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THE PROPORTIONS AND DESIGN OF LOCOMOTIVE CROSSHEADS.

W. F. Drysdale, S. Can. Soc. C. E.

Read before the Mechanical Section, 19th Jan., 1905.

DEVELOPMENT.

The locomotive crosshead is that block which connects the end of the piston rod with the small end of the connecting rod, and running between guides, prevents undue strain being transmitted to either connection. It must be so simple as to be easily handled and kept in repair, it must be strong enough to withstand a high amount of rough usage due to accident rather than piston thrust, and lastly it must be so designed that little work is absorbed by it in friction.

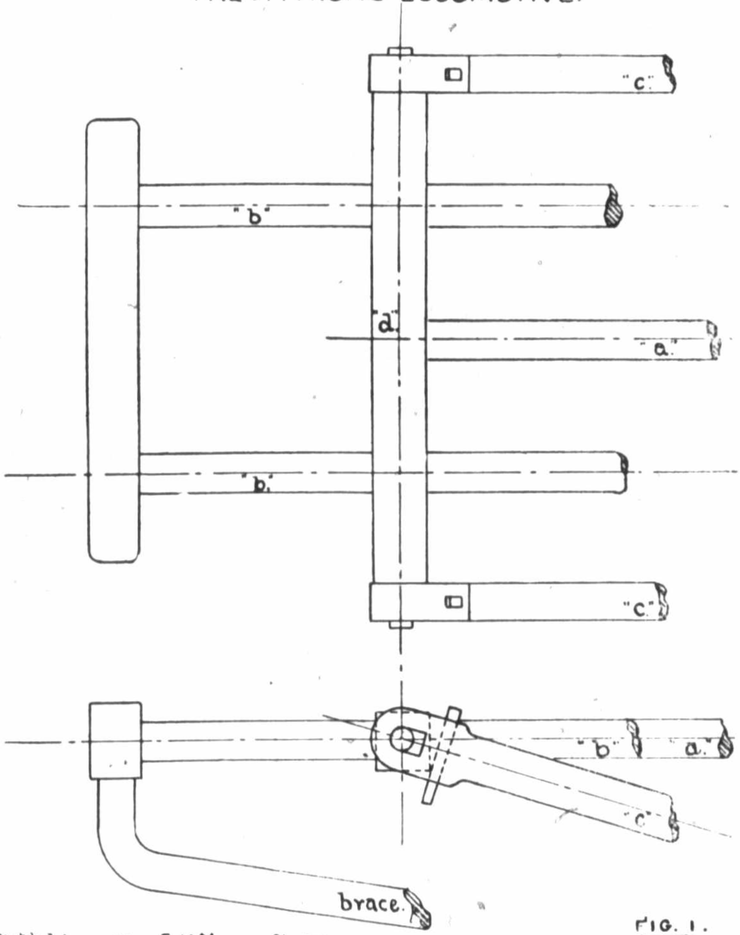
We shall endeavour to study its development from its earliest form to the standard types as now used on modern locomotives.

Although Trevithick's locomotive of 1803 had no crosshead, in it were embodied the three main features of one, namely, piston rod connection, main rod connection, and a common guide for both. Fig. 1 shows a plan and side elevation of this arrangement where "a" is the piston rod, "c, c" the connecting rods fastened to the beam "d" and guided by the bars "b, b."

Fig. 1. (A) shows a modification of the above, in which only one connecting rod was used.

Stevenson's "Rocket," 1829, was the first locomotive to use a crosshead. This consisted of a small block running between two guides; a short connecting rod, which must have caused great ver-

PISTON AND CONNECTING ROD MOTION
TREVITHICK'S LOCOMOTIVE.



Sketched from model in Field Museum. Chicago

FIG. 1.

tical thrusts on the guide bars, was a noticeable feature. In the early thirties American designers adopted a crosshead which was guided top and bottom by round bars. (fig. 2.) Lack of ready adjustment to wear and weakness were chief points in this design. Then came the two-bar crosshead as seen in fig. 3. The guide bars were made of boiler iron, a cast iron head being used.

Fig. 4, shows a crosshead used on the "James," built by Wm.

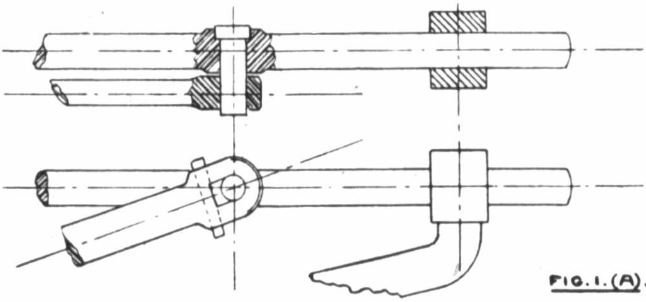


FIG. 1. (A).

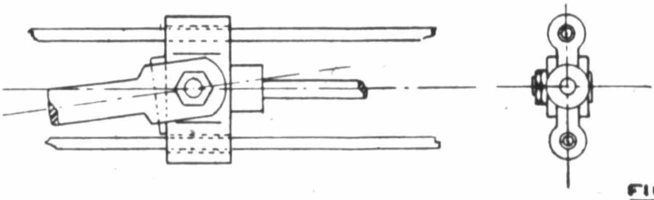
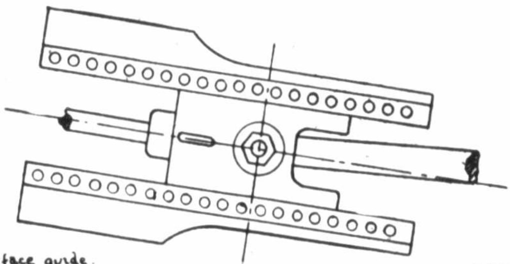


FIG. 2.



