the essential elements of an adaptation of the invention.

Figure 2 is a line diagram showing in some detail one form of device for occasioning evaluations of K for a laboratory perfect condenser in accordance with variations in water rate.

Figure 3 is a graphical representation of the mathematical relation between the factors K and R derived directly from the equation

$$K = \log_e \frac{1}{1-R}$$

Figure 4 is a graphical representation of the relation between the heat transfer coefficient of the condenser expressed as B. t. u. per square foot per hour per degree Fahrenheit mean temperature difference, and the inlet temperature of the cooling water. It will be noted that the graph shows four curves, thus allowing for the effect of condenser tube diameter. As indicated, all values are based upon a water velocity of seven feet per second. With different water velocities obtaining in any particular case, the value of the coefficient read from the graph is corrected as here-

tofore indicated by multiplying the factor obtained from the graph by the ratio of the square roots of the water velocities involved.

The mechanical adaptation of my invention in indicating condenser efficiencies may comprise, as depicted in Figure 1, a plurality of Wheatstone bridges in proper combination for effecting the desired result. Electrical balance throughout such an indicating system is obtained by means of galvanometers, as indicated in Figure 1, which may be used in combination with mechanical contrivances for occasioning changes, in the position of suitable resistance contacts, commensurate with the degree of change in the external force occasioning the original change in the deflection of the galvanometer.

Referring to Figure 1, B is a source of electromotive force, as, for example, a battery; 10 is a wire or ribbon of uniform resistance throughout its length, provided with movable contact arms TR and TD, the positions of which serve for the indication of the several temperature factors involved; 12 is a second element of uniform resistance throughout its length for the indication of the factor R as proportional to the potential at any point of contact with the movable arm shown; 14 is a third element of varying resistance throughout its length and provided with the movable contact arm, K_o, the position of which serves for the indication of the operating value of K in accordance with the proportionality existing between K and R; 16 is a fourth element also of varying resistance throughout its length and provided with the movable contact arm K_p, the position of which serves for the indication of the value of K for a laboratory perfect condenser at maximum water temperature, in accordance with changes in water rate; 18 is a fifth resistance element, also varying throughout its length and provided with the movable contact arm K_{gt}, the position of which serves to indicate values of K for a laboratory perfect condenser at the existing water temperature and water rate; and 20 is a sixth resistance element of uniform resistance throughout its length and provided with the movable contact arm E the position of which serves for indicating the efficiency of a condenser as the ratio of the operating value of K to the laboratory perfect value of K. 22 and 24 are control resistances, which, together with the movable arms C and D provide means for balancing the Wheatstone bridges of which they form a part. At the indicated points fixed resistances 13, 15, 17, 19, 21 and 23 are optionally provided for the more convenient adaptation of the proportionality existing between the particular factor being represented by the particular resistance and magnitude of that resistance. The respective values of these fixed resistances will usually be different and are determined by the necessities of the particular part of the circuit involved.

When the device is used in the determination of condenser efficiency the positions of the contact arms TR and TD on the resistance element 10 indicate respectively values of cooling water temperature rise and of difference in temperature between the steam being condensed and the cooling water entering the condenser. The voltage drop along the resistance 10 as far as the position of the movable contact arm TR will then represent the temperature rise factor and the voltage drop along the resistance 10 as far as the position of the movable contact arm TD will represent the temperature difference factor.

An indication of the value of the condenser

ratio R, as proportional to the voltage drop along the resistance 12, as far as the position at any particular time of the movable contact arm R, is occasioned, is indicated in Figure 1, according to the well known principles governing the operation of Wheatstone bridges. Inasmuch as the entire range of the ratio R from zero to unity will not usually be encountered in commercial operation, the fixed resistances 13 and 15 are incorporated into the system in order that the length of the resistance 12 will represent the range in the values of R of operating interest. In ordinary condenser practice, this range will have the limits 0.2 and 0.85. A scale 26 may be placed along the resistance element 12 if desired, in order to provide means for reading directly the value of the condenser ratio R under any given conditions of steam, inlet water, and outlet water temperatures.

