Golding's Horse Power Computer (1908)

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Since the beginning of the Industrial Revolution and on through progressive electrification the steam engine has been the main source for power. Engineers had to design and adapt steam enginges for different purposes. The calculating instrument introduced here served as an aid for calculation as well as for machine design.

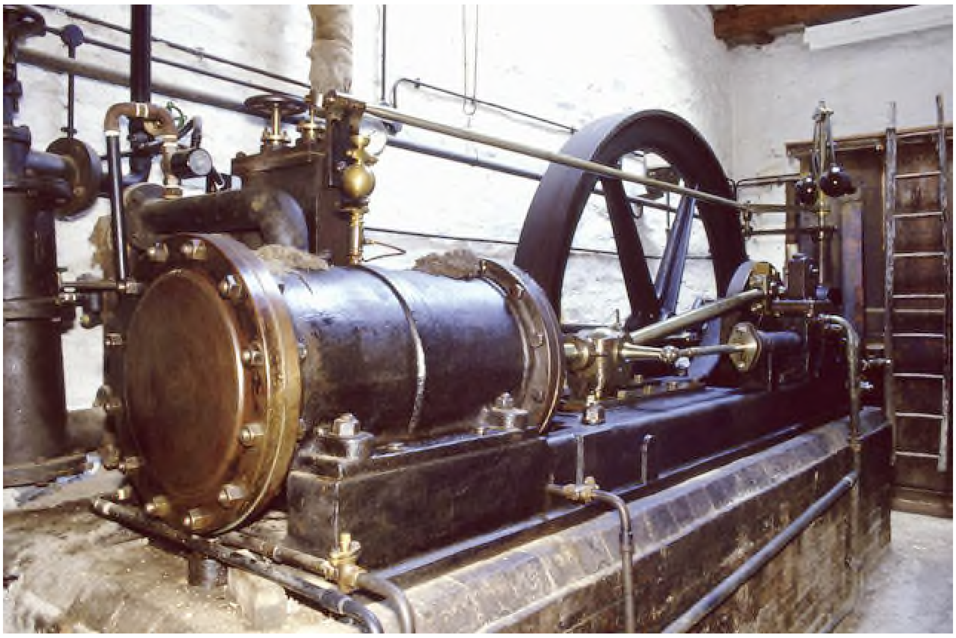

Figure 1: An Old Steam Engine

In 1908, Henry Albert Golding published a slide rule called *Horse Power Computer for Steam Engines*. My intention is to present Golding's *Computer* and to bring the variables used there into a context with the help of a short introduction to the underlying physical basics.

The slide rule is simply made of a thick base card measuring 16.5 cm (6.5 inches) square with three centrically mounted turnable disks (see Figure 2). Charles Griffin & Co., Ltd., London, is named as publisher. With the instrument comes a 12 pages accompanying booklet with the title *Horse Power Computer for Steam, Gas & Oil Engines* [1]. Whereas the instrument only works for steam engines, the booklet and the given examples therein are extended to three sources of energy: steam, gas and gasoline/petrol, and diesel oil.

Below the caption on the upper disk the note *Golding's Patent* is set in round brackets. The only appropriate patent I found is GB8196 from 1907 [3]. In the specification he describes three different slide rules with straight or optional round form. With three movable parts they are adapted for steam engines, with two movable parts for internal combustion motors and with one movable part for calculations related to the so called *de Prony* brakes to measure the power of an engine. Note that in 1908 Golding also published a simlified calculating disk named *Horse Power Computer for Petrol Motors* [8].

