

June 18, 1929.

E. O. ACKERMAN

1,718,100

METHOD OF OPERATING RAILWAY ROLLING STOCK TO PREVENT RAIL CORRUGATION

Filed Oct. 12, 1927

6 Sheets-Sheet 1

FIG. 1.

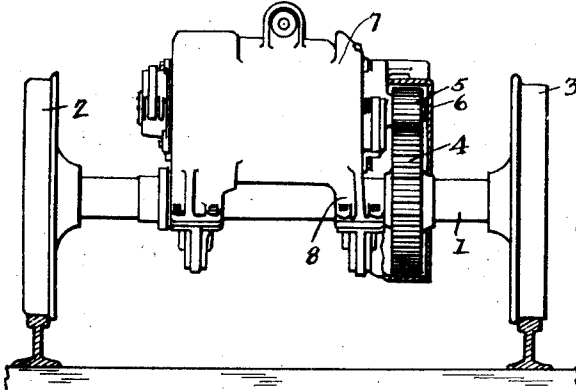


FIG. 2.

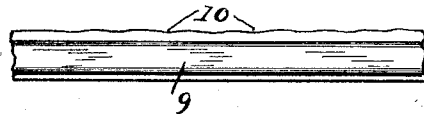


FIG. 3.

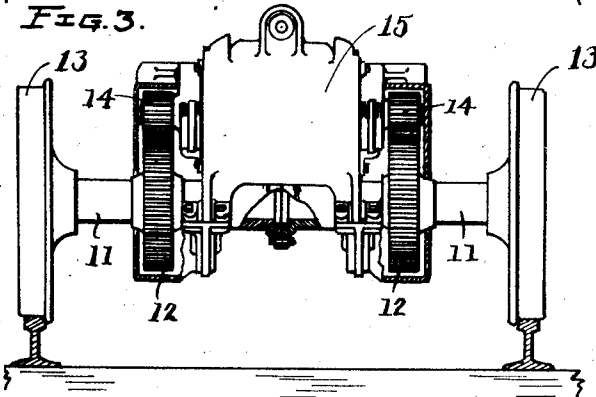


FIG. 11.

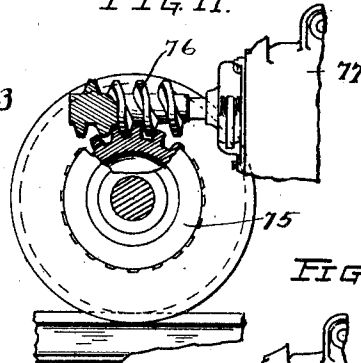


FIG. 12.

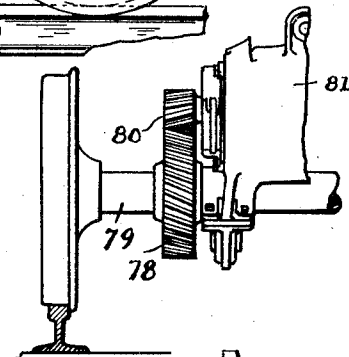


FIG. 4.

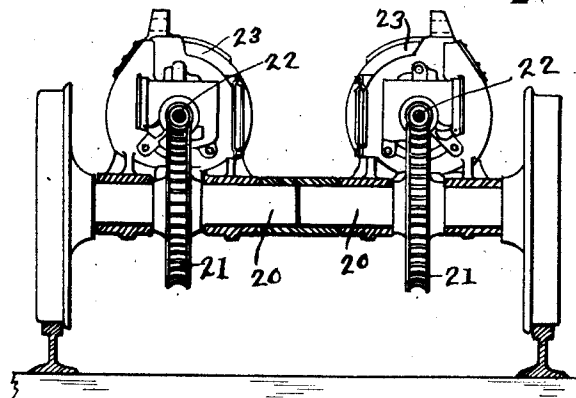
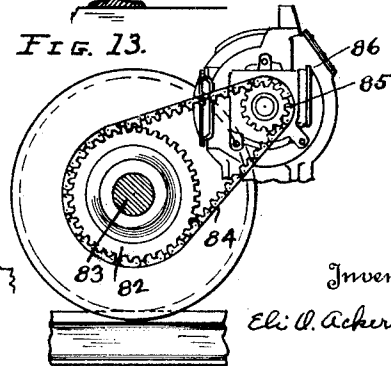


FIG. 13.



Inventor
Eli O. Ackerman

By

Frank S. Greene
Attorney

June 18, 1929.

E. O. ACKERMAN

1,718,100

METHOD OF OPERATING RAILWAY ROLLING STOCK TO PREVENT RAIL CORRUGATION

Filed Oct. 12, 1927

6 Sheets-Sheet 2

FIG. 5.

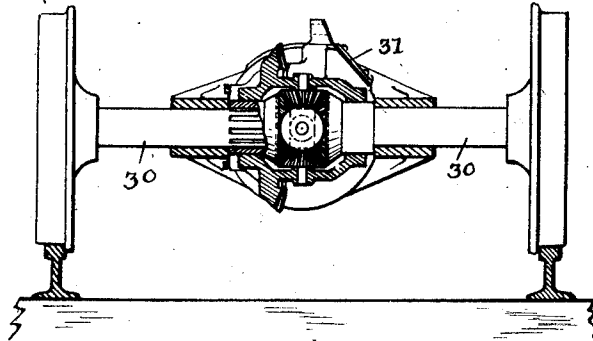


FIG. 6.

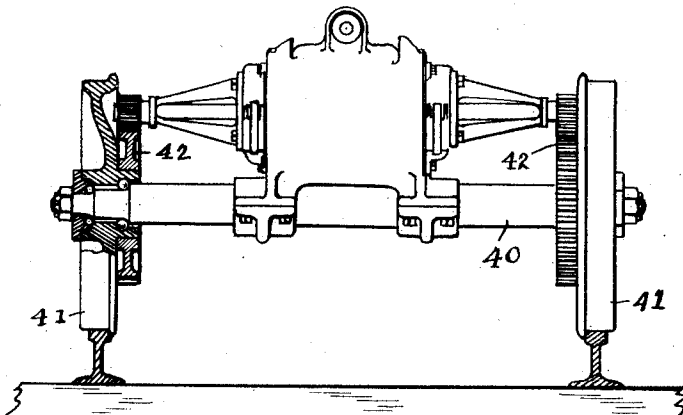
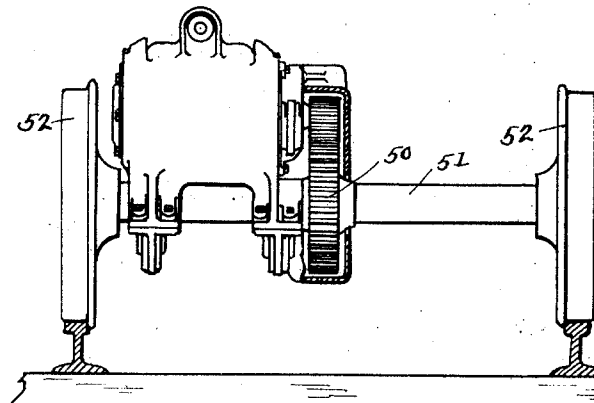


FIG. 7.