The evaluation of K for the condenser in operation is occasioned by means of the resistance element 14 and the movable contact arm K_o. As indicated in the early part of this specification, a definite relationship exists between K and R, and the resistance element 14 is so constructed as to vary throughout its length in accordance with this relationship. The contact arm K_o is rigidly attached to, but electrically insulated from, the movable contact arm R, and since the resistance of the element 14 varies throughout its length in accordance with the relationship existing between K and R, the operating value of K under any given conditions will always be represented by the voltage drop along the resistance 14 as far as the position assumed by the movable contact arm K_o. The fixed resistances 17 and 19 are of such value as to make the length of the resistance element 14 correspond to the range of values of R indicated by the resistance element 12. Movement of the contact arm R in accordance with changes in TR and TD will then occasion a simultaneous movement of the contact arm K_o such that the voltage drop along the resistance element 14 as far as the assumed position of the arm K_o will always represent the operating value of K corresponding to the determined value of R. If desired, a scale (not shown) may be placed along the resistance element 14 for direct indication of the operating value of K at any particular time. The contact arm K_o is electrically connected with the contact arm E on resistance element 20. A galvanometer A₁ is placed in this connection, as shown in Figure 1, so that the circuit thus created may be balanced, and, when so balanced, the voltage drop along the resistance element 20 as far as the assumed position of the arm E will be equal to the voltage drop through the fixed resistance 17 and along the resistance element 14 as far as the assumed position K_o at any particular time.

The next part of the device comprises a series of resistance elements providing means for the determination of the value of K for a laboratory perfect condenser under conditions of water temperature and water rate existent at any particular time, and further means for the representation of this value of K for a laboratory perfect condenser by the voltage drop, at any particular time, along the entire length of the resistance element 20.

The first of these necessary elements is embodied in the element 16, the resistance of which varies throughout its length in accordance with the relationship existing between K and G (the water rate). This element is designed to evaluate K for a laboratory perfect condenser at maxi-

mum inlet water temperature in accordance with changes during operation in the cooling water rate. In other words, the voltage drop along the resistance element 16 from the negative lead of the battery B to the assumed position of the arm K_p , will represent the value of K for a laboratory perfect condenser at maximum inlet water temperature and the prevailing water rate. As has previously been indicated, K will vary with the water rate inversely as the square root of that factor. The resistance of the element 16 therefore will vary throughout its length in accordance with this relationship between K and the water rate. Any desired mechanism, of which a preferred form is shown in Figure 2, may be used to occasion movement of the contact arm K_p in accordance with operating variations in the cooling water rate through the condenser tubes. The resistance element 16 may be of any convenient type and may be constructed in any manner desired by those familiar with the art. The fixed resistance 21 may be optionally inserted in this part of the circuit to limit the range of voltage drop along the element 16 to that range representative of values of K commonly encountered in commercial operation.

The elements 18 and 22 in conjunction with the element 16 aforementioned form a Wheatstone bridge with control galvanometer A_2 located as indicated in Figure 1. This bridge is designed to provide means for representing the value of K for a laboratory perfect condenser at maximum water temperature and the prevailing water rate, previously indicated by the voltage drop from the negative lead of the battery B to K_p along 16, as the voltage drop at any particular time through the fixed resistance 23 and along the entire length of the element 18. The resistance of the element 18 varies throughout its length in accordance with the relation existing between K and the inlet water temperature or t_i . The element 22 is of uniform resistance throughout its length. When this bridge has been electrically balanced, after movement of the contact arm K_p along 16, by proper adjustment of the resistance 22, the voltage drop through the fixed resistance 23 and throughout the entire length of 18 will represent the value of K for a laboratory perfect condenser at maximum water temperature and the prevailing water rate as indicated above. Consequently, the voltage drop along the element 18 as far as the assumed position of the contact arm K_{gt} at any particular time will represent the value of K for a laboratory perfect condenser under the prevailing conditions of water rate and inlet water temperature. Movement is imparted to the contact arm K_{gt} , in accordance with the variations in the inlet water temperature.

The distribution of resistance along the element 18 will, as indicated above, be such as to make the voltage drop along the resistance proportional to the relation between K and t_i . This distribution will not be uniform and is determined by the relationship between K and t_i , which in turn is computed from the characteristics of the particular condenser involved and the relation between the heat transfer coefficient and the inlet water temperature. The manner of determining this distribution is more fully described in the specific example of the operation of my device presented hereinafter.

