May 17, 1949. H. B. KOHN ET AL 2,470,495

CALCULATOR

Filed Sept. 13, 1946 2 Sheets-Sheet 1

Fig. 1.

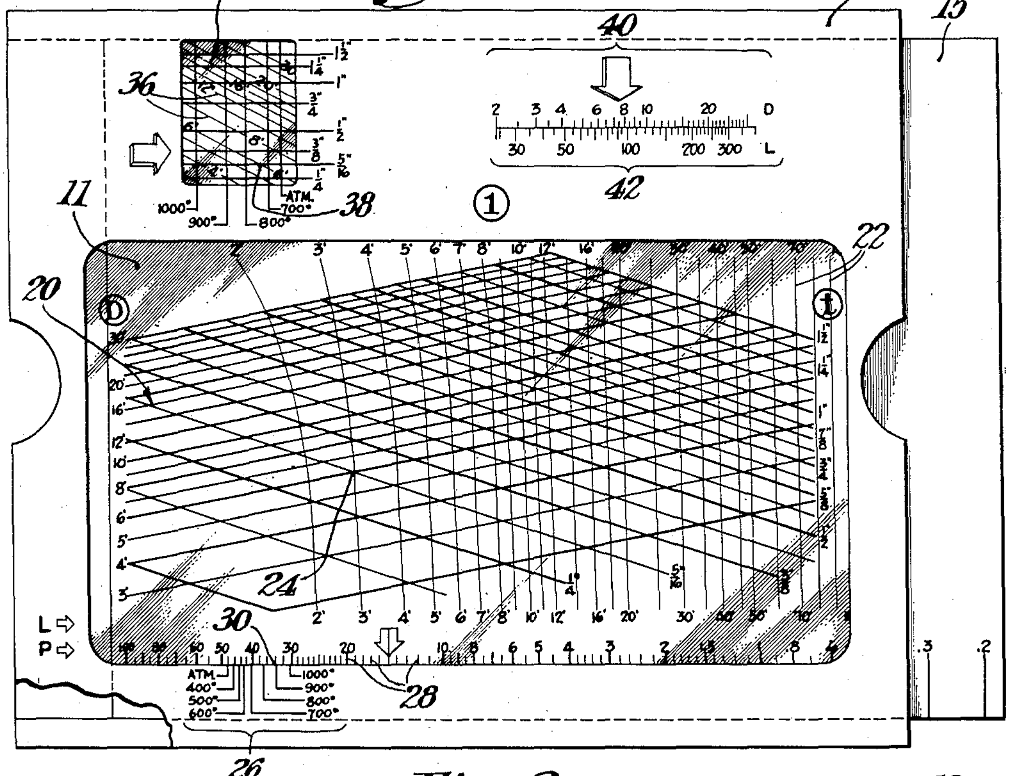

Fig. 2.

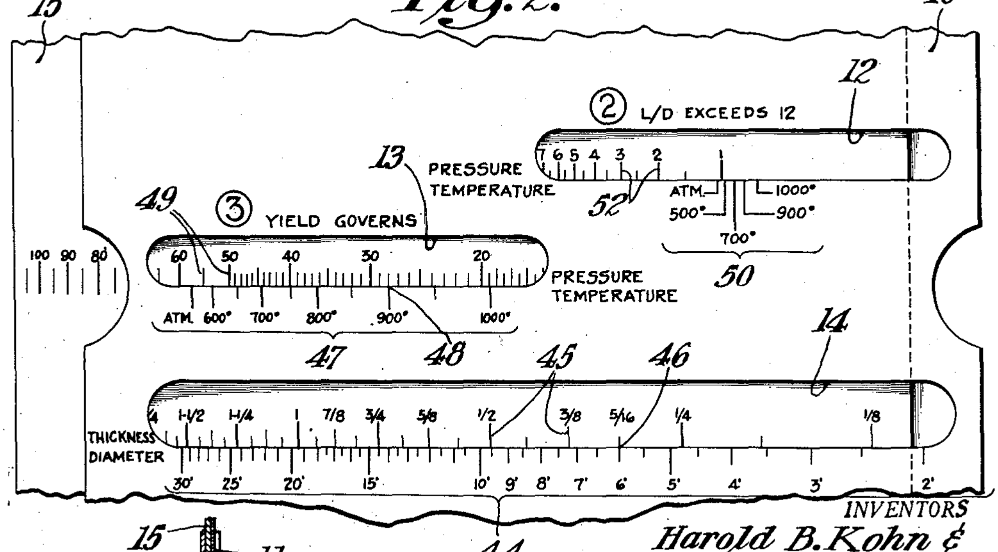

Fig. 3.