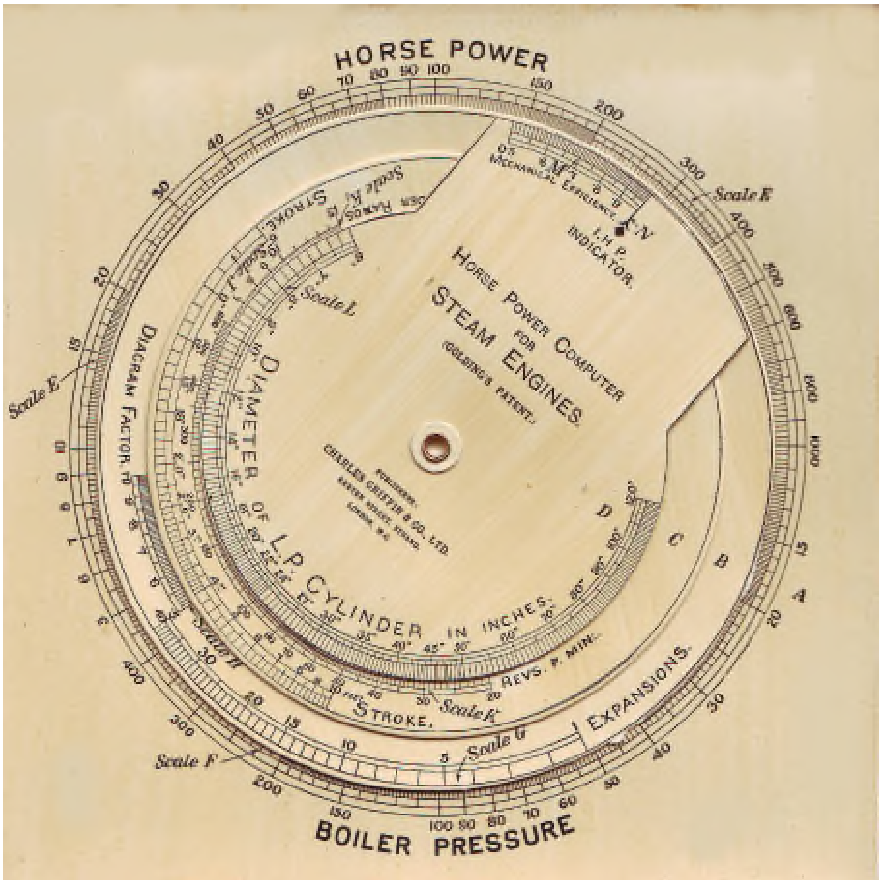

Figure 2: Golding's Horse Power Computer

While other slide rules for steam engines allow four or five state variables [4 to 7], with Golding's slide rule seven variables can be set independently to find the power of an engine as the 8th variable.

The inventor writes about usage and priciple of his instrument:

> The computer is an ingenious form of mechanical calculator for solving the numerous problems connected with the power, size and speed of steam engines of all kinds. Its action is based upon the well-known principle of logarithmic calculation, the operations of multiplication and division being effected mechanically by the addition and subtraction of distances proportional to the logarithms of the quantities represented. [1, first paragraph]

For collectors who like to have an understanding of scale operation, a very short overview of steam engine design will be given with reference to Figure 3. My explanations follow closely two sources: the small booklet added to the slide rule and the textbook the authors H. A. Golding, inventor of the slide rule, and Charles Edward Larard wrote for students and engineers in 1907 [2].

Physical basics

Inside a cylinder a piston with area A is sliding, traversing the **stroke of length L** (in the following text, variable names used on Golding's slide rule are set in bold). The piston drives with its rod, either directly or connected to a crankshaft, and a flywheel. Two valves at each end of the cylinder, not shown in Figure 3, direct the flow of steam. The piston is moved by steam of pressure P above athmospheric pressure (Figure 3 at bottom). With A in square inches, P in lbs. per square inch and assumed to be constant, and L in feet we get

$$\text{Work Done} = P * A * L \text{ (ft.-lbs.).} \tag{1}$$

The area A is expressed by the **diameter D** of the piston:

$$A = \pi/4 * D^2. \tag{2}$$

Here, for an initial approximation, any influences of valves on the pressure are neglected.

