United States Patent

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[54] **PLURAL MOTOR TRAIN CONTROL WITH SEQUENTIAL OR SELECTIVE STARTING FOR SPEED CONTROL**
15 Claims, 8 Drawing Figs.

[52] **U.S. Cl.** **318/102,** 318/87, 318/91, 318/103
[51] **Int. Cl.** **H02p 1/58**
[50] **Field of Search** 318/101–104, 113, 87, 91, 94

[56] **References Cited**

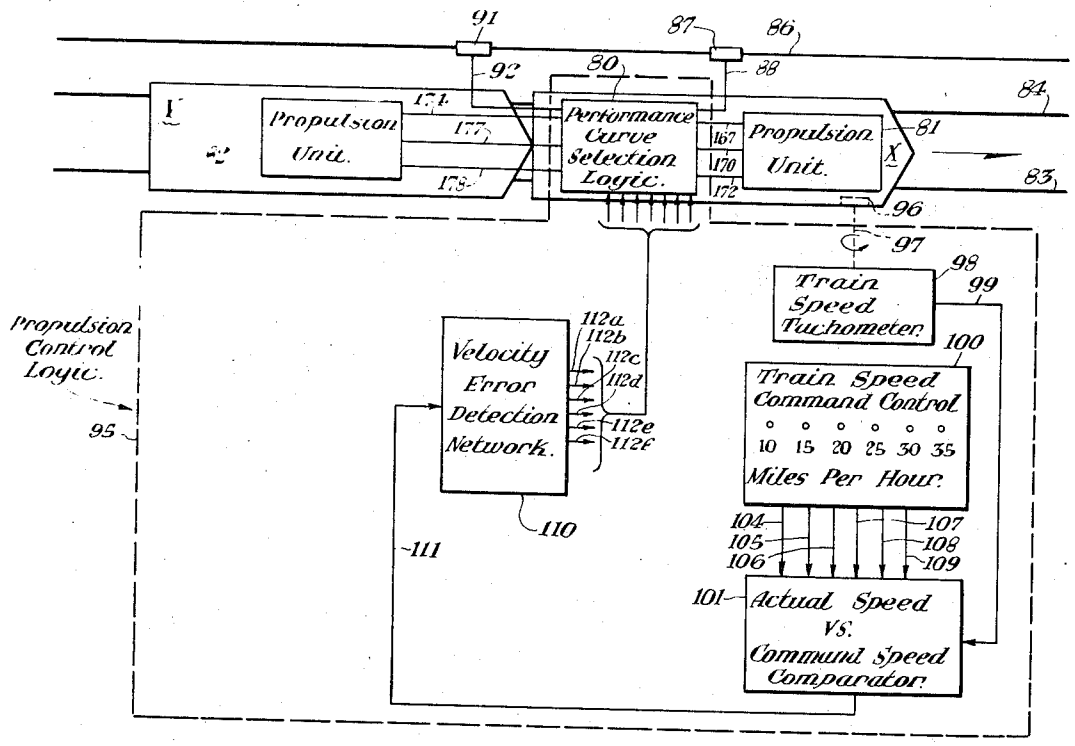
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ABSTRACT: This invention relates to a single or multivehicle propulsion control system having at least two propulsion units.

The system is comprised of at least one propulsion unit having a plurality of selectable operating modes and at least one other propulsion unit having a plurality of selectable operating modes. A propulsion control logic unit is operatively coupled respectively to the two just-recited propulsion units. These propulsion units are simultaneously controlled by the propulsion control logic unit to select a predetermined number of combinations of the modes of operation from the propulsion units, the predetermined number of combination modes available exceeding the number of modes available for any one of the propulsion units. The selected combination of modes closely approximates the propelling effort required to maintain the preselected vehicle or vehicles' speeds free from accelerating and decelerating effects.



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SHEET 1 OF 6

PRIOR ART.

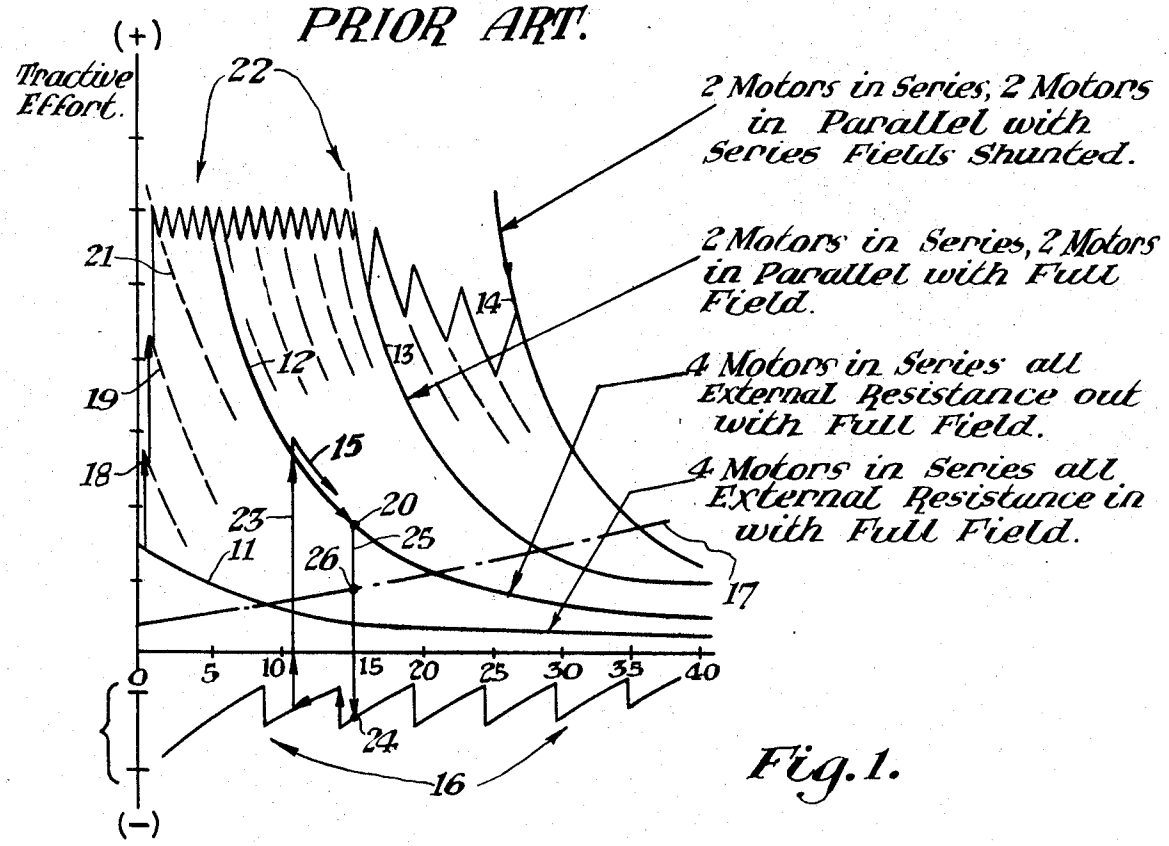


Fig. 1.

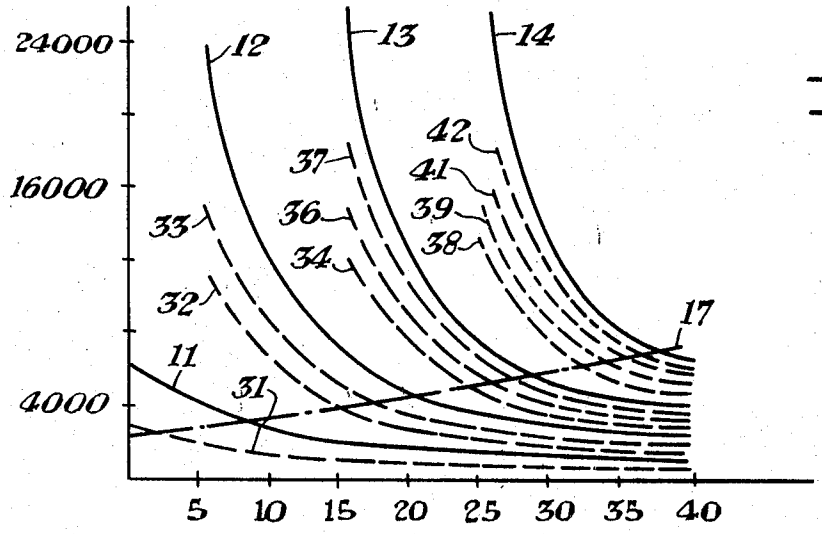


Fig. 2.

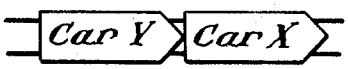


Fig. 2a.