Inventor

Eli O. Ackerman

By

Frank S. Greene
Attorney

June 18, 1929.

E. O. ACKERMAN

1,718,100

METHOD OF OPERATING RAILWAY ROLLING STOCK TO PREVENT RAIL CORRUGATION

Filed Oct. 12, 1927

6 Sheets-Sheet 3

FIG. 8.

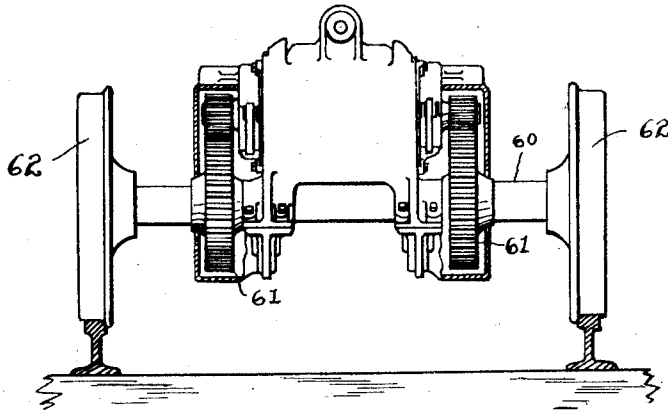


FIG. 9.

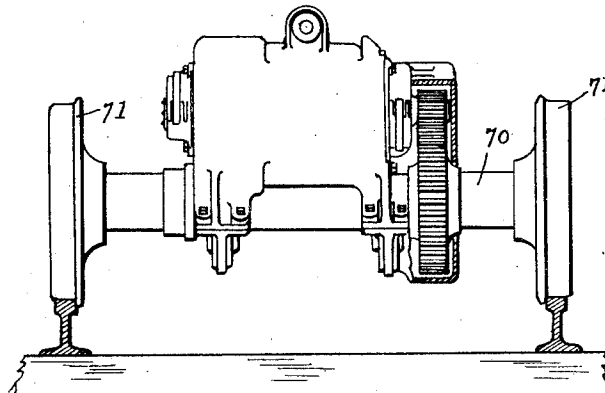
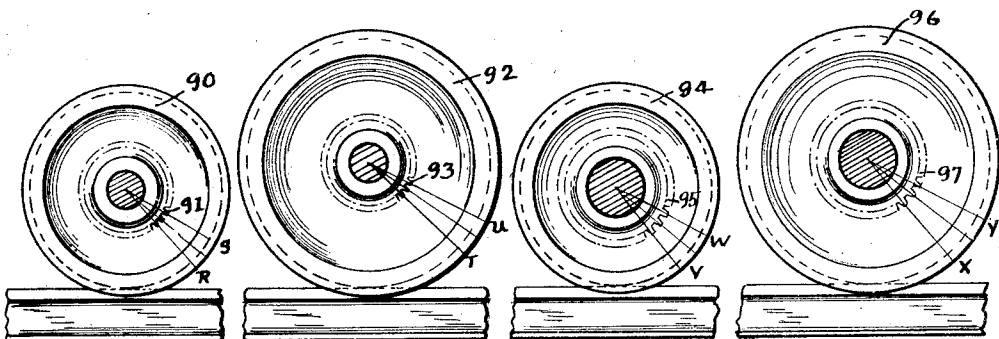


FIG. 10.



Inventor

Eli O. Ackerman

By

Frank S. Greene

Attorney

June 18, 1929.

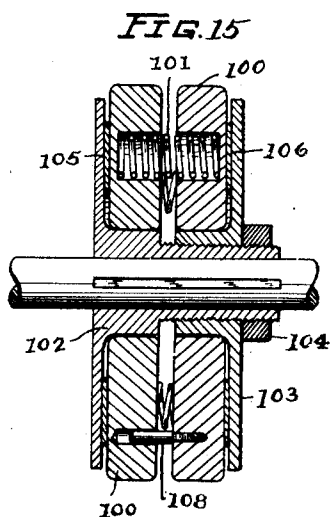
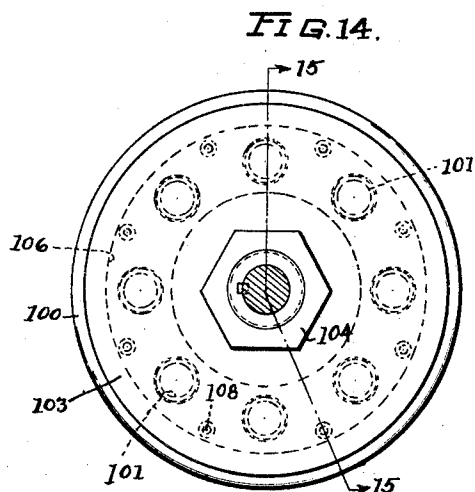
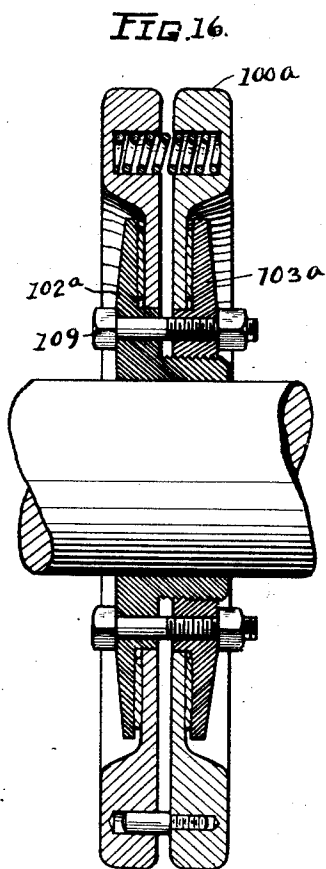
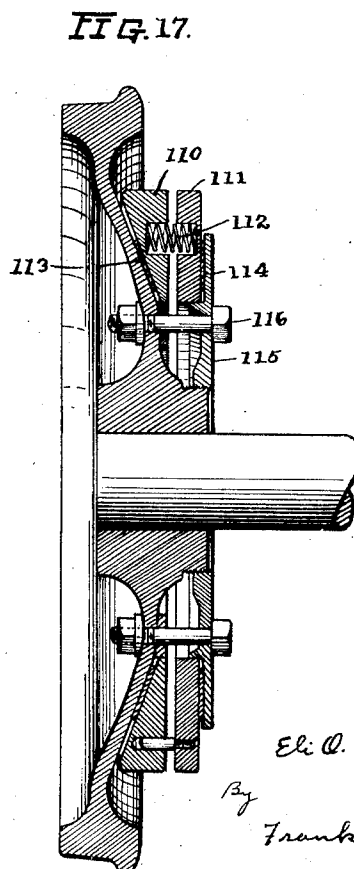
E. O. ACKERMAN