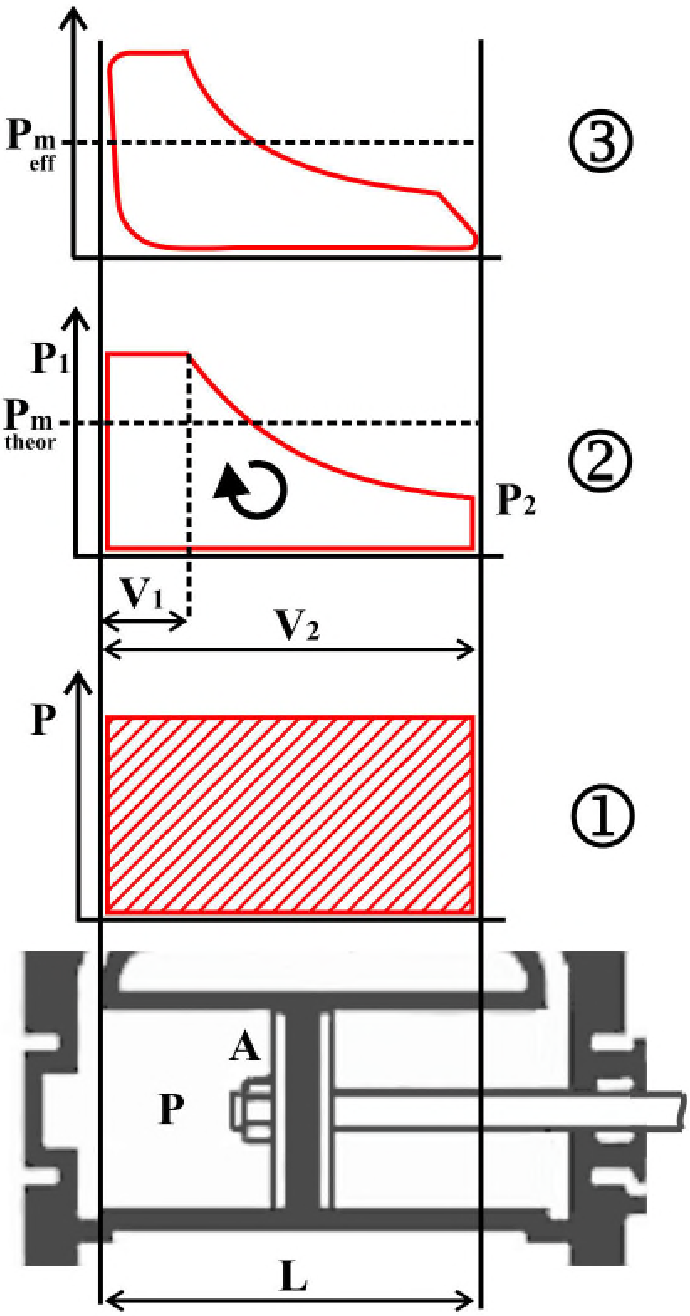

Figure 3: Various Diagrams for Steam Pressure Over Piston Stroke

The red lines in Figure 3 indicate the assumed pressure on the left side of the piston in relation to the piston's position and must be read clockwise. The work done during a stroke is proportional to the area within the red closed line. Figure 3, position 1 represents an assumed constant pressure.

Almost all engines were double-acting steam engines, which means that steam of high pressure acts alternately on both faces of the piston. For a movement backwards the piston area must be reduced by the cross-section of the piston rod a. We get the total work done during a double stroke or one revolution of the flywheel as

$$\text{Total Work Done} = P*2*L*(A - a/2). \qquad (3)$$

Now the first restriction must be taken into account: while the piston moves the pressure on the acting sides is by no means constant. Therefore, the design engineer works with a mean pressure P_m , assumed to be constant over the stroke.

When an actual engine ist tested for power, diagrams are taken by means of mounted steam engine indicators that record the pressure at every point of the moving piston [4]. Such a diagram appears similar to the one shown in Figure 3, position 3. Opening and closing of valves is directed by another piston or slider outside the cylinder and is not shown in Figure 3. As long as the first valve is open the high boiler pressure acts upon the piston. When this valve closes the steam expands and pressure falls in accordance with a hyperbolic function until the same valve opens again and steam escapes either to athmosphere or to the next low-pressure cylinder. When the piston returns with higher pressure on the other face steam is exhausted at approximately athmospheric pressure.

The area enclosed in the diagram is obtained from the indicator diagram either by graphical methods that divide the diagram into small stripes which are added, or by means of a planimeter. From this area we get the mean effective pressure with P_m eff = area within curve / length of stroke.

For an engine not yet built this later indicator diagram is of course unknown. During design the engineer had to estimate the later probable mean effective pressure P_m eff as accurately as possible. This estimation was performed either by graphics or by calculation. The graphical method is based on a theoretical diagram as shown in Figure 3 position 2. As long as the first valve is open the constant **boiler pressure P_1** acts upon the piston. When this valve closes isothermal expansion is assumed and the pressure reduces in accordance with a hyperbolic function to pressure P_2 when the valve opens again. In a first step, this theoretical diagram is drawn based on technical data of the planned engine and in the next step, an expected real indicator diagram as in Figure 3 position 3. is inserted.

The theoretical mean pressure in the diagram Figure. 3 position 2 throughout a stroke is calculated with help of Golding's computer by

$$P_m \text{theor} = P_1 * (1 + \ln(r)) / r \qquad (4)$$

with the **ratio of volumes r** = V_2 / V_1, also called ratio or **number of expansions**. Various tables tabulate values for that theoretical mean pressure according to the initial boiler pressure P_1 and the point when the valve closes (called the cut off) with which ratio r is defined.

