ABSTRACT OF PAPER ON THE COMPARISON OF INDICATOR RIGS.

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[Read before the Franklin Institute, May 18, 1883.]

Correct instruments may be applied and used in wrong ways, and give incorrect results.

The steam engine indicator is frequently so applied and used; the devices employed to reduce the motion of the crosshead often causing great errors in the diagram.

Among the methods we may consider

(1) Cord attachment from a pin in the end of the shaft or side of crank, direct to the paper barrel.

(2) Cord from a swinging lever slotted to receive a pin in the crosshead.

(3) Cord from a swinging lever connected with the crosshead by a vibrating link.

(4) Cord from a swinging lever attached to the crosshead; the pivot of this lever vibrating at the end of a swinging link.

(5) The reducing wheel.

(6) Pantograph.

(7) "Lazy Tongs."

In devices 2 and 3, which are the most commonly used, the cord may be either

(a) Attached directly to the lever.

(b) Wrapped around a circular arc or sector centered in the pivot of the pendulum.

No. 1 is irrevocably tainted with the angularity of the connecting-rod, compounded with that of the cord. It always gives less than $\frac{1}{4}$ the diagram-length, for the first quarter of the out-stroke of the piston; and gives longer cards on an indicator at the back end than at the crank end. The shorter the connecting-rod and cord, for a given stroke, the greater the errors.

(2) The slotted lever gives absolutely correct results when at mid-stroke, it is perpendicular to the crosshead path, and when,

(a) The cord gets its motion from a pin which is driven by a radial slot centered in the pivot of the lever, and perpendicular to the cord at mid stroke.

(b) With long cord attached directly to the lever the results are practically correct, provided that the "dip" of the cord is divided, and the cord is led off so that at mid-stroke it makes a right angle with the radial line from its attachment to the pivot.

(c) With a long cord wrapped around a circular arc, centered in the pivot, the results are practically correct, no matter how the cord is led off.

This theoretical, but practically immeasurable error, gives equal cord lengths for both halves of the stroke, but the end quarters give somewhat longer card lengths than the central quarters. The error decreases with the total angles of lever and cord swing.

Fig. 1.

Motion of Usual Pendulum and Link.

(3) The lever with fixed pivot, and linked to the crosshead, gives quite good results when properly applied, although not so accurate as a double-slotted lever of the same length.

At mid-stroke it should be vertical, and the link sufficiently below the crosshead attachment to divide the dip.

Remarks *b* and *c* concerning the cord attachment to the slotted lever apply to this rig. As in the latter rig also, the longer the lever, and the cord between lever and guide pulley, the more accurate the results.

Fig. 1 is reduced from a carefully made plotting, full size, of the motion of a rig with levers 36 and 24" long. The vertical line represents the position of the pendulum at mid-stroke. The dip of the

link was divided at this position. Four different cord angles gave as many varying results. When the angle of cord vibration was divided and the guide pulley placed at the point *GP* on the second horizontal line parallel to the crosshead path, the error in a 4" card was hardly measurable. Circular arcs swept from the upper point *GP*, from the points indicating successive positions of the point of cord attachment, show that with this position of guide pulley the first quarter of the forward piston stroke gives more, and the last quarter less, than a quarter of the card length, this being reversed on the back stroke.

Carrying the guide pulley below the line of divided cord vibration, the errors of card length are exactly the opposite of those made with the guide pulley above the line of divided cord vibration.

Fig. 2 shows in dotted lines the result of putting the guide pulley even so little below the line of divided cord vibration as the bottom of of

Fig. 2.

False Diagrams taken by Usual Pendulum and Link.

the arc described by the cord attachment. The correct cards for the plotted amount of clearance and points of cut-off and compression are in full lines.

(4) The pendulum with swinging centre is probably the most erroneous used or proposed. Fortunately it is not a usual rig. It does not permit of the use of a circular sector for cord attachment, nor can the cord be attached, as in where the pendulum pivot is stationary, anywhere but in the line of centers of the long lever; thus losing one of the main advantages of fixed centre levers, the dispensing with a guide pulley.

