Oct. 21, 1941. G. R. BURKHARDT 2,260,211

TORSION-RESISTING RAIL

Filed April 10, 1940 3 Sheets-Sheet 1

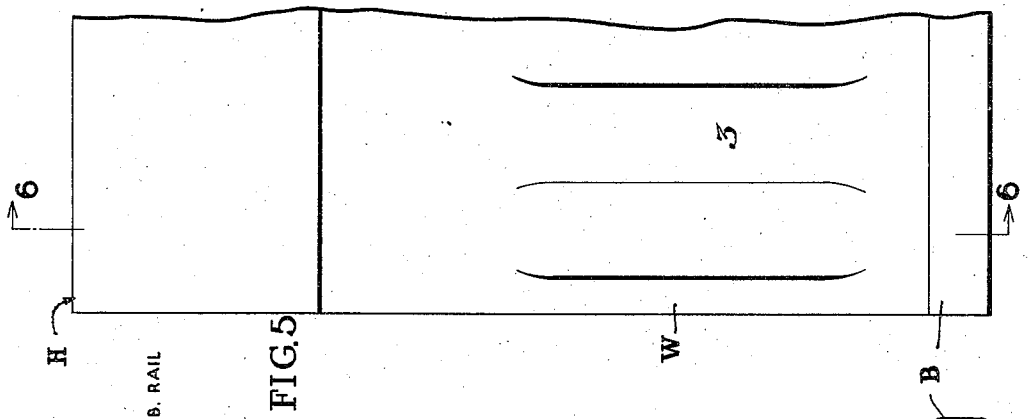


FIG. 5

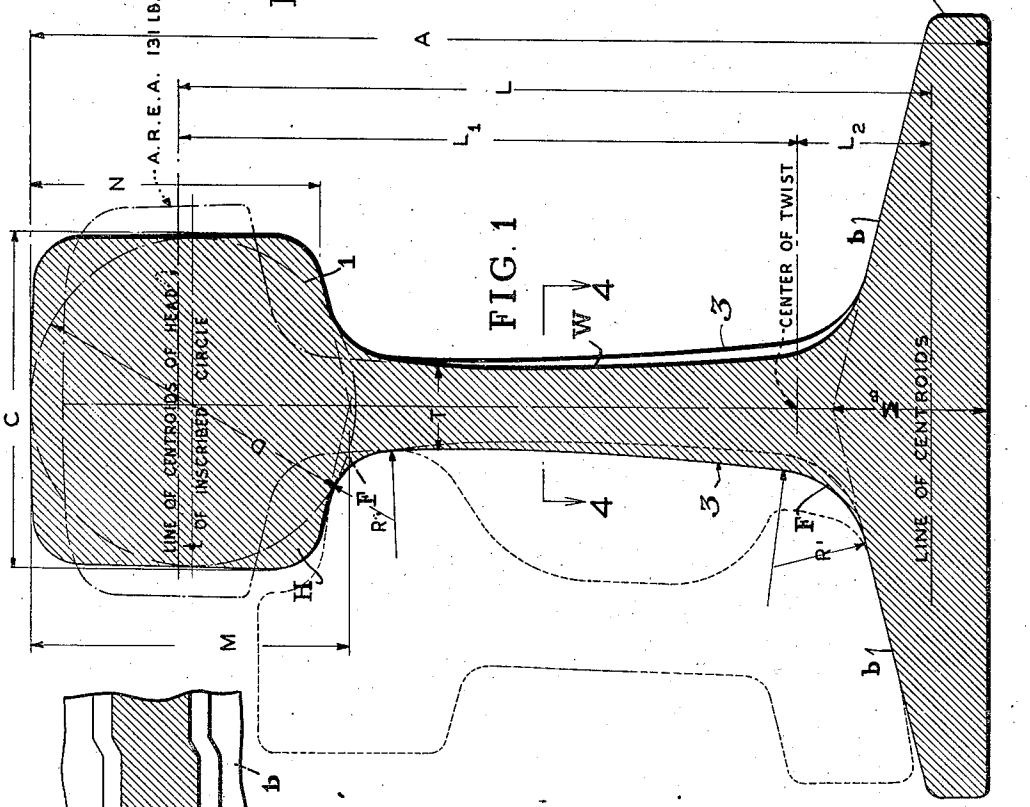


FIG. 1

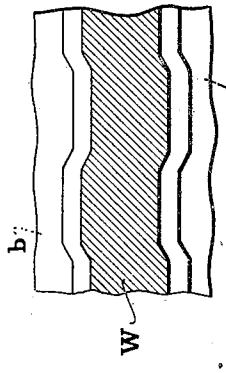


FIG. 4

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Oct. 21, 1941. G. R. BURKHARDT 2,260,211