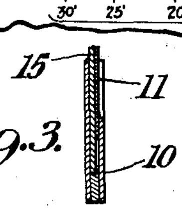

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Fig.4.

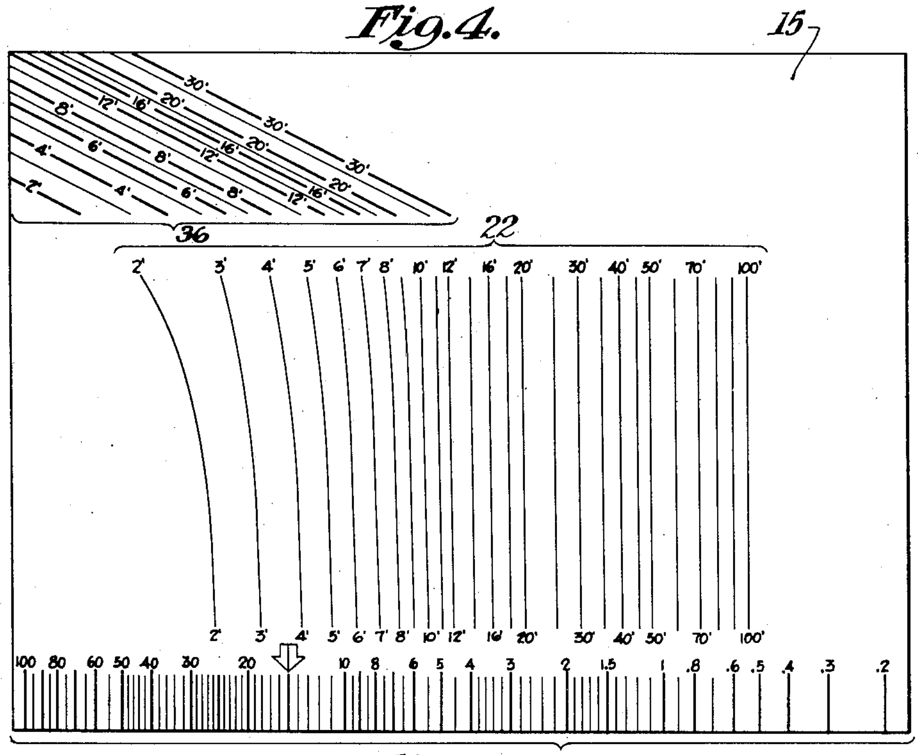
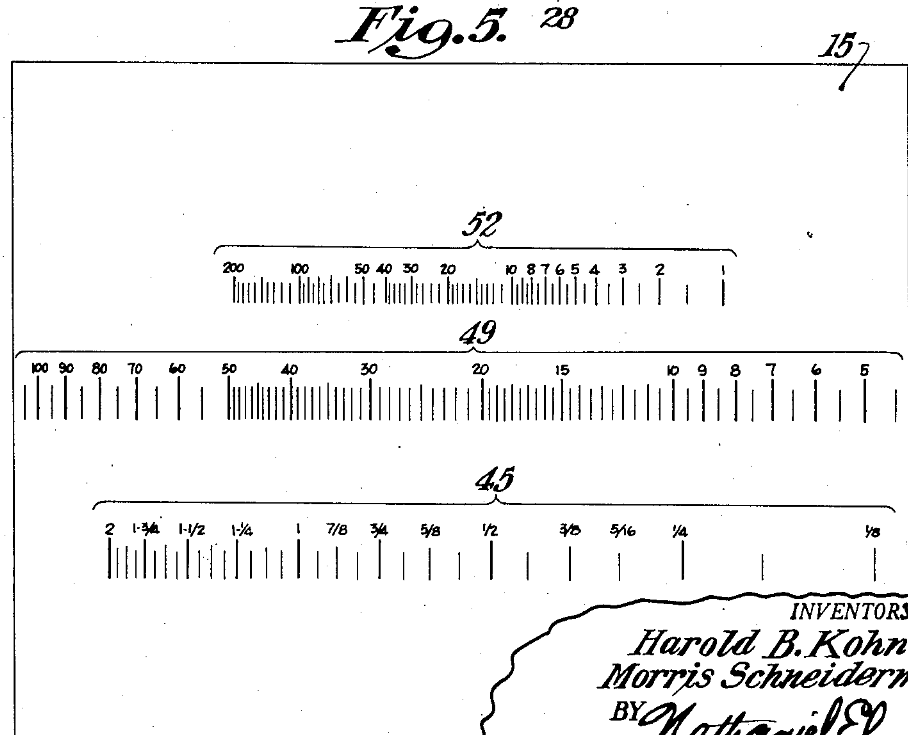