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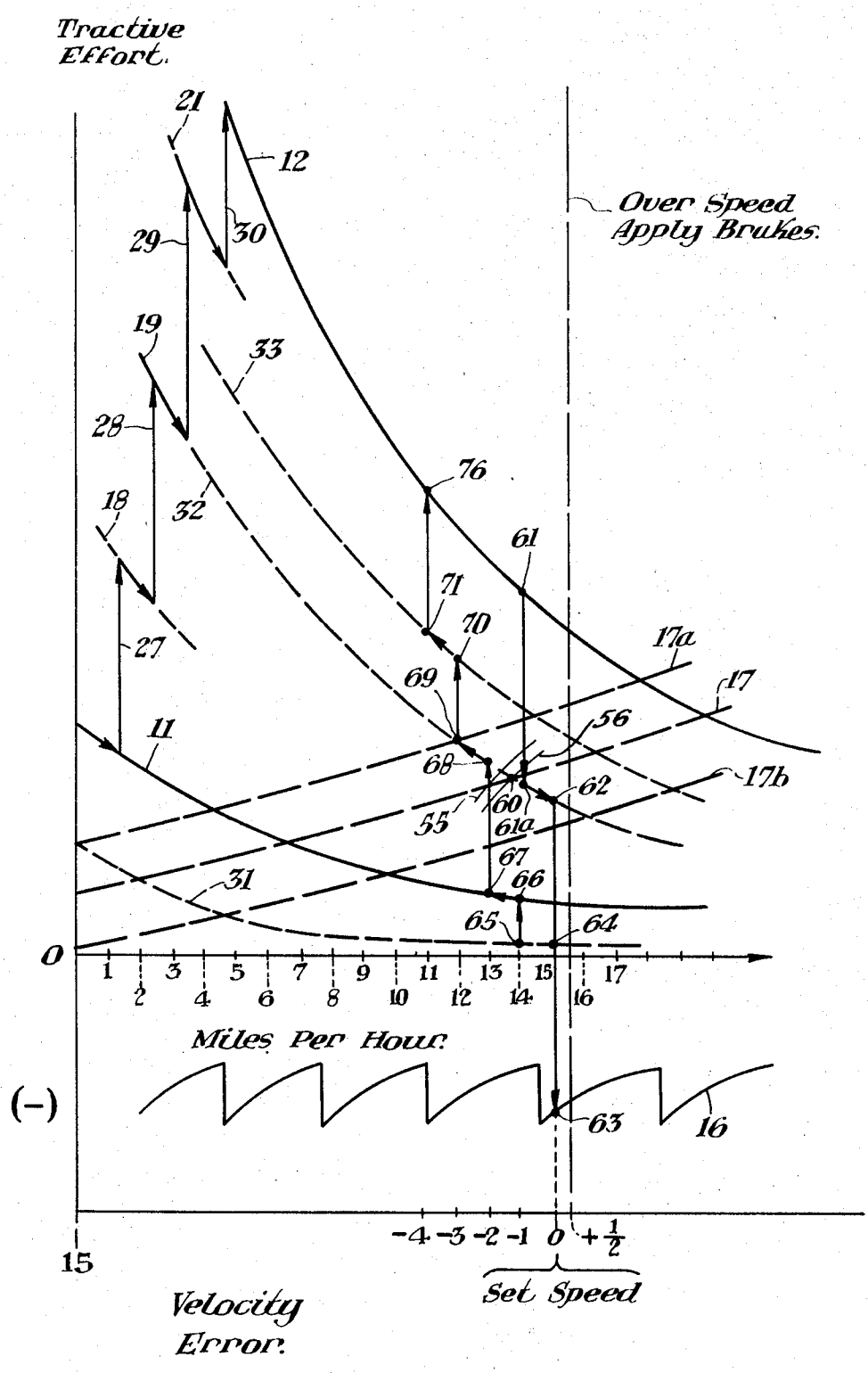


Fig. 3.

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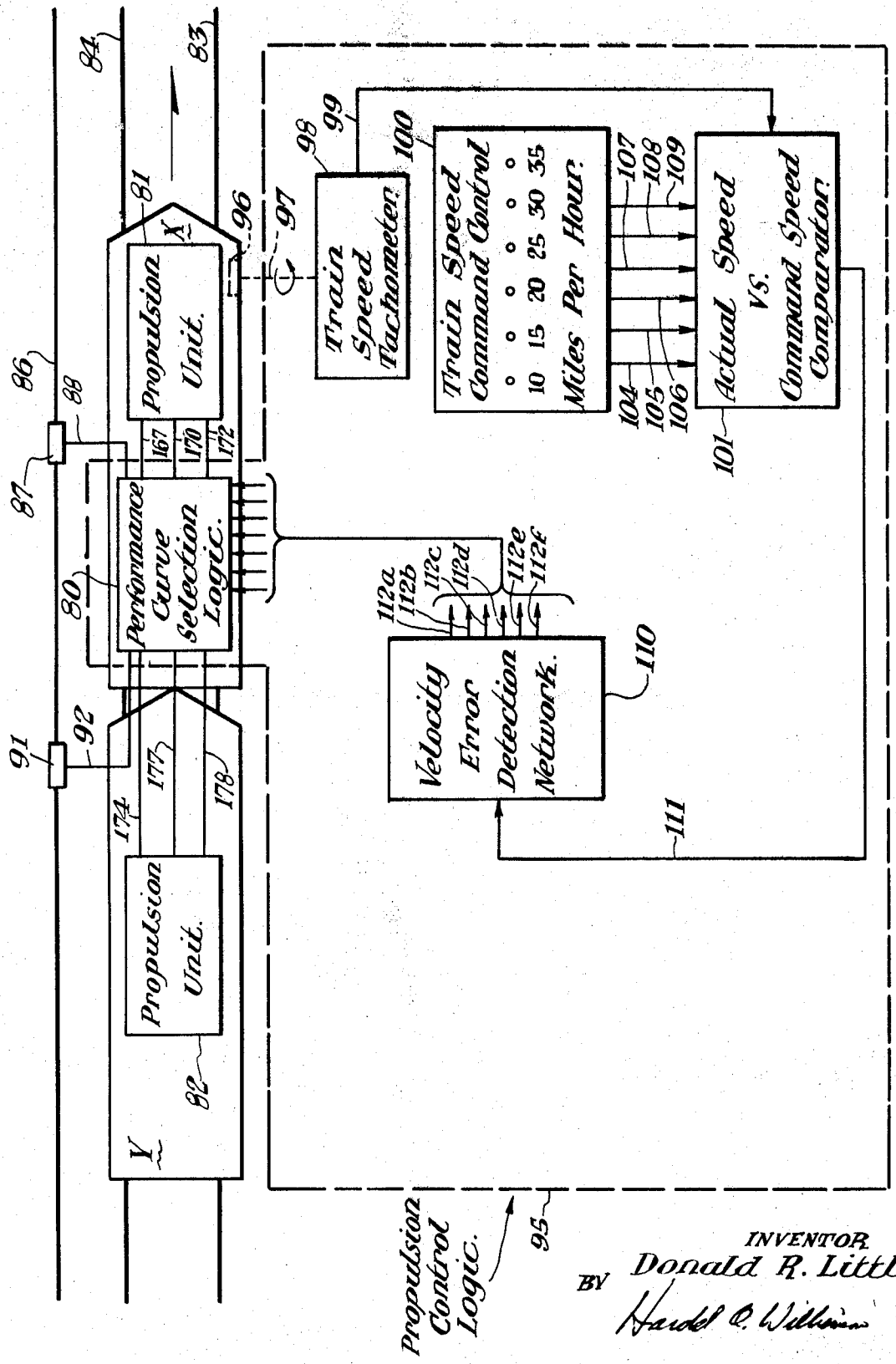

Propulsion Unit.
Train Speed Tachometer.
Train Speed Command Control
0 0 0 0 0 0 0
10 15 20 25 30 35
Miles Per Hour.
Actual Speed Vs. Command Speed Comparator.
Performance Curve selection Logic.
Velocity Error Detection Network.
Propulsion Unit.
Propulsion Control Logic.
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Fig. 4.

