An approximate, but logical, method of designing Walschaerts & Stephenson valvegear

Introduction

The method ignores secondary effects such as the angularity of the connecting rod and the eccentric rods; its purpose is to provide a starting point for an accurate analysis using a drawing board, or preferably a computer.

At this level of approximation, equations describing the valve motion have been around for at least a century. Unfortunately, however, they are often presented in such a manner that the important design requirements are obscured. These design requirements are:

1) Cut-off in full gear
2) Maximum port opening in full gear
3) Lead in full gear.

Quantities such as steam lap, eccentric throw, angle of advance etc. are important only insofar as they allow the above design requirements to be achieved. Yet in many presentations they are treated as quantities that must be fixed before the analysis can start. There is a reason for this: the algebra is more tractable if one proceeds that way round!

One or two people have done it the right way round - notably Professor Dalby in his splendid treatise on locomotive valvegear. We shall follow his example, and assume cut-off, port opening and lead (all in full gear) as a starting point of the design.

The Equivalent Eccentric

The first step is to determine the steam lap (L) and the throw (r_{eq}) and angle of advance (ψ) of a simple eccentric which would achieve the design objectives. The algebra is straightforward but rather tedious, so we present only the results.

Firstly some definitions: Fractional cut-off (full gear), ξ
Max. port opening (full gear), ω
Lead (full gear), λ

Define the quantities *A* and *B*, (whose significance will be described later)

$$A = -\left[\frac{\omega}{\xi}\left(1 + \sqrt{\left(1-\frac{\lambda}{\omega}\right)(1-\xi)}\right) - \omega + \lambda - \frac{\lambda}{2\xi}\right] \qquad (1)$$

$$B = -\left[(\omega-\lambda)\sqrt{\frac{1}{\xi}-1} + \omega\sqrt{\left(1-\frac{\lambda}{\omega}\right)\frac{1}{\xi}}\right] \qquad (2)$$

(Note: A and B involve only the primary design parameters ξ , ω , and λ , and can therefore be evaluated immediately)

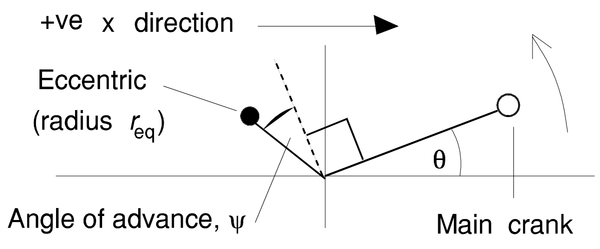
The steam lap and the details of the Equivalent Eccentric can now be found:

Steam lap $L = -A - \lambda$ (3)

Radius of equivalent eccentric $r_{eq} = \sqrt{A^2 + B^2}$ (4)

Angle of advance (radians) $\psi = \tan^{-1}\left(A/B\right)$ (5)

These results are true for both outside and inside admission, but remember that the angle of advance is measured from a position 90° ahead of the main crank for outside admission, and from a position 90° following for inside admission. The disposition of the eccentric and main crank, for a crank angle of θ, is shown in the diagram for the case of an outside admission valve.



The displacement, x, of the outside admission valve is thus $x = r_{eq}\cos\left(\theta + \psi + 90°\right)$. However, using the quantities A and B, it can also be expressed in terms of the crank angle alone, as follows:

$$x = A\cos\theta + B\sin\theta \qquad (6)$$

[For inside admission

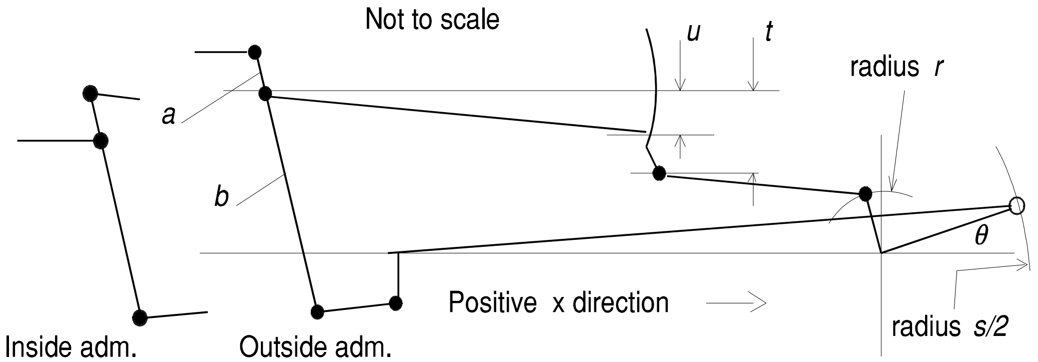
$$x = -A\cos\theta - B\sin\theta \qquad (6a)]$$

This shows that the valve motion is the sum of two sinusoidal motions, one in phase with the piston motion and of magnitude A, and the other 90° out of phase, and of magnitude B. This interpretation is especially appropriate for Walschaerts gear in which the valve motion is indeed the sum of two such components: one derived from the crosshead, and the other from the return crank, the two being combined in the combination lever.