1,718,100

METHOD OF OPERATING RAILWAY ROLLING STOCK TO PREVENT RAIL CORRUGATION

Filed Oct. 12, 1927

6 Sheets-Sheet 4



Inventor

Eli O. Ackerman

By

Frank S. Greene

Attorney

June 18, 1929.

E. O. ACKERMAN

1,718,100

METHOD OF OPERATING RAILWAY ROLLING STOCK TO PREVENT RAIL CORRUGATION

Filed Oct. 12, 1927

6 Sheets-Sheet 5

FIG. 18.

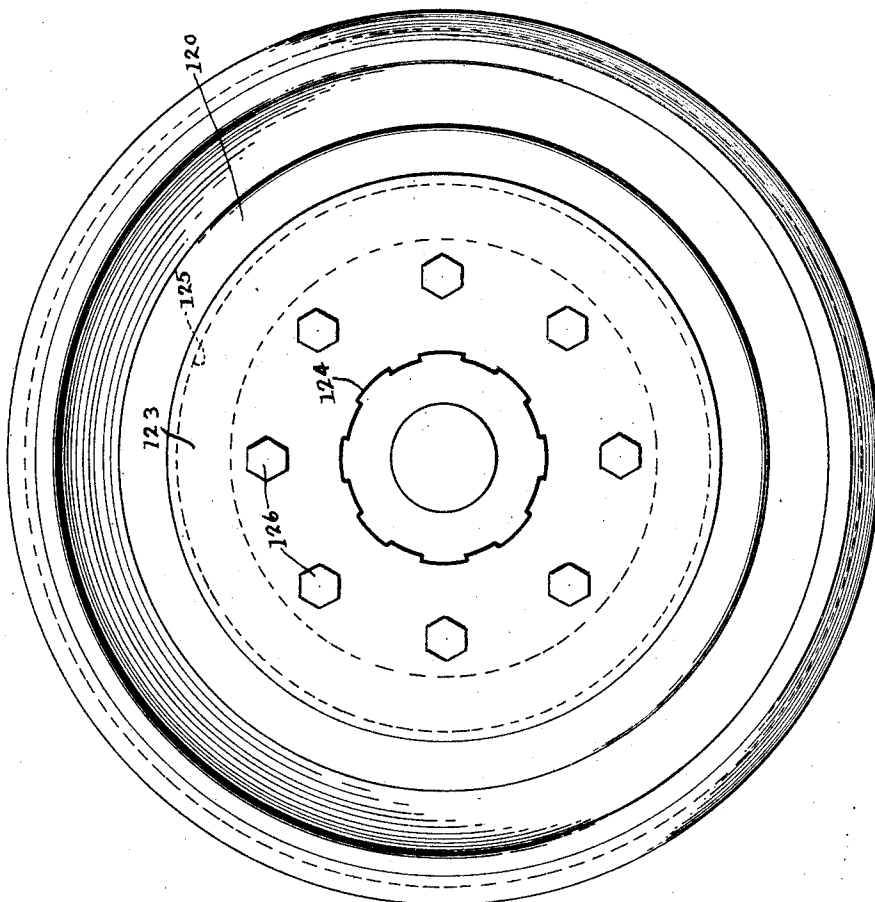
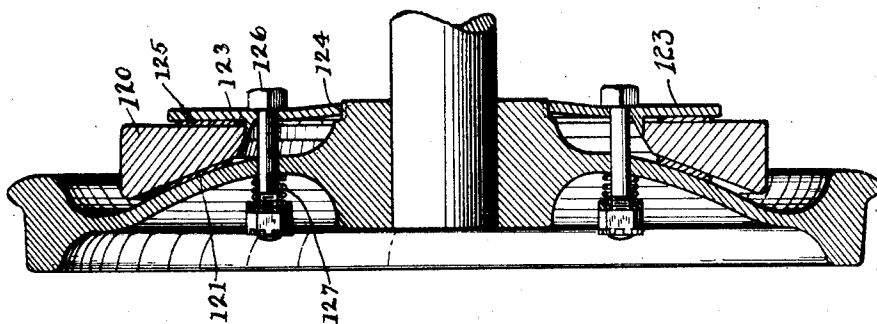


FIG. 19.



Inventor
Eli O. Ackerman

By

Frank S. Greene
Attorney

June 18, 1929.

E. O. ACKERMAN

1,718,100

METHOD OF OPERATING RAILWAY ROLLING STOCK TO PREVENT RAIL CORRUGATION

Filed Oct. 12, 1927

6 Sheets-Sheet 6

FIG. 20.

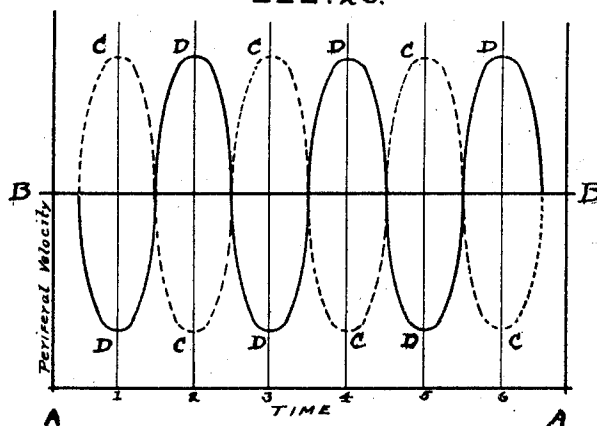


FIG. 21.