Fig.5.



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CALCULATOR

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Application September 13, 1946, Serial No. 696,862

3 Claims. (Cl. 235—61)

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This invention relates to a calculating device and is more particularly adapted for use in determining the safe external pressure and related factors for unfired pressure vessels in accordance with the API-ASME Code.

The API-ASME Code for unfired pressure vessels covers the design and construction of fusion welded unfired cylindrical vessels for petroleum liquids, and, or gases.

The principal factors which require consideration include the thickness of the vessel, the diameter, the yield strength of the metal, the modulus of elasticity, the working pressure, the corrosion allowance, and the factor of safety. The relationships between these factors are expressed under the code, in a series of formulae substantially as follows:

"The formula used to determine the working pressure for short vessels is:

$$4p=\frac{2Sy(t-c)/D}{1.05} \qquad (1)$$

where 'p' is working pressure, 'Sy' is the yield strength of the material; both being expressed in the same units. Formula 1 is merely the simple hoop stress formula with a 5 per cent reduction factor. This factor is based on both theoretical consideration and experience.

For vessels which fail by instability of the shell at stresses below the yield strength, the Windenburg formula, which takes into account tangential and axial stress, is used to determine the working pressure and is:

$$4p=\frac{2.42E}{(1-\mu^2)^{0.75}}\times\frac{((t-c)/D)^{2.5}}{L/D-0.45((t-c)/D)^{0.5}} \qquad (2)$$

where the length 'L,' thickness $(t-c)$, and diameter 'D' are all expressed in the same units, the working pressure 'p' is expressed in the same units as the modulus of elasticity 'E.' μ is Poisson's ratio.

This formula may be simplified by substituting an average value of $\mu=0.25$ for the entire temperature range. It then becomes:

$$4p=\frac{2.54E((t-c)/D)^{2.5}}{L/D-0.45((t-c)/D^{0.5}} \qquad (2a)$$

These formulas are based on an L/D ratio not to exceed 12.

The formula used to determine the working pressure for vessels with an L/D ratio greater than 12 at normal temperature is:

$$4p=\frac{1}{1.27}\times\frac{2E}{1-\mu^2}[(t-c)/D]^3 \qquad (3)$$

This is the generally accepted Bresse-Bryan

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theoretical formula for geometrically perfect, long thin tubes under external pressure with a 27 per cent reduction factor. This factor makes Formula 3 identical (at normal temperatures) to the empirical equation of Stewart and Carman derived from tests on long commercial tubes and pipes. It has long been incorporated in the Boiler code, and it has been satisfactory in practice. By substituting the average value of $\mu=0.25$ in (3), it becomes:

$$4p=1.68E\left[\frac{(t-c)}{D}\right]^3 \qquad (3a)$$

It will be apparent that the determination of the various factors for the safe design of any external pressure unit involves a substantial number of operations which are largely trial and error calculations, and which may or may not give a correct answer. This is particularly so in view of the fact that the vessels subjected to external pressure can thus be classed in three groups as follows:

(*a*) Short vessels, with heads or stiffeners so close together that they prevent the collapse of the shell until it is stressed to the yield point. The strength of these vessels is practically independent of the length, and depends upon the $(t-c)/D$ ratio only. Also vessels subject to very high external pressure where the $(t-c)/D$ ratio is over 0.04. Equation 1 applies.

(*b*) Vessels of intermediate length between heads or stiffeners. The strength of these vessels not only depends on the $(t-c)/D$ ratio, but on the L/D ratio as well. Equation 2*a* applies.