The elements 20 and 24, in conjunction with the element 18 aforementioned, form a Wheatstone bridge with control galvanometer A_3 located as in Fig. 1. This bridge is designed to

provide means for representing the value of K for a laboratory perfect condenser at the prevailing water rate and water temperature, previously indicated by the voltage drop from the negative lead of the battery B to K_{gt} along 18 as the voltage drop at any particular time along the entire length of the element 20. The resistance of the element 20 varies uniformly throughout its length, as does the resistance of the element 24. When this bridge has been electrically balanced for the movement of the contact arm K_{gt} along 18 by proper adjustment of the resistance 24, the voltage drop throughout the entire length of 20 will represent the value of K for a laboratory perfect condenser at the prevailing water temperature and the prevailing water rate as indicated above. The element 20 is further provided with a movable contact arm E, which is connected through the galvanometer A_4 to the movable contact arm K_o on element 14. These two elements then form a Wheatstone bridge controlled by the galvanometer A_4 . When this bridge is electrically balanced the voltage drop along the resistance element 20, as far as the assumed position of the arm E will be equal to the voltage drop along the resistance 14 as far as the assumed position of K_o at any particular time. Thus the voltage drop along the element 20 as far as the position of the arm E will be a measure of the value of K_o or the operating value of K at any particular time. A scale 25 may be, if desired, placed along the element 20, which when properly graduated, will give values of the condenser efficiency determination as the ratio of the operating value of K to the value of K for a laboratory perfect condenser.

From the information set forth above we may now proceed to derive the values of the various factors in the equation:

$$E = \frac{\log_e \frac{1}{(1-R)}}{(\sqrt{G})}$$

The numerator of the above equation is determined through resistance elements 10, 12 and 14, and transferred as a voltage to contact E on element 20. The denominator is determined through elements 16 and 18, and transferred as a voltage to the right hand end of element 20. The efficiency desired is then obtained by balancing the circuit by means of the galvanometer A_4 , thereby obtaining the ratio of the operating value of K to the laboratory value of K for the condenser in question.

Further, it will be noted that element 10 is used to determine R, as a voltage, element 12 to obtain an indication of R and transfer it through connected contacts R and K_o , and element 14 is used to determine the operating value of K as a voltage. The element 16 is used to determine and properly introduce into the circuit the value of

$$(\sqrt{G})$$

and 18 is used to determine the (function t_o).

As an illustration of a manner in which a device of the type described may be adapted to the determination of the characteristics of a steam surface condenser, the following specific example is presented. It is to be clearly understood, however, that I am not in any way limited in the scope of my invention by the specific data given in this example or by such operating limi-

tations as are necessary to define the operation in this particular case.

Assume that the steam surface condenser involved conforms to the following specifications:

- 5 15,000 square feet of condensing surface.
2980 tubes—18 gauge— $\frac{7}{8}$ diameter.

Two pass water circuit designed for 15,000 G. P. M. of circulating water (this corresponds to a linear water velocity of 6.8 feet per second).

- 10 Range in water quantity—15,000 G. P. M. to 7,000 G. P. M.

Range in water temperature 40° F. to 90° F.

- From the above data, and the curves and mathematical relationships incorporated in this specification, one familiar with condenser design and operation can compute the following values of K based on the performance of a laboratory perfect condenser.

	40° F.	70° F.	90° F.
(15000 G. P. M.) Water vel.	6.80 /sec.	6.80 /sec.	6.80 /sec.
H.	865	1030	1105
K.	1.73	2.06	2.21
(10000 G. P. M.) Water vel.	4.53 /sec.	4.53 /sec.	4.53 /sec.
H.	705	840	900
K.	2.12	2.52	2.70
(7000 G. P. M.) Water vel.	3.17 /sec.	3.17 /sec.	3.17 /sec.
H.	590	703	752
K.	2.53	3.01	3.22

- 30 For an actual condenser in operation the factor R will vary between 0.85 and 0.20. From Fig. 3, the corresponding values of K will be 1.90 and 0.223.