Two bar plane surface guide.
Adapted on first mogul ever built.
Eastwick & Harrison. 1839.

FIG. 3.

T. James, of New York, for the Baltimore and Ohio Ry. in 1832.

Fig 5 as on the "Sandusky" built in 1837. Fig. 6 that on the "Pioneer," the first locomotive to run into Chicago. In the early fifties American designers adopted the single bar type. Commencing

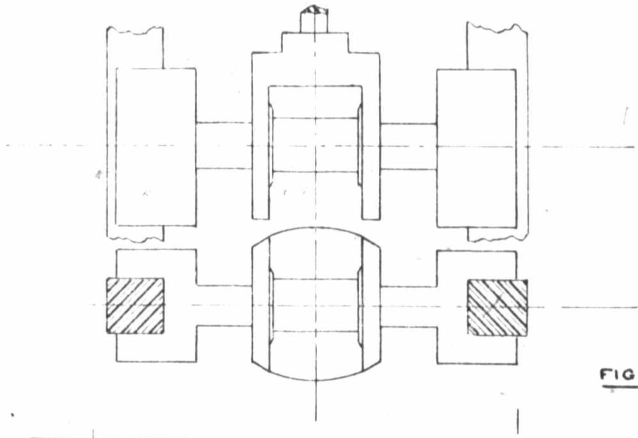


FIG. 4.

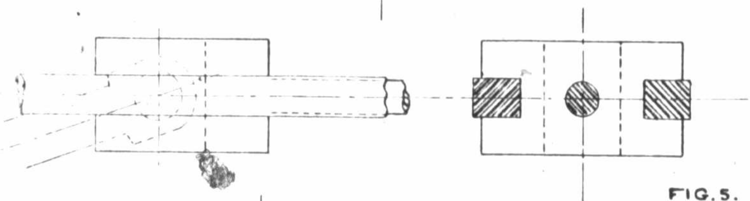
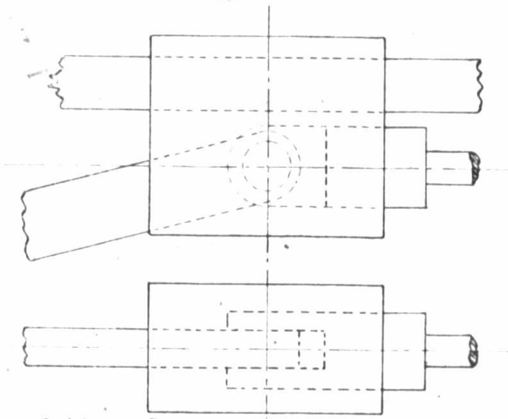
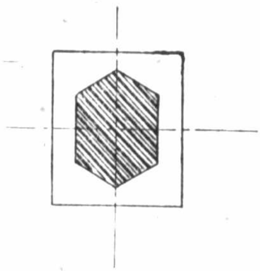


FIG. 5.





Sketched in Field Museum. Chicago

FIG. 6

FIG. 7.

with a bar of section shown in fig. 7, they finally adopted the simpler rectangular shape (fig. 15.). We may here note that the early designers made no attempt to transmit their power through a parallel motion, and we shall presently see that they were justified in sacrificing force for the sake of simplicity of construction.

MODERN FORMS.

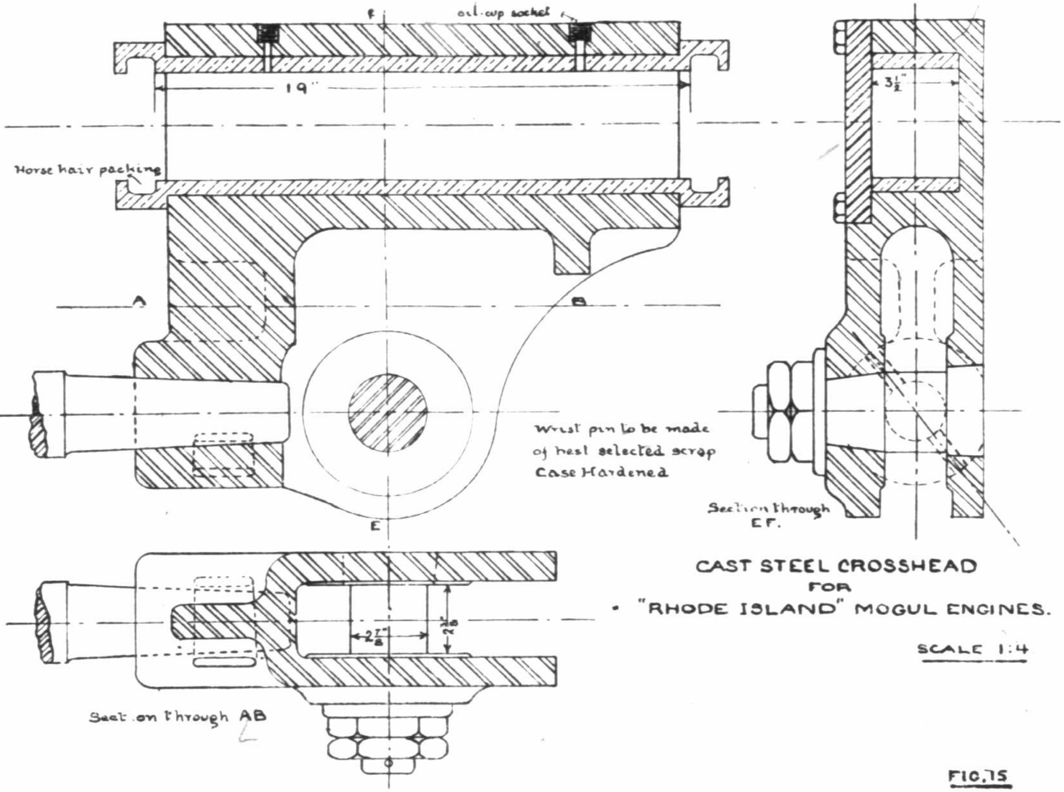
Locomotive crossheads, the world over, belong to three classes: namely, the two-bar, the four-bar, and the single bar types. It is true that there are many heads that do not come under the above classification, but they are special designs and not standard. The two-bar type, as seen in figs 8, 9, 10, 11, is the most common head seen on the American Continent. The guide bars are equi-distant top and bottom from the piston rod and are central with the vertical plane of the cylinders. The pin is always separate, and lies under the centre of the slipper block. The heads are usually made in cast steel with brass shoes top and bottom, and steel pin, as seen in fig. 8.