(*c*) Long vessels with heads or stiffeners so far apart that they do not exert an appreciable influence on the central portion of the shell. The strength of these vessels is independent of the length and depends on the $(t-c)/D$ ratio only." Equation 3*a* applies.

In order to aid in the prompt checking of vessels, we have devised a simple compact calculator which is based upon the foregoing formulae, so arranged that by simple motions of the calculator which has the characteristics of a slide rule, it is possible to quickly and accurately determine whether or not any particular conditions are safe.

It is the principal object of our invention to provide a simple compact calculator which will solve certain complex equations by a simple single adjustment which would ordinarily require multiple and tedious operations of a mathematical nature.

A further object of the invention is to provide a calculator which will permit a prompt check to determine which of several equations applies to the particular variables in accordance with the determination of the above "Code."

Further objects and advantages of our invention will appear from the following description of a preferred form of embodiment thereof taken in connection with the attached drawings in which:

Figure 1 is a plan view of our calculator showing the transparent face and the adjustment slide in a particular set position.

Figure 2 is a partial plan view of the back of the calculator showing the slide in a particular position.

Figure 3 is a cross sectional view showing the arrangement of the slide.

Figure 4 is a plan view of the graphs shown on the slide (front side).

Figure 5 is a plan view of the scales shown on the slide (rear view).

In the following description the characters have the following meanings:

L=length in inches
D=diameter in inches
t=thickness, in inches, after corrosion and is equivalent to $(t-c)$ of Code
Sy=yield strength
E=modulus of elasticity
$4p$=collapsing pressure
p=safe working pressure

The yield strength varies with the temperature above a temperature of 550° F., and such variations have been taken into account based on the chart which is shown in Figure 25 of the API-ASME Code, 1943 edition, page 84.

The modulus of elasticity varies with temperature and its values have been chosen from Figure 26 of the API-ASME Code, 1943 edition, page 85.

The calculator in accordance with our invention consists of an envelope generally indicated at **10** having a transparent portion, generally indicated at **11**, on its face, as shown on Fig. 1 and having slots **12**, **13**, and **14** in its back as shown on Figure 2. The calculator also includes a slide generally indicated at **15** which is provided with certain graphs shown in Figures 4 and 5 hereinafter to be designated. The first graph or grid generally indicated at **20** in Figure 1 is drawn on the transparency **11** in the face of the envelope **10**.

This grid is plotted in accordance with the parametric equation:

$$X=\log=\frac{t^{2.5}}{D^{1.5}}\times 10^{6}$$

$$Y=\log .45\sqrt{tD}$$

The thickness (t) is plotted for the customary thickness from ⅛″ to 1½″. The abscissa and ordinate values are plotted from any convenient common origin. It is to be noted that the "Code" does not apply to vessels with external working pressures of less than 15 pounds per square inch. However, it is important to determine the safe external pressure of all vessels so as to indicate where vacuum relieving devices are required. The diameter (D) is selected for customary sizes ranging from 2 feet to 30 feet. It is further noted that the "Code" does not apply to vessels having an inside diameter of 6 inches or less.

Cooperating with the transparent grid on the front face of the envelope **10** are the curves shown in Figure 4 on the slide **15**. The curves **22** cooperate with the grid **20** as the lines of one are superimposed over the lines of the other, and are adjustable by moving the slide in and out of the envelope.

Curves **22** are plotted for various lengths of vessels in accordance with the following formula:

$$Y=\log\,(L-\text{antilog}\,X)$$

In this case, Y is in the same unit value and is based on the same origin of coordinates as the main grid **20**.

The face of the envelope **10** also has a temperature scale **26** which is graduated from atmospheric to 1000° F. This may be plotted as follows:

$X=-\log E$ (values of E being obtained from Fig. 26 of the code in terms of varying temperatures).

A cooperating scale **28** is graduated in terms of pressure and is mounted on the slide **15**. The limits as shown are from 0.2 to 100 pounds per square inch absolute, the arrow **29** indicating the atmospheric line. This scale is plotted as follows:

$$X=-\log p$$

An example of the operation of this calculator is now given for the determination of the safe external pressure to which a vessel may be subjected which has a shell thickness after corrosion of $\frac{5}{16}$″, an outside diameter of 6′-0″ and an unsupported length between stiffeners of 3′-0″ to operate safely at 900° F.