- Thus the total range of K to be encountered will be 0.223 to 3.22. Then assuming the battery to have a potential of 10 volts, and further assuming each circuit to have a total resistance of 100 ohms, the distribution of resistance along the various elements indicated in the wiring diagram Fig. 1, may be determined in the following manner:

- Considering the resistance element 12, together with the fixed resistances of 13 and 15 completing the element designed to indicate values of R, the resistance will be so distributed as to make the voltage drop along the element 12 proper equivalent to a range in values of R from 0.20 to 0.85. In other words, considering a value of unity for R as equal to a voltage drop of 10 volts, then the voltage drop through the fixed resistance 13 must be 2.0 volts, the voltage drop through the resistance 15 must be 1.50 volts, and the voltage drop throughout the resistance 12 proper must be 6.5 volts. Inasmuch as the total resistance of the circuit is set at 100 ohms, this means that the resistance of the element 12 will be 65 ohms, which will be uniformly distributed throughout the length of this element.

- In determining the distribution of resistance along the element 14, the relation between K and R as shown by Fig. 3 is considered, since points on the element 14 must indicate values of K_o corresponding to values of R indicated by points on the element 12. As indicated heretofore, the highest value of K to be encountered will be 3.22, which is a value of K for a laboratory perfect condenser under maximum conditions of operation. This is therefore represented by the full voltage of the battery, or 10 volts. The voltage drop at any point on the element 14 representing the value of K_o corresponding to a value of R on the element 12 will be determined by simple proportionality. For example, since a value of 1.90 for K_o corresponds to the highest value of R to be encountered, therefore

this value will be represented by a voltage drop of 5.90 volts. This value is obtained by multiplying the full voltage value of the battery, or 10 volts, by the ratio of 1.9 to 3.22. Similarly, the voltage drop representing the value of K corresponding to a value of R of 0.20 will be determined as 0.69 volts. Hence the resistance of the element 17 will be 6.9 ohms, the resistance of the element 14 will be 52.1 ohms, and the resistance of the element 19 will be 41 ohms. The resistance of 52.1 ohms for the element 14 will not be uniformly distributed throughout the length of this element, but the distribution may very readily be determined by means of the proportionality relationship indicated above. It is only necessary then to pick a number of points along this element and determine by proportionality the necessary resistance to that point required to give the desired value of K_o corresponding to a value of R indicated on element 12.

The element 16, together with the fixed resistance 21 constitute the means provided for the determination of the value of K for a laboratory perfect condenser at maximum water temperature and the prevailing water rate. These values have been shown above to be 3.22 for the minimum water rate to be encountered, or 7000 gallons per minute, and 2.21 for the maximum, or 15000 gallons per minute. Referring to Fig. 1, it will be noted that no fixed resistance is placed in this particular circuit at the left hand end corresponding to the fixed resistance 21 at the right hand end. This element is so arranged because it is desired to have the full voltage of the battery represent the maximum value of K to be encountered, which in this example is shown to be 3.22. The voltage drop through the fixed resistance 21 will then represent the value of K up to the minimum to be expected, or 2.21. By proportionality, this voltage drop will be 6.85 volts. The total resistance of this particular circuit will then be divided between the two portions of this element in the proportion of 68.50 ohms for the fixed resistance 21, and 31.50 ohms for the element 16 proper. Movement of the contact arm K_g along the element 16 is occasioned by means of a suitable mechanism, a suggested form of which is indicated in Fig. 2. This mechanism comprises essentially two cylinders N provided with flexible diaphragms L and conduits P leading to the water chambers W of the condenser S. A valve V is placed in an auxiliary line connecting the two cylinders with each other, to provide for venting in the event of air becoming entrapped in the first cylinder. The friction of the water flow, through the tubes of the condenser will occasion a loss of pressure so that the water pressure in the inlet box will be greater than that in the outlet box. These pressures are respectively transmitted to the cylinders adjacent each water box, and the pressure thus set up within the particular cylinder occasions a movement of the diaphragm. Any convenient lever arm arrangement, as for example, that shown in the drawings, is arranged to provide movement of the contact arm K_g along the resistance element 16, in accordance with changes in water pressure, which changes in pressure are a measure of changes in the rate of water flow. The factor K for a laboratory perfect condenser varies inversely as the square root of the water rate. This relationship may be allowed for either by the arrangement of the lever arm system or by so proportioning the distribution of resistance along element 16 as to express this relationship. In the

embodiment shown the latter alternative is employed. The contact arm K_g is influenced by pressure differentials that are approximately proportional to the square of the water velocity or water quantity flowing through the condenser tubes. In other words, the movement of K_g in the apparatus as shown is directly proportional to the difference in pressures in the cylinders N. Because of the distribution of the resistance along the element 16 so as to express the relationship above mentioned for the laboratory perfect condenser and the association therewith of the contact arm K_g which is moved in direct relation to the difference in pressures in the cylinders N as above stated, the position assumed by the arm K_g at any particular time will indicate the value of K for the laboratory perfect condenser for the water rate that is obtaining at that time. In order to show this value visually the contact arm K_g may be provided with an extension 16a which moves over a suitable scale 28.