A cast iron type (fig. 9) is common in which the socket is reinforced by ribs cast between it and the shoe supports—see "a, a" in fig.

It is usual on this type to use brass liners on the sliding surfaces, with a cast iron flange bolted on as shown at "b b." This head is not as simple as that seen in fig. 8, and is being supplanted by the latter on many of the large American Railway Systems. The four-bar type, seen in figs. 13, 14, and 16, consists of two blocks which run on either side of the piston and connecting rods, and are joined in one casting which forms connection for piston rod and also the pin around which the connecting rod end oscillates. The casting is made of good wheel C.I. or cast steel. Although the crosshead pins are usually part of the casting, on some roads separate pins are used. The weak features of this design are that the pin does not always lie under the centre of the slipper block, giving uneven distribution of pressure on it; when the pin is cast, it is always a difficult operation to machine it and keep it in order; also four sliding surfaces are more difficult to deal with than two. When made in C.I. this type is weak at points "a, a," "b, b" and "c, c." To prevent breaking some roads have ordered W. I. bands to be shrunk around the flanges next to the inside of the bars.

The guide bars are made of W. I., case-hardened, and ground with emery wheel to the proper surface.

A crosshead which belongs to this class is seen in fig. 14, which represents the head used on the Vauclain compound made by Baldwins, of Philadelphia. In this the high and low pressure

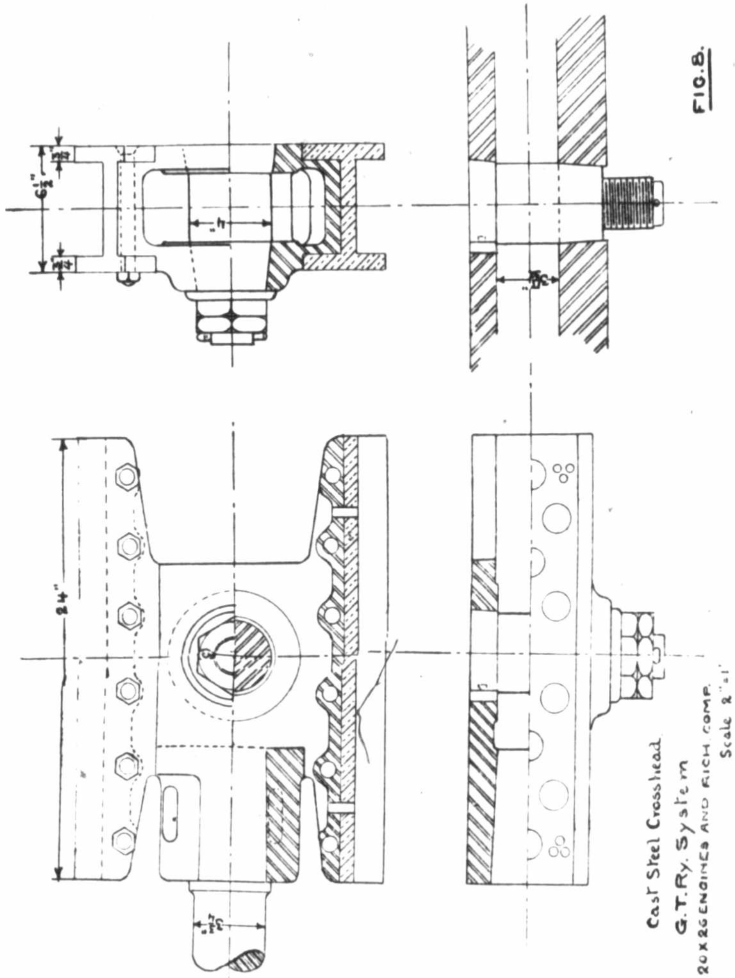


CAST STEEL CROSSHEAD
FOR
"RHODE ISLAND" MOGUL ENGINES.

SCALE 1:4

FIG. 15

piston rods are connected on each side to a single head. The four sliding surfaces are situated horizontally outside and vertically between the piston rods. An open hearth steel casting with block tin,



1-16" thick, lining, for all bearing surfaces, and a separate steel pin, are the principal features. It is a well designed crosshead and gives very little trouble on the road.

The single-bar type:—Fig. 15 shows a crosshead which has been used successfully for many years on roads in the United States. In it the crosshead embraces a single guide bar, the lower rubbing surface being lubricated by means of oil holes drilled in the guide bar. It is a strong head and gives a large amount of clearance for the connecting rod, and other parts, besides it is simple in construction and easily lined up.

Fig. 18 represents a form of crosshead where both guide bars are placed above the centre line of the piston rod. A forked jaw carries the pin, whose centre is in direct line with cylinder and piston rod centres. "A" (see fig.) is a crosshead filling piece which is bolted between the two checks "b" and "c" of the crosshead. This is a simple crosshead to set up, all that is necessary being to clamp up both bars to embrace the filling piece, raise the crosshead up, and bolt it in position. This crosshead is used where the driving wheels come opposite the slide bars, as in mogul or consolidation engines. One weak feature of this design is that it is hard to adjust the sliding surfaces for wear. Fig. 11 shows a design used by Baldwins on their Vauclain compounds. It has evidently been designed to give clearance for a short connecting rod.

