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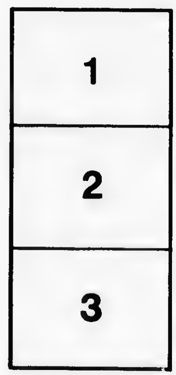

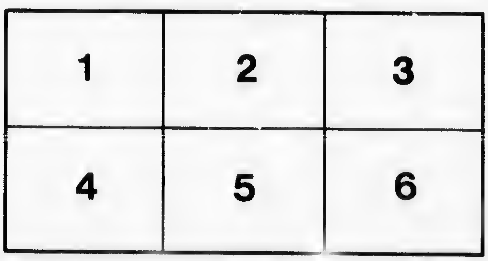

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Canadian Society of Civil Engineers.

INCORPORATED 1887.

TRANSACTIONS.

RAILWAY TURNOUTS.

(To be read Thursday, 1st February, 1894.)

By H. K. Wicksteed, M.Can.Soc.C.E.

Having occasion to lay out a railway terminal yard not long ago, and being cramped for room and steel, and having frogs of only 2 or 3 numbers on hand, which, out of respect for the shareholders' pockets, he felt bound to use up if possible rather than have others made, the writer had quite a lot of figuring and scheming to do, and was struck with the utter inadequacy of the pocket-book tables and formulas.

In the first place, all the books with which he is familiar take a slide rail swinging on its heel through an angle of from 45 minutes to 3° as a point, or rather a line of departure, and with this as a tangent and the swinging end as P.C. start a curve running to the frog and proceed to investigate its form and length. This always has seemed to the writer wrong and clumsy, not only in theory but in practice. In the first place, the slide-rail is not a rigid bar, and no matter how well lubricated its bearings, a steel rail 24 to 28 ft. long will spring slightly in being thrown, and instead of forming a tangent to the lead there is an arc from the heel to toe and then a sharp elbow in the reverse direction.—(See plate.)

In the second place, the wheel path, even should it conform with that intended, is not theoretically or practically the most perfect. A sharp change in direction, necessitating an angular movement of the car truck about its center, then a piece of straight line necessitating a second movement in the opposite direction, and lastly a curve necessitating a third slight movement in the same direction as the first. Practically, I believe all these movements are rendered unnecessary by play between rail and flange, and a bodily transverse sliding on the rail; but, however they take place, here is a source of increased wear and tear and resistance.

Thirdly, the lead required is unnecessarily long, which means increased yard room and more steel than absolutely wanted; and lastly, and by no means unimportant, the mathematical formulas are so complex, that to my knowledge no engineer tries to figure them for himself, but takes what he can from the tables and leaves the balance to the foreman's eye, if indeed he troubles about the matter at all beyond pointing out the position of the head-block. Take, for instance, the following for the very simplest problem of all—to find the frog distance having given the throw of switch and frog angle, etc., copied verbatim from Trautwine's pocket-book:

$$\text{Frog distance} = 2\,(\text{gauge}-\text{throw}) \times \frac{\text{cotan switch angle} \times \text{cotan frog}}{\text{cotan switch angle} + \text{cotan frog}}$$

$$= \frac{2\,(\text{gauge}-\text{throw})}{\text{sin frog angle} + \text{sin switch angle}}.$$

It will be noticed that the denominators of the fractions preclude the use of logarithmic functions.

The writer asked one very painstaking and competent engineer of long experience, whom he found one day superintending the laying down of a double throw switch with somewhat unusual elements, how he obtained the positions of frogs, etc., he replied that he got them all by scale from a plot on a large scale—graphically, in fact, which is the way Trautwine recommends. Now, the author is far from being opposed to graphic methods, and is especially fond of them in his own practice; but in the case of complicated switch and turnout problems, the graphic method (except as a check on final results when it is invaluable) is extremely tedious, and necessitates a large amount of trial and error work, plenty of paper and table room and lots of time. A man cannot have all these things with him in the field, and more time is wasted in going to his office perhaps 30 or 40 miles and coming back with the results.

For above mentioned reasons, the writer long ago came to the conclusion that the lead of the turnout should be circular from the heel of switch to the point of the frog, the slide rail being part of the circular curve instead of external to it, and being bent around stop spikes driven into the ties to this circular form. So far, so good; and he believes that this is not only his own practice but that of many others. Now to find the frog distance. Let A, fig. 2, be the frog, and a its angle. Produce its line to meet the opposite rail at P. then AP.C $= a$. Let g represent the gauge of track

$$AP = g. \operatorname{cosec} a \text{ or } \frac{g}{\sin a}$$

but A.P. is the subtangent of the circular arc AB, and the angle being small the arc and chord are for practical purposes equal to one another, and also to the sum of the subtangents = 2 AP = frog dist.

