Feb. 2, 1960 H. BARTHELMESS 2,923,254

MONOBEAM TRANSITION SECTION CONSTRUCTION

Filed Oct. 6, 1953 2 Sheets-Sheet 1

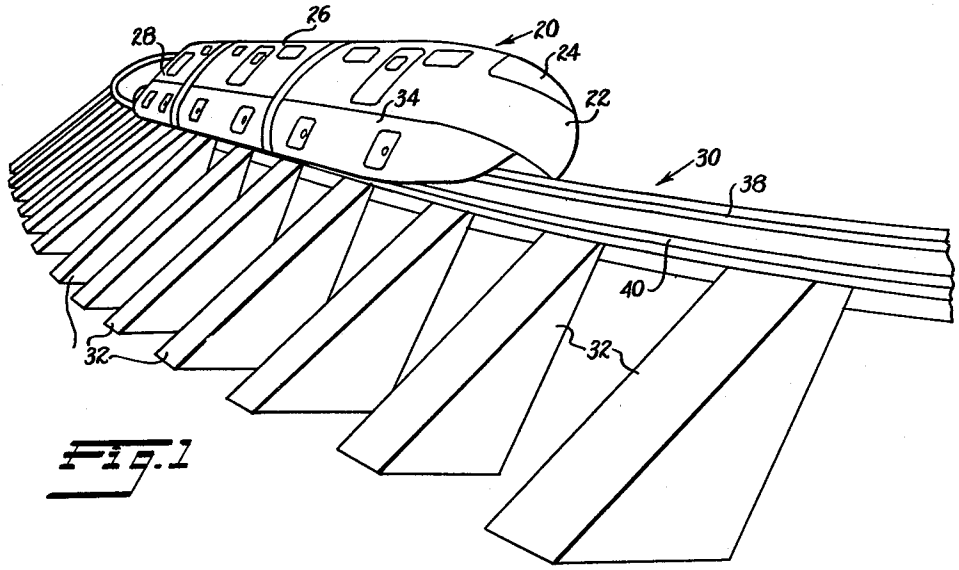


Fig. 1

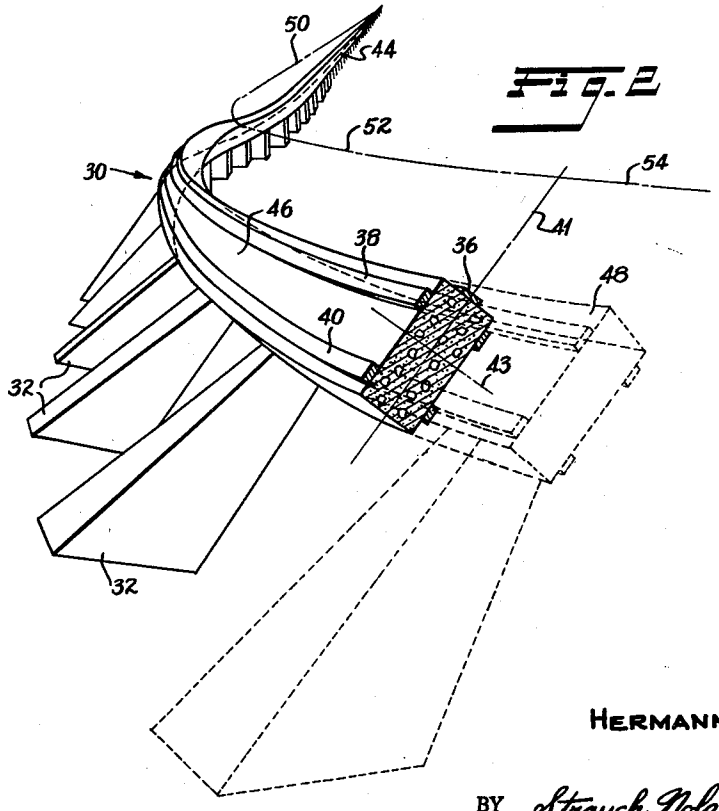


Fig. 2

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Fig. 1

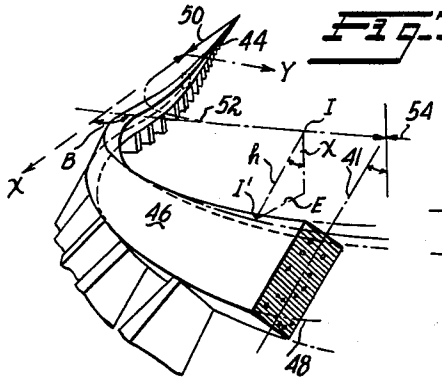


Fig. 2

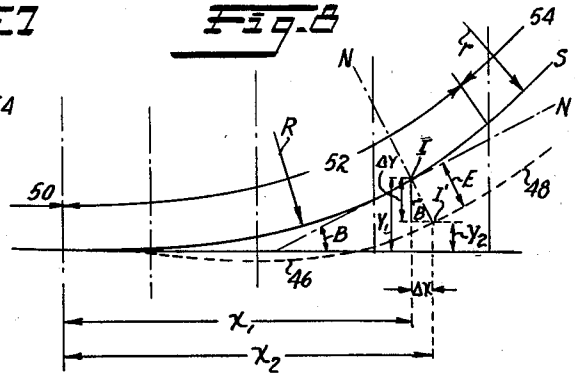


Fig. 4

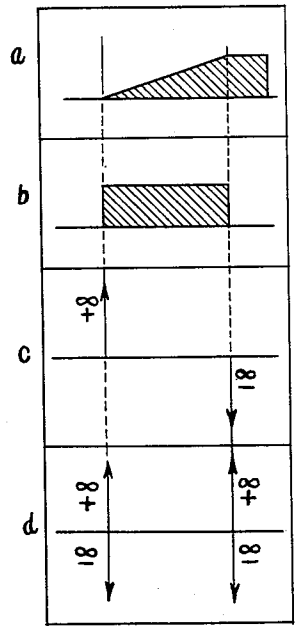


Fig. 5

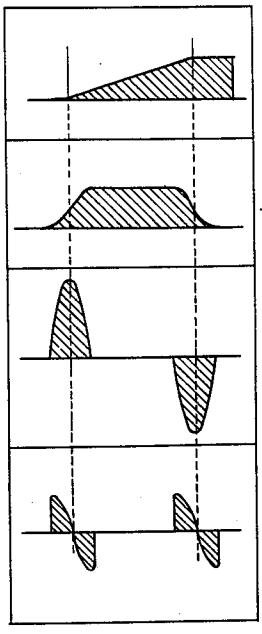


Fig. 6