It may be interesting, at this point, to glance at some of the designs used on British locomotives. In Fig. 16 we have a form which is in common use on inside and outside connected engines. It belongs to the four-bar type; a wrought iron crosshead carries a pin which acts as journal for the forked end of the connecting rod "a, a" and the cast iron slide blocks "b, c."

Brass liners are sometimes inserted between the surfaces of blocks and guides to reduce friction. In all of its other features it is similar to the American four-bar type, as already described. Fig. 17 illustrates a head in which the piston rod and slide block are forged in one piece, and the whole is free to turn round a case-hardened W.I. journal, which is keyed to the connecting rod, except for the constraint of the guide bars. This is an expensive design, is weak in support, and would withstand little side twist. Fig's 19 and 20 show by end views the chief feature of construction of three-bar types, which are in use to-day. The guide bars are shown in section.

Comparison of Parts.

Strength of Guide Bars.—All guide bars should be made strong enough to withstand excessive shocks such as they would be subjected to if a rod were knocking at its brasses badly, or any one of the extra destructive effects due to an engine jolting over a rough track.

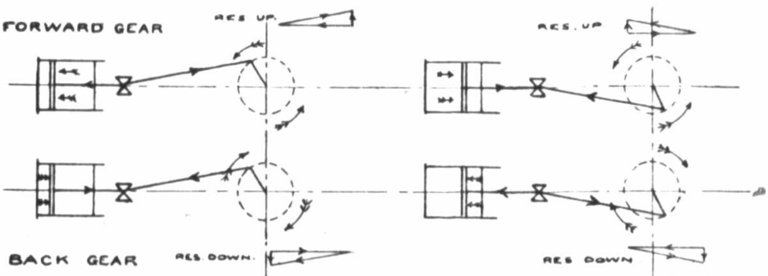
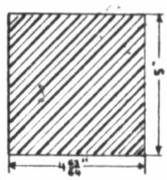


FIG. 21.

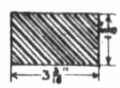
TABLE I.



MORSE MOGUL
G.T.Ry. System.
20" x 26" x 63" DRIVERS.

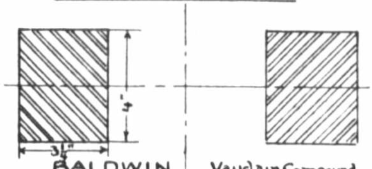
l — 39½"   I — 52   f — 6000 #/□"   y — 2½".
M — 125000 "#   m — 68500 "#.

In considering max. bending moment on bar it having fixed ends, take $m = \frac{Wl}{8}$ where W = max. force acting at centre.



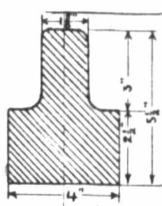
BALDWIN
14" x 22" SWITCH. ENG.

length of slide bar (l)	47 5/8 "
moment of inertia (I)	11.41
safe stress per sq in. (f.)	6000 #
neutral axis to outside (y.)	13/16 ".
moment of resistance (M)	84200 in. lbs.
max. moment on bar (m)	17275 in lbs.



BALDWIN   Vauclain Compound.
15½ & 26" x 28" stroke.

l — 64"   I — 17.33 for each bar
f — 7000 #/□"   y — 2"
M — 60700 x 2 = 121400 "#
m — 69500 "#



G.T.Ry. Mogul.
18" x 24" STROKE

l — 55 3/8 "   I — 33.54   f — 3000 #/□"
y — 2¼"   M — 44720 "#.   m — 44200 "#.
Cast Iron bars break frequently, but give excellent satisfaction while running

STRENGTH OF GUIDE BARS.

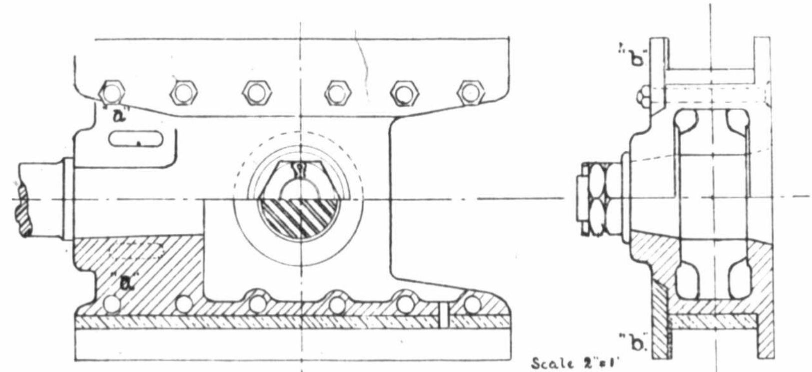


FIG. 9.

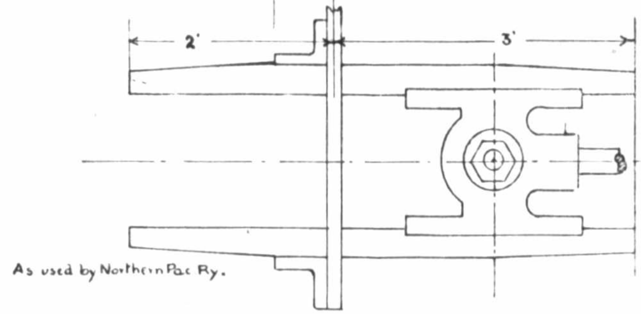
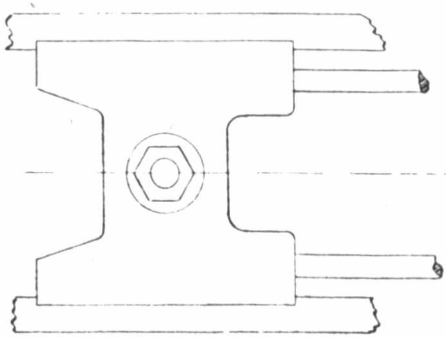


FIG. 10.