TORSION-RESISTING RAIL

Filed April 10, 1940 3 Sheets-Sheet 2

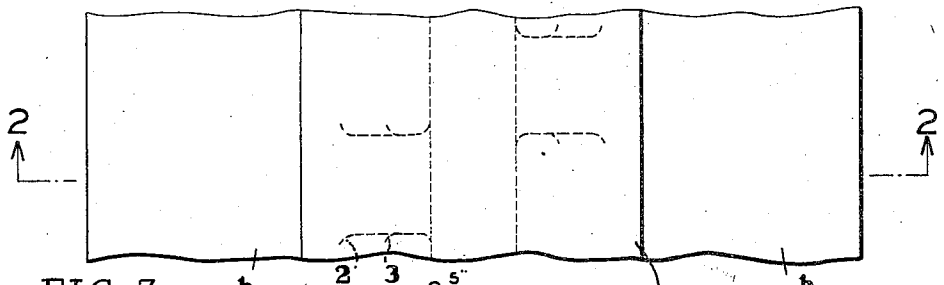


FIG. 3

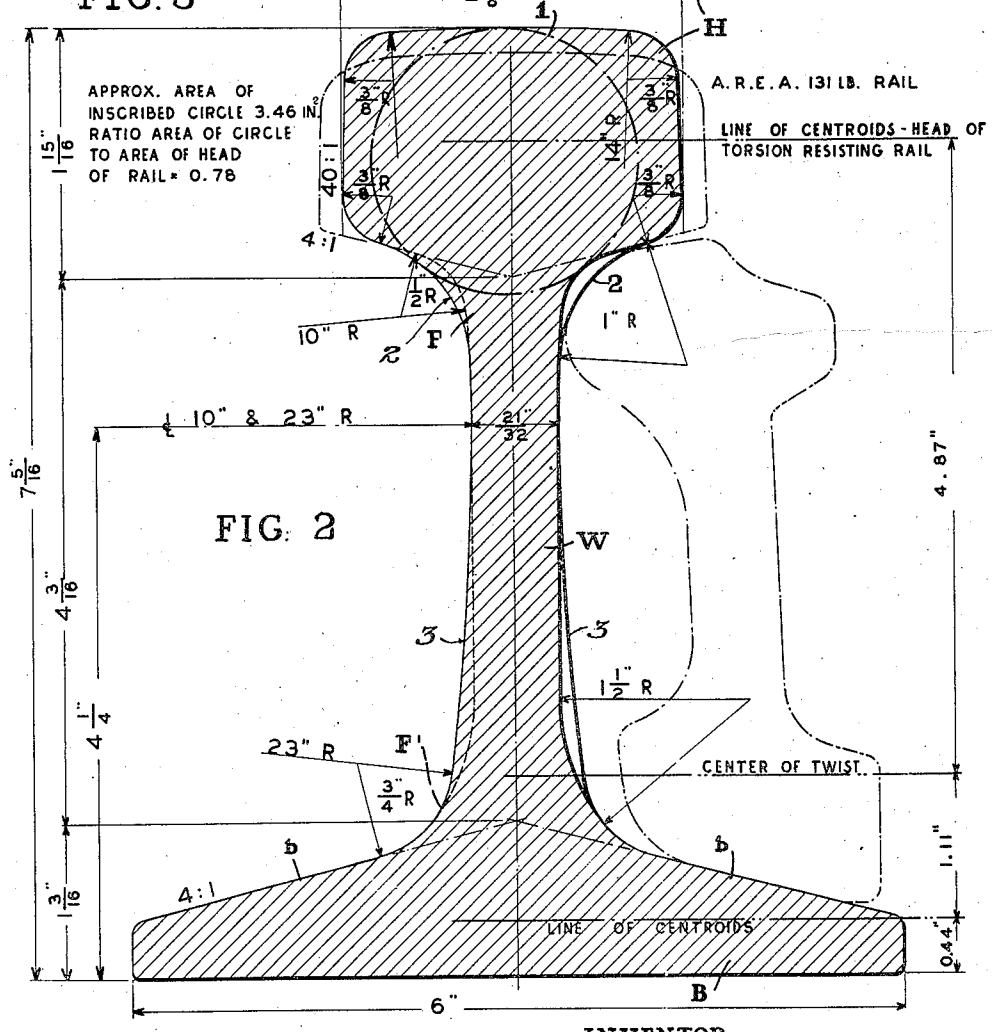


FIG. 2

	TORSION R'G. 130 LB. RAIL	A.R.E.A. 131 LB. RAIL
AREA OF HEAD	4.44 IN.²	4.49 IN.²
AREA OF WEB	3.41 IN.²	3.46 IN.²
AREA OF BASE	4.87 IN.²	4.87 IN.²
TOTAL AREA	12.72 IN.²	12.82 IN.²
INERTIA MOMENT ABOUT HORIZ. N.A.	90.8 IN.⁴	88.5 IN.⁴
WT. PER YARD	129.7 LBS.	130.8 LBS.