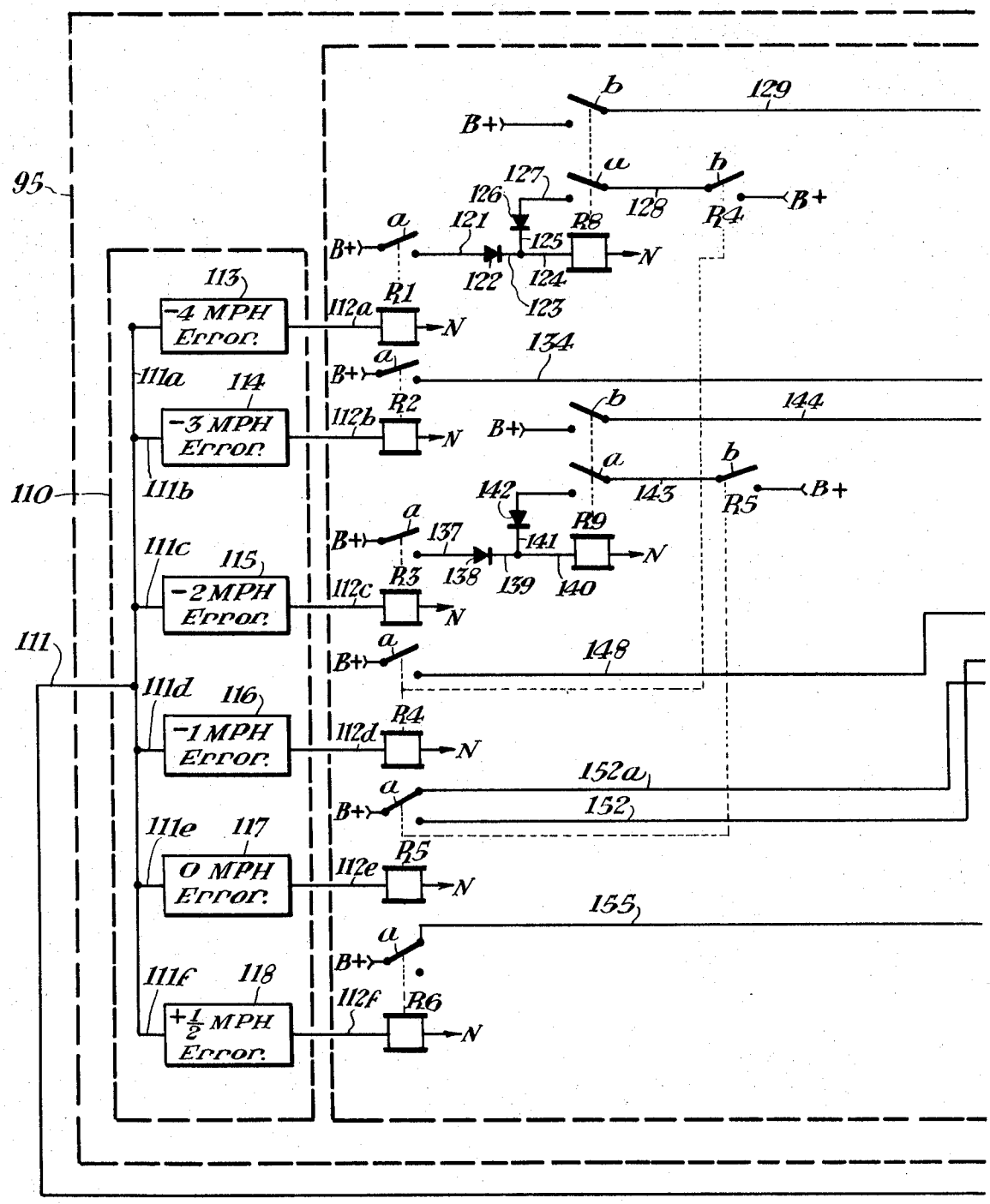


Fig. 5A.

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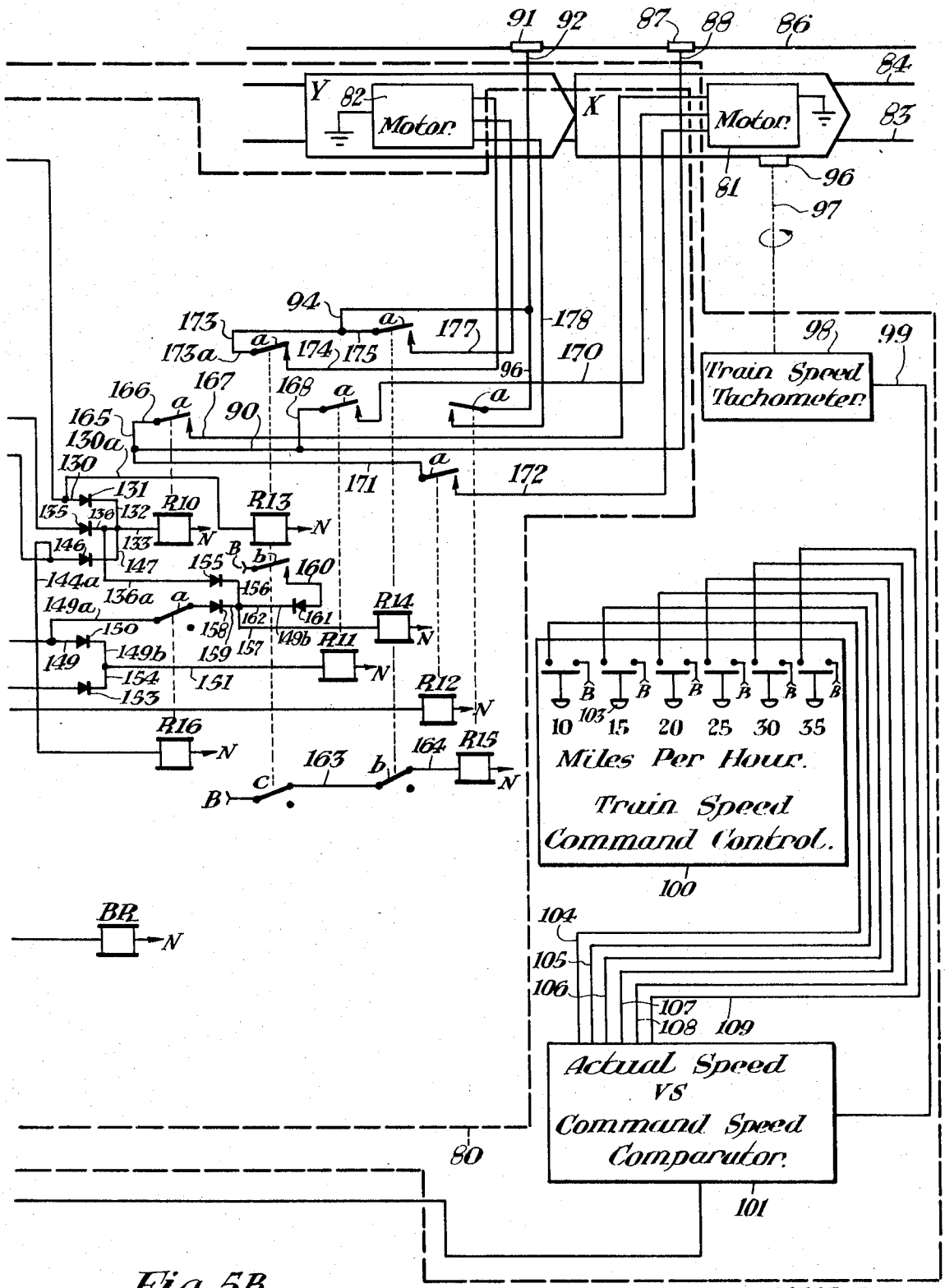


Fig. 5B.

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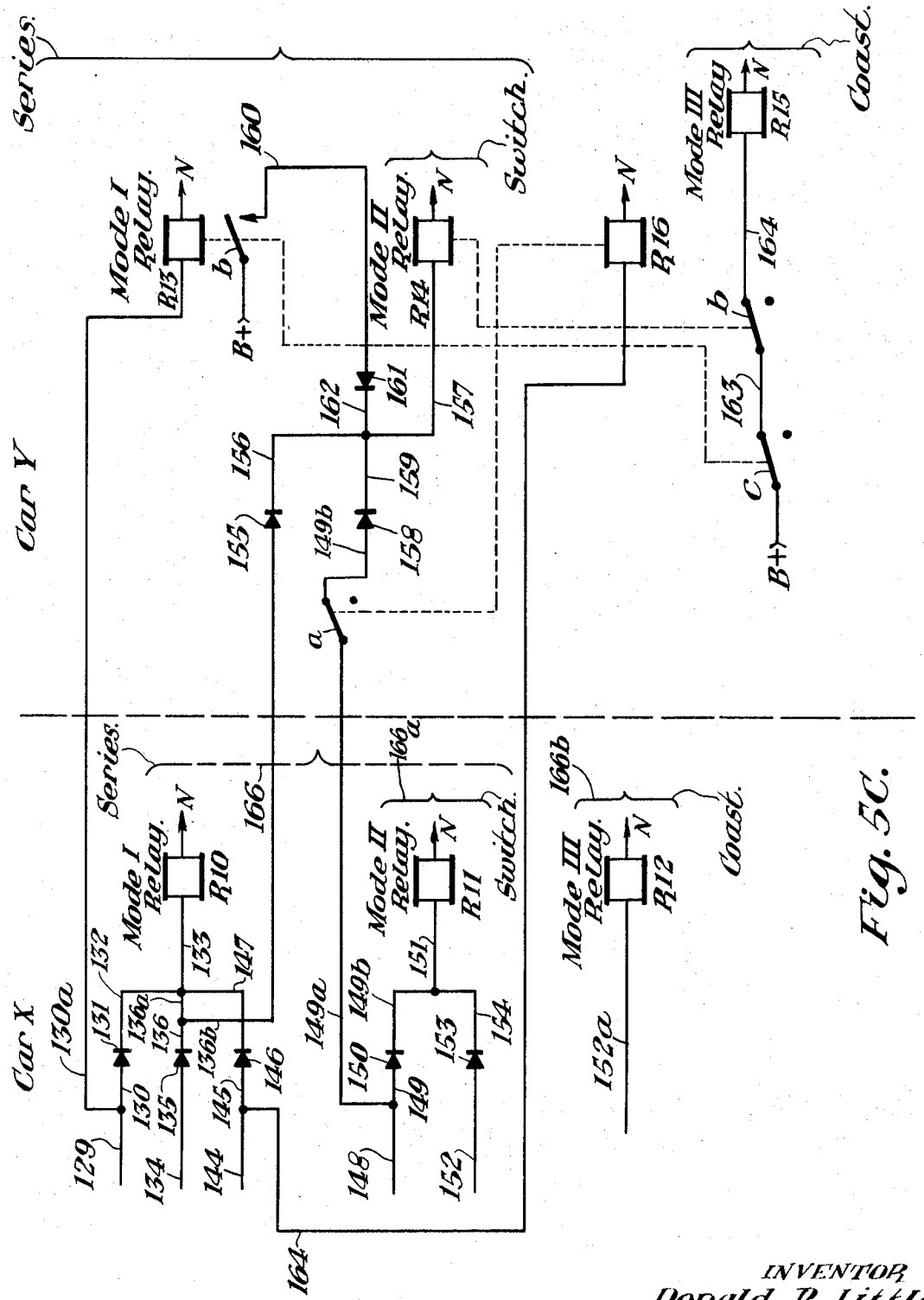


Fig. 5C.