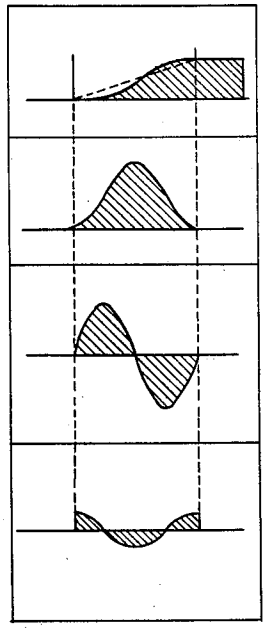
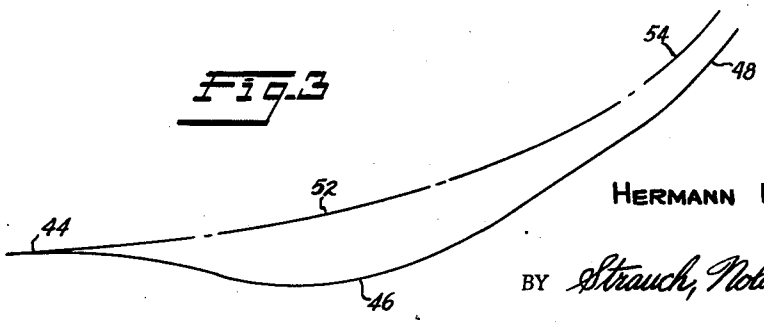


Fig. 3



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2,923,254

MONOBEAM TRANSITION SECTION CONSTRUCTION

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Application October 6, 1953, Serial No. 384,441

Claims priority, application Germany October 8, 1952

4 Claims. (Cl. 104—118)

This invention relates to improvements in transportation systems and more particularly to integrated vehicle and track structures.