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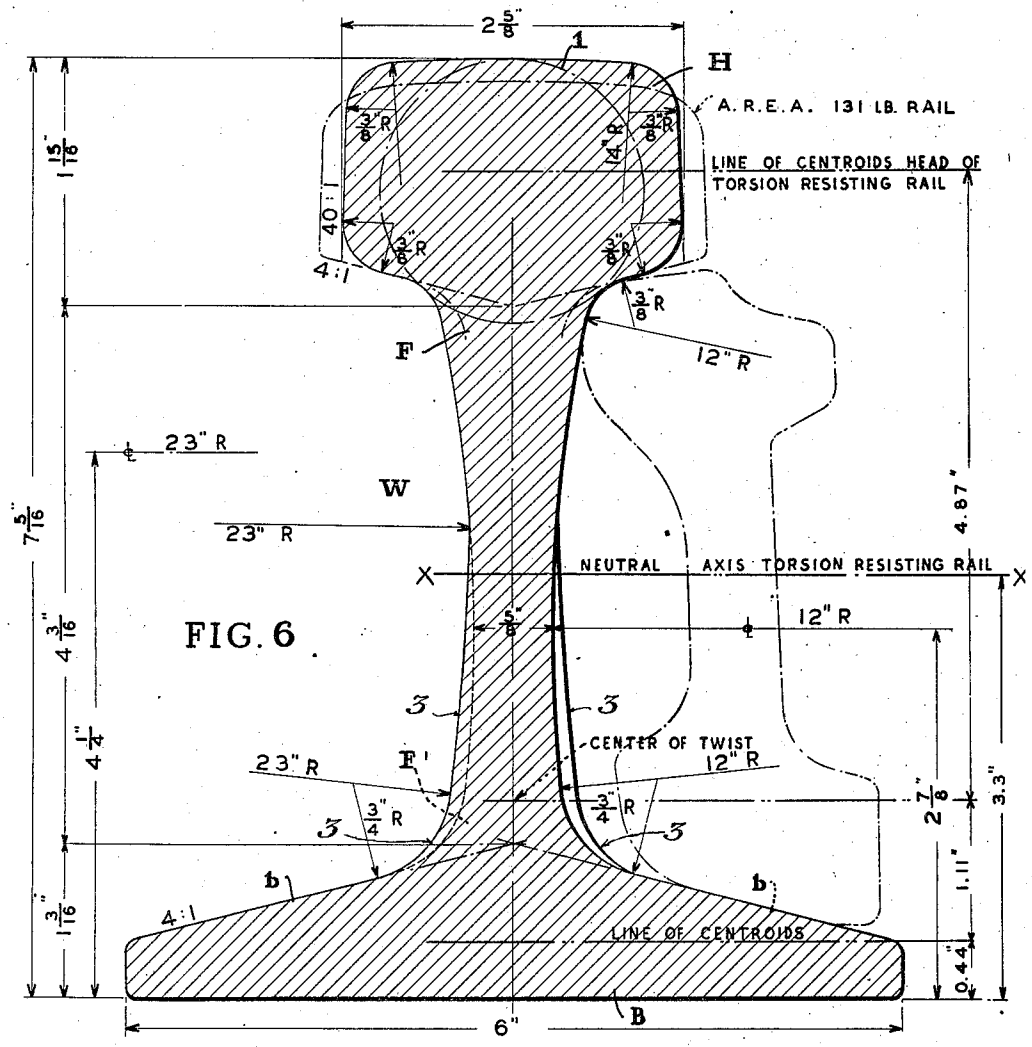
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Oct. 21, 1941. G. R. BURKHARDT 2,260,211

TORSION-RESISTING RAIL

Filed April 10, 1940 3 Sheets-Sheet 3

AREA OF CIRCLE INSCRIBED IN HEAD OF RAIL 3.33 IN^2
" " HEAD OF RAIL 4.44 IN.^{2}
RATIO: AREA OF CIRCLE TO AREA OF HEAD = 0.75



		TORSION R'G. 131 LB. RAIL	A.R.E.A 131 LB. RAIL
TOTAL AREA	A	12.88 IN^2	12.82 IN.^{2}
WT. PER YD.		131.4 LBS.	130.8 LBS.
INERTIA MOMENT ABOUT X-X	I	91.3 IN^4	88.5 IN.^{4}
RATIO $\frac{I}{A}$		7.1	6.9

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Patented Oct. 21, 1941 2,260,211

UNITED STATES PATENT OFFICE

2,260,211

TORSION-RESISTING RAIL

George R. Burkhardt, Chicago, Ill.