BALDWIN

VAUCLAIN TYPE

FIG 11

The guides are always subjected to great vertical strains. To resist these they must be strongly bolted at the front end to the back cylinder head, and at the back end to the guide yoke (see fig. 18) which in turn is bolted to the engine frame, and usually also to the boiler.

The section of the guide-bar is always greatest opposite the centre of the crosshead stroke, as this is the place where the maximum upward thrust takes place, and, since most bars are supported to the ends, here the greatest bending moment is found. Guide bars are made of steel, C.I., and W.I. It is the opinion of many railroad men that the C.I. bar gives the best satisfaction of all. The rubbed faces of these bars are often chilled in diagonal strips to make them wear better. All W.I. bars are case-hardened and ground.

It is preferable that the surface of the slipper blocks should wear before the guide bars: to ensure this the slipper blocks are lined with a softer metal than the guides are made of.

The top bar must be made stronger than the bottom bar, for in locomotive work the engine is running in forward gear more often than it is running backwards—now while in forward gear all pressure comes on the top bar and vice versa—the reason that this is so may readily be seen by examining fig 21. By taking the connecting rod in two positions for each direction of motion, and resolving the forces and reactions which keep it in equilibrium, by the triangle of forces we can see that this statement is so. Of course we here suppose that the centre of the cylinder comes in direct line with the crank pin centre; if this is not so, the statement is not absolutely correct.

In fig. 10 we see a bar supported at a point two-fifths of its length from the end. This is a good feature, in that the bar receives the maximum thrusts close to its point of support.

The stress on the guide bars is due to the pressure of the steam on the piston, acting obliquely on the crank, and is greatest when the crank is at right angles to the connecting rod. We shall here only consider the maximum thrust, and for simplicity, we will imagine the steam pressure constant throughout the stroke; neglecting the weight of parts, inertia forces, and frictional loss in cylinder and gland. See fig. 24.

S. is max. when A. B. C. is a right angle. From similar triangles it may readily be seen that

$$\frac{R}{nR} = \frac{S}{P} \quad \therefore \quad S = \frac{P}{n}$$

We shall by the above formula, knowing the values of P, n, and moment of inertia of the guide bar, etc., determine the relative resistances of four types of bar. See "Table 1."

Clearance cuts, at the end of the guide bars (see "d d." fig. 18) are placed there to prevent the formation of a ridge at the point where the crosshead reverses, thus preventing binding and

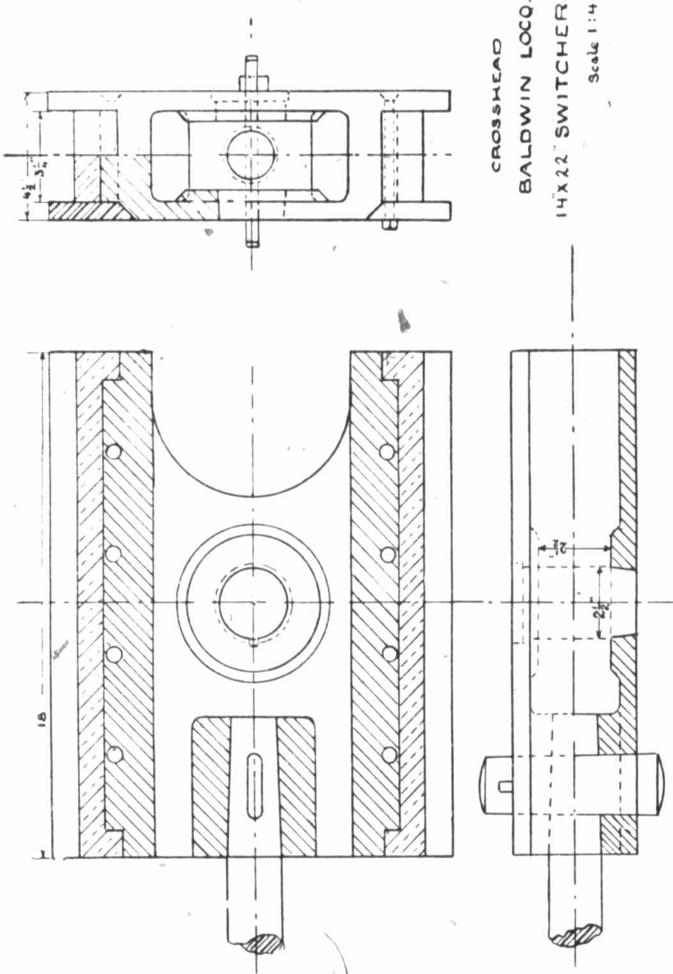
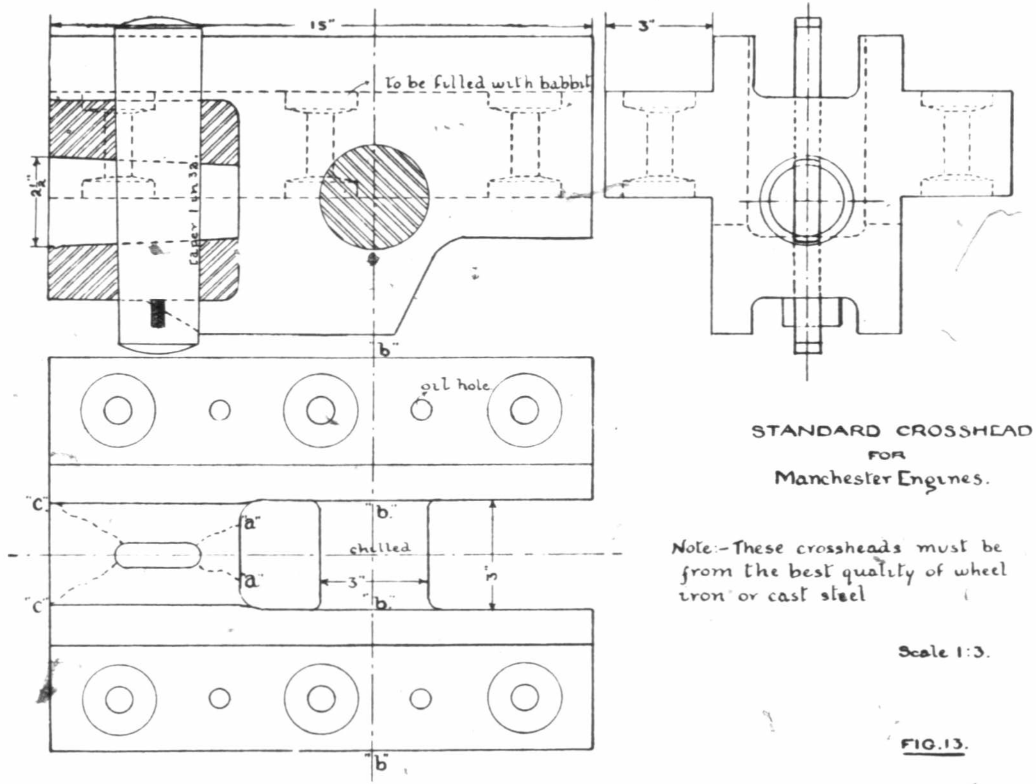