While it is presently contemplated that the systems herein disclosed will find their primary utility in connection with the so-called mono-track railway systems as disclosed for example in application Serial No. 371,106, filed July 27, 1953, certain aspects of these systems are also applicable to the two-rail railway systems now in widespread use.

The systems with which the present invention is primarily concerned are capable of safe, smooth and economical operation at speeds in excess of 200 miles per hour. This type of operation is achieved through the provision of improved track and train assemblies and also through the unique correlation of these assemblies. Such correlation, which is notably lacking in prior systems, is particularly necessary in operating the train at high speed over curved sections of the track structure.

In accordance with the present invention the track curvature and inclinations are correlated with the train structures in such manner as to permit considerably higher and safer speeds and more comfortable passenger rides than have been obtainable heretofore. As a result of this correlation the train is moved along a path closely approaching the turning path of a vehicle moving in non-solid media.

It is generally recognized that, particularly at higher speeds, curved sections of track must be banked to avoid the imposition of excessive lateral forces upon the train and track structure. It has further been recognized that at the entrance and exit sides of curved track sections which are connected to straight or reversed curved sections, a transition curve must be provided to reduce the lateral forces incident to turning. Generally such transition curves connect a straight line and the radius of the final curve. In conventional two-rail railway systems such banking is usually effected in the transition curve merely by raising one of the two rails above the other. Thus, the outer wheels of a train traveling along such a banked curve are suddenly raised, tilting the entire vehicle about an axis defined by the inner rail thus imposing severe lateral shocks upon passengers and cargo. Such transition curves now in use are generally based on the cubic parabola or closely related curves and have been selected arbitrarily without consideration of the cooperation between the vehicle and the track structure.

While such transition curves are relatively satisfactory for the relatively low speeds of present day two-rail systems, they have proved entirely unsatisfactory for the very high speeds which are now practical for the first time with the systems of the present invention. Since the forces acting on the vehicle and the track structure in such a curve are a function of the square of the velocity, the high speed travel tends to magnify disproportionately the defects of previous transition curves. Accordingly, particularly at high speeds, sudden shock loads are imposed on the equipment and cargo and the passengers are subjected to sudden and unaccustomed movements.

Because of the linear increase of the transverse inclination which is inevitably produced in transition curves based on the cubic parabola a very high rotary acceleration of the vehicle around the axis of the inner rail is established at the beginning and end of the curves since theoretically the rotary speed suddenly increases to its full value at the entrance side of the curve and remains constant over the full length of the transition curve and then suddenly falls to zero. This factor imposes high lateral forces on the equipment, passengers and cargo, causes extreme passenger discomfort, imposes heavy stresses on the track and vehicle running gear and causes instability at high speeds. Further, in such prior systems which utilize the inner rail of a curve as the rotational axis, the center of gravity of the passengers and cargo are subjected to a sudden lateral shift as the train enters and leaves the transition curve. The unpleasant effects of this lateral shift are well known to any experienced railroad passenger.

It has been discovered that passenger discomfort may be substantially eliminated even at high speeds by developing the transition curve in such a manner that the entire train is turned about a longitudinal "tilt" axis disposed well above the level of the track. The curve is further developed so that the selected longitudinal "tilt" axis is not shifted laterally toward the center of curvature and is guided along a smooth curve so that the train performs only tilting movements. To accomplish this, the track is shifted outwardly away from the center of curvature to the extent dictated by the physical dimensions of the train and the amount of tilt and the desired path of the tilt axis. The tilt axis is guided in space along a smooth regular curve. In practice, in the case of a passenger train, the rotational or tilt axis is preferably disposed in a transverse plane lying slightly above the level of the passenger seats and in the case of a cargo train the axis is preferably located approximately at the center of gravity of the cargo. In a train carrying passengers and cargo at different levels, the location of the axis of rotation of the train may be determined empirically.