Application April 10, 1940, Serial No. 328,971

13 Claims. (Cl. 238—125)

This invention relates to railway rail and particularly to a torsion-resisting rail involving certain physical and dimensional changes and a novel distribution of metal, and having for its principal object a practical solution of overcoming undesirable and dangerous conditions in railway track due to torsional strains, as well as to eccentric loading conditions and impacts.

The tendency of American rail design has been in the direction of increasing vertical rail stiffness resulting in the making of a thin high section, and experience has shown that the rapid change in cross-section of the conventional rail has resulted in very high stresses, concentrating in the fillets joining the head and web, and it is one of the important objects of the present invention to provide a novel metal distribution which will equalize the stresses at all points and at the same time obtain a greater torsional and flexural rigidity. More specifically other definite objects of the invention are to improve the torsional rigidity of the head to give greater resistance to web roll, to relieve peak stresses by increased thickness of the top of the web; reinforcing or ribbing the web, not only for strengthening purposes but also improving the texture of metal; increasing the inertia moment of the whole rail and improving the point or position of loading.

It has been found that most rails measured in track have been subjected to large lateral loads, as well as eccentrically applied vertical loads, and maximum stresses have been found concentrated in the fillet under the head. The combination of these lateral and eccentric vertical loads operate to twist and bend the rail, and according to the present invention a new construction is provided for a rail which results in a uniform distribution of stresses and in the bringing of the wheel load nearer the center of the rail, with a consequent reduction in peak stresses in the fillet under the rail head. It is therefore the purpose and object of the present invention to provide a novel distribution of metal which will distribute the stress equally, thereby overcoming the weakness of present comparable rails under the head and in the head itself.

Another object of the invention is to provide a new rail structure having such high torsional and vertical rigidity as to make the same well suited to excess loading resulting from the dynamic augment of the counterbalance of locomotive drivers, as well as eccentric loading conditions and impacts; the new metal distribution involved in the new rail serving to greatly reduce, if not entirely eliminate, the counterbalance kinks found in present comparable rail in track, as well as reducing transverse fissures, resulting from growth of fatigue cracks, by reason of the fact that the new rail is so designed as to relieve torsional and flexural stress.

With these and other objects in view which will readily appear to those familiar with the art, as the details of the invention are better understood, the same consists in the novel construction and features hereinafter described and illustrated in the drawings, in which:

Figure 1 is a cross-sectional view of the new torsion-resisting rail illustrating the theory upon which the same is designed and the metal distribution therein; this view illustrates the new rail structure superimposed over a comparable Standard A. R. E. A. 131 lb. rail and showing a maximum depth of rail head in which the fishing surfaces at the underside of the rail head are disposed a distance below the corresponding fishing surfaces of the comparable rail. However, the bar for this rail is fully as stiff as the bar for the A. R. E. A. rail since the greater depth of the present rail head permits a deep joint bar section as shown in dotted lines.

Figure 2 is a similar view, on the section line 2—2 of Figure 3, showing a practical form of the invention embodied in a 130 lb. rail and compared with the A. R. E. A. 131 lb. rail shown in dotted lines; this rail has the major portion of the area of the head equal to that of the largest circle that can be inscribed in the head, also the desired position of the center of twist; and the height of the fishing space is substantially that of the height of the comparable A. R. E. A. 131 lb. rail, permitting the use of existing bars for 131 lb. rail; the said figure of the drawings having placed thereon the designations, in inches and fractions of inches, giving the permissible dimensions of the various parts of the rail and their new and novel proportionate relations to each other in accordance with the mathematical demonstrations herein.

Figure 3 is a detail fragmentary plan view indicating by dotted lines a practical width of the web stiffening ribs.

Figure 4 is a horizontal sectional view through a portion of the web of the rail showing the alternating or staggered relation of the stiffening ribs upon opposite sides of the rib.

Figure 5 is a side elevational view of a fragment of the rail illustrating the ribbing of the sides of the web and the base fillets in accordance with the illustration of the following Fig. 6.

Figure 6 is a view similar to Fig. 2 comparing a 131 lb. rail of the new invention with a 131 lb. A. R. E. A. rail and showing the fishing height of the two rails approximately the same, thereby permitting the use of existing joint bars for 131 lb. rail.

Like references designate corresponding parts in the several figures of the drawings.

As shown in the drawings the new rail includes the head H of pentagonal shape, the web W and the base B, the latter being inclusive of the usual base flanges *b*, and F and F' designate respectively the fillet connecting the head with the web and the fillet connecting the web with the base.