The first point to establish is the intersection of the thickness-diameter relation between the $\frac{5}{16}$″ line and the 6 foot line. This is the point **24** on the grid **20**. The slide is then moved until the length of the 3 foot line shown on the curves **22** coincides with the point **24** as represented in Figure 1.

It is then possible to read from scale **26** on the face of the envelope **10**, the coincidence at **30** between the 900° F. line on scale **26** and the safe effective pressure indication of **34** pounds per square inch shown on the (p) or pressure scale **28**.

This reading would be the answer if the strength of vessels of short and intermediate length were always dependent upon both the ratio of thickness to diameter as well as the ratio of length to diameter. If, however, the length of vessel is below a predetermined amount, only the ratio of thickness to diameter applies and it is thus necessary to determine whether or not the scales on the face of the calculator are controlling.

For this purpose we provide a "check" grid **34** which consists of crossing lines representing thickness and temperature. The lines representing temperature which may be plotted within the customary limits of atmospheric to 1000° F. are graduated as follows:

$$P=\log\,133.5\frac{E}{Sy}\times 10^{-6}$$

As before mentioned, the values of Sy and E were obtained from Figs. 25 and 26 of the "Code" in terms of various temperatures concerned.

The lines representing thickness, which are graduated from ¼″ to 1½″ are plotted as follows:

$$Y=\log t$$

Cooperating with grid **34** are the curves **36** on slide **15** which are laid out as normal diameters in feet varying from 2 feet to 30 feet. These lines are based on the same origin of coordinates as the small t lines of the check grid **34**. The parametric equations used are:

$$X = \log D/t$$
$$Y = \log t$$

In checking the setting of the grid **34** with curves **36**, it will be seen that the intersection of a diameter of 6 feet shown on the curves **36** with a thickness of $\frac{5}{16}$'' at point **38** is to the right of the 900 F. index line. This indicates that the pressure previously read at point **30** does not govern as the length is not controlling and the ratio of t/D controls. It is necessary, therefore, to use the rear face of the calculator to obtain the proper safe external pressure from the scales, "yield governs," or if L/D exceeds 12, then the safe external pressure is obtained from such scales.

It is now necessary to determine which of the secondary scales control. Scales **40** and **42** on the face of the envelope are direct reading fixed proportional scales of length and diameter. These show that a diameter of 6 feet corresponds to a length of 72 feet on the L scale. As the original problem concerned a length of only 3 feet, the "L/D exceeds 12" scale therefore is not controlling. Thus "yield governs" is the controlling scale in the particular problem. In such case only the rear face of the calculator, as shown in Figure 2 is used.

In the particular problem lower scale **44** is used to bring into coincidence a thickness of $\frac{5}{16}$'' shown on scale **45** on slide **15** with 6' diameter as shown at point **46**. Then, by reference to scale **3** "yield governs." It will appear that for the 900° F. temperature on scale **47** on envelope **10**, a safe pressure is 28 pounds per square inch as shown at the point **48** on scale **49**.

This latter calculation is based on the use of a diameter scale **44** on the envelope set out on the following formula:

$$X = -\log D$$

and the thickness scale **45** which is shown on the slide, lower part of Figure 5 which is based on the formula:

$$X = -\log t$$

It is also based on the use in scale **3** "yield governs" in which the temperature scale **47** on the envelope is based on the following formula:

$$X = -\log (Sy)$$

and the use of a pressure scale **49** shown in the center of Figure 5 which is based on the formula:

$$S = -\log p$$

Using a second problem to show the operation of "L/D exceeds 12," and using the same shell thickness and a diameter of 6 feet and an unsupported length between stiffeners of 73 feet, the procedure is the same. It would be apparent, however, that under such conditions we would find that 34 pounds per square inch was shown on the main scale, but that the check scale would show the main scale not applicable. Checking with scale **40** would also show that L/D was more than 12.

In such cases, it would still be necessary to proceed with scale **44** and set the 6 foot diameter line in alignment with the $\frac{5}{16}$'' thickness line, but in such cases the answer would be read on scale **2** where "L/D exceeds 12." This particular case (as shown in the drawing) is beyond the reading of the calculator. If, however, having a column 6 feet in diameter, a thickness of 1½'', we set the value **6** on scale **44** at the thickness 1½ on scale **45**, then at a temperature of 900° F. on scale **50**, it would be possible to have a pressure in excess of about 78 pounds as would be indicated on scale **52**.