Further, the transition curves in accordance with the present invention are so arranged that all aspects of rotary movement of the train cars about the preselected axis change in accordance with a smooth curve rather than linearly as was common in prior constructions. The train and track structure are so correlated that the preselected axis of rotation of the train tangentially follows an ideal transition curve from which the actual track transition curve is developed. Broadly the track transition curve is developed by initially directing the track transition curve away from the center of curvature of the final track curve and subsequently swinging the track curve back so that at its exit end it approaches tangentially a vertical projection of the transition curve followed by the rotational axis of the train. All of the forces developed in the train and track structure due to the passage of the train through such a transition curve are parallel to the vertical axis of the train.

Accordingly, it is the primary purpose and object of the present invention to provide improved train and track structures which are constructed and correlated to facilitate a change of direction of the path of movement of the train in a smooth, safe manner at speeds heretofore unattainable.

It is a further object of the present invention to provide novel curved train guiding and supporting structures.

It is also an object of the invention to provide novel correlated train and curved track structures which eliminate or materially reduce the shock forces heretofore

incident to a change of direction of the path of movement of the train.

It is an additional object of the invention to provide novel correlated and curved track sections which effect a rotational movement of the train about an axis disposed substantially above the level of the track structure as the train moves over the track structure.

It is also an object of the invention to provide novel transition curves for transportation systems.

It is a further object of the invention to provide improved correlated train and curved track structures which are effective as the train passes over the track structure to produce a rotary motion in the train which varies in accordance with a smooth substantially sinusoidal curve.

Further objects and advantages will become apparent as the description proceeds in connection with the accompanying drawings in which:

Figure 1 is a perspective view of a train and track system embodying the novel features of the present invention;

Figure 2 is a view of a track structure embodying the transition curve of the present invention with the path of travel of the rotational axis of the vehicle indicated in phantom lines;

Figure 3 is a diagrammatic vertical plan view of the track structure showing the relation between the curve followed by the axis of the vehicle and the actual track curve;

Figures 4 and 5 illustrate graphically the characteristics of the motion of a vehicle as it passes over curved track sections constructed in accordance with prior practice;

Figure 6 is a graph similar to Figures 4 and 5 illustrating the same factors for the systems of the present invention; and

Figures 7 and 8 are views similar to Figures 2 and 3, respectively, but with references and coordinates added to facilitate analysis of the track structure.

For purposes of illustration the present invention has been shown and will be described as a mono-track system in which the track structure is a mono-beam of novel construction since it is in such a system that the unique advantages of the invention are most fully realized. However, it is to be understood that the invention in several of its aspects may be utilized to advantage in conjunction with or as a modification of conventional two-rail railway systems or of prior mono-rail systems.

Referring now more particularly to the drawings and especially to Figures 1 and 2 the principal cooperating components of the railway system shown are the train, indicated generally at **20**, which may comprise a front or nose car **22** having an operator's compartment **24** and any desired number of identical intermediate cars **26** (one shown) and a rear or tail car **28**. The system also comprises a mono-beam track construction indicated generally at **30** and supporting pylons **32** which support the mono-beam at any desired elevation above ground level.