The point of cord attachment describes a mixed curve which is neither regular nor symmetrical, one limb being variably convex, and part of the other being decreasingly convex and then increasingly concave.

With the lever plumb at mid-stroke, the "dip," or versed sine of the swing of both levers divided at mid-stroke, and the cord running off parallel to the crosshead path, the results, while not so correct as those from the other lever rigs, and not accurate enough to set valves by, will do to give a general idea of engine performance and an approximation as to horse-power.

The greater the angular vibration of pendulum, link and cord, and the greater the angle made by the cord with the path of the crosshead, particularly where the cord makes an acute angle with the radius between cord attachment and swinging centre, the greater the error.

This tendency to error is so great, that some cord angles likely to

Fig. 3.

Motion of Lever with Vibrating Pivot.

be chosen by any one not thoroughly conversant with the errors of this rig, actually give a negative movement to the paper drum, during the first portions of the outstroke; so that for an engine with a lazy steam valve the admission line would appear as compression to initial pressure, and with cut-off at $\frac{1}{16}$ stroke the diagram would commence with the expansion curve and have two vacuum loops so large as to prove the engine to be driven by the main belt and pumping into the boiler.

Fig. 3 is a photo reduction from a plotting made with scrupulous care, with a 36" pendulum swinging on a 24" link, the "dip" or versine of the latter being divided by the vertical line, which represents

position at mid-stroke. The curved trace was made by inserting a pencil point in the hole for cord attachment; the line being the "raised curve" referred to in a previous paragraph. The nine small circles on this curve show the successive positions of the cord attachment at equidistant portions of the piston stroke. With the angle of cord vibration divided, the error on a 4" card is measurable, but not serious for rough calculations of horse-power, though sufficient to throw the cards out for plotting true theoretical expansion curves. The slightest variation from this height of guide pulley produces an error so great as to vitiate any cards with early cut off, even for horse-power calculation.

With the guide pulley much above the line of divided card vibration, as shown in the diagram, there is produced the astounding result referred to in a preceding paragraph:—During the first eighth of a

Fig. 4.

False Diagram by Lever with Swinging Pivot.

forward stroke the cord slacks, and is not again tightened until the end of the third eighth of the stroke. The positions of the point of cord attachment at successive eighths of the forward stroke are shown in Fig. 3; while in Fig. 4, the dotted lines show the false cord which would be produced with 60 lbs. absolute initial pressure, and cut off at $\frac{1}{8}$ stroke (clearance and compression being as shown in the correct theoretical diagram hatched in full lines). The numbers 0, 3, 6, etc., on the lower line indicate correctly successive piston positions; the same numbers on the upper line showing where the piston would be represented to be, by the rig shown.

(5) The reducing wheel gives absolutely correct results when properly applied, which is seldom the case. The cord should be led from an offset from the crosshead, so that it will, at all piston positions, be

absolutely parallel to the piston rod. When it makes an angle with the rod, it gives a shorter card than due to the stroke, but not only that, the card for any given fraction of the out-stroke is shorter than that for the succeeding one.

These errors being due to the decreasing angle of the cord as the piston advances, it follows that if the indicator is screwed into first one end of the cylinder and then the other, the diagram from the crank end will be not only shorter than that from the back, but more distorted; and that the further the wheel is from the central line of the

Fig. 5.

Motion with Wrongly Applied Reducing Wheel.

Fig. 6.

False Diagrams taken by Reducing Wheel.

engine, and the nearer the crosshead attachment to that same axis, the greater the error.

False cards by this rig always show the cut-off too early and horsepower too low on the out-stroke, and the reverse on the return.

In Fig. 5 there are plotted eight equal successive portions of a 24" forward piston stroke, and a 4" reducing wheel wrongly applied. The angles made by the tangents representing the successive positions of cord, are greatest for the earlier equal portions of the outward stroke;

so that instead of correct diagrams like the full lines in Fig. 6, three are taken such as are shown by the dotted lines; the right hand card being from the back end.