The metal distribution of the new rail involves certain structural characteristics involving a radical departure from comparable Standard rails of substantially equal area and weight. These structural characteristics in general are first a departure in the dimensional characteristics of the head, as distinguished from the comparable Standard rail, which for purposes of comparison is shown in the drawings to be the A. R. E. A. 131 lb. rail. This Standard type rail is representative of most Standard rails now in use in the particular that its head has oppositely extending flanges of unnecessary width and which in practice have proven to be responsible for split rail heads due to the eccentric loading thereof, and always the total width of the head of this Standard rail is materially greater than the diameter of the largest circle that can be inscribed within the head, and the ratio of the area of the circle to the cross sectional area of the head is less than 65% whereas, according to the present invention, the width of the head of the new rail may be equal to the diameter of a circle so inscribed and the ratio of area of circle to the cross-sectional area of head is substantially 75% or more.

A fundamental phase of the metal distribution in the head of the new rail is determined from the well known predicate that for two sections having the same area, the section more nearly cylindrical or circular has the greater torsional stiffness, and that outstanding changes and excessive widths, as found in present rail sections, have little or no improving effect as to that stiffening function. Therefore, the metal distribution in the head of the new rail is computed from the ideal cross-sectional shape most resistant to torsional stresses, that is, from a cylindrical cross-sectional shape, which is represented in the present disclosure by what is termed as an "inscribed uniform stress circle" designated by the numeral 1 in the drawings and corresponding to the ideal cylindrical shape. With reference to this uniform stress circle it will be noted that the new head structure preferably has a width approximately equal to the diameter of the inscribed circle between the top of the head and the fillets F joining the head and web of the rail. From this it will be seen that for two rails having the same area, the same web and the same base, the rail is stiffest when the area of the inscribed circle approximately equals the major portion of the cross-sectional area of the head. In the illustration of Fig. 1, representing the basic phase of the present invention, it will be seen that only relatively small portions of metal, of comparatively little stress value are left outside of the inscribed stress circle. It will be apparent from Figures 2 and 6 that the primary basis of the new metal distribution is provided for by having the area of the inscribed circle equal to substantially 75% of the area of the cross-section of the head of rail.

Furthermore, the new head construction, involving the metal distribution therein according to the present invention, provides for locating the line of centroids of the head substantially at or above, but not below, the center of the circle tangent to the sides of the head and the fillets F, and with reference to the total width of the new rail head structure of the present invention it will be understood that a fractional mill tolerance must necessarily be allowed on either side of the circle, as for instance, $\frac{1}{16}$'' plus or minus, or a total of $\frac{1}{8}$'' plus or minus. In connection with this total depth of the new rail head structure an important consideration of the invention is to provide the maximum ratio of the depth of the head to its width, as shown in Fig. 1 and a minimum ratio of its depth to its width, as shown in Figs. 2 and 6, as well as to provide for maintaining approximately the ratio of the width of the web to the width of the head as in the preferred ratios shown in Figs. 2 and 6 of the drawings. It should also be noted that the new metal distribution of the present rail provides for an inertia moment of the head about its symmetry axis which is greater than about its horizontal line of centroids since the width of the head is greater than its depth.

Another feature of practical importance in the new rail of the present invention is to provide a metal distribution resulting in a predetermined position of the center of twist of the rail section. The location of this center of twist is an important factor contributing to the torsion-resisting capacity of the new rail, and therefore the location of the center of twist of the new rail is correlated to the new metal distribution in the head and bottom fillet portions of the rail. In most forms of the invention this center of twist, as shown, is nearest to the stiffest flange and its elevation is at or below the elevation of the point of intersection or compounding of the web curve and the fillet curve which joins the web and the base.

In proportional relation to the head structure and the web structure the present invention involves a widening or thickening of the head and base fillets F and F' as compared with the thickness of those fillets in the comparable Standard rail and in its preferable embodiment the invention also includes, at and within the head fillets, projecting fillet stiffening ribs 2 struck on a radius adapting the same for engagement by the head of a suitable rail joint bar indicated in dotted lines in the drawings and said stiffening fillets are staggered or alternated on opposite sides of the rail, thereby maintaining a uniform cross-sectional thickness of the head fillet neck throughout the length of the rail. Corresponding web and base fillet stiffening ribs 3 are formed at opposite sides of the web of the rail and extend into and over the base fillets F', said stiffening ribs 3 preferably extending upward from the base fillets to a point approximately at the neutral axis of the new rail and being in alternated or staggered relation upon opposite sides of the rail thereby maintaining uniformity of section of the rail throughout.