The train unit is constructed with depending side portions **34** which extend downwardly over the sides of the mono-beam **30** to a point adjacent the lower surface thereof. Each of the cars is resiliently supported on chassis or truck structures which are described in detail in the aforesaid application Serial No. 371,106. The chassis structures (not shown) include carrying or load supporting wheels which are adapted to ride on a flat rail **36** at the top of the mono-beam **30** and guiding and tilt control wheels adapted to resiliently engage rails **38** and **40** disposed on the opposite vertical sides of the mono-beam **30**. The car bodies and supporting means are so disposed with respect to the mono-beam **30** that the top rail **36** passes through the car bodies or sections substantially at their center of gravity. Consequently the lateral forces imposed upon the mono-beam **30** necessary to guide the vehicle and to prevent the tilting thereof are reduced to a minimum and the coaction of the train and track structures are such as to minimize the weight and strength requirements of both train and track.

The mono-beam **30** and the supporting pylons **32** are preferably formed of poured concrete which may be reinforced as desired in accordance with conventional practice, and may be of hollow construction to conserve weight and materials and to provide a closed internal space for power telephone, telegraph, water, gas and fuel lines.

The top and side rails are preferably of steel and are preferably supported on a shock absorbing or damping material such as creosoted wood stripping to provide a yielding rail assembly to prevent the direct transmission of shock loads incident to the normal operation of the vehicle between the concrete beam structure and the train.

As seen in Figure 2 the mono-beam **30** is preferably of rectangular section and its height (the dimension along its major axis **41**) is preferably twice its width (the dimension along its lateral axis **43**). However, other forms of beams may be used. For example, the beam may correspond to the form shown except that it may be provided with beveled corners to minimize turbulence and eddy loss as the vehicle passes over the beam at high speed. However, in all cases the beam will have parallel side faces as shown for supporting the guiding rails **38** and **40** and a top surface normal to the side surfaces for supporting the load carrying rails **36**.

A curved section of track incorporating the novel transition curve of the present invention is illustrated particularly in Figure 2. The portions of the track there shown include a straight track section **44**, the section **46** of the track incorporating the transition curve and the main curve section **48**. Beyond the illustrated main track curve section **48** the track is provided with a further transition curve section identical to the section **46** which merges into a final straight section of the track similar to that shown at **44** or into a further curve.

The path of movement of the axis of tilt of the train as it passes over the section of the track shown in Figure 2 is shown in phantom lines. It will be seen that this path includes a straight section **50**, a transition curve section **52** and a main curve section **54** corresponding, respectively, to the track sections **44**, **46** and **48**. The path comprising the sections **50**, **52** and **54** may be referred to for convenience as the ideal track curve. It will be seen that this ideal curve is so related to the actual track curve so that any point on the ideal curve lies on an extension of the major axis of the beam.

The track beam is gradually and increasingly inclined along the entering transition curve section until it is fully banked for a predetermined top speed of the train around the main curve section where the bank or tilt of the train is uniform and the tilt decreases gradually in the exit transition curve section to zero when the top surface of the beam is horizontal at the end of the transition curve or to another tilt as required by the radius and direction of the following main curve which may have the same or the opposite direction of curvature as the preceding curve.

Development of the transition curve depends upon the determination of the optimum position of the axis of rotation of the train for average minimum passenger or load disturbance and the desired rotary speed about this axis at each point in the transition curve. The location of the axis of rotation in freight trains depends solely on mechanical considerations and the optimum result is achieved when the axis of rotation coincides with the average axial center of gravity of the loaded cars. However in the case of passenger train operation the positioning of the axis of rotation depends on a number of physiological factors which determine passenger comfort.

In general the axis of turning of the train on the transition curve will be in the proximity of the center

of gravity of average load. When the axis is so positioned both the load and the passengers will be subjected substantially only to lifting or lowering movements and sudden lateral shocks which cause passenger discomfort or impose severe stresses on the loads are eliminated. The rotary speed of the train about the preselected axis of rotation will depend on the lateral distance of the passengers or the load from the selected axis and the desired rotary speed will vary inversely with this distance.