Walschaerts gear

Now we have to arrange that the movement of the crosshead and the return crank are suitably scaled so as to yield the motions defined by Equations (6) and (6a) at the valve spindle. The following diagram shows the dimensions a, b, u, t, that must be chosen so as to achieve this. By comparing the magnitude of the 'in phase' component as represented by the quantity A in equation (6) or (6a) with the crosshead movement scaled by the appropriate combination lever ratio we find the ratio (a/b) in terms of A (defined by Equation (1)) and the known value of the piston stroke, s :

$$a/b = -A/(s/2) \qquad \text{(For outside admission)} \qquad (7)$$



and a/b = - A / (s/2 + A) (For inside admission) (7a)

In principle we can make ‘a’ and ‘b’ any dimension we wish, as long as the ratio a/b remains the same as the value given by Equation (7) or Equation (7a) as required. Practical considerations will determine the choice; in particular, the dimension ‘a’ must be large enough to accommodate the bearings at the junction of the combination lever with the radius rod and the valve spindle.

Next we must choose, as an input to the design, the ratio (u/t) of the die displacement in full gear to the distance from the expansion link trunnion to the 'tail pin' connecting the expansion link to the eccentric rod. Comparison of the 90° component B with the return crank throw, scaled in this case by the ratio (u/t), and the appropriate combination lever ratio fixes the radius ‘r’ of the return crank.

Thus r = - B / [(u/t) . (a/b + 1)] (For outside admission) (8)

and r = - B . (a/b + 1) / (u/t) (For inside admission) (8a)

We now have to choose values for ‘u’ and ‘t’ consistent with the selected value of the ratio (u/t). The issue here is the effect this has on the swing of the expansion link. The smaller the value of ‘t’ and ‘u’, the larger the swing. If we specify the total angle of swing, ϕ the value of ϕ can be calculated as:

$$t = r / \sin \phi \qquad (9)$$

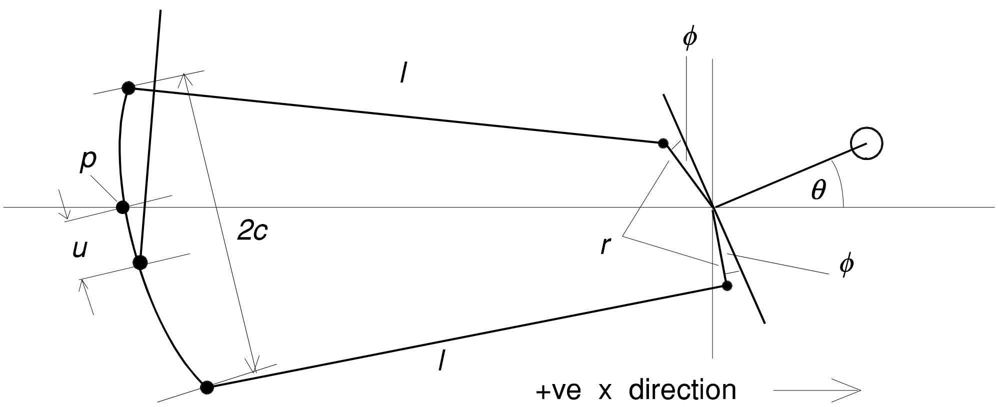
The value of ϕ should lie between 40° and 50°. Given the value of ‘t’, ‘u’ is found from the specified value of (u/t), thus completing the design. It may of course be helpful to try different values of (u/t) in Equations (8) and (8a) , yielding different values for r, t, and u.

Stephenson gear.

The initial stage of the analysis which determines the details of the 'equivalent eccentric' is the same as for Walschaerts gear. However, in this case it is less easy to relate the valvegear mechanism to the equivalent eccentric.

The following approximate analysis is basically that of Dalby, and leads to the equations:

$$A = -r\left[\sin\phi + \left(1 - \frac{\left(u/c\right)^2}{l/c}\right)\cos\phi\right] \qquad (10)$$



$$B = -r\left(\frac{u}{c}\right)\cos\phi \qquad (11)$$

where, as before, A and B are given by equations (1) and (2). By substituting (11) in (10) we get the following expression for the angle of advance, , of the **real** eccentrics:

$$\varphi = \tan^{-1}\left[\frac{A}{B}\left(\frac{u}{c}\right) - \frac{1-\left(\frac{u}{c}\right)^2}{\frac{l}{c}}\right] \qquad (12)$$

The radial throw of the eccentrics can then be determined from equation (11) :

$$r = \frac{-B}{\left(\frac{u}{c}\right)\cos\phi} \qquad (13)$$

It now remains to ensure that the actual magnitude of 'c' (and therefore 'u') is such that the swing of the expansion link is not too great; 50 degrees is about the maximum. If the total angle of swing of the link is to be 'ω' , then the magnitude of 'c' is given by;

$$c = -\frac{r\cos\phi}{\sin\left(\frac{\omega}{2}\right)} \qquad (14)$$

It is assumed in the above analysis that the motion of the valve follows the motion of die (point P shown in the diagram , which is drawn for the case of outside admission). Inside admission would require the main crank to be displaced by 180° . Further scaling will be required if a lever is interposed between P and the valve spindle.

Computer programmes

For those who wish to bypass the algebra, the above calculations have been programmed for:

a) The Archimedes or Risc_PC computers (file 'walste')
b) IBM PC (or compatible) running Windows (file 'stewal.exe')

W B Hall, 1995