Frog distance, $$F = \frac{2g}{\sin a} \quad (1)$$

Now the number of the frog is the reciprocal of the chord of the angle, or in small angles such as generally occur on railways practically of its sine. Thus a No. 10 frog has a chord or sine of $\frac{1}{10}$.

Hence approximately the frog distance

$$F = 2 N g. \quad (2)$$

g being taken as 4.7 feet a No. 10 frog will then have a frog distance of 94 feet. We shall see further on how well this agrees with another formula obtained in a different way.

F in this and subsequent formulas and equations means the distance of frog point from the heel of the switch instead of from the toe, as in the pocket-book tables we have quoted.

This last distance we shall refer to as the lead, and denote by the letter L. The length of slide rail we will call S.

g is the gauge usually 4.7 ft.

T is the throw of switch usually 5 inches, which for simplicity and with ample accuracy we may consider as .4 ft.

Now to obtain the length of slide rail S. Take the diagram in Fig. 3, a simple turnout with a 1 in 10 frog. For such a small arc as 94 ft. we may consider the curve as being a parabola and that the offsets from the tangent are proportional to the squares of the distances from the heel of switch or point of curvature.

Now at the toe we have an offset by hypothesis of T, or .4 ft. At the frog we have the gauge or 4.7 ft.

Hence $$\frac{S^2}{F^2} = \frac{T}{g}$$

$$S^2 = F^2 \left(\frac{T}{g}\right)$$

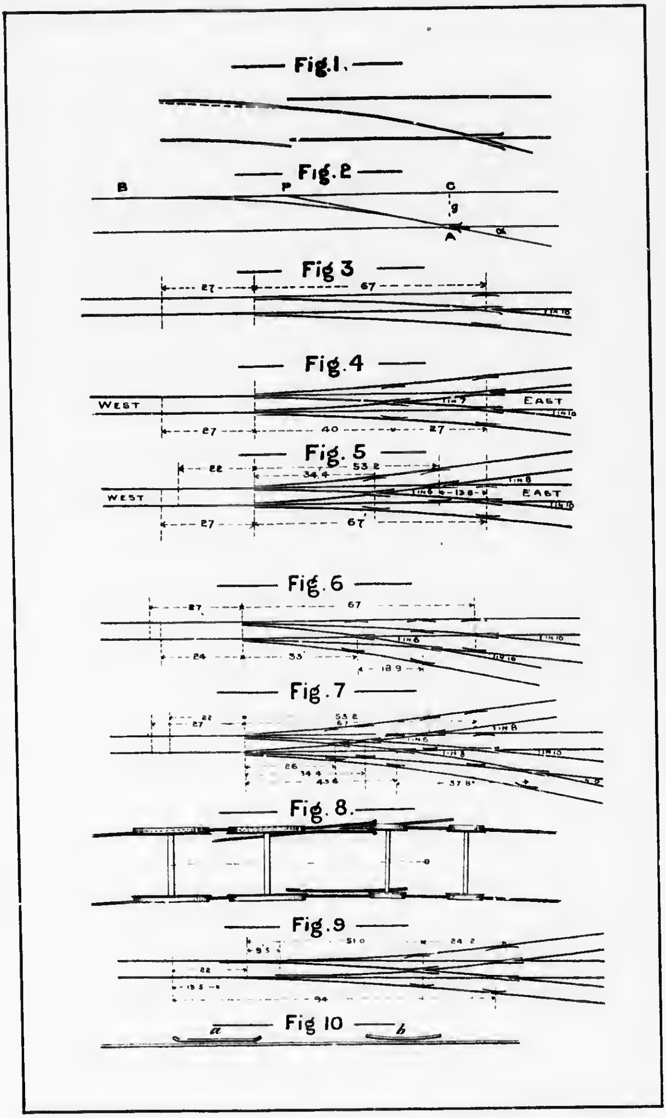
and $$S = F \sqrt{\frac{T}{g}} \quad (3)$$

For all ordinary railway cases T and G are constants

and $$\sqrt{\frac{T}{G}} = \cdot 29$$

Hence $$S = \cdot 29 \text{ F} \quad (4)$$

or in Fig. 3 S = ·29 × 94 = 27.3 feet.