Once the axis of rotation and the desired rotary speed about this axis is determined the "banking" position of the vehicle at any point on the transition curve will be established which, in turn, fixes the radius of curvature of the ideal transition curve at any point. In this manner the coordinates of all points on the ideal curve may be determined step by step and from these coordinates the vertical and horizontal coordinates of the actual track curve may be finally determined. The length of the transition curve depends upon the capacity of the cars to resist torsional loads, the strength of the nose boggies of the train and the desired comfort of the passengers. In practice the length of the curves can be determined by mathematical formulae depending upon experimental constants developed empirically in accordance with each of these factors.

The relation of the ideal curve and the track curve is further illustrated diagrammatically in plan in Figure 3. As there shown, the two curves are in vertical alignment along the straight portions **44, 50**. At the entrance side of the transition section the track curve is swung outwardly away from the center of curvature with respect to the ideal curve followed by the longitudinal axis of rotation of the train. At the exit side of the transition section the track curve tangentially approaches parallelism with a downward vertical projection of the ideal curve. This parallelism continues throughout the main curve section at the end of which the illustrated transition curve or a curve having similar characteristics is repeated.

Figures 4, 5 and 6 illustrate graphically the dynamics of the movement of the train along prior transition curves (Figures 4 and 5) and the transition curve of the present invention (Figure 6). In each of these graphs, sections *a*, *b*, *c* and *d*, respectively, plot the angle of rotation, the rotary speed about the axis of rotation, the rotary acceleration around this axis and the rate of change of rotary acceleration against length and thus show the variation in these factors over the length of the transition curve.

Figure 4 is applicable to a transition curve now in widespread use in two-rail systems. It will be seen from part *a* that the angle of rotation increases linearly and from sections *b*, *c* and *d* that the rotary speed increases to its full value instantaneously at the entrance side of the curves and decreases instantaneously from its full value to zero at the exit side of the curve producing infinitely high positive and negative rotary accelerations and rates of change of rotary acceleration in turn producing extreme passenger discomfort and imposing severe shock loads on the train and track structure.

Figure 5 graphically illustrates the dynamic conditions occurring as the vehicle passes over transition curves based on the cubic parabola or closely related curves in limited current use.

It will be seen from a comparison of Figures 4 and 5 that the deleterious effects of the curve of Figure 4 have to some extent been mitigated in the curve to which Figure 5 applies. However, it will be noted that the rotary angle still changes approximately linearly and that the rotary acceleration at the entrance and the exit sides of the curve is objectionably high and it is apparent from section *d* of Figure 5 that the rotary acceleration varies abruptly in a comparatively short time interval.

It will be seen from Figure 6 that in the transition curve according to the present invention all of the dynamic factors relating to the motion of the vehicle about its turning axis vary in accordance with smooth curves which are sinusoidal in nature. In accordance with the present invention it has been discovered that the rate of change of the rotary acceleration around the preselected turning axis of the vehicle should be sinusoidal, the maximum values of the rate of change being determined by physiological conditions. Such a rate of change of rotary acceleration achieved by the ideal curve of the present invention is shown in section *d* of Figure 6. The integration of this curve produces a sinusoidal variation of the rotary acceleration around the longitudinal axis of the vehicle as shown in section *c* and a further integration results in a rotary speed about this axis which also varies in a smooth curve of sinusoidal form as shown in section *b*. As a result the rotary angle also changes in a smooth continuously varying curve.

As stated above, after the coordinates of all points on the ideal curve are determined to produce the dynamic conditions illustrated in Figure 6 the coordinates of the actual track curve may readily be established mathematically on the basis of physical factors such as the size of the cars, etc.

The following example illustrates the development of a section of transition between a straight track section, that is a track section having an infinite radius of curvature and a section having a constant radius of curvature assumed to be 1000 meters. For purposes of analysis, it may be assumed that the length of the transition section is 200 meters and the vehicles pass the section at an average velocity of 140 kilometers per hour. The distance *h* between the lines **50, 52** and **54** and the top of the track is assumed to be one meter.