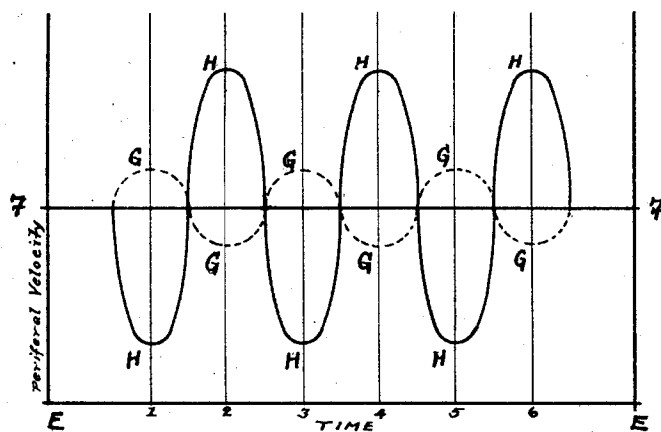


FIG. 22.

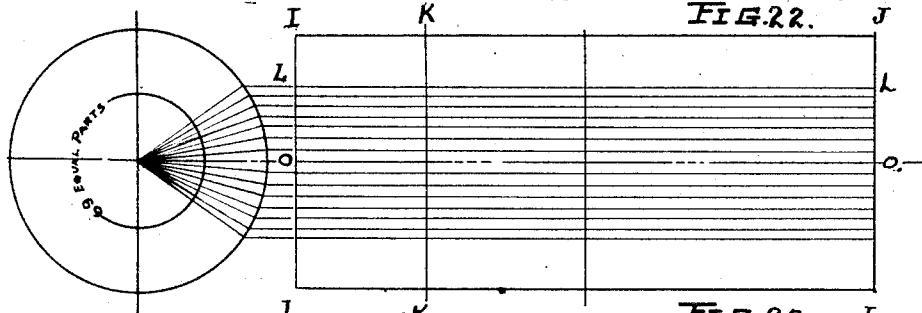
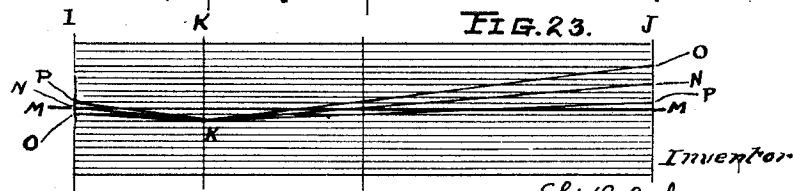


FIG. 23.



384

Eli O. Ackerman
Frank S. Greene
Attorney

UNITED STATES PATENT OFFICE.

ELI O. ACKERMAN, OF COLUMBUS, OHIO.

METHOD OF OPERATING RAILWAY ROLLING STOCK TO PREVENT RAIL CORRUGATION.

Application filed October 12, 1927. Serial No. 225,795.

This invention relates to a method of preventing rail corrugation in electric railway lines or systems and has for its object to provide a method of operating the rolling stock of electric railway lines or systems by which the cumulative rail deforming action of traction wheels which results in rail corrugation is avoided.

Rail corrugation has been for over twenty years, one of the most puzzling problems confronting electric railway officials all over the world. It has caused rapid deterioration and destruction of track work and rolling stock everywhere and has continued unchecked throughout the world to destroy inestimable millions of dollars in property annually. The problem of rail corrugation has been the subject of many careful and exhaustive investigations by individual electric railway companies and by electric railway associations. The results of many of these investigations have been published, but no adequate and complete remedy has been found. Prior to the present invention, various theories have been advanced as to the cause of rail corrugation and various remedies have been proposed for the prevention thereof, but in so far as I am aware, none of the proposed remedies have succeeded in more than slightly mitigating the evil.

I have discovered that the real cause of rail corrugation is the cumulative torsional vibrations set up repeatedly in the driving axles and traction wheels of electric railway cars during their travel over the rails. The present invention has for its object to so operate the rolling stock on electric railway lines as to prevent cumulative rail deforming action by controlling the torsional vibratory action of the individual units of railway rolling stock in such a manner as to prevent cumulative rail deforming action on the rails due to repeated passage over a given portion of track of traction wheels having the same wave length tendency with respect to torsional vibrations and subjected to cumulative torsional vibrations during their passage over the given portion of the track.

With the above and other objects in view, the invention may be said to comprise the method as illustrated in the accompanying drawings hereinafter described and particu-

larly set forth in the appended claims, together with such variations and modifications thereof as will be apparent to one skilled in the art to which the invention appertains.

Reference should be had to the accompanying drawings forming a part of this specification in which Figure 1 is a diagrammatic view showing the standard electric railway car axle together with the gearing by which the axle is driven from the electric propelling motor.

Fig. 2 is a side elevation showing on an exaggerated scale rail corrugations such as are produced on the rails of all electric railway lines.

Fig. 3 is a diagrammatic view showing a divided driving axle and gearing for driving same from the motor.

Fig. 4 is a view similar to Fig. 3 showing a two motor worm gear drive.

Fig. 5 is a view showing a differential drive for a two part axle.

Fig. 6 is a view showing a continuous non-rotatable axle with separately driven wheels rotatably mounted thereon.

Fig. 7 shows an axle driven through gearing located at its center or nodal point.

Fig. 8 shows a drive in which power is applied simultaneously to the axle at points adjacent its opposite ends.

Fig. 9 shows traction wheels of relatively small diameter on an axle of relatively large diameter for the purpose of increasing the natural torque vibration frequency of axle and wheels to a point where it will not synchronize with the pulsations of power through the main gear at any ordinary speed at which the car will travel in service.

Fig. 10 illustrates means by which corrugation of rails may be avoided by employing rolling stock on a given line in which there are several classes of cars, the cars of each class having a wave length tendency different from that of cars of other classes, due to differences in the sizes of wheels, axles and gears.

Figs. 11, 12 and 13 show forms of gearing adapted to drive traction wheels without appreciable fluctuations of torque, Fig. 11 showing a worm drive, Fig. 12 a helical gear drive and Fig. 13 a silent chain drive.

Fig. 14 is a side elevation of a vibration

dampener applied to a traction wheel axle.

Fig. 15 is a section taken on the line indicated at 15—15 in Fig. 14.

Fig. 16 is a sectional view showing a modified form of vibration dampener.

Fig. 17 is a sectional view showing a vibration dampener attached to a car wheel.

Fig. 18 is a side elevation of a car wheel with a dampener applied thereto.

Fig. 19 is a radial section through a car wheel having a dampener attached thereto.

Fig. 20 is a wave diagram showing torsional vibrations of a shaft having a disc at each end.

Fig. 21 is a wave diagram showing velocity variations due to torsional vibrations in the standard car axle.

Fig. 22 is a diagrammatic view of a car axle showing the surface divided by parallel lines which are spaced in accordance with the spacing of the teeth of the driving gear.

Fig. 23 is a diagrammatic view showing the deflexion of the axle upon application of driving force thereto.