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PLURAL MOTOR TRAIN CONTROL WITH SEQUENTIAL OR SELECTIVE STARTING FOR SPEED CONTROL

This invention relates to a vehicular propulsion control system.

More specifically, this invention relates to a single or multivehicle propulsion control system having at least two propulsion units. Where a single vehicle is involved the two or more propulsion units would be on the single vehicle, while in the case of a multivehicle operation each vehicle could have as few as one propulsion unit per vehicle. The propulsion control system will cause the vehicle to move along a predetermined path at a preselected speed relatively free from accelerating and decelerating effects. The system is comprised of at least one propulsion unit having a plurality of selectable operating modes and at least one other propulsion unit having a plurality of selectable operating modes. A propulsion control logic unit is operatively coupled respectively to the two just-recited propulsion units. These propulsion units are simultaneously controlled by the propulsion control logic unit to select a predetermined number of combinations of the modes of operation from the propulsion units, the predetermined number of combination modes available exceeding the number of modes available for any one of the propulsion units. The selected combination of modes closely approximates the propelling effort required to maintain the preselected vehicle or vehicles' speeds free from accelerating and decelerating effects.

Mass transit in the years just past has been and will continue to be like a struggling giant shackled by the enormous capital investment that gave the birthright to rapid transit nearly a half century ago. Something must be done to revitalize the quality of the ride experienced by the passengers. Recent years have seen an exodus of passengers from rapid transit forms of transportation to the now ubiquitous automobile. The poor quality of the ride from the passengers' viewpoint has been a factor. The mass transit giant has been in urgent need of a transfusion to keep it alive. This transfusion is underway as new ideas and innovations are pumped into the existing systems. The most common approach has been to propose entirely new schemes to enhance rapid transit passenger comfort and thereby lure the masses back to the train. These approaches invariably require that entire existing systems be abandoned. There is no question but the creation of sophisticated solid-state speed control systems available today is to be lauded.

The heart of the problem lies in passenger comfort while moving in transit from one spot to another. Almost all recent development work in the field of automatic operation of rapid transit systems has generally required fairly precise (±1 to 2 m.p.h.) speed regulation to permit short headway operation in combination with various safety assurance methods such as overspeed protection. The majority of existing transit systems use contacts to switch resistance in series with the propulsion motor armature, shunts in parallel with the motor field, and various motor configurations to provide propulsion control. This type of speed control has only a few, usually three or four, permanent operating states. Precise speed regulation with these types of propulsion controls has severe limitations. There are only a few speeds at which the available tractive effort exactly balances the forces tending to retard the train and these speeds vary widely with grade.

Anyone who has traveled on the subways and intracity transit trains is familiar with the annoying acceleration, coast and jerky ride that continually vexes the passengers aboard such trains. The invention to be described hereafter solves all the above-noted problems related to passenger comfort without the need to go to new transit propulsion systems, all at a cost and simplicity that elevates the invention to be described into the realm of invention of the highest order.

Not only does the invention to be described cope with the problems of existing systems but also provides a teaching that will greatly enhance the operation of future systems which will call for discrete velocity operating speeds. These latter-noted advantages will become evident as the description that follows progresses.

It is therefore an object of this invention to provide an improved propulsion system for existing transit systems without the need for replacing the existing propulsion units.

Another object of this invention is to provide a smoother ride while maintaining a preselected speed by the utilization of various combinations of modes of propulsion effort available when two or more propulsion units are involved.

Yet another object of this invention is to provide an inexpensive highly effective propulsion control system suitable for incorporation in existing rapid transit systems which, because of its simplicity, is much lower in cost than currently available propulsion control systems of comparable control capabilities.

Still another object of this invention is to provide a propulsion control system which, because of its automated nature and basic simplicity, greatly reduces the training time required of motormen currently employed.

Another object of this invention is to provide propulsion unit control which will enhance all future propulsion unit control whenever the propulsion unit control has preselected operating states or modes.

Another object of this invention is to provide a propulsion control system that inherently requires fewer cycling of control modes of operation than existing propulsion systems to thereby maintain precise speed control which results in lower maintenance cost.

And still yet another object of this invention is the provision of a propulsion control system that makes special use of inherent dynamic braking provided by selected propulsion unit or units of a train to establish an overall train performance curve that exactly balances the forces tending to retard the train, thereby establishing a relatively constant velocity which results in enhanced passenger comfort and a smoother ride.

In the attainment of the foregoing objects a vehicular propulsion control system is provided which includes at least two propulsion units for causing vehicle movement along a predetermined way at a preselected speed at a relatively constant velocity.

Basically, the system operates with propulsion units having a plurality of selectable operating modes. The propulsion unit in the preferred embodiment is a series-connected DC electric motor. The practice of the invention requires that there be at least two propulsion units having a plurality of selectable operating modes. A propulsion control logic unit is electrically coupled respectively to the propulsion units.

The series-connected DC electric motors of the propulsion units are simultaneously controlled by the propulsion control logic unit to select a predetermined number of combinations of the modes of operation from the propulsion units, the predetermined number of combination modes available exceeding the number of modes available for any one of the propulsion units. The selected combination of modes approximates the propelling effort required to maintain the preselected vehicle speed.

The propulsion control logic unit could include acceleration- and deceleration-responsive devices, but for purposes of setting forth the most basic approach there need only be a mechanism that is responsive to change in velocity. Therefore, while velocity is the only parameter being measured, acceleration and deceleration inherently play a part in the selection of the combination modes of operation. The detection of the change in velocity results in the selection of a combination mode of operation closely approximating the propelling effort required to maintain the vehicle speed free from accelerating and decelerating effects.

Other objects and advantages of the present invention will become apparent from the ensuing description of illustrative embodiments thereof, in the course of which reference is had to the accompanying drawings in which:

FIG. 1 illustrates train propulsion curves typical of prior art single- or multi-train car operation.

FIG. 2 illustrates train or vehicular performance curves which result from the incorporation of the invention.

FIG. 2*a* illustrates a two-car arrangement, each car having five modes of operation, including coast.

FIG. 3 depicts a low speed portion of the train or vehicular performance curves shown in FIG. 2, as well as velocity error which arises during normal operation.

FIG. 4 sets forth in block diagram form a preferred embodiment of the invention.

FIGS. 5*a* and 5*b* represent a circuit diagram of the embodiment set forth in block diagram form in FIG. 4.

FIG. 5*c* depicts a portion of the performance curve selection logic in FIGS. 5*a* and 5*b*.

A description of the above embodiments will follow and then the novel features of the invention will be presented in the appended claims.

Reference is now made to FIG. 1 which illustrates train propulsion curves typical of prior art single or multitrain operation. This graph shown in FIG. 1 is of importance to the contribution to be described hereafter because it sets forth in graphic detail the mode and manner in which prior art train propulsion systems operated. As has been noted in the past, trains that operated in our rapid transit environments were limited to a group of train propulsion curves which were generally defined as being an "inching mode" of operation or "switching mode," a "low-speed" mode of operation, a "-medium-speed" operation, and a "high-speed" mode of operation.

Reference is now made specifically to FIG. 1 in which the curve **11** is a switching or inching curve. This curve is a train motor propulsion curve and, as one can see, as the velocity increases the tractive effort, which is measured on the ordinate axis, decreases as the velocity increases as it is shown on the abscissa. Accordingly, the vehicle may operate on this switching or inching curve for a few seconds of its initial operation when the train is starting to move from a zero velocity. It should be recognized that whenever trains of this type are employed, the operator of the train may only select a single discrete mode of operation. In other words, he may move a master controller lever, not depicted in the drawing, to a point which is indicative of low-speed operation. When this occurs the inching or switching mode of operation is automatically entered. In the alternative he may select a medium, or two higher speed modes of operation. Whenever this is done, the entire train and all the propulsion units in each of the cars on the train operate in exactly the same mode. In other words, all train cars connected one after the other are placed in the switching or inching mode as the vehicle starts its initial movement.

The second curve of significance here is the curve designated by the reference numeral **12** which is the low-speed propulsion curve. To the right of it appears the medium-speed propulsion curve **13**, as well as the high-speed propulsion curve **14**. As the legends indicate, when the inching mode of operation, or switching as it may be termed, is being accomplished, the motors on the respective cars are connected in series and, as is well known in the art, all external resistance is placed in series with the motors creating the speed-tractive effort curves shown in the figure. The curves that are depicted in FIG. 1 are typical of all train propulsion curves wherever there is a series motor employed and portions of the series resistance is shorted out in steps as the vehicle increases in speed. Therefore, it will be appreciated that if a train is commanded to enter into a low-speed mode of operation, which is defined by the train propulsion curve **12**, there will of necessity be certain mechanisms on the trains which will be activated to control the deletion of resistances in series with the motors. As these resistances are deleted, a family of train propulsion curves will be generated and these curves are shown as dotted lines in this figure as curves **18**, **19** and **21**. These may be termed incremental resistance curves and when the train throttle is positioned in a low-speed mode of operation, the train will automatically follow the path shown by the arrows which originate or curve **11**, which is the switching curve, and which arrows meet the incremental resistance curve **18**, and then after a brief moment of performance along this incremental resistance curve, determined by timing and/or a current limit relay, the next incremental resistance curve is approached as is indicated by the arrow which originates on the curve **18** and stops on curve **19**.