FIG. 12.

throwing off any grease or dirt which the crosshead may have gathered.



STANDARD CROSSHEAD
FOR
Manchester Engines.

Note:- These crossheads must be from the best quality of wheel iron or cast steel

Scale 1:3.

FIG. 13.

FRICTION BETWEEN SLIPPER AND GUIDE.

Considering the fact that parallel motions are not used in locomotive construction, particularly in transmitting power from the cylinder to the driving wheel crank, we have to reckon with a considerable loss of power in friction, due to the resisting forces of con-

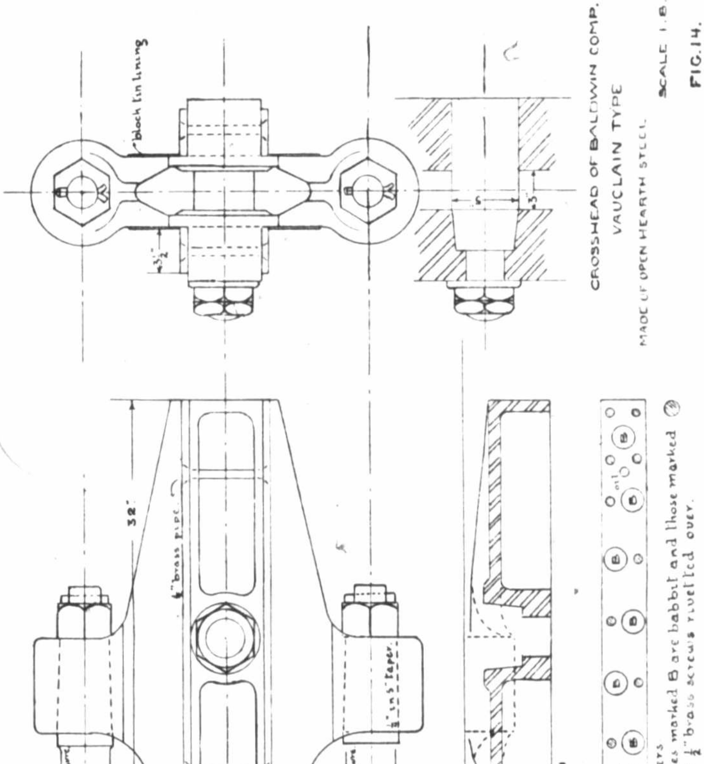


FIG. 14.

strained motion. It is the duty of the designer to so construct his parts that this loss may become a minimum. The frictional loss due to the weight of the reciprocating parts on the bars is negligible as compared with that due to the upward and downward thrusts caused by the angularity of the connecting rod. To reduce friction we must therefore lengthen our connecting rod and thereby reduce its angularity. Again, the frictional loss may be reduced by having the rubbing surfaces made of, or lined with, some form of

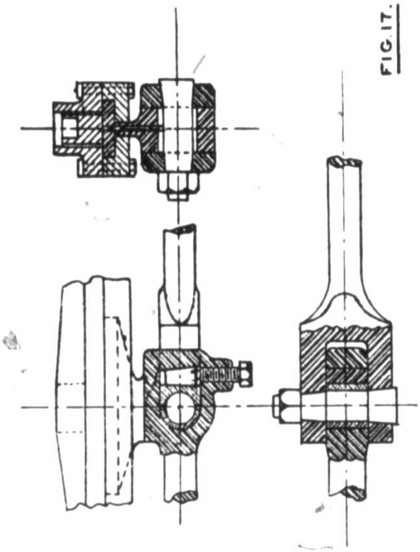


FIG. 17.