My investigation of the phenomena of rail corrugation indicates that the cause of the rail corrugations is a vibrating body with a pulsating, energizing force which approximates synchronism with the vibrations of that body.

Since the wheel is the agent which ultimately produces the corrugations, it follows that the wheel itself must either vibrate or transmit the effect of the vibrations. Of the various vibrations which might be transmitted through the wheels of the car, torque vibration in the axle causing alternate circumferential movements of the wheel surfaces is the only vibration as it now seems to me which could produce the fluctuations in pressure on the rail which would result in deformations of the rail surface corresponding to the corrugations produced by an electric railway car.

This torsional vibration may be illustrated by firmly fixing two metal discs to a small steel shaft, one near either end of the shaft, suspending the shaft in any suitable way, holding the shaft from revolving by clamp at the center which will be the nodal point and drawing a well resined belt along the periphery of the disc, which will set up torque vibrations in the steel shaft, the discs oscillating alternately forward and backward. If this unit (two discs and shaft) while vibrating is caused to revolve rapidly, it will be apparent that the movement of the periphery of either disc will be a succession of rapid advances interspaced by periods of less rapid advances, which is the resultant of the vibrating and spinning movements, the oscillation of one disc being exactly balanced by the oscillation of the other disc, the nodal point being at the center of the shaft.

Fig. 20 is a development of curves showing the peripheral speed of each disc in which the perpendicular distance from line "A—A" to line "B—B" represents the speed due to spinning, which we will call normal speed and the curves represent the modifications of that speed due to vibration. The dotted line "C—C" represents the peripheral speed of one disc and the solid line "D—D" that of the other disc. It is to be noted that the average of these two speeds at any instant is equal to the normal speed and that each curve in making a complete cycle passes the normal line twice.

In an electric car, the axle with its two wheels serves as a vibrating unit, (the vibrations being torque vibrations in the steel axle), and it is further equipped with a heavy gear located between the center of the axle and one wheel. The combined moment of inertia of the gear and adjacent wheel being greater than the moment of inertia of the opposite wheel, the nodal point will be brought over from the center toward the gear causing the wheel farthest from the gear to oscillate through a greater arc.

Fig. 21 is a development of curves showing the peripheral speeds of wheels modified by the unbalancing of the moments of inertia due to the adding of the large gear. The perpendicular distance from line "E—E" to line "F—F" represents the peripheral speed of the wheels due to spinning and the curved lines represent the modification of that speed due to the torque vibration of the axle, the dotted line "G—G" representing the speed of the periphery of one wheel, the solid line "H—H" that of the other wheel. It is to be noted that the average of the two speeds does not equal the normal speed except the instant the two curves are passing the normal line and that in one full cycle each curve passes the normal line twice.

Fig. 22 represents a car axle in which "I" represents the position of one wheel, "J" the position of the other and "K" the position of the gear wheel. The surface of the axle is divided by parallel lines "L—L" into equal parts, each part being the amount subtended by the angle between centers of gear teeth.

Fig. 23 represents a small part of Fig. 22 in which the diametrical scale is largely increased and each division is subdivided into minutely small parts by parallel lines which may represent the fibers of steel at the surface of the axle. If torque be applied to the axle, it being elastic material, these lines will become twisted about the center of the axle, the amount of the twist depending upon the amount of the torque applied. The straight line "M—M" parallel to the center of the axle would represent the position of a fiber of steel on the surface of the axle when the axle is not stressed and the line "N—N" 130

would represent the position of the same fiber when power is applied at "G" and both ends of the axle are equally stressed. In the case of a car axle, the torque is applied at "K" and the wheel "I" being close to gear "K" will be driven in advance of the wheel "J" located at the other end of the axle which will lag slightly, it being at greater distance from "K", the steel fibers would be equally stressed and assume the position shown by the line "N.K.N." If the car be caused to move forward at the speed required for two gear teeth to pass in the exact time of one complete torque vibration of the wheels and axle, including gear wheel and wheel I moved forward in advance of the other as noted in the paragraph above, there will come a time when the stress in the axle between gear K and wheel J reaches its maximum at which time wheel I will tend to rebound and wheel J will start to rotate forward more rapidly, the steel fiber being twisted, will assume a position similar to that shown by line O.K.O. When wheel J has begun its more rapid forward rotation, the second gear tooth comes into action and augments that movement while the wheel I is tending to rebound. Wheel J continues its movement until the maximum stress in the axle between the gear K and wheel I has been reached when the wheel J tends to rebound, wheel I begins a more rapid movement, the steel fiber being twisted will assume a position similar to that shown by line P.K.P. If this process is repeated with synchronism between the torque vibrating time of the wheels and axle and the time of the passing of two gear teeth, a violent vibration will be set up which accumulates in intensity until the synchronism is broken, thus causing a series of vibrations which result in sharp periodic fluctuations in the pressure of each wheel on the rail. These series are repeated over and over as the car approaches the critical speed. The more closely the critical speed is approached, the greater will be the number of waves in each series.

Experience has shown that any electric car of the designs that have been in common use up to the present time, travelling with power under ordinary conditions, will readily produce corrugations.

In this connection, it is noted that practically all electric cars in common use up to the present time are driven by gears mounted near one end of the axle so that when power impulses through the gears synchronize with the torque vibrations of the vibrating unit (wheels and axles), the effect will be to produce cumulative torsional vibrations in the wheels and axles and this effect will be produced at a given critical speed for each vibrating unit, the effect being to produce corrugations in the track.

It is also a fact that a set of cars operating at a comparatively low speed and not producing corrugations may, when operated at a greater speed, cause corrugations to become general. In this connection, it is apparent that cars operating at comparatively low speeds do not produce corrugations because the speed is below the critical speed at which the power impulses are synchronized with the time of torque vibration of the wheels and axles and that increase of the speed to the critical speed for the given units causes the cumulative vibrations which produce rail corrugation.

It has been found that the wave length or distance from crest to crest of the rail corrugations on any system, approaches remarkably close to uniformity. The uniformity in length of corrugations is the result of the uniformity of diameter of traction wheels and of the number of teeth in the driving gears. An examination of the relation that the main driving gears of the car bear to the length of the wave of the corrugations show the following results:

In Columbus, the average length of the waves of corrugations on the No. High Street tracks was found to be 2.801 inches. On the cars in service on this line, the diameter of car wheels when new was 33 inches and when worn to the point where they were discarded, 31½ inches.

