The Radial Cursor: a new addition to the Slide-Rule

To cite this article: F W Lanchester 1895 *Proc. Phys. Soc. London* **14** 8

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II. *The Radial Cursor: a new addition to the Slide-Rule.*

By F. W. LANCHESTER.*

THE slide-rule in its ordinary form is chiefly useful in working simple problems involving multiplication and division, also involution and evolution where the indices occurring are integers. When an expression involves fractional indices its solution is only possible, on a slide-rule of ordinary construction, by employing the scale of logarithms on the back of the slide in the same manner as a table of logarithms, when the process becomes so clumsy as to practically destroy its utility.

The object of the present improvement is to enable the operator to solve problems of the latter class with the same ease and degree of accuracy as that only previously attainable in connexion with the simpler cases.

In thermodynamic problems such as arise in dealing theoretically with gas- and other heat-engines, the need of some method of computation more rapid than that of ordinary arithmetic involving many references to tables becomes evident, and it was in connexion with work of this description that the author was led to devise the instrument which is the subject of the present paper.

In the case of the isothermal curve of a perfect gas, the ordinary slide-rule is all that can be required, for the curve is represented by the simple expression

$$pv = \text{constant.}$$

For the sake of brevity let us name the scales in a rule of the ordinary "Gravet" type thus

A
<hr/>
B
C
<hr/>
D

* Read October 25, 1895.

becoming when the slide is inverted,

Then with the slide in the inverted position the corresponding pressures and volumes of an isothermal can be read off directly on the scales A and g.

In the case of an adiabatic curve, however, we have an expression of the form

$$pv^\gamma = \text{const.},$$

where γ has a value 1.4 more or less according to the physical properties of the gas or mixture of gases we are dealing with. In order to deal with an expression of this form, it is necessary to provide some ready means of dividing the scales A and g proportionately to the value of γ which corresponds to the division and multiplication of the respective logarithms of the quantities dealt with, in the proportion of the indices of p and v , that is $1 : \gamma$.

This proportionate division of the scales is effected in the new Cursor by a radial index-arm, indicated in fig. 1 by lines f and g : this is arranged to swing about a stud which is itself carried on a sliding bar running in guides at right angles to the rule. All readings are taken at the points of intersection of the line with the edges of the slide. In the actual instrument the radial arm is made of a transparent slip of celluloid on which is scratched a straight line true to the centre of the stud-hole. The back view shows (fig. 2) the transverse bar graduated to give the indices to which it is desired to work. In fig. 2 this transverse bar is shown set to 1.408, the γ of a perfect gas.

A few words may be added with regard to the method of graduation of the transverse bar. Referring to fig. 3, in which MN is the width of the slide, and O is the centre of

Fig. 1.

Fig. 2.

the radial arm stud-hole, for any index γ , we have

$$\gamma = \frac{MK}{NJ} = \frac{MN + NO}{NO} = \frac{MN}{NO} + 1,$$

where OK is any position of the index line, or

$$NO = \frac{MN}{\gamma - 1}.$$

Fig. 3.

The following examples will serve as an illustration of the class of calculation for which the instrument is designed.

1. *To determine the maximum pressure of an adiabatic compression.*

Set the slide on back of cursor to 1.408 (γ). Suppose, for example, that the initial pressure be 15 lbs. per square inch, and that 100 vols. be compressed to 26 vols.

Invert slide. Set index line of cursor to 15 on A, then set 1 (100) on $\mathfrak{G}$ to index line of cursor. Now set index line to 26 on $\mathfrak{G}$ and read on scale A the corresponding pressure = 100 lbs. absolute, 85 above atmosphere (figs. 1 and 2).

2. The work done in any adiabatic compression can easily be calculated from the above by the following formula:—

$$W = \frac{1}{\gamma - 1} p_1 V;$$

where W = work done in ft.-lbs., V = final vol. of the gas (after compression) in units of 12 cub. in. (to harmonize with ft.-lbs. and pressure in pounds per square inch), and p_1 = difference of pressure between adiabatic and isothermal maximum pressure for the given ratio of compression (fig. 4).