The deletion of resistances as a vehicle comes up to a speed of approximately 6 miles per hour is automatic, and when this speed is reached the vehicles operate on the low-speed propulsion curve **12**. This automatic deletion of resistance forms no part of the invention which will be described hereafter.

Once the vehicle has reached a speed, for example, of approximately 6 miles per hour, the train propulsion curve **12** is the curve which the vehicle's propulsion units will then follow. This assumes that the master controller, which is conventional, is in its proper position. This is true whenever two or more vehicles are employed and in actuality will also occur when a single vehicle is employed. This figure, though, is intended to convey the situation where at least two vehicles are employed, having two individual propulsion units.

Returning now to the description of the performance of these vehicles, once the low-speed propulsion curve **12** is reached the arrow **15** designates the direction which the train propulsion effort will follow. Accordingly, as speed increases, the vehicle's tractive effort will decrease until we reach, for example, a preselected speed of 15 miles per hour, as shown as point **20** on the curve **12**. At this point the operator of the vehicle, not desiring to exceed the 15 miles per hour, would move the throttle handle to its off or coast position and the tractive effort would drop to small negative tractive effort, as is indicated by point **24** at the tip of the arrow **25**. This small negative tractive effort is present because both train cars are in a coasting mode of operation and are experiencing slight dynamic braking. The negative tractive effort of dynamic braking is illustrated by the plurality of dynamic braking curves **16** shown interconnected by solid vertical lines.

If, as has been proposed in this suggested illustration, the operator of the train desires not to exceed 15 miles per hour, he would wait a period of time, and the train, because of train resistance and small dynamic braking effort, would begin to decelerate. The operator would then have to make a decision as to when to return to his low-speed propulsion effort, and this might be determined by a velocity error which he could note in a speedometer located in the cab of the train. Accordingly, should, as this figure illustrates, the speed drop to 11 miles per hour, the operator of the train would then put the throttle into its low-speed mode of operation, and as the arrow **23** indicates the tractive effort would return to a point on the curve **12** as shown by the arrow **23**.

With all the motors connected in series with all the external resistance removed, the train would follow the train propulsion curve **12** back down again to the point **20**, and at that point the operator would again turn the controller to its off position and the tractive effort would drop to the coast mode of operation, that is, point **24** on one of the dynamic braking curves **16**. It can therefore be seen that the vehicle, in order to maintain a constant speed of 15 miles per hour, would have to hunt over a velocity error which may well be as much as 3 or 4 miles per hour, and in so doing there must be a repeated application of low-speed propulsion effort to bring the vehicle back to the desired 15 miles per hour. It is this hunting action that provides the present discomfort experienced by passengers when the vehicle is suddenly accelerated in order to bring it back up to the desired speed.

Not mentioned up to this point is the presence of the curve **17** which is termed a train resistance curve, and which train resistance curve has been reduced to a formula referred to as the Davis formula. This formula appears below:

$$R=(1.3/w)++0.45V+(0.002AV2/Wn)$$

where:

R = train resistance in lb./ton

n = number of axles

A = in miles per hour

A=front area in square feet

W = wt./axle in tons

It can be appreciated from a review of this formula that the train resistance curve will be one in which the train resistance increases as the velocity increases. Of special importance to us here is the fact that this train resistance curve passes through the area enclosed by the arrows **25** and **23**, propulsion curve **12**, and dynamic braking curve **16**. It should be noted that there is no train propulsion curve which passes through the point **26** which is the point where the train propulsion effort, if it could match the train resistance, would exactly balance the load and therefore allow the train to remain at a constant velocity. It is to this problem that the invention to be described hereafter provides a solution in that by the incorporation of the invention there may be accomplished an almost perfect balance of tractive effort versus train resistance, and thereby provide an extremely smooth ride at a relatively constant velocity.

Before leaving FIG. **1**, mention should be made of the incremental resistance curves **22** at the top of this figure, which incremental resistance curves are automatically utilized as the train is brought up to its maximum speed, or its medium speed, in a manner which forms no part of this invention but is conventional in train propulsion systems now in use. To reiterate further the curve **13**, which is the medium-speed curve, employs two motors in parallel with full field and two motors in series, hereafter referred to as the series parallel mode. The high-speed propulsion curve **14** employs two motors in series, two motors in parallel, with series fields shunted, hereafter referred to as the series parallel with shunted field mode. These propulsion curves, of course, are typical of all series motors used in rapid transit today.

As noted earlier, FIG. **1** depicts a set of dynamic braking curves **16**, which curves reflect the variable nature of dynamic braking. The dynamic braking curves **16** enter the picture whenever the vehicles are in their coast mode of operation. The fact that this curve is shown as a stepped curve is due to the fact that the curve **16** is brought about by the automatic addition or deletion of resistance to the motor windings. The availability of this stepped curve plays a significant role in the invention to be described. Curve **16** has been shown as a stepped curve but in reality is made up of a plurality of curves which have been shown connected by vertical lines.

Reference is now made to FIG. **2**. This figure illustrates train or vehicular performance curves which result from the incorporation of the invention which is to be described more fully hereafter. FIG. **2***a*, which is positioned to the right of the graph of FIG. **2**, illustrates a two-car arrangement, and while not shown it is to be understood that each car has four propulsion modes of operation plus coast. The first of the five modes of operation which were illustrated in FIG. **1** is the coasting mode with both vehicles having their propulsion motors turned off, and this of course produces the dynamic braking mentioned with reference to FIG. **1**. The second mode is that of the switching or inching represented in FIG. **1**, as well as FIG. **2**, by the curve **11**. The third mode is the low-speed mode of operation represented by the curve **12** in both FIG. **1** and FIG. **2**. The fourth mode of operation is that of medium-speed operation depicted by the curve **13** in FIG. **1** and FIG. **2**, and the fifth mode of operation, of course, is that of the high-speed which is represented by the curve **14** in both FIG. **1** and FIG. **2**.

At this point it should be kept in mind that today rapid transit systems are limited to one of these five modes of operation unless some solid-state motor speed control has been added to give them an infinite variation of tractive effort over a given velocity change. But, as has been noted, this is expensive. Therefore, it is in this environment that applicant's invention emerges because there has been recognized that there are in fact more performance curves to operate on than previously recognized by anyone in the rapid transit art. This invention recognizes the fact that there are actually more train performance curves than there are train propulsion curves. In the past, because all propulsion motors were operated simultaneously on all vehicles of a train, the propulsion curves which were shown in FIG. **1** also became the train performance curves. But this invention recognizes the fact that aside from the train propulsion curves there are a host of other train performance curves which may and will appear when the propulsion motors of the various train cars are placed in different modes of operation. For example, a train propulsion curve **31** not present before will appear when the car X of FIG. **2***a* is in its switching mode of operation and the car Y is in a coast mode of operation and therefore applying a dynamic braking. We can see that the curve **31** intersects the ordinate at approximately half the tractive effort shown by the switching curve **11**. Accordingly, we now have a train performance curve heretofore not available.

In a similar fashion it will now be explained how all the dotted curves which appear in this figure are derived, keeping in mind that the dotted curves represent train performance as distinguished from propulsion effort. The solid lines of course are both train performance and train propulsion curves. When the car X is operated in a series mode and car Y is in its switching mode of operation, the curve **33** will represent the overall train performance that will result. Accordingly, when the car X is in series operation and the car Y is coasting, the train performance curve **32** will appear, and as may be seen this train performance curve **32** initially represents less than half the tractive effort that would appear were both cars X and Y in series operation. The effect of dynamic braking in the train car y causes this curve **32** to be less than half tractive effort when both cars X and Y were in the series mode of operation. Series operation is of course represented by the train propulsion and performance curve **12** shown above performance curve **33**.

Turning now to train performance curves **34**, **36** and **37**, train performance curve **34** will appear, for example, when car X is operated in series parallel and car Y is coasting. Train performance curve **36** will arise when car X is operated in series parallel and car Y is in switching mode or the inching mode of operation, as earlier noted. Train performance curve **37** will arise when the car X is operated in series parallel mode of operation and car Y is in series operation. As has been noted, the curve **13** is both a train performance curve as well as a train propulsion curve, and of course represents that situation where all the motors in car X, as well as the car Y, are operated in series parallel to two motors in series.

Turning now to the next family of train performance curves **38**, **39**, **41** and **42**. The train performance curve **38** will arise when car X and its motors are operated in series parallel with shunted field and car Y is coasting. The train performance curve **39** will come into being when car X and its motors are operated in series parallel with shunted filed and car Y is in the switching or inching mode of operation. In a similar fashion, train performance curve **41** will arise when car X and its motors are operated in series parallel with shunted field and car Y is operated in series. The last train performance curve that arises in this particular environment is train performance curve **42**, which curve **42** arises when car X has its motors operated in series parallel with shunted field and car Y is operated in series parallel. As has been noted, the curve **14** is both a train performance curve and a train propulsion curve arising when both car X and car Y and their motors are operated in series parallel with shunted field.