$F_1 = 66.6$

$L_1 = 40$ (nearly)

This last problem can of course be readily solved by a drawing, but not without considerable construction work and labour.

and $\sqrt{\frac{T}{G}} = \cdot 29$

Hence $S = \cdot 29 \, F$ (4)

or in Fig. 3 $S = \cdot 29 \times 94 = 27.3$ feet.

These three equations:

$$F = \frac{29}{\sin a} = 2Ng = \frac{9.4}{\sin a} \text{ or } 9.4N$$

$$S = .29\ F$$

and $$L = F - s \quad (5)$$

will solve all the simpler problems of single throw turnout, but in the double and treble throw something more is wanted. It was cases like figs. 4 and 5 which set the writer thinking on the following lines.

Returning to fig. 3 again, the offset at the end of a 100 feet chord of a 1° curve is 0.87 ft., and increases proportionally to the degree of curvature. Hence for a curve of D° it will be .87 D and as above for any other distance (within moderate limits) from the point of curvature, it will be for N feet

$$.87\ D \times \left(\frac{n}{100}\right)^2$$

The total deflection at the end of this distance will be $\frac{Dn}{100}$

Then for fig. 3 we have $\frac{F^2}{100} \times .87\ D = g \quad (a)$

and $\frac{F}{100} \times D = a \quad (b)$

Simplifying (a) and (b) $F^2D = \frac{10000g}{.87}$ and $FD = 100a$

$$F^2D = 100\ a\ F$$

therefore $100\ a\ F = \frac{10000g}{.87}$

$$F = \frac{100\ g}{.87\ a} = 115\ \frac{g}{a} \quad (6).$$

Substituting in (b) $\frac{100\ g}{.87\ a} \times \frac{D}{100} = a \quad D = .87\ \frac{a^2}{g} \quad (7).$

Substituting for—a and g—the same values as before, 1 in 10 or 5°.75—and for g—4.7 ft., we get:

$$F = 94 \text{ ft. as before}$$
$$D = 6°.12 \text{ or } 6° 07'$$

and
$$S = 27 \text{ ft.}$$
$$L = 67 \text{ ft.}$$

Comparing with Trautwine's tables, we find for a 26 ft. slide rail, a lead of 72.7 or F = 99.7.

and R = 877 or D = 6° 30′

We have therefore saved 6 ft. of lead or 12 ft. of steel, and got a slightly easier curve on it.

Lower down in the same table we will find that with a 16 ft. slide rail, we will have a lead of 67.8 and a curvature of 6° 15′ practically the same as above, but with an angle at the heel of 1° 30′ which is rather abrupt for high speeds and certainly not as desirable as a continuous curve.

Let us now take up fig. 4, a three throw switch with two 1 in 10 frogs, on the main line. We wish to determine the longitudinal position of the third frog. We have given the curvature D = 6°.12 the offset for which for 100 ft. or 0 = .87 D = 5.3 ft. (from the tables).

Since the third frog is evidently in the centre of the gauge, we have the total offset = ½ g or 2.35. hence the equation

$$\left(\frac{F_1}{100}\right)^2 \times 5.3 = 2.35$$

$$F_1^2 = 4434$$
$$F_1 = 66.6$$
$$L_1 = 40 \text{ (nearly)}$$

This last problem can of course be readily solved by a drawing, but not without considerable construction work and labour.

The following fig. 5 is not quite so simple, but it is probably a better arrangement because no two frogs come opposite one other, and there is no point on the main line unprotected by a guard rail as there is in fig. 4.

The frog in north rail, fig. 4, being 1 in 8 from equation (2), we get:

$$F = 2\ Ng = 2 \times 8 \times 4.7 = 75.2 \text{ ft.}$$

from (4) $S = .29\ F = 75.2 \times .29 = 21.8$, say 22 ft.

(5) $L = F - S = 75.2 \times 22 = 53.2$

(7) $D = 87\ \frac{a^2}{g} = \frac{.87 \times (7.16)^2}{4.7} = 9.°49$ or 9° 30′ nearly.

Now, to determine the position of the third frog, which is not now in the centre of track. The tangential offset for the south curve is as above, 5.3, for the north 8.3. If F be the frog distance on the north line, F + 6 will be that on the south, the switch being 6 ft. longer. This we may say, before going fur her, involves no difficulty in practice, the spikes on the north side being driven 6 ft., or 3 ties, nearer the toe than on the south.