Fig. 4.

$$\text{Work done} = \frac{1}{\gamma - 1} p_1 V.$$

3. The temperature of an adiabatic at any point can be determined from either pressure or volume by using suitable indices for

$$v \cdot T^{\frac{1}{\gamma-1}} = \text{constant};$$

also

$$p \cdot T^{\frac{\gamma}{1-\gamma}} = \text{constant}.$$

In determining temperatures from volumes or *vice versa* it is only necessary to proceed as before (1). In dealing, however, with pressures and temperatures the index is negative (where γ is $>$ unity), the interpretation of this being that an increase of pressure is accompanied by an increase in the temperature. The slide therefore does not require to be reversed as in $p v$ and $v T$ calculations; but with a rule of the Gravet type, owing to the scales C and D being the square roots of A and B, it is necessary to use a fictitious index obtained by dividing $\frac{\gamma}{1-\gamma}$ by the logarithmic ratio of the scales, giving $\frac{\gamma}{2(1-\gamma)}$. It would also be quite possible to graduate one edge of the index slide with fictitious values to compensate for the ratio of the scale-readings.

4. In the process described in (1) we have the means of plotting a series of adiabatics or isentropics, and each position of the radial cursor on the rule gives in its readings on the index line a corresponding isentropic, and a movement of the cursor to the left corresponds to a gain in entropy and *vice versa*, and it can be shown that equal increments of linear movement of the cursor correspond to equal increments of entropy. In other words, the scale of inches or centimetres on the edge of the rule may be regarded as a scale of entropy in arbitrary units.

5. The following is a very good example of the use of the radial cursor in practice.

The theoretical efficiency of an Otto cycle gas-engine is independent of the working temperatures and is given by the expression $1 - \left(\frac{v_2}{v_1}\right)^{\gamma-1}$, where v_1 is the total effective volume of the cylinder and compression-space, and v_2 = volume of compression-space alone.

Fig. 5.

$$\text{Efficiency of Otto Cycle Gas Engine} = 1 - \left(\frac{v_2}{v_1} \right)^{\gamma-1}.$$

Taking $\gamma = 1.408$, $\gamma - 1 = .408$. This is beyond the range of the instrument, so we will employ $\frac{1}{.408} = 2.45$.

Let us suppose that in the case we are dealing with $\frac{v_2}{v_1}$ comes out at .32 (an actual example, see 'The Engineer,' April 6th, 1894).

Set the index slide to 2.45 and place cursor accurately opposite middle 1 on scale A (use one of end lines on slide to centre with), and set index line to .32 $\left(\frac{v_2}{v_1}\right)$ on scale A (over to the left, fig. 5).

Now using one of the end lines on slide read on scale A opposite to intersection of index line on scale D, *but read backwards from the centre* 1. This will be found to give .37, or the theoretical efficiency of an Otto engine having ratio of expansion .32 is .37.

6. To determine x in such an expression as

$$7^x = 3.$$

Here x will be a fractional index, and we shall first find $\frac{1}{x}$.

Set cursor to 1 in centre of scale A.

Set index line to 7 on scale A, and keeping it there move slide of cursor till index line intersects scale D opposite figure 3 on scale A (use end line of slide).

Now read result on index-scale

$$= 1.76,$$

Or

$$x = \frac{1}{1.76} = .568.$$

DISCUSSION.

Mr. C. V. BOYS said that owing to the kindness of the author he had been able to try the cursor and had found it of great service in dealing with questions of adiabatic expansion. The new addition to the slide-rule suffers under the same disadvantage as the rule itself, namely, that a verbal or written description seems so very much more complex than is the actual operation when using the rule. The author's device might be described as an indiarubber

slide-rule, for it performed the function of a slide-rule, in which the graduations of the slide were made on indiarubber, so that the ratio of the length of the scale on the rule to the length of the scale on the slide might be altered at will, and thus involution and evolution with fractional indices performed.

Prof. S. P. THOMPSON and Mr. TROTTER expressed their admiration for the author's method of "stretching" the scale.

Mr. BURSTALL said he had attempted to apply a similar method to the Fuller rule, but did not succeed, since in this rule there was only one scale. He hoped the author's method could be applied in a form such that a greater accuracy than 1 in 300 could be obtained.

Mr. BOURNE thought the fact that the point of intersection of two lines inclined at an acute angle had to be read was likely to limit the accuracy.

III. *The Latent Heat of Evaporation of Benzene.* By E. H. GRIFFITHS, M.A., F.R.S., *Sidney Sussex College, Cambridge*, and Miss DOROTHY MARSHALL, B.Sc., *University College, London**.

1. THE method of experiment and the nature of the apparatus employed have been fully described in previously published papers. Although it appears somewhat presumptuous to assume, on the part of the reader, a knowledge of such communications, it would on the other hand seem redundant to devote many pages to the mere repetition of what has already appeared in print. We therefore propose to give an explanatory statement of the theory and methods employed, but to omit all detailed description of the apparatus. Full references to former communications will be given when necessary, so that all particulars can be ascertained by any who desire them.

* Read November 8, 1895.