Based on these assumptions and known constants, the angle *x*-max which is the angle of tilt of the uniformly curved track section **48** and the angle of tilt of the adjacent transition track section **46** is determined as follows:

$$x\text{-max}=\text{arc sin}\frac{140^2}{3.6^2\times 9.8\times 1000}=\text{arc sin } 0.15385=8^\circ\ 45'$$

The definitions of the several angles, radii, distances, increments and decrements which determine the coordinates of the system illustrated in Figures 7 and 8 are as follows:

h=distance of lines **50, 52** and **54** from the top of the track

x=variable angle of track tilt (in any point I)

x-max=angle of track tilt at junction with section **48**

$$A=\frac{\text{distance of any point I from the origin}}{\text{length of section of transition track}}$$

R=radius of curvature of the line **52** at any point

r=radius of curvature of section **48**

ΔB=increment of angle B between the section **50** and a tangent to the line **52** at a selected point I

d=distance between consecutive points I (10 meters)

ΔX_1, ΔY_1=increments of the rectangular coordinates X_1, Y_1 of the line **52**.

$E=h.\ \sin x$, for any point I

ΔX_2, ΔY_2=increments and decrements for arriving at the coordinates X_2, Y_2 of a point on the track section **46** from the coordinates X_1, Y_1 of a point I on the line **52**.

The system of coordinates shown in Figures 7 and 8 has its origin at the junction of the straight track section and the transition curve, the abscissa being tangent to the longitudinal axis of the straight track section at the origin while the ordinate is normal to the longitudinal axis of the straight track section.

The formulae for determining the increments and decrements of the coordinates X_1 and Y_1 of the ideal transition line are as follows:

$$x=x-\max\left(A-\frac{1}{2\pi}\sin 2\pi A\right)=x\text{-max}.f(A)$$

(This formula represents the sinusoidal change of the angle x over the length of section **52**.)

$$\frac{1}{R}=\frac{\tan x}{r.\ \tan x\text{-max}}=\frac{\tan x}{153.85}$$

$$\Delta B=\frac{1d}{R}=\frac{d\tan x}{r\tan x\text{-max}}\cdot\frac{180}{\pi}=3.72413\tan x;\ B=\Sigma\Delta B$$

$$\Delta N=\frac{d^2}{2R}=\frac{d^2\tan x}{2r\tan x\text{-max}}=0.32499\tan x$$

$$\Delta X_1=d\cos B-\Delta N\sin B;\ \Delta Y_1=d\sin B+\Delta N\cos B$$

The formulae for computing the coordinates X_2, Y_2 of the top of the actual transition track section are as follows:

$$E=h\sin x$$
$$\Delta X=E\sin B \qquad X_2=X_1+\Delta X$$
$$\Delta Y=E\cos B \qquad Y_2=Y_1+\Delta Y$$

The coordinates X_2 and Y_2 are orthogonal projections upon the horizontal plane of the line **52**.

For clarity an optional point I is shown in Figure 8, the figure also indicating the coordinates X_1Y_1 of the point I on the line **52** as well as the coordinates X_2Y_2 of a corresponding point I′ on the top surface of the track beam. In practice the transition track section is divided into segments. In the example given, twenty segments of ten meters each are selected and the coordinates for each of the twenty points are determined using the above formulae and are connected by smooth curves to form the ideal transition line **52** and the corresponding transition track beam.

In the specific example given above, the angle of tilt x of the beam in the transition section will be 47′ 42″ at a point 50 meters from the entrance end of the transition section, will be 4° 22′ 30″ at the midpoint of the transition section, 7° 57′ 18″ at a point 150 meters from the entrance end of the section and the final inclination of the beam will be 8° 45′ 00″.

The transition curves discussed above have been developed to produce optimum results insofar as promoting passenger comfort and minimizing shock loads are concerned. However, it is to be understood that improved results may also be obtained with transition curves in which the variation in dynamic factors departs somewhat from that shown in Figure 6.