Taking into consideration the physical and dimensional changes involved in the new rail structure over that of the comparable Standard rail it will be seen from the physical properties of these comparable rails, appearing on the drawings for convenient reference, that for approximately

the same area of head, web, base and approximately the same weight, the new torsion-resisting rail, of the present invention has a substantially increased moment of inertia over that of the corresponding Standard rail, two comparisons being shown respectively in Figs. 2 and 6. In the comparison of physical properties shown in Fig. 2 of the drawings there is illustrated in this drawing the new rail of a 130 lb. superimposed over and compared with the 131 lb. A. R. E. A. rail, showing the new metal distribution to provide a definite increase of the moment of inertia over that of said comparable Standard rail in addition to the uniform stress distribution avoiding concentration of stresses in the head fillets of the rail; and, in Fig. 6 the properties given show that for 131 lb. torsion-resisting rail according to the present invention compared with the same weight Standard rail the increased moment of inertia is even more pronounced over that of the comparable rail, in addition to the uniform stress distributing function of the rail as an entirety.

From the foregoing it is to be noted that in the new rail the moment of inertia is very high with a minimum area, the concentration of stresses found in the head fillets of the present rails are eliminated and the head of the rail has been lightened considerably. In short, the general result of the metal distribution of the present torsion-resisting rail is to equalize the stresses at all points, and at the same time obtain a greater torsional and flexural rigidity, and the basis of the new metal distribution accomplishing these highly desirable results is mathematically demonstrable according to the succeeding explanation of the theory underlying the invention:

The torsional resisting moment of a rail section is a function of the torsional constant K; θ, the angle of twist in radians per inch and the shearing modulus of elasticity G, and equals the product $KG\theta$.

The torsional constant is a measure of the torsional rigidity and twisting deflections. For a circular section, K equals the polar moment of inertia and is less for non-circular sections such as the rail.

The torsional constant of a rail or I beam is the sum of the constants of the flanges (head and base), the constant of the connection of web and flanges and of the web, and the torsional constant of the head of the rail may be shown to vary as the third power of the thickness of the head and that increasing the width of the head has small effect.

Saint Venant has shown that the constant for a rectangle of depth n and width C is

$$K=\frac{n^3C}{3}-2Vn^4$$

where V is a factor depending on the ratio

$$\frac{C}{n}$$

and may be derived by test. The expression $-2Vn^4$ represents a term known in studies of torsion as the end or corner loss. For sections such as the rectangle, the area at the ends have little or no resistance to torsion. From stress evaluation by Prandtl's method of membrane analogy the "end loss" is shown by the sloping down of the membrane or soap film to meet the edges of the short dimensions of rectangular or trapezoidal sections. If the ends were made discontinuous, one might state

$$K=\frac{n^3C}{3}$$

very nearly, and for any differential width dx along the section

$$K=\frac{n^3dx}{3}$$

The constant of the flange of the rail shown Fig. 1 may be approximated by considering it to be two trapezoids and a rectangular part. Let the thickness at any point on the trapezoids be taken as y and C' the width. Then if the ends are assumed discontinuous

$$K=\frac{1}{3}\int_0^{C'}y^3dx$$

The total slope of either of the trapezoids is very nearly

$$\frac{m-n}{C'}$$

from which y may be expressed in terms of m and n, and the integral becomes

$$K=\frac{C'}{12}(m+n)(m^2+n^2)$$

From this the end loss should be deducted and the constant becomes

$$K=\frac{C'}{12}(m+n)(m^2+n^2)-Vm^4-Vn^4$$

Considering the head of the rail as the sum of two trapezoids and a rectangle of width T and depth M_1, and if the effect of the corner curves are omitted, the torsion constant of the head is approximately

$$K_H=\frac{C-T}{12}(M_1+N)(M_1^2+N^2)+\frac{M_1^3T}{3}-2VN^4$$

The torsion constant K_H of the head as shown in Fig. 1 may be more closely determined by mechanical integration or by the well known method of thin strips of width dx and depth y obtained by scaling and the formula

$$K_H=\frac{1}{3}\Sigma y^3dx$$

The torsion constant of the web of an I section or web of rail of uniform thickness T_1 is readily obtained from Saint Venant's formula by considering the web as a discontinuous section between the flanges, giving

$$Kw=\frac{1}{3}(A-[M_1+M_b]T_1^3$$

in which A equals the depth of rail or I section and M_b equals the depth of the base.

For a curved web as shown in Fig. 1 Kw may be obtained by mechanical means.

The torsion constant of the connection between head and web and base and web of I-sections has been shown in text books to be $K_I=\alpha D^4$ where D equals the diameter of the inscribed circle and α is a factor dependent on the ratios

$$\frac{\text{width of web (T)}}{\text{thickness of flange (M)}_1}$$

and

$$\frac{\text{radius of fillet (R)}}{\text{thickness of flange (M)}_1}$$

The values of α for structural beams have been obtained by G. W. Trayer and H. W. March, Advisory Committee for Aeronautics report No. 334 and appear in structural hand books, and other

authorities upon which the foregoing mathematical formulae are based are:

Inge Lyse, Mem. A. S. C. E. and B. G. Johnston, Jun. A. S. C. E. on Torsion in Structural Beams.
Raymond J. Roark's Formulas for Stresses and Strains.
Timoshenko's Strength of Materials.
Seely's Advanced Mechanics of Materials.