The function of the resistance element 18, together with the fixed resistance 23 is, as has been heretofore indicated, to indicate values of K for the laboratory perfect condenser at the prevailing water rate and prevailing water temperature. The variation of this factor with the inlet water temperature is dependent upon the variation of the coefficient of heat transfer with changes in the inlet water temperature, according to the curves set forth in Fig. 4. The division of resistance between the fixed resistance 23 and the element 18 proper is determined in a manner similar to that used in treating the preceding elements. Then having determined the total amount of resistance to be incorporated in the circuit as resistance element 18 proper, the distribution of this resistance along the length of this element will be determined by the proportionality method used in arriving at the distribution of the other resistance throughout the elements.

The simplest manner of using the device in the determination of condenser efficiency is by manual operation thereof as follows: Four items of operating data are obtained at regular intervals (for example, hourly) from the condenser in operation. These items are:

- (1) The inlet temperature of the cooling water.
- (2) The outlet temperature of the cooling water.
- (3) The temperature of the steam.
- (4) The cooling water velocity or rate.

The several movable contact arms shown in Figure 1 are then positioned along their respective resistance elements in the Wheatstone bridge arrangement as follows: The position of the arm TR is determined by the value of item (2) minus item (1) and the position of the arm TD is determined by the value of item (3) minus item (1). The arm R is then moved along the element 12 until the galvanometer A_1 shows a zero reading. The arm K_o , being rigidly attached to the arm R, moves with the latter arm and is positioned thereby along the element 14. The position of the arm K_g is determined by the value of item (4) while the arm K_{gt} is positioned in

accordance with the value of item (1). The galvanometers A_2 and A_3 are then brought to zero reading by adjusting the setting of the contact arms C and D along the elements 22 and 24 respectively. Finally, the contact arm E is moved along the element 20 until the galvanometer A_4 shows a zero reading; and the efficiency of the condenser read directly from the scale 25. Scales 27, 28 and 29 may be advantageously disposed in operative relationship to the resistance elements 10, 16 and 18. The calibrations on these scales will be determined in accordance with the variables set up by such resistances in the manner hereinbefore described.

I claim:

1. In an apparatus for determining the operating efficiency of a steam surface condenser, means for obtaining in terms of electrical values the ratio between the temperature rise of the water and the temperature difference between the inlet water and steam temperatures, means for obtaining in terms of electrical values the operating efficiency of a laboratory perfect condenser at the prevailing water rate and water inlet temperature, and electrical means electrically connected to both of said means for comparing the resultant values to determine the operating efficiency of said condenser in terms of the operating efficiency of the laboratory perfect condenser under like operating conditions.

2. In an apparatus for determining the operating efficiency of a steam surface condenser; a Wheatstone bridge including a resistance having contacts adjustable in accordance with the observed temperature rise of the water and the temperature difference between the inlet water and steam temperature, and a balancing resistance to which the ratio between said factors is transferred in electrical terms; and a variable resistance associated with said Wheatstone bridge having an adjustable contact electrically connected to the balancing control of said bridge for setting up an electrical value proportionate to the ratio of said factors for a laboratory perfect condenser.

3. In an apparatus for determining the operating efficiency of a steam surface condenser, means for obtaining in terms of electrical values the ratio between the temperature rise of the water and the temperature difference between the inlet water and steam temperatures, means electrically connected to and controlled by said means for setting up the ratio between said factors in electrical terms proportionate to the ratio of the same factors for a laboratory perfect condenser, means for obtaining in terms of electrical values a calculation factor for a laboratory perfect condenser based on the prevailing inlet water temperature and prevailing water rate, and electrical means connected to said calculation factor-obtaining means and said last ratio-obtaining means to determine the efficiency of said condenser in terms of the efficiency of a laboratory perfect condenser under like operating conditions.

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