In view of the above discussion it should now be readily apparent that there are actually available a far greater number of train performance curves than heretofore recognized. In fact, we see in this particular embodiment a total of 14 train performance curves plus a 15th coasting curve not shown which may be contrasted to the five performance curves which were available in the prior art arrangements. This means that if there is provided a means to jump from curve to curve, as shown in FIG. **2**, the operator of such a train would then be able to select a train performance curve which most nearly approximated the tractive effort necessary to balance the train resistance as shown by train resistance curve **17**. This ability of course will allow the maintenance of a relatively constant

velocity free from the inherent necessity to apply large amounts of tractive effort to bring the train back up to speed once the train has slowed to some preselected velocity error. In fact, while this description has been directed to the situation where there are two cars X and Y employed, it must be recognized that any number of cars may be employed. As the number of cars is increased, the number of combinations of modes of train performance available will also increase. At this point it should also be understood that, while the description up to this point has been of typical train cars having four propulsion motors, it is intended that the four propulsion motors of each car be recognized basically as a propulsion unit, having different modes of operation.

The invention, of course, is not to be limited to the situation where there are only four propulsion motors employed, but is to be extended to wherever there is a propulsion unit or motor which has more than one mode of operation. Therefore, all descriptive material hereafter will refer to the propulsion motors as a unit and reference will be made to the different modes of operation of the propulsion units rather than going into the detail of noting that these propulsion units have in this preferred embodiment a number of separate propulsion motors within the propulsion motor units.

The number of propulsion combination modes may be expressed in the formula that appears below:

$$\text{number of propulsion combination modes} = \frac{(n+1)(n+2)\cdots(n+[m-1])}{(m-1)!}$$

where

$n \geq 2$; $m \geq 2$; n and m are integers

n = the number of propulsion units

m = the number of propulsion modes per unit

As may well be appreciated from the recent study of FIG. 2 and FIG. 2*a*, there is the presence of a multiple of train performance curves that may be utilized in the operation of a train. FIGS. 4, 5*a*, and 5*b* are directed to a system which will function in a manner to select the appropriate curves to optimize train performance. For purposes of illustrating the invention, only the curves 31, 11, 32, 33 and 12, shown in FIG. 2, will be treated as it is quite apparent that the invention when explained in this environment will make obvious the added structures and circuits that would be necessary to cover the full range of 15 available train performance curves that are established by the incorporation of this invention. Accordingly, all discussion hereafter will be directed to a system which is functioning between the curve 31 and the curve 12 shown in FIG. 2.

With specific reference to FIG. 3, only the five above-noted curves have been illustrated along with dynamic braking curve 16. It is in the environment of FIG. 3 where the train performance curve selection will take place and to which the description of FIGS. 4, 5*a*, and 5*b* is tied for purposes of functional operation.

Reference now is made specifically to FIG. 3 which illustrates the train propulsion performance curves of a train having at least two propulsion units where each propulsion unit is considered to have only three modes of operation. The first is the coasting mode which is represented by the stepped curve 16. The second is depicted by the curve 11, which has been termed the switching curve, and the third mode of operation is the series operation train propulsion curve 12. From combinations of these three modes of operation, as has been pointed out earlier, the curves 31, 32 and 33 may be generated. Superimposed on FIG. 3 are two additional curves not shown in FIG. 2. These curves are train resistance curves 17*a* and 17*b*. It will be noted that these curves appear in a relatively parallel relationship to train resistance curve 17, and it is intended that these curves 17*a* and 17*b* represent different grades upon which the vehicles are operating. Accordingly, the train resistance curve moves upward toward 17*a* when an up grade is being approached, and this train resistance curve would fall below curve 17 should the train be moving on a downgrade. Curve 17*b* reflects the change in position of the train resistance curve should the train approach a downgrade.

Before entering a discussion of the meaning of the curves of FIG. 3, it would be well to point out in advance the desired pattern of train operation that is to be explained by this series of curves. Here, for example, if a selected speed of 15 miles an hour were preselected, then it would be desirable for the train to start from zero or standing position and move at the maximum rate of acceleration possible up until approximately 15 miles per hour. In order to prevent overshooting the 15-mile-per-hour mark and reaching an overspeed condition which would require the application of brakes, it has been arbitrarily selected to reduce the tractive effort applied when the train is approximately 1 mile below the set or desired speed of 15 miles an hour. This hopefully would in some situations, depending on the grade, allow the train to come up to the set speed and the propulsion effort would just balance the train resistance force and the desired speed of 15 miles per hour would be maintained. But this is a rare situation and more than likely will be only infrequently encountered. Once the speed of 15 miles per hour is reached it is, of course, important to automatically reduce the tractive effort to zero and then start what will be described as a search of the existing train propulsion and performance curves for a curve which nearly matches the train resistance at the given velocity. Once this matching is accomplished the train will then stay on the train performance curve which most closely approximates the tractive effort necessary to maintain the speed of the vehicle close to the set speed desired, in this case 15 miles per hour.

With this thought in mind attention is directed to FIG. 3. When the train starts from zero, the tractive effort presented to the wheels is represented by the train performance curve 11. The vehicle would then, in its operation, move down along the curve 11, which is called the inching curve, to a point where the arrow 27 interrupts this curve. At this point, due to the change in velocity, there would be an automatic subtraction of resistance from the propulsion units causing the motors to move to the new incremental resistance curve 18, and then after a suitable change in velocity there would be another shift, as indicated by the arrow 28 to the incremental resistance curve 19, and again on change in velocity another shift to a higher curve 21, as indicated by the arrow 29. Finally in the last step, with the train operating along the curve indicated by reference numeral 21, the train would then shift onto the train performance curve 12, as indicated by the arrow 30. The train then would proceed down along the train performance curve 12 to a point 61, which point 61 can be seen to be directly above the 14-mile-per-hour indication shown on the abscissa. At that point the train would reduce its tractive effort by one-half. This would be accomplished by maintaining the first car in series operation and permitting the second car to coast. This would cause the tractive effort at this point to drop, as shown by the arrow that starts at point 61 and goes down to the curve 32 of point 61*a*. If the train resistance is represented by curve 17, the train operating point would move to the left along curve 32 to point 60 where a balance point is reached. If the train resistance is less, the train will continue to accelerate to the point 62 along the curve 32, at which point 62 the set speed having been reached the tractive effort would drop to coast, i.e., minimum dynamic brake, which is at point 63 on curve 16. It is apparent that with the tractive effort negative and the train resistance curve 17 positioned where it is, the load on the train and its inherent resistance will result in the train decelerating.

As the train decelerates the curve selection process will take place. This curve selection process has been arbitrarily selected in this figure to depict the utilization of all the curves available, but it should be recognized that not all curves need necessarily be employed, and the description that will follow now coupled with the description of FIGS. 4, 5*a*, and 5*b* is not in any way intended to be limited by the specific following of each available train performance curve that may exist. For as a practical matter there may be a decision made which causes

the selection of only a few of the available curves to produce the desired balancing of the train resistance versus tractive effort to maintain a speed.

Going on now with the description of the selection of different train performance curves, it will be seen that when the vehicle has reached its set speed of 15 miles per hour or zero velocity error, then upon the outset of deceleration the train propulsion control logic, to be explained hereafter, will select curve **31** and the point **64** thereon will be the starting point. The train will then decelerate along curve **31** until it reaches a velocity error of −1 mile per hour. This error is shown as point **65** on curve **31**. At this velocity error the train will continue to decelerate due to the fact that the train resistance curve **17** is greater than the tractive effort provided by the propulsion effort afforded by the train operating on train performance curve **31**. The train propulsion control logic would then select train propulsion curve **11**, and as the arrow indicates there would be a move to curve **11** and point **66** thereon, whereupon the curve **11** would be followed back to point **67** which is representative of a −2-mile-per-hour velocity error. Here again since the tractive effort is insufficient to balance the train resistance as represented by curve **17**, a continued deceleration would be experienced and to cope with this the train propulsion control logic would select train performance curve **32**, and as the arrow indicates there would be a move from point **67** on curve **11** to point **68** on curve **32**. Here it will be noted for the first time that at point **68** on curve **32** the tractive effort available is greater than the train resistance as shown by curve **17**. Accordingly, the train will begin to accelerate and the train will follow train performance curve **32** from point **68**, as indicated by the arrow down to point **60** where the tractive effort will just balance the train resistance. If the grade remains constant, the train will proceed at a constant speed with just slightly more than 1-mile-per-hour velocity error. It should be understood that while the set speed of 15 miles per hour is desirable, it is permissible to have errors on the order of 1 or 2 miles per hour. These errors are quite acceptable as long as the train maintains the given error without significant variation in velocity.

There is a further feature that should be recognized at this point and that is, as shown in this figure, there is superimposed on this graph two additional curves **55**, **56** which are reality portions of curves. These curves **55** and **56** are meant to reflect the fact that when a train is operating on the train performance curve **32**, the second car in a two-car combination will be coasting. With a car coasting the propulsion motors are operating in a dynamic braking manner as these motors are driven in generator fashion. At this point it should be understood that when a car is in a coast operation, the dynamic braking that takes place varies depending upon the velocity and the amount of resistance being switched automatically into the motor winding arrangement to prevent overloading due to the generator action. Accordingly, the coasting car presents a varying dynamic force which varies as a function of the train speed or as a result of the resistance being added or subtracted. It is this varying loading effect of the coasting car which is intended to be conveyed by the curves **55** and **56**, which in effect are added to the train resistance at that given velocity. In other words, since the second car is dynamically braking at increasing or decreasing amounts, depending upon the resistance being provided by the dynamic braking, the curve **17** will actually experience a fluctuation which will move in a range defined by the curves **55** and **56**, and by so doing it will cause the overall train operation to float back and forth across the train resistance curve **17** and provide a dynamically fluctuating situation in which the tractive effort will continuously balance the train resistance load required to maintain the train at any given speed with a minimum of acceleration and deceleration.