The manner of plotting the temperature scale **50** in scale **2** on the envelope is as follows:

$$X = -\tfrac{1}{3} \log E$$

The manner of plotting the pressure scale **52** for scale **2** which is on the slide is as follows:

$$X = -\tfrac{1}{3} \log p$$

It will be apparent that the calculator will permit immediate calculation of the three basic formulas with one setting of the slide, and if any four of the five basic variables (thickness, diameter, length, temperature, safe external pressure) are known, the fifth may be found directly. Furthermore, the calculator automatically indicates which formula is valid for the particular conditions.

The face transparent portion bearing grid **20** and scale **26** may be referred to as a principal transparent portion, and the cooperating slide curves **22** and scale **28** may be designated collectively as a principal scale portion of the slide. Likewise, the face portion bearing check grid **34** and its temperature scale may be regarded as an auxiliary transparent portion of the face of envelope **10** cooperating with an auxiliary scale portion of the slide **15** as represented by the curves **36**.

The calculator has been particularly arranged for compliance with the API Code but it may also be used for other codes such as the ASME unfired pressure vessels code. It may also be made in circular rather than linear scales if desired.

While we have shown a preferred form of embodiment of our invention, we are aware that modifications may be made, and we, therefore, desire a broad interpretation of our invention within the limitations of the claims appended hereinafter.

We claim:

1. A calculator for indicating the inter-relation of factors of thickness, temperature, diameter, length and pressure in accordance with formula whereby any unknown factor can be obtained when the other factors are known, which comprises an envelope having a face formed to provide a first transparent portion with a grid of crossing lines, one family of which represents thickness and the other of which represents diameter, and a correlated temperature scale, and a second transparent portion having a grid of crossing lines representing thickness and temperature; and a slide member relatively movable in said envelope, said slide member having on the side adjacent the transparent portions of the face of said envelope a family of curves representing length indexable with the grid of thickness and diameter lines, a correlated pressure scale indexable with the temperature scale, and a system of lines representing diameter concurrently indexable with the grid of thickness and temperature, whereby limitations imposed by formula on the solution obtained by use of the first transparent portion will be indicated at the second transparent portion.

2. A calculator for indicating the inter-relation of factors of thickness, temperature, diameter, length and pressure of unfired pressure vessels in accordance with established formula whereby any unknown factor can be obtained when the

other factors are known, which comprises an envelope having a face formed to provide a first transparent portion with a grid of crossing lines, one family of which represents thickness and the other of which represents diameter, and a correlated logarithmic temperature scale, and a second transparent portion having a grid of crossing lines representing thickness and temperature, said face being also provided with a length to diameter ratio scale; and a slide member relatively movable in said envelope, said slide member having on the side adjacent the transparent portions of the face of said envelope a family of curves representing length indexable with the grid of thickness and diameter lines, a correlated logarithmic pressure scale indexable with the temperature scale, and a system of lines representing diameter concurrently indexable with the grid of thickness and temperature, whereby limitations imposed by formula on the solution obtained by use of the first transparent portion will be indicated at the second transparent portion, the back of said envelope and the side of said slide adjacent thereto being formed to provide relatively movable cooperating scales of thickness and diameter, two separate relatively movable sets of cooperating scales of pressure and temperature, all of said scales being concurrently indexable and the selection of a set of pressure and temperature scales being governed by indications read on the grid of the second transparent portion and the length to diameter ratio scale.

3. A calculator for indicating the fixed formula inter-relation of five factors whereby any unknown factor can be obtained when the other factors are known, which comprises a face member with principal and auxiliary transparent portions, a slide member movable relative to said face member and having principal and auxiliary scale portions arranged for cooperation with the corresponding transparent portion of said face member, said principal portions being formed to provide a grid of crossing lines representing the first and second factors and a correlated scale representing the third factor on one principal portion, and a family of curves representing the fourth factor and a correlated scale representing the fifth factor on the other principal portion, and said auxiliary portions being formed to provide a grid of crossing lines representing the first and third factors on one auxiliary portion, and a system of lines representing the second factor on the other auxiliary portion, the factors displayed by the principal and auxiliary portions being correlated and concurrently indexable, whereby limitations imposed by fixed formula on the solution obtained by use of the principal portions will be indicated by the auxiliary portions.

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