The number of teeth of the large driven gear on part of the cars is 67 and on part, 69. Therefore, the average peripheral movement of the wheel while the gear moves from one tooth to the next is 1.490 inches or a little more than half the wave length. Experiments have shown that more or less slipping of wheels occurs on all cars propelled by electric power and it is probable that more slipping occurs during the cumulative vibrations of wheels and axles than when the car wheels roll smoothly over the track. Assuming the slipping during the vibrating period to be approximately 6%, it will be noted from the data given above that the average movement of cars while the gear moves over two teeth will be 94% of $1.490 \times 2 = 2.801$, which is the exact length of the average wave length of the rail corrugations noted above. Apparently to produce cumulative vibration in the wheels and axle while spinning, we should have two power impulses represented by the passing of two gear teeth during the time of each complete vibration. If the car is caused to move forward at the speed required for two gear teeth to pass in the exact time of one complete torque vibration of the wheels and axle and one wheel moves in advance of the other, as would be the case in the torsional vibration of the wheel and axle, there will come a time when the stress in the axle reaches its maximum at which time one

wheel will tend to rebound and the other to rotate forwardly more rapidly. The steel fibers of the axle being twisted, will assume a position such as illustrated by the line "O.K.O." in Fig. 23, and the first half of the cycle will have been completed. When the second wheel has begun its more rapid forward rotation, a second gear tooth comes into action and augments that movement, while the first wheel is tending to rebound. The second wheel continues its movement until maximum stress in the axle between the gear wheel and the first wheel has been reached when the second wheel tends to rebound and the first wheel begins a more rapid movement, the steel fibers being twisted will then assume a position similar to that shown by the line "P.K.P." in Fig. 23 and the second half of the cycle will have been completed. This process being repeated in time to create synchronism between the torque vibrating time of the wheels and axle and the time of the passing of two gear teeth, sets up violent torque vibrations in the axle which accumulates in intensity until the synchronism is broken, thus causing a series of vibrations. These series are repeated over and over as the car approximates the critical speed, the more closely the critical speed is approached, the greater being the number of waves in each series.

It has also been found that wherever rail corrugations appear on both rails of a track, they are never directly opposite each other, but the crest of the corrugation on one rail is directly opposite the hollow of the corrugation on the other rail. This necessarily follows since the torque vibration moves the wheels always in opposite directions.

It is also true that corrugations seldom or never appear on the wheel surface. The wheel tread is of harder material than the rail and the teeth in the driven gear being an odd number will cause each revolution of the wheel to balance the corrugating effect of previous revolutions and prevent corrugation.

Well defined corrugations appear more generally in series of varying numbers of waves, and seldom appear in a continuous line of regular waves for any considerable length of track. The varying number of waves in the corrugations and the breaks in the continuity of the waves are due to the fact that synchronism between the driving impulses and the natural torque vibration period of a wheel and axle may be closely approached, but is never exactly maintained for any great period of time, the series of corrugations being produced when synchronism is approached and the length of a series of corrugations depending upon the degree of synchronism. If all cars were operated at the exact critical speed, cor-

rugations would be continuous, but obviously such operation is impossible.

It has been generally observed that corrugations appear more abundant on one rail than on the other one. The greater number of corrugations on one rail is due to the fact that the vibrating movement of one wheel is greater than the other due to unbalancing of the moments of inertia of the wheels on opposite ends of the axle, the combined moment of one wheel and the adjacent gear wheel being greater than that of the other.

In the case of a car wheel resting on a track, the wheel being conical and the rail surface oval, the contact would, if the wheel and rail were not elastic, be a point and the wheel being loaded would exert a compression stress upon that point of infinity per square inch. The wheel and rail, however, being elastic, are deformed by the compression stress so as to make the point which we will call the first point of contact, spread out into a spot (an area of contact) the shape and magnitude of which depends upon the diameter of the wheel, the contour of the wheel tread and of the rail surface and their relative positions, together with the load and the degree of elasticity of the wheel and rail. The metal of both the wheel and the rail at the first point of contact will be stressed beyond its elastic limit and the stress of the metal of both the wheel and the rail will decrease as we move in any direction from the first point of contact. The metal of the first point of contact is, however, held in place by the surrounding metal until the stresses become too great, when the metal will flow, the movement being along the line of least resistance. When the thrust producing rotary motion of the wheels and their travel along the rails is caused to pulsate and the pulsations are augmented with regularity by the vibrations of the axles, the stress transmitted through the spot of contact of wheel and rail will be simultaneously pulsed and the effect of the pulsations will cause the metal to flow from under the wheel at one point of the pulsatory movement and to be piled up at another point of said pulsatory movement with the same degree of regularity.

It is apparent, therefore, that if the periodic variations in angular velocities of traction wheels which cause the fluctuations in pressure on the rail can be so controlled as to be ineffective to deform the rail surface either by preventing cumulative torsional vibrations of wheels and axles or by eliminating the cumulative effect of continual passage of traction wheels of the same wave length tendency, the deformation of the rail surface may be prevented.

Fig. 1 of the drawing shows diagrammatically, the conventional drive employed on practically all railway cars at the present

time. The axle 1 has fixed thereto at its opposite ends, traction wheels 2 and 3, and between the central point of the axle and one of these wheels, there is mounted a large spur gear 4, which is driven by a pinion 5 on the shaft 6 of an electric motor 7 suitably supported along side the axle. As explained above, the unit consisting of the two traction wheels and the axle to which they are fixed will have a natural tendency to vibration about a nodal point 8 which is positioned at one side of the center of the axle toward the gear 4 due to the increase in the moment of inertia at that end of the axle, due to the mounting of the gear wheel thereon.

Fig. 2 of the drawing shows a section of rail 9, which has been corrugated by the passage of electric railway cars, the corrugations 10 being shown on an enlarged scale for the purpose of illustration.

It will now be apparent that if the individual units of railway rolling stock on a given line or system are so operated that torsional vibrations are substantially eliminated or so that synchronism between pulsations of driving power and the natural periods of torque vibration of the axles are prevented, corrugation of rails in the system may be avoided.

Fig. 3 shows diagrammatically, a two part axle 11 which is divided at the center and which has a gear 12 adjacent each traction wheel 13, each gear being driven by a pinion 14 on the shaft of a motor 15, the gears being on opposite sides of the motor and the two sections of the axle being driven at equal speeds. Since the axle is divided at its center, the wheels and axle do not form a vibrating unit and there will be no harmful torque vibration in the wheels and axles. Furthermore, cumulative vibrations due to fluctuations in the application of power to the axles in synchronism with the torque vibrations are prevented.