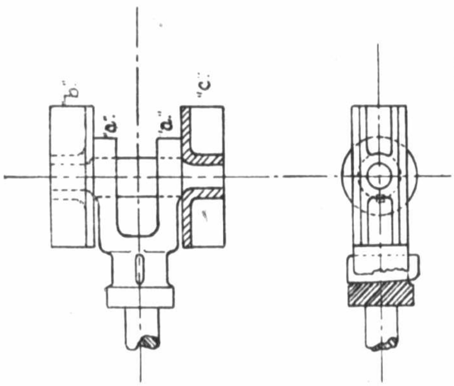
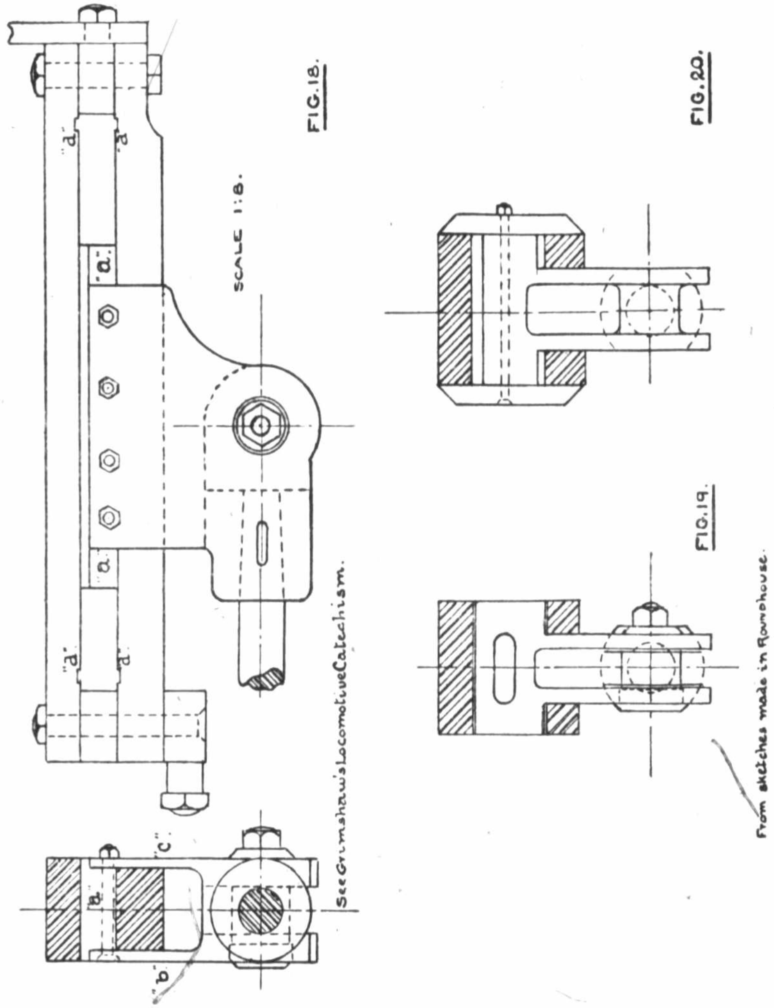


FIG. 16.

See Unwin's Machine Design Vol II pp 124-128

anti-frictional material; also by taking care to have these surfaces at all times well lubricated.

Knowing the pressure on the sliding blocks, and their dimensions, we shall compare the intensities of pressure to which the various materials used are subjected. In a preceding paragraph the means of determining the maximum thrust on the guide bars was explained. Taking this value and dividing it by the area of the



slipper block we arrive at the intensity of pressure. It is true that this intensity decreases at the ends of the stroke, and as the speed rises, but we are here dealing with the severest test it must undergo, which will take place on starting, when the value of the co-efficient of friction (u) is greatest. Knowing the amount of thrust on the guide bar, and the value of "u" for rest, we can readily compute the amount of force required to move the crosshead from rest.

Speaking of intensity of pressure on guide bars, an authority says:—"In locomotives having steel or case-hardened W.I. bars the pressure is sometimes as high as 120 lbs. per sq. in. This is much too high, and will soon wear down the guides and crosshead gibs. The pressure per square inch should not exceed 40 lbs."

Compare the above with values seen in "Table II."

The pressure of oil or other lubricant between the rubbed surfaces tends to reduce the friction and lessen the heating.

The guide bar, slipper block, and crosshead casting must be of sufficient volume to allow the heat to dissipate freely, or else it will collect and result in "running hot."

In order to determine the starting effort, maintaining effort, and horse power wasted in friction, a value of "u" for crosshead and guide is necessary. All mechanical engineer's hand books contain values which are approximately true. Local conditions, such as the temperature of sliding surfaces, lubricant used, speed of rubbing, etc., have a great deal to do with these values.

In order to find the co-efficient for crosshead and guide as used on locomotives now being built by the Grand Trunk Railway in their Point St. Charles Works, the writer resorted to the following simple method:—A bottom guide bar was placed flat on the floor, a block and tackle was fastened to one end of the bar, while the crosshead was allowed to lie freely on the level surface of the bar. The block and tackle then gradually raised one end of the bar while the other end acted as a pivot. This operation was performed slowly, the bar being constantly rapped with a copper hammer to prevent sticking, until the angle of repose was reached and the crosshead started from rest. The angle ϕ was determined by means of a spirit level and protractor.

The following were the results:—

As experimentally determined.

Surfaces.	u.	Conditions.	Remarks.
Brass on W. I.	.1405	dry.	Atmospheric temp.
do.	.1317	oiled.	about 82° Fah.

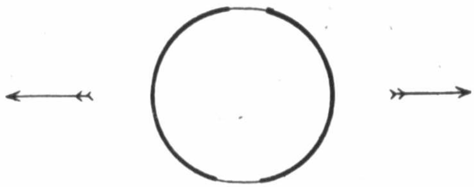
Jenkin and Ewing's results.

Surfaces.	u.	Conditions.
C. I. on W. I.	.171	dry.
Steel on Brass	.146	oiled.

DESIGN OF CROSSHEAD PIN.

The crosshead pin must be placed in a position where it will create no bending moment, and will distribute the vertical thrust equally over the slipper block. This being so, there only remains one place for it, and that is the intersection of the line through the cylinder and piston rod, and a line dropped vertically from the centre of the slipper block. Its position having been determined, it must be so dimensioned as to resist shear and bending moments on it as transmitted to the connecting rod; it must be of large enough diameter to reduce the intensity of pressure on it to within certain limits; and it must be short enough to allow for the side twist which is present at times on locomotives. It must always be of sufficient volume to absorb and conduct the heat of friction, and be so prepared as to give little trouble when running.