Since, as stated, the torsion constant K_R of the whole rail is the sum of the constants derived above, it is readily seen that the rigidity of the rail is most efficiently obtained by incorporating the major portion of the area of the head in the circle inscribed between top of the rail and fillets at the juncture of web and head and tangent to the sides of the head as shown in Fig. 1. In torsion tests it was found that a very slight variation in the diameter of the inscribed circle effected rapid change in the stresses.

It has been pointed out that the result of the broad or excessively wide head of the comparable Standard T-rail brings about an early flow of the metal in the head toward the outside and also involves a high percenatge of split heads due to the concentration of the stresses in the head fillets of the rails, so one of the important objects of the present invention, as stated, is to provide the ultimate in a high moment-minimum area section in which the following features are important.

(1) A rail inclusive of a head in which the area of inscribed circle equals the major portion of the cross sectional area of the head.

(2) Control of position of center of twist.

(3) A rail inclusive of a head of width equal to or greater than its height with the center of gravity of the head above the center of the circle inscribed between the sides of the head and tangent to the fillets joining the head and web.

In connection with the foregoing importance must be given to locating the center of twist of the rail and this is definitely determined from the equations:

$$L_1=\frac{L\times I_2}{I_1+I_2} \qquad L_2=\frac{L\times I_1}{I_1+I_2}$$

I_1 and I_2 respectively denote the moments of inertia of the head and base sections with respect to the axis of symmetry of the rail sections. L equals distance between line of centroids of head and base. L_2 equals distance from line of centroids of base to center of twist. L_1 equals distance between line of centroids of head to center of twist. The center of twist is nearest to the stiffest flange, and the new metal distribution locates this center in the thickest part of the web, that is, the elevation of this center of twist in the new torsion-resisting rail is usually at or below the elevation of the point of compounding of the web curve and the fillet curve joining web and base.

As to the dimensional phase of the new rail that is important in the further particular that the fishing angle of the new rail is approximately within the range of 13° or 15° and that the rail is so proportioned that its height is greater than the width of the base and that the width of the base is at least twice the width of the head; the major portion of the cross sectional area of the head being substantially equal to the area of an inscribed circle tangent to the head fillet curves, and the top of the rail. Furthermore, it will be observed from the illustrations that the planes of the underside of the head are preferably sloped in the ratio of 4:1 to the horizontal, and it is also of practical importance in carrying forward the invention to have the side faces of the rail head sloped upwardly toward the vertical center line of the rail at 7° or less to the vertical.

From the foregoing it is thought that the essential features of the invention will be understood without further description, and changes or modifications within the scope of the appended claims may be resorted to without departing from the spirit or sacrificing any of the advantages of the invention.

I claim:

1. A rail comprising a base, web and head, provided at and within the head fillets with projecting fillets stiffening ribs and arranged to maintain a uniform cross-sectional thickness of the head fillet neck throughout the length of the rail.

2. A rail comprising a base, web and head, provided at and within the base fillets with projecting fillets stiffening ribs and arranged to maintain a uniform cross-sectional thickness of the base fillet neck throughout the length of the rail.

3. A rail comprising a base, web and head and provided upon opposite sides with projecting stiffening ribs extending downward from a point approximately at the neutral axis of the rail to a point within the base fillets and alternately arranged upon opposite sides of the rail thereby to maintain uniformity of cross-section of the rail throughout within the area of the said ribs.

4. A rail comprising a base, web and head having the major portion of the cross-sectional area of the head within an inscribed circle tangent to the top and to the fillets joining the head and the web, and provided in both the head and web fillets with projecting stiffening ribs arranged in staggered relation upon opposite sides of the rail thereby to maintain uniformity of cross-sectional area throughout.

5. A rail inclusive of a head in which the area of an inscribed circle therein is at least 75% of the entire cross-sectional area thereof, the said rail being further provided at and within the head fillets with projecting fillet stiffening ribs and arranged to maintain a uniform cross-sectional thickness of the head fillet neck throughout the length of the rail.

6. A rail inclusive of a head in which the area of an inscribed circle therein is at least 75% of the entire cross-sectional area thereof, the said rail being further provided at and within the base fillets with projecting fillet stiffening ribs and arranged to maintain a uniform cross-sectional thickness of the base fillet neck throughout the length of the rail.