Returning now to the system operation and a further study of the curves of FIG. **3**. While the discussion up to this point has been directed to that situation where the train resistance curve **17** has been principally considered, it should be recalled that curves **17***a* and **17***b* also show train resistance curves that reflect respectively the tractive effort necessary when a train is on an upgrade and a downgrade.

In the functional description of a train coming up to a set speed of 15 miles per hour with train resistance curve **17** in mind no mention was made of train resistance curve **17***b*. Should train resistance curve **17***b* have been the curve under consideration, then the train would have proceeded, functionally speaking that is, to hunt over the performance loop defined by the points **62**, **64**, **65**, **66**, **67**, and **68**. It should be noted that this is a very small loop in comparison to the prior art loop shown in FIG. **1** and defined therein by point **20**, line **25**, point **24**, line **23**, and curve **12**.

Returning now to an expanded discussion of FIG. **3** and particularly the selection and operation on the remaining performance curves. In the event that the train resistance curve was even higher than curve **17***a*, namely, above the point **71** on curve **33** and below the point **61** on curve **12**, then when the train would be experiencing a continued deceleration at point **68** on curve **32**, the train would continue on train performance curve **32** until it reached point **69**. At point **69** there would be a velocity error of −3 miles per hour and the propulsion control logic would select train performance curve **33** and the operation of the train would move from point **69** on curve **32** to point **70** on curve **33**. Here again the tractive effort provided by the train operating on performance curve **33** would be insufficient to overcome the train's resistance and deceleration would continue from the point **70** to the point **71** on curve **33**, at which point there would be a velocity error of −4 miles per hour and performance curve **12** would be selected by the train propulsion control logic. Accordingly, there would be a move from point **71** on curve **33** to point **76** on curve **12**. There would the be sufficient tractive effort to overcome the train's resistance and there would be a halt to the deceleration. The train would then accelerate up to the point **61** on curve **12**, at which point the velocity error would be −1 mile per hour and, as noted earlier, the train propulsion control logic would select train performance curve **32** and move from point **61** to point **61***a*. The train would then hunt over the loop defined by points **61**, **61***a*, **68**, **69**, **70**, **71**, and **76**. As was noted earlier, the selection of the train performance curves has been an arbitrary one intended only to be an example and not a limiting embodiment of the invention. In addition the selected train performance of FIG. **3** has been tailored to the circuits and apparatus described in FIGS. **4**, **5***a* and **5***b*.

Reference is now made to FIG. **4** which illustrates a preferred embodiment of the invention in block diagram form. In this preferred embodiment and the one depicted in FIGS. **5***a* and **5***b*, only three modes of operation are considered to be present in the propulsion motors depicted in order that the curves set forth in FIG. **3**, which show the capability of moving from train performance curve to train performance curve, be employed to point out how the invention may be readily involved in any multipropulsion unit system. Specifically, FIG. **4** shows a car X and a car Y having respectively propulsion units **81** and **82**. The cars X and Y travel along rails **83** and **84** and receive power for their propulsion units from third rail **86**, via, respectively, contact **87** and lead **88**, which enters the unit called the performance curve selection logic, and by contact **91** via lead **92**, which also enters the performance curve selection logic **80**, which performance curve selection will be described more fully hereafter.

There is shown entering the performance curve selection logic **80** the three lines from propulsion unit **81**; they are the leads **167**, **170** and **172**, while to the left of the performance curve selection logic **80** there are three lines from propulsion unit **82** which are leads **174**, **177** and **178**.

There has been designated by the legend to the left of the dotted outline portion the title "Propulsion Control Logic," also referred to by numeral **95**. This propulsion control logic **95** includes, immediately beneath the propulsion unit **81** and shown in schematic form, a train speed tachometer **98** which has a driving connecting link, shown by dotted line **97**, conn-

nected to a wheel **96** of a train. This rotating input **97**, or driving link, will provide the train speed tachometer **98** with a rotary input that will be converted into a DC output which is a conventional output for this type of tachometer. The DC output will appear on lead **99**, and have a direct relationship to the velocity at which the train cars are traveling. Immediately beneath the train speed tachometer, and also a portion of the propulsion control logic **95**, is a train speed command control **100**. It will be seen in this block **100** that there are a number of circular-shaped buttons designated by their markings 10, 15, 20, 25, 30 and 35 miles per hour. In operation this train speed command control unit **100** would be normally located in the lead vehicle, in this case car X, and the selected speed would be made by pushing one of the buttons just noted which would produce an output on one of the leads **104**, **105**, **106**, **107**, **108**, **109**, which in turn would be delivered to the actual speed versus the command speed comparator **101**, which has, as has been noted, the lead **99** from the train speed tachometer **98** entering on the right-hand side of this comparator **101**.

The output signal which would appear from this conventional voltage comparator would be a DC signal indicative of the velocity error as a measure of the difference in voltage that exists between the train speed commanded and the actual speed at which the train is moving as has been measured by the train speed tachometer **98**. This DC signal will be delivered over the electrical lead **111** to a velocity error detection network **110**. This velocity error detection network will, depending upon the velocity error, provide an output on one of the leads **112***a* through **112***f* which will in turn be delivered to the performance curve selection logic **80**, which, as was noted with reference to FIG. **3**, will cause, depending upon the velocity error present, a selection of a train performance curve that ultimately will balance the train resistance with a tractive effort sufficient to maintain a constant velocity, or cycle between selected modes to maintain the average speed.

Reference is now made to FIGS. **5***a*, **5***b*, and **5***c*, which will be studied in conjunction with FIG. **3**, previously discussed. FIGS. **5***a* and **5***b* contain a circuit illustration of one embodiment of the invention which sets forth the manner in which the train performance curves noted earlier may be selected as the train moves in a dynamic fashion up to a preselected speed. Shown in the upper right-hand corner of FIG. **5***b* is the train with cars X and Y having propulsion units **81** and **82**, respectively. The train is traveling on rails **83** and **84** and receiving power from a third rail **86**, over contacts **87** and **91**. In the case of propulsion unit **81**, the power delivered from the contact **87** is delivered via the leads **88**, **90**, **165**, over a front contact *a* of relay **R10**, to the line **167** to place propulsion unit **81** in one mode of operation, referred to hereafter as Mode I of propulsion unit **81**. Thus whenever front contact *a* relay **R10** is closed, propulsion unit **81** will be in Mode I. In a similar fashion power is delivered to propulsion unit **82** by the leads **88**, **168**, over front contact *a* of relay **R11**, line **170** to provide a second mode of operation for propulsion unit **81**, referred to hereafter as Mode II of propulsion unit **81**. Thus whenever front contact *a* of relay **R11** is closed, propulsion unit **81** will be in Mode II. In a still similar fashion power is delivered to the propulsion unit **81** via leads **88**, **90**, **171**, over front contact *a* of relay **R12**, to the line **172** to provide a third mode of operation for propulsion unit **81** referred to hereafter as Mode III of propulsion unit **81**. Thus whenever front contact *a* of relay **R12** is closed, propulsion unit **81** will be in Mode III.

In case of propulsion unit **82**, the power delivered from the third rail **86** through contact **91** is delivered via leads **92**, **94**, **173**, over front contact *a* of relay **R13** to the line **174** to provide one mode of operation for propulsion unit **82**, referred to hereafter as Mode I of propulsion unit **82**. Thus whenever front contact *a* of relay **R13** is closed, propulsion unit **82** will be in its Mode I. In a similar fashion power is delivered over leads **92**, **94**, **175**, over front contact *a* of relay **R14**, to the line **177** of propulsion unit **82** to provide a second mode of operation for propulsion unit **82**, referred to hereafter as Mode II of propulsion unit **82**. Thus whenever front contact *a* of relay **R14** is closed, propulsion unit **82** will be in its operational Mode II. In a still similar fashion power is delivered to propulsion unit **82** via the leads **92**, **96**, front contact *a* of relay **R15** to the line **178** of propulsion unit **82** to provide a third mode of operation for propulsion unit **82**, referred to hereafter as Mode III of propulsion unit **82**. Thus whenever front contact *a* of relay **R15** is closed, propulsion unit **82** will be in its Mode III.

As has been noted, propulsion units **81** and **82** will provide cars X and Y with levels of tractive effort corresponding to the train propulsion curves of FIG. **3**, depending on what lines of the respective propulsion units have power delivered to them. The circuitry of propulsion units **81** and **82** is such that in order for either unit to produce its highest tractive effort output both Modes I and II and not Mode III must be employed. This highest tractive effort output is called the series mode of car X or car Y in this embodiment, and car X will be in its series mode whenever front contacts *a* of relays **R10** and **R11** are closed, while car Y will be in its series mode whenever front contacts *a* of relays **R13** and **R14** are closed. Further, if Mode II of propulsion unit **81** or **82** is in effect, while Modes I and III of propulsion unit **81** or **82** are not, the propulsion unit **81** or **82** produces its next higher tractive effort output called the "switch mode of car X or car Y" in this embodiment. Still further, if Mode III of propulsion unit **81** or **82** is in effect, and Modes I and II are not, the propulsion unit **81** or **82** produces its next higher tractive effort output called "the coast mode of car X or car Y," in this embodiment. It should be understood that more or less respective tractive effort outputs of cars X and Y may be employed by additional circuitry, but for the purposes of simplified explanation of the instant invention only the three modes of the respective cars will be employed. It should also be understood that different combinations between modes of car X and modes of car Y will cause the train performance to correspond to different propulsion curves as set forth in FIG. **3**.