Due to losses within the cylinder, rounding of the corners in an indicator diagram and the fact that expansion is not exactly isothermal, the effective mean pressure is smaller than the theoretical mean pressure. The effective mean pressure is obtained by multiplying by a factor called **diagram factor** that is less than 1, thus:

$$P_m \text{ theor} * \text{diagram factor} = P_m \text{ eff.} \qquad (5)$$

Given the known effective mean pressure the engine will work with, the physical work done during one revolution of the fly wheel can be calculated. This work multiplied with the **speed of engine** in revolutions per minute, followed by a division of 33000, gives the Indicated Horse Power (I.H.P.).

When Golding published his slide rule, the power of an engine was measured with the unit "horse power" (H.P.), which equals 33000 foot-pounds per minute (ft-lbs./min.). The additional word "indicated" power comes from the fact that the pressure inside the cylinder has been measured with an instrument called indicator.

Due to the friction inside the engine that has to be overcome with a small amount of power, the usable power, also called effective or **Brake Horse Power** (B.H.P.), is smaller than the indicated power. The quotient B.H.P. / I.H.P., always less than 1, is called **mechanical efficiency**. As an equation:

$$\text{B.H.P.} = \text{I.H.P.} * \text{mechanical efficiency.} \qquad (6)$$

In former times, the power of an engine was determined by use of a mechanism equipped with friction brakes. From those test constructions the name "brake" power for effective or usable power survived.

With the variables already mentioned above and with the relationships

$f(r) = (1 + \ln r) / r$; $f(D) = \pi/4 * D^2$;

and with 'df' for diagram factor, 'me' for mechanical efficiency and 'R' for revolutions per minute, Golding's *computer* calculates directly from boiler pressure to B.H.P.

$$\text{B.H.P} = P_1 * f(r) * df * L * f(D) * me * R / 33000 \qquad (7)$$

Arrangement and Range of Scales

The variable names, identified with bold letters in the preceding explanation, are arranged on a base plate A and on three concentric disks B, C, D. The provided scales are (see Figure 4):

- On plate A:
  scale E: horse-power 5-1000;
  scale F: boiler pressure 10-400 lbs. per square inch.
  These two main values, representing input to and output from the engine, are highlighted with capital letters on the base plate.
- On disk B:
  scale G: values of f(r) for the number of expansions r = 1-40;
  scale H: diagram factor 0.5-1.0.
- On disk C:
  scale J: stroke of engine 6 inches to 10 feet;
  scale K: speed of engine in revolutions per minute 20-600. Scale K is extended with scale K_1 up to 15 which really stands for 1500. In conjunction with scale L, K may also act as a scale representing the ratio of cylinder areas and L provides

simultaneously the appropriate diameters. An example is given in the booklet page 11, example IV.

- On disk D:
  scale L: diameter of cylinder 6-120 inches;
  scale M: mechanical efficiency 0.5-1.0. Value 1.0 is marked with indicator N that points to the value of I.H.P. on scale E.