In Fig. 4 of the drawing, there is shown a drive similar to the drive shown in Fig. 3 except that the axle sections 20 carry worm gears 21 which are driven by worms 22 on shafts of two separate motors 23. The drive shown in Fig. 4 insures with more certainty, uniform rotational movement of the wheels since the worm drive applies a non-fluctuating torque to each part of the axle.

Fig. 5 of the drawing shows a drive through a two part axle 30 in which a differential gearing 31 is interposed between the two parts of the axle, so that the torque is applied independently to each half of the axle and the traction wheel fixed thereto.

Fig. 6 of the drawing shows a continuous axle 40, which has a traction wheel 41 rotatably mounted upon each end thereof.

In this case, the power is applied through suitable gears 42, directly to the two wheels.

Fig. 7 of the drawing shows a drive in

which the driving gear 50 is attached to the center of an axle 51 which has traction wheels 52 fixed to its opposite ends. By placing the gear 50 at the center of the axle, the moments of inertia are balanced on opposite sides of the center and the drive is through the nodal point so that cumulative torque vibrations of the axle and wheel are prevented.

Fig. 8 shows a drive for a traction wheel unit in which the axle 60 has a gear 61 attached thereto adjacent each of the traction wheels 62, the gears 61 being driven by suitable pinions driven by the same or separate motors. The result of driving an axle simultaneously through gears adjacent its opposite ends is to dampen the torque vibrations of the axles and wheels and prevent them from becoming cumulative.

Fig. 9 of the drawing shows a means by which synchronism between the pulsations and power and the natural torque vibrations of the axle and wheels is prevented so that cumulative torque vibration cannot occur. In this case, the axle 70 is of relatively large diameter and the traction wheels 71 fixed thereto are of relatively small diameter so that the natural torque vibration frequency of the axle and wheels is increased to a point such that it will not synchronize with the pulsations of power through the main gear at any ordinary speed at which the car will travel in service.

In order to eliminate cumulative torsional vibrations in wheels and axles, it is desirable that the axles or wheels be driven with a substantially non-fluctuating application of power thereto and it is preferable regardless of whether the wheels are driven separately or through a common axle that the usual spur gear drive should be replaced by a drive which will give a non-fluctuating application of power.

In Fig. 11, there is shown a worm drive in which the worm gear 75 is fixed to the car axle and is driven by a worm 76 on the shaft of the motor 77.

In Fig. 12, there is shown a helical gear drive in which a large helical gear 78 on the axle 79 is driven by a small helical gear 80 on the shaft of the motor 81.

In Fig. 13 of the drawing, there is shown a silent chain drive in which a sprocket 82 on the axle 83 is driven through a silent chain 84, extending over the sprocket 82 and a smaller sprocket 85 on the shaft of an electric motor 86. It is to be understood that a non-fluctuating driving mechanism such as shown in Fig. 11, Fig. 12 or Fig. 13 is the preferred driving mechanism in any of the traction units shown in Figs. 3 to 9. By replacing the ordinary traction wheel unit such as shown in Fig. 1 on any given electric railway line or system, by traction wheel units such as above described, cumulative torsional

vibrations of wheels and axles may be prevented, it being immaterial in so far as the present invention is concerned whether one or several of the above described vibration
5 controlling means be employed on individual cars of a given line or system.

The changing of the driving equipment or of wheels and axles involves a relatively large expenditure of money and would require overhauling of the entire equipment of
10 the line and the installation of such equipment while desirable in the long run would in most instances have to be a more or less gradual process extending over a considerable period of time.

The present invention, however, contemplates the operation of existing rolling stock on a given line or system with minimum changes or additions thereto to prevent the
20 corrugation of rails so that the desired results may be accomplished without extensive replacement or alteration of the rolling stock at present in use.

The continually repeated passage of traction wheels with corresponding periodic fluctuations in pressure on the rails of the same wave length tendency over any given portion of track which results in corrugating action may be avoided by operating several
30 different classes of cars, the cars of each class having a wave length tendency different from those of any other class. When the cars are so operated, it is not possible for the corrugating tendency of one car to fall in step with the corrugating tendency of another car of different wave length tendency, and each class of cars having a wave length tendency different from that of other classes will cause each class of cars to efface the corrugating effect of other classes and thus prevent the development of corrugations on the rail. It will often be possible by rerouting the present equipment in a given system to provide a sufficient number of classes of different wave length tendencies on a given
45 line to prevent the development of rail corrugations.

Fig. 10 shows various types of standard equipment which may be used in combination on a given line or system to prevent the corrugation of rails. This figure shows traction wheel units of different wave length tendencies due to different sizes of wheels and gears. The wave length tendency in each case is the length of the arc on the tread of the wheel subtended by two successive teeth of the gear. Certain of the cars may have traction wheels 90 of relatively small diameter which are driven through a gear 91 on the axle, two teeth of which subtend an arc R.S. on the rail engaging periphery or tread of a wheel. Other cars may have relatively large wheels 92 driven through a gear 93 on the axle of the same size as the gear 91, two teeth of the gear
65

93 subtending an arc T.U. on the wheel tread of greater length than the arc R.S. on the wheels 90. Other cars may have relatively small wheels 94 driven through a gear 95 of a size different from that of gears 91 and 93, two teeth of this gear subtending an arc V.W. on the wheel tread of a length different from that of the arcs R.S. or T.U. Other cars may have relatively large wheels 96 driven through a gear 97 of the same size as gear 95, two teeth of the gear 97 subtending an arc X.Y. of a length different from R.S., T.U. or V.W. By selecting cars for a given line with sufficient number of different wave length tendencies, rail corrugation may be prevented.

The torque vibrations in individual units of railway rolling stock may be controlled by attaching to the driving axle or to the traction wheels, vibration dampeners such as shown in Figs. 14 to 18 of the drawing. The vibration dampener shown in Figs. 14 to 15 consists of a flywheel 100, divided into two parts which are held apart by means of a series of coil springs 101. The flywheel is mounted in a flanged hub 102 which is keyed to the axle and which carries a flanged collar 103, which is screwed on the hub and held in place by a jam nut 104. An annular piece of friction fabric 105, which may be made of material similar to brake band lining, is riveted to the flange of the hub between the flange and one section of the flywheel and a similar band 106 is riveted to the flange of the collar nut 104 and lies between the other section of the flywheel and the collar flange. The two sections of the flywheel are held against relative circumferential movement by means of pins 108 which are fixed to one section and project into sockets formed in the other section. The springs 101 hold the two parts of the flywheel against the pieces of friction fabric 105 and 106 with whatever pressure is required and the pressure is adjustable by turning the collar nut 103 and locking it in adjusted position with the jam nut 104. The flywheel 100 may revolve independently of the hub and axle and when the axle revolves, the flywheel will be driven through the friction fabric face members 105 and 106. Should any attempt be made to quickly reverse the direction of revolution of the axle, the momentum of the flywheel 100 will oppose such attempt. When the spring pressure is adjusted so that the fabric will slip at the alternating speed of natural torque vibration of wheels and axle, the inertia of the flywheel will serve as a drag or dampener to oppose the torsional vibration of the axle.