Now we have for the distance of the frog from the north rail the expression $\left(\frac{F+6}{100}\right)^2 \times 5.3$

from the south rail the expression $\left(\frac{F}{100}\right)^2 \times 8.3$

But the sum of these two is the gauge.

Whence we get the equation :—

$$\left(\frac{F+6}{100}\right)^2 \times 5.3 + \left(\frac{F}{100}\right)^2 \times 8.3 = 4.7$$

$$\text{Simplifying—}(F^2 + 12\ F + 36)\ 5.3 + 8.3\ F^2 = 47000$$

$$13.6\ F^2 + 63.6\ F = 47000 - 191 = 46809$$

$$F^2 + 4.68\ F + (2.34)^2 = 3442 + 5.5 = 3447.5$$

$$F + 2.34 = 58.71$$

$$F = 56.4$$

$$F + 6 = 62.4$$

$$L = 34.4$$

This determines the longitudinal position—substituting the above values in the expressions

$\left(\frac{F+6}{100}\right)^2 \times 5.3$ and $\left(\frac{F}{100}\right)^2 \times 8.3$—we get the values.

Distance from North Rail............	2.06
" " South "	2.64
	4.70

The angle of the frog will be the sum of the deflections of the two turnouts.

$$a = \frac{F}{100} \times 9.5 + \frac{F+6}{100} \times 6.12$$

$$= \frac{15.6\ F + 36.6}{100} = 9.°16 \text{ or } 9°10'$$

A No. 6 frog, pinched a little with the crow or rail bender and with the point set back a trifle from the theoretical as obtained above, will fit the place quite well in practice; but if we wish to be very exact about it, the following analysis of the problem in Fig. 6 a double throw both on same side of main line will suggest a means of calculating. This is not a common combination, but it actually, or rather one almost identical with it, occurred in the writer's practice. One turnout was for a main siding and the other for a Y, and in order to save room and switch frames and unnecessary complication it was decided to start both from the same headblock. The main turnout was already laid with a 67 ft. lead and a 1 in 10 frog, as in Fig 3. We had on hand a No. 6 and a No. 10 frog, which we desired to use. Putting the 1 in 6 first in the main line we get from equation (2)

$$F = 2g \times N = 9.4 \times 6 = 56.4,$$

or as in such an obtuse angle as 9° 32′ the sine and chord commence to differ appreciably—we may take the more exact value by (1):

$$F = \frac{2g}{\sin a} = \frac{9.4}{\sin 9^\circ 32'} = 56.8$$

T is in this case 10 inches or .83 ft.

Substituting in (3) $s_1 = F \sqrt{\frac{T}{g}} = 23.8$

$$\frac{F\ D}{100} = a, \text{ therefore } D = \frac{100\ a}{F} \pm (8)$$

$$= 16^\circ.78 \text{ or } 16^\circ\ 44'$$

We have still to obtain the position of the 1 in 10 frog—between the two turnout rails. Let x be the unknown distance from the point of the last one considered (the 1 in 6), and D the curvature per 100 ft. over this piece x.

Then $\frac{x\ D}{100}$ will be the deflection of the South turnout between the two frogs, and the total deflection from ma line to point of 1 in 10 frog will be $\frac{x\ D}{100} + 9^\circ\ 32'$. On the north turnout the deflection to same point will be that for a distance $27 + 33 + x = x + 60$, and will be represented by the expression $\frac{x + 60}{100} \times 6^\circ.12$. But by hypothesis the difference between these is the angle of the frog or 5° 44′ hence the equation:

$$\frac{x\ D}{100} + 9.^\circ 53 - 6.12\ \frac{x + 60}{100} = 5.^\circ 73$$

$$x\ D + 953 - 6.12\ x - 367 = 573$$

$$x\ D = 6.12\ x - 13$$

$$D = \frac{6.12\ x - 13}{x}$$

Again we have for the lateral position of the frog from south rail of main line:—

on the north turnout $\left(\frac{x + 60}{100}\right)^2 \times 5.3$

on the south " $x \sin 9^\circ\ 32' + 87\ D \left(\frac{x}{100}\right)^2$

equating $\frac{(60 + x)^2 \times 5.3}{10000} = .1656\ x + \frac{.87\ D\ x^2}{10000}$

$$(60 + x)^2 \times 5.3 = 1656\ x + .87\ D\ x^2$$

$$19080 + 636\ x + 5.3\ x^2 = 1656\ x + .87\ D\ x^2$$

substituting the value of D in terms of x above.