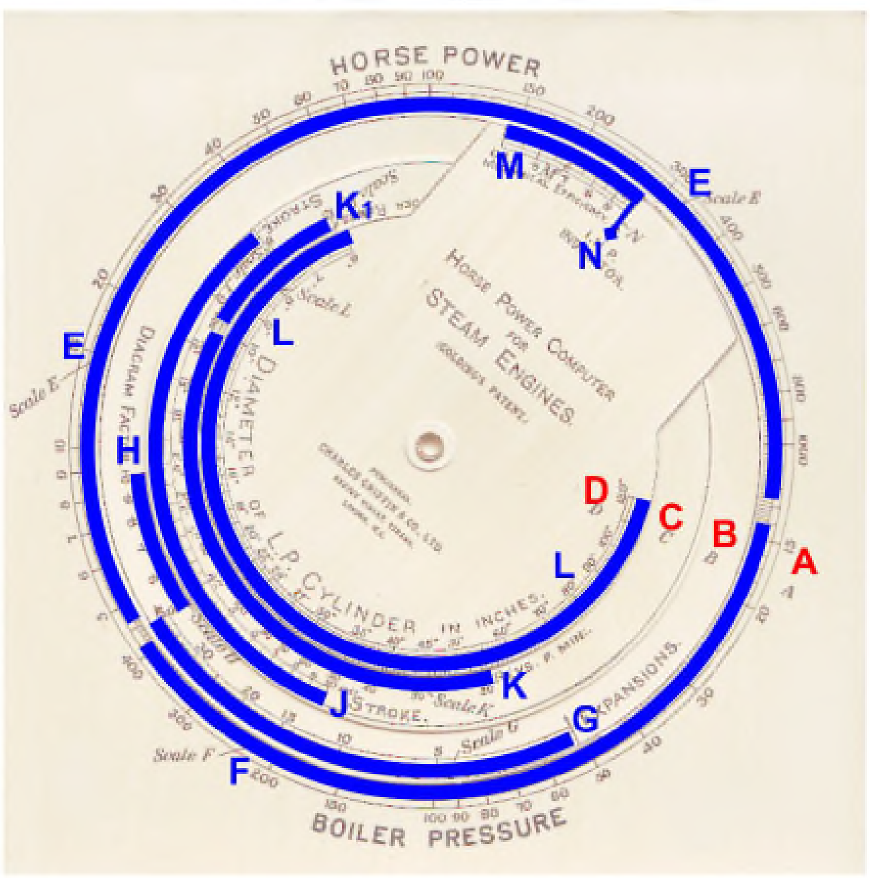

Figure 4: Arangement of Disks and Scales on Golding's *Computer*

The direct connections between the scales are F to G, H to J, K to L and M to E. After setting the variables on disks B and C, read scale E on the base plate by rotating disk D with the cutout so that indicator N on the protrusion points to the calculated efficiency value. Similarly, the power can be set on scale E with indicator N, then disks B and C rotated to determine various combinations of the variables to achieve the same output.

Examples of usage

Two examples may illustrate the usage of the instrument. Both are taken from the booklet provided with the slide rule. The first example is straightforward.

> Example I.—To find the I.H.P. of any engine, given the sizes of the engine, speed, and pressure. Set the number of expansions on scale G to the boiler pressure on scale F. Read the theoretical mean effective pressure on scale F opposite 1 on scale G, and subtract a suitable back pressure (say 3 lbs. for condensing engines, and 16 lbs. for non-condensing engines) by rotating disc B anti-clockwise. Set the given stroke on scale J to a suitable

> value of diagram factor on scale H; set the diameter of the cylinder (or L.P. cylinder as the case may be) on scale L to the given speed in revolutions per minute on scale K, and the indicator N will point to the I.H.P. on scale E. [1, page 4]

The slide rule is not only suitable for the determination of power, but is also very useful to estimate the value of a variable while the other variables are changed. Thus the slide rule avoids complicated calculations and even allows optimization, as shown in this example:

> Example V.—To find the boiler pressure required for a given power, size of engine and speed. Reverse the operations described in I., starting with the given I.H.P., when 1 on scale G will point to the theoretical mean effective pressure required on scale F, or the given number of expansions on scale G will point to the required steam pressure on scale F. As this is absolute pressure, subtract 15 lbs., and add a suitable amount for loss of pressure between boiler and engine. [1, page 5]

Conclusion

I have tried to give an overwiev of the usage of this sophistcated slide rule. As might be expected there are much more specialities hidden in the process of machine design not mentioned above, for example a compound steam engine or a four-cycle gas engine. Moreover, further knowledge and exprience is needed to select appropriate values for diagram factor and number of expansions. For collectors and scientists who now want to go deeper into that subject, I recommend Golding's publication *Practical Calculations for Engineers,* together with the booklet provided with the slide rule. The subject matter is not difficult.

Notes

[1] Golding, Henry A., *Horse Power Computer for Steam, Gas & Oil Engines,* Explanatory Pamphlet Accompanying This Instrument, London 1908.

[2] C. E. Larard, H. A. Golding, *Practical Calculations for Engineers,* London 1907.

[3] Golding, Henry Albert, British Patent Nº 8196, *Improvements in Power Computing Slide Rules for Steam and other Engines*, 1907.

[4] Babcock , Bruce E., *Slide Rules and the Steam Indicator*, Journal of the Oughtred Society, 13:2, Fall 2004, pages 46-54.

[5] Wyman , Thomas, *The K&E 4135 "Power Computer",* Journal of the Oughtred Society, 21:1, Spring 2012, pages 60-62.

[6] Riches, David M., *Hudson's Computing Scales,* Slide Rule Gazette, Issue 10, Autumn 2009, pages 109-116.

[7] Pickworth, C. N., *The Slide Rule A Practical Manual,* 6th edition 1900, page 87.

[8] Golding, Henry A., *Horse power Computer for Steam, Gas and Oil Engines* / *Horse Power Computer for Petrol Motors,* Reviews in The Electrician, volume 63, Oct 1, 1909, pages 997-998

Image credits

Fig. 1: Steam engine, Stott Park Bobbin Mill (near to Lakeside, Cumbria, Great Britain), Photo Chris Allen for Wikipedia
All other figures from the author and from the author's collection.