(6) The pantograph can be made to give perfect cards, the only danger being in oblique cord connections.

(7) The same remarks apply to the lazy tongs; but in this there appear two special sources of error: lost motion in a multiplicity of joints, and springing of the frame at high speeds, prolonging the card at the two ends, hence making cut-off appear too early and horse-power too low.

In all cases, the cord should be light and non-stretchable. Braided cord is best, if cord is to be used; piano wire is better, and absolutely prevents the objectionable use of a guide pulley.

[Since preparing this paper, Mr. B. F. Teal has submitted a model of a method of reducing the crosshead motion by differential pulleys carried on the crosshead, and giving the paper-drum positive motion on each stroke.]

The results of my investigations and tests are, that for accurate results at high speeds, the slotted lever is by far the best rig, from its simplicity, cheapness, ease of attachment while engine is running, lack of spring, direct cord connection, and adaptability to various lengths of stroke and position of indicator.

[Before this abstract was in type, the appearance of a lengthy mathematical discussion of this question in a well-known magazine, by a gentleman who commenced a discussion of the paper itself at the meeting at which it was presented, renders it necessary for the writer to add to the abstract a memorandum of the manner in which the tests and measurements were made.

Hard wood pendulums and links were made, with the pivot centres accurately laid down, drilled squarely with a $\frac{1}{8}$ " twist drill, and their distances carefully measured. Scribe lines were drawn and carefully drilled in the same manner to mark successive eighths of 24" piston strokes. With a tested T square, the mid-stroke positions of the levers were laid down previous to drilling the centres for piston position holes. The levers were then accurately centred, and the point of cord attachment drilled for a metal-marking point which should not only make a trace of the entire motion-curve of the point of cord attachment, but would prick the positions of that point at each piston position. The distances from guide pulleys were transferred by stiff trammels, and the card lengths measured to hundredths of an inch as well as graphically recorded.

In addition to the graphical tests and proofs made by the levers themselves, full-sized diagrams were made with a hard pencil, and these were measured to check the graphical records.

In still further corroboration, an indicator was clamped to the drawing-board in various positions, and the successive eighths of piston stroke recorded on the usual paper card by direct cord attachment to the levers.

The levers, thus connected to the indicator, were shown at the Institute meeting, and cards from the "swinging-pivot" lever were taken by the author, and handed out at the meeting, corroborating those portions of the paper which referred to that rig. After the meeting, the writer offered the indicator to the member who upheld that rig, if he would either take a correct card with that rig, or disprove the methods and measurements there offered. The author still owns the indicator.

The writer's measurements, particularly those of the swinging-pivot lever, were checked by skilled engineers and draftsmen in various

ERRATA.

Page 22, third line from top, for "raised curve" read "reversed curve;" on fourteenth line from top, for "a" read "the;" on tenth line from bottom, for "cord" read "card."

Page 24, first line, for "three" read "there."

Page 25, formula should read: "Given, $a = b$; then, $a^2 - b^2 = ab - b^2$; $(a+b)(a-b) = b(a-b)$; $a+b = b$; $2 = 1$."]'

same as in the Daniell cell. The intensity is equal to that of the zinc does not need amalgamating; the constancy is greater; the waste of zinc is less, and there is very little smell. A battery of 25 elements was used for four days without disturbing the mounting and was employed every evening to produce electric light.—*Comptes Rendus*. C.

Magnetism of Rotation.—Tresca has reported to the French Academy some experiments by Selim Lemström upon the causes of terrestrial magnetism. He used a paper tube with two concentric walls, rotating rapidly around a cylinder of soft iron, and his results confirmed the theories of Edlund and Chase, which explain magnetic effects by æthereal movements. The experiments were substantially the same as those which were performed by Chase in 1864 and 1865, and reported in the ninth and tenth volumes of the Proceedings of the American Philosophical Society.—*Comptes Rendus*. C.