7. A railway rail comprising a pentagonal-shaped head, a web, a pentagonal-shaped base, head-web fillets at the junction of said head with said web and base-web fillets at the junction of said web and base forming a 13° to 15° fishing angle, the width of said head being greater than its depth and within one-and-three-eighths times its depth and less than one-half the width of said base, the width of said base being less than the height of the rail, the radii of said head-web-fillets being not less than one-half the minimum thickness of said web, and the minimum thickness of said web being not less than one-fourth the width of said head so that the torsional constant of said head plus end loss is not less than one-tenth times the fourth power of the width of said head.

8. A railway rail comprising a pentagonal-

shaped head, a web, a pentagonal-shaped base, head-web fillets at the junction of said head with said web and base-web fillets at the junction of said web and base forming a 13° to 15° fishing, the width of said head being greater than its depth and within one-and-three-eighths times its depth and less than one-half the width of said base, the width of said base being less than the height of the rail, the radii of said head-web fillets being not less than one-half the minimum thickness of said web, and the minimum thickness of said web being not less than one-fourth the width of said head so that the torsional constant of said head plus end loss is not less than one-tenth times the fourth power of the width of said head; the area of a circle inscribed in said head tangent to the head-web fillets and to the top of the head being equal to at least 75% of the area of the head.

9. A railway rail comprising a pentagonal-shaped head, a web, a pentagonal-shaped base, base-web fillets at the junction of said base with said web and head-web fillets at the junction of said head with said web forming a 13° to 15° fishing angle, the width of said head being greater than its depth and within one-and-three-eighths times its depth, the minimum thickness of said web being at least one-fourth the width of said head, the radii of said head-web and base-web fillets being at least one-half the minimum thickness of said web, the width of said head being less than one-half the width of said base, and said base having a width less than the height of the rail, whereby the torsional constant of the head plus end loss is at least one-tenth times the fourth power of the width of said head and the center of twist of the rail is located below the points of compounding of the base-web fillets with the web.

10. A rail comprising a pentagonal-shaped head, a web, a pentagonal-shaped base, base-web fillets at the junction of said base with said web and head-web fillets at the junction of said head with said web forming a 13° to 15° fishing angle, the width of said head being greater than its depth but not more than one and three-eighths times said depth and not more than four times the width of the web and less than one-half the width of the base which is less than the total height of the rail, the radii of said fillets being at least one-half the width of the web and the area of the circle inscribed in the head tangent to the web joining fillets and to the top of the head being at least 75% of the area of the head so the torsional constant of the head-web fillets is at least 25% greater than that, e. g., of a comparable A. R. E. A. Standard T-rail of a given weight.

11. A railway rail comprising a pentagonal-shaped head, a web, a pentagonal-shaped base, base-web fillets at the junction of said base with said web and head-web fillets at the junction of said head with said web, said rail having a proportional distribution of metal throughout characterized by having at least 75% of the area of its head within a circle inscribed in the head tangent to the head web fillets and to the top of the rail, and having the minimum web thickness of at least one-fourth the head width and not more than twice the radii of the head-web fillets to provide, as compared, e. g., with a Standard A. R. E. A. T-rail of approximately equal weight, an increased moment of inertia, diminished area for the head, a torsional constant (K_h) for the head of greater torsion resisting capacity than that of said comparable A. R. E. A. Standard T-rail, and a torsional constant (K_f) for the head-web fillets at least 25% greater than the torsional constant of the head-web fillets of the said comparable T-rail.

12. A railway rail comprising a head, a web, a base, head-web fillets at the junction of said head with said web, and base-web fillets at the junction of said base with said web, said rail having a proportional distribution of metal throughout characterized by having the major portion of the area of its head within a circle inscribed in the head tangent to the head web fillets and to the top of the head, and a minimum web thickness of at least one-fourth the head width and not more than twice the radii of the head-web fillets to provide, as compared, e. g., with an A. R. E. A. Standard T-rail of approximately equal weight, a torsional constant (K_h) for the head of greater torsion-resisting capacity than that of said comparable T-rail.

13. A railway rail comprising a pentagonal-shaped head, a web, a pentagonal-shaped base, head-web fillets at the junction of said head with said web and base-web fillets at the junction of said base with said web, said rail having a proportional distribution of metal throughout characterized by having the major portion of the area of its head within a circle inscribed in said head tangent to said head-web fillets and to the top of the rail, with the horizontal line of centroids of the head lying above the center of said circle, a minimum web thickness of at least one-fourth the head width and not more than twice the radii of the head-web fillets, and a base width less than the total height of the rail but more than twice the width of the head, to thereby locate the center of twist of the rail in the thickened lower portion of the web below the point of compounding of the base-web fillets with the web, and to also provide torsional constants for the rail head and for the head-web fillets of greater torsion-resisting capacity than those, e. g., of a Standard A. R. E. A. T-rail of approximately equal weight.

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