Crosshead pins are usually made of high grade steel or case-hardened W.I. and sometimes, where the pin is part of the cross-head casting, of C.I. They are made flat top and bottom to give clearance for the oscillations of the brass and to leave a bearing where the thrust comes. Thus:—



Locomotive wearing parts must be so designed that they can be readily adjusted to wear. In crosshead pins the wear is usually taken up by wedging the brass bushes together. Now, the greatest pressure comes on the front and back of the brasses; and as these are closed together the sides have to be eased off with file or scraper. This is the reason that pins are often made of elliptical shape, and the brasses are always eased off before being put into place.

Knowing the maximum thrust on the connecting rod, and the area of the surface bearing it, we can easily determinte the intensity.—See "Table II."

TABLE II.

A COMPARISON OF INTENSITIES

Class of Engine	Area of Single Sliding Surface	Force "S"	Max. Intensity on Slipper	Area of Mainrod Brass Contact	Force "T"	Max. Intensity on Pin
Baldwin 14"x22	54□"	2590#	48#/□"	9.82□"	25050#	2500#/□"
Kingston 18"x24"	90□"	6560#	73#/□"	14.14□"	63400#	4000#/□"
Baldwin 15½"&26"x28" Vauclain Comp	112□"	8680#	77.5#/□"	23.57□"	93600#	3900#/□"
Morse Mogul. 20"x26" stroke.	120□"	8950#	74.5#/□"	25.6□"	78500#	3000#/□"

Forces "T" and "S" are maxima the angle ABC being 90°. Force "T" = mP where m is a coefficient depending upon angular thrust & inertia of parts, and here taken as 1.25. When the rod, brasses receive the max intensity of pressure they are oscillating very slowly.

FEATURES OF DESIGN IN SIDE AND VERTICAL TWIST.

A criticism of the main features of the locomotive from a theoretical standpoint generally results in the discovery of many glaring malformations. The frames lack the necessary triangular brace, and there is apparently a looseness about the parts which, to the uninformed, betokens a serious lack of judgment and craftsmanship. But beware! Watching an engine as it "stands at ease" in railroad station or on roundhouse pit is a very different matter to watching it as it speeds along at 70 or 80 miles per hour—as it slackens up to leave a tangent track and turn on an 8° or 10° curve. Watch the bending of its parts, notice how nicely it hugs the rail, without a bind or buckle, riding as smoothly as can be; only now can one readily see the necessity of having this automaton made loose-jointed. Since locomotive crossheads, like all other parts, are subject to side and vertical twists there must be plenty of side and bottom clearance on their guides, and the bearings must have sufficient slack; besides both the pin and slipper block must not be made too long.

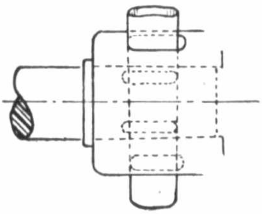


FIG. 22.

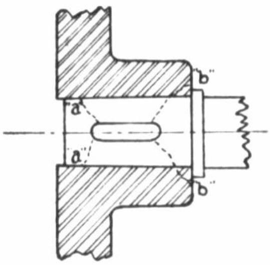
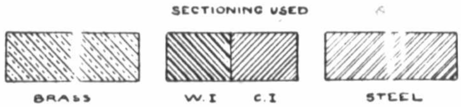


FIG. 2



STRENGTH OF PISTON ROD CONNECTION.

There are two distinct ways of fastening the piston rod to the crosshead. Sometimes the rod end is so forged that it receives the pin on which the connecting rod and guide journals work (see fig. 16). More frequently it enters a socket which is a fixed part of the crosshead and is keyed to it (see figs. 8—15). The strength of this connection depends largely upon—the amount of draw allowed for keying up, that is to say, the amount of compression that takes place between the rod and socket when the key is driven in; the ageing of the rod, it sometimes requiring a pull of 4,000 lbs. per sq. in. to start an old rod from its socket; the strength of the key;

and lastly the strength of the socket. Sufficient to say that seldom does this part give bother, and then only when some employee, through lack of knowledge or direct negligence strains or breaks a part. For instance, a common sight in any railroad shop is to see a mechanic driving in a key with a five ton blow, when a little grinding or filing of the tight part would have done the work far better.

The usual method of connection is shown in fig. 22. Here the pressure of the key on the socket and the opposite pressure of the rod end in the socket hold them fixed.

Breaks may be caused by lack of metal, but they are more frequently the result of misfitting or misdriving. See fig. 23. The key may be broken or the socket may break out in triangular pieces as at "b, b" when the rod does not fit tightly into the socket, and as a consequence gives rise to a "bump." Or else, if the key is driven in too hard, the rod end may break at "a, a."

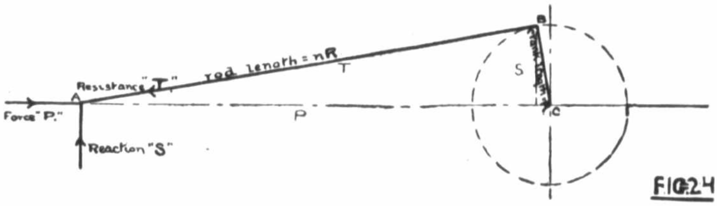


FIG. 24

CONCLUSION.

We have now followed the development of the crosshead from its earliest form, to its most modern design. We have studied the main features of its construction, and looked into the comparative strength of its details; perhaps it would not be out of place to here make a small forecast. The index of modern engineering development points us to that stage where reciprocation shall have become a dead issue, and where rotation will appear in each and every form of motion. The advent of the steam turbine to marine and stationary engines only precedes its advent to locomotion. In such an era, the crosshead will have passed into history, and the many integrals of work now absorbed by it in friction shall be reckoned with as useful motive power.