$$5.3\ x^2 + 636\ x + 19080 = .87\ x^2 \times \frac{6.1\ x - 13}{x} + 1656\ x$$

$$= 5.3\ x^2 - 11.3\ x + 1656\ x$$

$$1009\ x = 19080$$

$$x = 18.9.$$

Substituting in the equation of D in terms of x,

$$D = \frac{6.1\ x - 13}{x} = \frac{115.3 - 13}{18.9} = 5^\circ.41 \text{ or } 5^\circ\ 25'$$

Substituting in the expression for the offset or lateral position of the frog point, we have:

$$0 = \left(\frac{60 + x}{100}\right)^2 5.3 = .789^2 \times 5.3 = 3.3 \text{ ft.}$$

Fig. 7 is a combination of the arrangements in Figs. 5 and 6, and is an example of a 4 throw switch, something not often seen in actual practice. For reasons explained further on, it would not be advisable to break up the sharp curve forming the lead of south turnout by inserting another frog. A 1 in 8 has therefore been instituted.

Making F = 75.2, D = 9° 30′, S = 31.6, L = 43 6

The only element left not solved as in the preceding is the position of frog between the extreme north and south turnouts and its angle.

Both tracks have now a curvature of 9.°30. $\theta = 8.3$, but one curve starts 10 ft. behind the other. We have then the equation:—

$$\left\{\left(\frac{F}{100}\right)^2 + \left(\frac{F+10}{100}\right)^2\right\} \cdot 8.3 = 4.7$$

$$2\,F^2 + 20\,F + 100 = \frac{47000}{8.3} = 5662$$

$$F^2 + 10\,F + (5)^2 = 2831 - 50 + 25 = 2806,$$

$$F + 5 = 53$$

$$F = 48 \qquad L = 26$$

Distance from south rail and main line as above

$$\frac{F^2 \times 8.3}{10000} = 1.9 \text{ ft. or } 1' \ 11''$$

For the angle of frog we have:

$$a = \frac{2\,F + 10}{100} \times 9.5 = 10.°07 \text{ or } 10° \ 04'$$

It is quite possible to add a fifth track making a 5 throw switch; but as it necessitates 4 extra frogs and 8 guard rails, the extra complexity and cost will generally outweigh the advantages of convenience in operation.

Some of the writer's mathematical contemporaries, who discussed the transition curve, will, he feels sure, be dissatisfied with some of the above methods, because they are not precise. For the sake of simplicity in resulting formulas he has treated the curve of the turnout at one moment as a circular arc, and at the next as a parabolic. He has assumed the sum of the subtangents as being equal to chord and the co sine of a considerable angle x being unity. His answer to them is that a difference of a few inches in the lead on either side will make no difference whatever in the practical utility of the results; and as frogs are made in a forge and machine shop, and not by a mathematical instrument maker, the errors in them will often amount to more than those due to the want of precision in the formulas. And, further, whether the curve be circular, parabolic or something a little different from either matters not one particle, provided the radius of curvature is nearly constant and there are no sharp angles or breaks in it. The methods and formulas given above have been repeatedly tested in practice, and found to yield good results in every case.

On the other hand, some of the practical men will say that it is useless to spend time and figures on such work, and that a foreman with a good eye will run them out by himself just as truly as can be done by the engineer. The writer has been a good deal with track men, and has repeatedly officiated as foreman himself, and believes he has as true an eye as most. He has found that, if left to themselves, they will make, even the best of them, the most surprising errors, not of inches but of feet, in the simplest problems, such as in Fig. 3. The track layer, who is judged mainly by the quantity of work he does, will almost invariably get his leads too short; and the section-foreman, who is judged by the quality, and who sees the failings of his predecessor's work, is almost invariably impressed with the necessity for very long leads, and acts accordingly. As a matter of fact, a lead extremely long necessitates a sharp kink somewhere, just as an extremely short one does, and is only a trifle less objectionable and unsightly. Such problems as have been solved in the preceding with the use of only one unknown quantity may generally be worked out on the ground by any tolerably intelligent man by stakes and tape measurement, in some such way as Trautwine suggests, but this is merely a graphical solution on a full sized drawing. On a road where trains are passing and sometimes standing every few minutes, it will not be found a very economical method, especially when half a dozen or more men are waiting to go to work; and in any case it is a longer operation than the algebraic solutions given above. The problems above, in which we have used two unknowns, are almost indeterminate on the ground, except by the method of successive trials and approximations, which also is not economical of time.