Fig. 16 shows an adaptation of the torsional vibration dampener to an axle of large diameter and is similar to the dampener as shown in Figs. 14 and 15, except that the flywheel 100^a is held in a hub 102^a which

has a shorter flange and the flange nut 103^a is held in adjusted position by bolts 109 instead of by a jam nut as shown in Figs. 14 and 15.

5 Fig. 17 shows an adaptation of the torsional vibration dampener for attachment directly to a car wheel, this dampener being useful where there is not sufficient room on the axle to mount a dampener such as shown
10 in Figs. 14 to 16. In this form, the flywheel consists of inner and outer sections 110 and 111 which are pressed apart by coil springs 112. Section 110 of the flywheel is of substantially wedge form in radial section to fit
15 against the inner face of the web of the car wheel and is pressed against an annular piece of friction fabric 113. The inner section 111 is pressed against a similar annular piece of friction fabric 114 secured upon the inner
20 face of a flange nut 115, which is screwed upon the hub of the wheel and held in adjusted position by means of bolts 116 extending through the plate and the web of the car wheel.

25 Figs. 18 and 19 show a similar form of dampener adapted to be attached directly to a car wheel and in this form, the flywheel 120 is formed in one piece with its outer face of substantially conical form to conform to the inner face of the web of the car wheel. The flywheel bears against an annular piece of friction fabric 121 secured upon the face of the car wheel and is yieldingly pressed toward the car wheel by means
30 of an annular plate 123 which has a central opening provided with notches 124, which receive lugs of similar form formed on the hub of the car wheel. The plate 124 carries on its inner face an annular piece of friction fabric 125 and is yieldingly pressed
40 toward the flywheel to clamp the flywheel between the friction fabric on the car wheel and the friction fabric on the plate by means of bolts 126, carrying springs 127, which
45 serve to maintain a spring pressure on the plate 123 to maintain pressure between the flywheel and the friction fabric on opposite sides thereof.

It will be understood that the elimination
50 of rail corrugation by the method of the present invention requires changes from the present methods in operation of all the rolling stock used on a given line or system and that any or all of the specific means herein
55 described for controlling the torsional vibrations in individual units to prevent the cumulative rail deforming action of traction wheels may be employed on a given line or system.

60 What I claim is:

1. The herein described method of operating the rolling stock on electric railway lines or systems to prevent cumulative rail deforming action of traction wheels

which results in the corrugation of rails 65 which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause apprecia- 70 ble periodic fluctuations of pressure on the rails during their travel along the track by controlling, in the units of the railway rolling stock passing over any given portion of the track, the torsional vibrations which 75 cause periodic variations in angular velocity of the traction wheels.

2. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative 80 rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substan- 85 tially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure on the rails during their travel along the track by substantially eliminating torsional vibra- 90 tions in the driving wheels and axles of the individual units of the railway rolling stock.

3. The herein described method of operating the rolling stock on electric rail- 95 way lines or systems to prevent the cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially 100 the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure on the rails during their travel along the track by driv- 105 ing the traction wheels of the individual units of railway rolling stock with continuous substantially non-fluctuating application of torque thereto to substantially eliminate cumulative torsional vibrations causing pe- 110 riodic variations in the angular velocity of traction wheels.

4. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative 115 rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially 120 the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations in pressure on the rails during their travel along the track by main- 125 taining during the propulsion of individual units along the track a substantially non-fluctuating application of torque from the propelling motors to the axles of the traction wheels.

5. The herein described method of operating the rolling stock on electric railway lines or systems to prevent cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations in pressure on the rails during their travel along the track by applying torque independently to each traction wheel in the propulsion of individual units of railway rolling stock along the track.

6. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure on the rails during their travel along the track by maintaining while the individual units of the railway rolling stock are being propelled, a substantially non-fluctuating application of torque from the propelling motors to the individual traction wheels.

7. The herein described method of operating the rolling stock on electric railway lines or systems to prevent cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations in pressure on the rails during their travel along the track by balancing moments of inertia on opposite ends of the driving axles of individual units of railway rolling stock and applying driving torque from the propelling motors to the axles at nodal points of natural torque vibration.

8. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure on the rails during their travel along the track by balancing moments of inertia on opposite ends of the driving axles of individual units of railway rolling stock and applying a substantially

non-fluctuating driving torque from the propelling motors to the axles at nodal points of natural torque vibration.

9. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure on the rails during their travel along the track by dampening torque vibrations in individual units of railway rolling stock.

10. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure on the rails during their travel along the track by dampening torque vibrations in individual units of railway rolling stock and preventing them from becoming cumulative by applying torque from the propelling motors to driving axles simultaneously at longitudinally spaced points on the axles.

11. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure on the rails during their travel along the track by dampening torque vibrations in individual units of railway rolling stock and preventing them from becoming cumulative by maintaining a substantially non-fluctuating application of torque from the propelling motors to driving axles simultaneously at longitudinally spaced points on the axles.

12. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure on the rails

during their travel along the track by employing in individual units of the railway rolling stock, wheels and axles of a natural torque vibration frequency non-synchronous
5 with pulsations of driving power at any ordinary speed of travel of the units.

13. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative
10 rail deforming action of traction wheels which results in the corrugation of rails which consists in preventing continually repeated passage over any given
15 portion or track of traction wheels having substantially the same wave length tendency with respect to vibrations which cause appreciable periodic fluctuations of pressure
20 on the rails during their travel along the track by increasing the natural torque vibration frequency of axles and wheels of individual units of the railway rolling stock to a point where they will not synchronize

with the pulsations of power through the main driving gears at any ordinary speeds at which the units will travel in service. 25

14. The herein described method of operating the rolling stock on electric railway lines or systems to prevent the cumulative rail deforming action of traction wheels which results in the corrugation of rails
30 which consists in preventing continually repeated passage over any given portion of track of traction wheels having substantially the same wave length tendency with respect
35 to vibrations which cause appreciable periodic fluctuations in pressure on the rails during their travel along the track by operating on a given line of track several different
40 classes of cars, the driving axles and traction wheels of each class having a torque vibration wave length tendency substantially different from that of other classes.

In testimony whereof I affix my signature.

ELI O. ACKERMAN.