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The present embodiment is therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

What is claimed and desired to be secured by United States Letters Patent is:

1. In a vehicle track, a transition curve track section for connecting main track sections, at least one of said main track sections being curved on a constant radius, comprising a rigid beam having a top running surface and parallel side running surfaces all adapted to be engaged by the wheels of a vehicle, the portion of said transition section remote from said curved main track section curving smoothly outwardly away from the center of curvature of said curved main track section, the portion of said transition section adjacent said curved main track section approaching said curved main track section tangentially, and the intermediate portion of said transition section being smoothly reversed to curve in the same direction as said curved main track section, each of said portions merging smoothly into the adjacent portion, and said transition section being gradually and increasingly tilted along its length about a line located within said vehicle a fixed predetermined distance above the top surface of said track, one end of said line being tangent to a vertical projection of the longitudinal axis of the main track section remote from the curved main track section, the opposite end of said line being curved on the same radius as said curved main track section and said line being smoothly curved along its length toward the center of curvature of said curved main track section, and said line being midway of extensions of the side surfaces of said track.

2. In a vehicle track, a transition curve track section for connecting main track sections, at least one of said main track sections being curved on a constant radius, comprising a rigid beam having a top running surface and parallel side running surfaces all adapted to be engaged by the wheels of a vehicle, the portion of said transition section remote from said curved main track section curving smoothly outwardly away from the center of curvature of said curved main track section, the portion of said transition section adjacent said curved main track section approaching said curved main track section tangentially, and the intermediate portion of said transition section being smoothly reversed to curve in the same direction as said curved main track section, each of said portions merging smoothly into the adjacent portion, and said transition section being gradually and increasingly tilted along its length about a line located within said vehicle a fixed predetermined distance above the top surface of said track, said distance being substantially equal to the distance between said top running surface of said track and the center of gravity of the load carried by said vehicle, one end of said line being tangent to a vertical projection of the longitudinal axis of the main track section remote from the curved main track section, the opposite end of said line being curved on the same radius as said curved main track section and said line being smoothly curved along its length toward the center of curvature of said curved main track section, and said line being midway of extensions of the side surfaces of said track.

3. In a track for a vehicle having passenger seats, a transition curve track section for connecting main track sections, at least one of said main track sections being curved on a constant radius, comprising a rigid beam having a top running surface and parallel side running surfaces all adapted to be engaged by the wheels of a vehicle, the portion of said transition section remote from said curved main track section curving smoothly outwardly away from the center of curvature of said curved main track section, the portion of said transition section adjacent said curved main track section approaching said curved main track section tangentially, and the intermediate portion of said transition section being smoothly reversed to curve in the same direction as said curved main track section, each of said portions merging smoothly into the adjacent portion, and said transition section being gradually and increasingly tilted along its length about a line located within said vehicle a fixed predetermined distance above the top surface of said track, said distance being slightly greater than the distance between said top running surface of said track and said passenger seats, one end of said line being tangent to a vertical projection of the longitudinal axis of the main track section remote from the curved main track section, the opposite end of said line being curved on the same radius as said curved main track section and said line being smoothly curved along its length toward the center of curvature of said curved main track section, and said line being midway of extensions of the side surfaces of said track.

4. In a monobeam track, a transition curve track section for connecting a straight track section to a curved track section formed on a constant radius comprising a rigid beam having a top running surface and parallel side running surfaces all adapted to be engaged by the wheels of a vehicle, the portion of said transition track section adjacent said straight track section curving

smoothly outwardly away from the center of curvature of said curved track section, the portion of said transition section adjacent said curved section approaching said curved section tangentially and the intermediate portion of said transition track section being smoothly reversed to curve in the same direction as said curved section, each of said portions merging smoothly into the adjacent portion and said transition track section being gradually and progressively tilted along its length about a line located within said vehicle a fixed predetermined distance above said top running surface of said track, one end of said line being tangent to a vertical projection of the longitudinal axis of said straight track section, the opposite end of said line being curved on the same radius as said curved section, said line being smoothly curved along its length toward the center of curvature of said curved track section and said line being midway of extensions of the side surfaces of said beam.

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