Given the position of frogs and toe of switch, and almost any foreman may be trusted to make as fair a line as need be.

The whole subject is precisely one of those involving the commonplace details of a railway, which are so often neglected as too simple and well understood to be worth the attention of a first class engineer. I have instanced one engineer who did not think so. These every-day details, if only because they are so oft a repeated, are those which really have most to do with the safe and economical operation of a railway; and I think the writer need make no apology for a further explanation of his deeming it worth while to study the question and to lay the results before the engineering fraternity.

Split switches are displacing the old-fashioned stub switches we have heretofore been considering for any service involving high speed. The advantage is of course the continuity of the rails and the absence of jar and jerk. The objections are higher cost and that they are not susceptible of being worked into 3 and 4 throw turnouts, hence they will probably never displace them altogether. The split switch differs essentially from the stub, in having a moveable rail planed down to a bevel edge having an angle of from 1 to 2 degrees, and moving into position alongside its neighbour instead of *vis-à-vis* to its end. There is thus an inevitable angle as in the stub switches discussed in the pocket books. As it is impracticable to bring this bevelling to an actual feather edge, the virtual point is a foot or so back of the actual. For convenience of calculation and other practical reasons, which need not be gone into here, but which may be understood from a study of the diagram of the position of the wheels of an ordinary 8-wheeled engine on a curve (Fig. 8), the writer's practice is to consider this angle as merely an elbow in the continuous turnout curve, as worked out in the first example, Fig. 3, and the virtual point as the intersection point of the subtangents corresponding to the angle. If, as in Fig. 1, the frog angle be 1 in 10, the curve 6° and the angle of fly-rail 1° 30′ we shall have these subtangents 12.5 ft. each, the P. C. will therefore be 12.5 ft. back of the virtual, or 13.5 ft. from the actual point of the fly-rail, and the inner edge of this last must be straight for 11½ ft., after which it will be bent to the curve of the turnout. Its total length must be at least sufficient to secure the necessary clearance for the wheel flanges, which we have heretofore taken at .4 ft. For an angle of 1°30′ this will be 15 ft. and for 2° 11 ft. The total frog distance in Fig. 3 was 94 ft. Subtending 13.5, we get 80.5 for the length of lead.

With these considerations borne in mind, the various problems for 2 and 3 throw turnouts may be worked just as in the case of stub switches. I have already said that 3 throw switches are impossible with the split switches, but it is quite common to find a double turnout arranged as in Fig. 9, with one switch a little ahead of the other. Except that the distances are longer, this is a precisely similar case to that in Fig. 5. The writer has already alluded to the diagram in Fig. 8. It is introduced for the sake of demonstrating the objection to a frog in the middle of a sharp curve. The leading driver will inevitably strike the elbow, if indeed it does not ride over it; and the trailer will wrench the guard rail badly. The truck wheels traverse well enough, and as both drivers tend towards the inside rail the point of frog is easily taken care of. Hence, while the lead may be made fairly sharp with safety, there should always be a piece of straight or easy curve beyond the frog, hence the flattening in Fig. 6 in the south turnout between the 1 in 6 and 1 in 10 frogs. In regard to guard rails, they will be seen in the older roads made so as to be parallel with the main rail for quite a distance, with a sharp kink at each end. Fig. 10 *a*. These are required to be made in the forge. The writer has always been in the habit of making them as in Fig. 10 *b*, leading the stray wheel gradually into its proper line and then letting it go immediately the point of frog is passed. These can be made on the ground in a few minutes with a jim-crow and cold chisel, and he is glad to see them coming into general use.

If, as the writer believes, the methods and principles enunciated above have never been used in connection with turnout problems except by himself, he thinks the maintenance of way engineer will be well repaid by a study of them, as he has himself been in the increased rapidity with which he can arrive at accurate results, and which is perhaps of more consequence in clean cut easy curves and turnouts.

Inasmuch as the equations often involve large numbers, squares and square roots, he can never be far astray in plotting the results afterwards as a check on the arithmetical work. It is much easier and takes less time to plot a result than to arrive at it graphically; and as an evidence of its being worth while to employ some means of locating frogs and switches before going to work, it is only necessary to point out one or two of the many clumsy, ill-fitting ones which any tyro can detect in almost any large yard as the result of haphazard work under no system whatever.