Attention will now be particularly focused on FIG. **5***c* which depicts a portion of the performance curve selection logic **80**. As shown, Mode I operation occurs when relay **R10** located in car X has been energized by signals appearing on either lead **129**, **134**, or **144** or any combination thereof. Accordingly, when a signal is present on lead **129** a path is completed through lead **129**, lead **130**, diode **131**, lead **132**, lead **133**, relay **R10** to the N battery terminal, thus energizing relay **R10**. Alternative energization paths for relay **R10** are through lead **134**, diode **135**, leads **136**, **136***a* lead **133**, relay **R10** to battery N, and also via lead **144**, lead **145**, diode **146**, lead **147**, lead **133**, relay **R10**, to battery terminal N.

Mode II of propulsion unit **81** on car X will be attained by the energization of Mode II relay **R11**. Relay **R11** may be energized due to signals being present on lead **148** or lead **152**, or both. Accordingly, with signals present on lead **148** there will be a path through lead **148**, lead **149**, diode **150**, lead **149***b* lead **151**, relay **R11**, to battery terminal N. This will energize relay **R11**. Another signal exists on a path through lead **152**, diode **153**, lead **154**, lead **151**, relay **R11**, to battery terminal N and this will also energize relay **R11**. As shown by the bracket **166** in FIG. **5***c*, simultaneous energization or relays **R10** and **R11**, i.e., the Mode I and Mode II relay of propulsion unit **81**, will produce the series mode of operation in car X, while the energization of relay **R11** only as indicated by bracket **166***a* will produce the switch mode of operation in car X.

Mode III of propulsion unit **81** on car X will be attained by the energization of Mode III of relay **R12**. Relay **R12** is energized whenever a signal is present on lead **152***a*, thus completing path through lead **152***a*, relay **R12**, to the N battery terminal which thereby energizes relay **R12**. As indicated by the bracket **166***b*, the exclusive energization of relay **R12** will provide the coast mode of operation for car X.

Turning now to car Y it will be seen that the Mode I relay **R13** of car Y will be energized whenever a signal appears on the lead **129**, resulting in a completed path through lead **129**,

lead 130*a*, relay R13, to the N battery terminal, thereby energizing relay R13.

Mode II of propulsion unit 82 of car Y will be attained upon the energization of Mode II relay R14 of car Y. Relay R14 will be energized under a number of conditions now to be described, for example, whenever a signal appears on lead 134 or 148, as long as front contact *a* of relay R16 is in the position shown in FIG. 5*c*, which occurs whenever relay R16 is deenergized, or in the alternative when a signal is present on lead 129 or there is a signal present on any or all of leads 134, 148, and 129, as previously noted. Accordingly, when a signal is present on lead 134, a path is completed through lead 134, diode 135, lead 136, lead 136*b*, diode 155, lead 156, lead 157, relay R14, to the N battery terminal which will energize relay R14. Likewise, assuming that relay R16 is deenergized, now a path can be completed with a signal present on lead 148 from lead 148 through lead 149*a*, front contact *a* of relay R16, lead 149*b*, diode 158, lead 159, lead 157, relay R14, to the N battery terminal which will result in the energization of relay R14. Relay R14 may also be energized in conjunction with the energization of relay R13, i.e., with a signal present on lead 129 a path is completed from lead 129, through lead 130*a*, relay R13, to the N battery terminal which will energize relay R13, thereby closing front contact *b* of relay R13. With front contact *b* of relay R13 closed, a path is completed from the B battery terminal over front contact *b* of relay R13, lead 160, diode 161, lead 162, lead 157, relay R14, to the N battery terminal, thereby energizing relay R14. As shown in FIG. 5*c*, the simultaneous energization of relays R13 and R14 will produce the series mode of operation in car Y, as is designated by the bracket with the legend "Series" alongside thereof, while exclusive energization of relay R14 will produce the switch mode of operation in car Y, as is designated by the legend "Switch" alongside thereof.

Mode III of propulsion unit 82 on car Y which is a coast mode will be attained whenever relays R13 and R14 are deenergized. When relays R13 and R14 are deenergized, back contacts *c* of relay R13 and *b* of relay R14 will be in the positions shown in FIG. 5*c* and thus a circuit will be completed from the B battery terminal over back contact *c* of relay R13, lead 163, back contact *b* of relay R14, lead 164, relay R15, to the N battery terminal, thereby energizing relay R15 and producing the coast mode of operation in car Y, as is designated by the bracket with the legend "Coast" alongside thereof.

Returning now to FIG. 5*b*, and summarizing the functional results that will occur in the system illustrated when the circuits of FIG. 5*c* operate in the manner just described, the following will be seen:

1. Energization of relay R10 will cause front contact *a* of relay R10 to close, thus completing a circuit which places propulsion unit 81 of car X in its first mode of operation.

2. Energization of relay R11 will cause front contact *a* of relay R11 to close, thus completing a circuit which places propulsion unit 81 of car X in its second mode of operation.

3. The simultaneous energization of relays R10 and R11 will place the propulsion unit 81 of car X in its series mode of operation.

4. Exclusive energization or relay R11 will place propulsion unit 81 of car X in its switch mode of operation.

5. Energization of relay R12 will cause front contact *a* of relay R12 to close, thus completing a circuit which places propulsion unit 81 in its third mode of operation and car X in its coast mode of operation.

6. Similar results are achieved for car Y by substituting into the above statements relays R13, R14, and R15, respectively, for relays R10, R11, and R12, propulsion unit 82 for propulsion unit 81, and car Y for car X.

Looking now to FIG. 5*a*, it will be seen that the velocity error detection network 110 contains a plurality of voltage level detectors to be referred to hereafter as velocity error sensors which in actual practice might consist of a voltage-dividing network. The velocity error sensors 113 through 118 are designed such that when a signal appears on the lead 111 and is delivered to the velocity error sensors 113, 114, 115, 116, 117, and 118, they will pass a signal to the leads 112*a* through 112*f*, if and only if the velocity error signal present on lead 111 is greater than the error designated by the respective error sensors. It can be seen that the velocity error detection network 110 has provision for determining when there is velocity error of −4 miles per hour, −3 miles per hour, −2 miles per hour, −1 mile per hour to zero miles per hour error, which is the set speed, and finally a +½-mile-per-hour error, which is the overspeed condition requiring braking.

SYSTEM OPERATION

Considering FIGS. 5*a*, 5*b*, and the system's functional operation set forth in FIG. 3, let us assume that a desired velocity for the train including cars X and Y is 15 miles per hour, in order to better understand the circuitry set forth within the propulsion control logic 95. At this point in the description it is again reiterated that selection of a 15-mile-per-hour set speed is intended only to be illustrative of the function of one embodiment of the invention. Accordingly, the 15-mile-per-hour button 103 of train speed command control unit 100 is pushed and a circuit is completed from a battery terminal B, to the contacts of the button 103 and the lead 105 to the actual speed versus command speed comparator 101. It should be noted at this time that each of the contacts for the set speeds of 10, 15, 20, 25, 30 and 35 miles per hour has respectively electrical connections to the actual speed versus command speed comparator 101 which are leads 104, 105, 106, 107, 108, and 109. Hence, assuming a speed of 15 miles per hour is desired, a signal indicative of the desired speed of 15 per hour is present on lead 105 and is delivered to the actual speed versus command speed comparator 101 along with the signal on lead 99 from train speed tachometer 98 indicative of train velocity which we will consider to be initially zero miles per hour. Accordingly, a signal will appear on output lead 111 of the actual speed versus command speed comparator 101 indicative of a −15-mile-per-hour speed error and the velocity error signal will be delivered to the velocity error detection network 110. Since this −15-mile-per-hour speed error is less, i.e., more negative than any of the speed errors shown by velocity error sensors 113 through 118, all of the velocity error sensors 113 through 118 will pass a signal to leads 112*a* through 112*f*. Accordingly, all the relays R1 through R6 will be energized via circuits from leads 112*a* through 112*f*, respectively, through relays R1 through R6, respectively, to N battery terminals. The energization of relays R1 through R6 will cause the respective front contacts *a* of relays R1 through R6 to be pulled down completing several circuits and interrupting several circuits all of which will now be explained.

The pulling down of contact *a* of relay R1 will cause a circuit to be completed from the B battery terminal, over front contact *a* of relay R1, leads 121, diode 122, lead 123, lead 124, relay R8 to the N battery terminal, thereby energizing relay R8 and closing front contacts *a* and *b* of relay R8. It will be noted that due to the energization of relay R4, front contact *b* of relay R4, is also closed. Hence, a holding circuit for relay R8 is completed from the B battery terminal, over front contact *b* of relay R4, lead 128, front contact *a* of relay R8, lead 127, diode 126, lead 125, lead 124, relay R8, to the N battery terminal. Since front contact *b* of relay R8 is also closed, lead 129 will be energized via the B battery terminal over front contact *b* of relay R8 as long as relay R8 is held energized which is until relay R4 becomes deenergized, due to the holding action just noted.

The pulling down of front contact *a* of relay R2 will cause the energization of lead 134 from the B battery terminal over front contact *a* of relay R2. It should be noted that the functional effect on the system of energizing lead 134 has been discussed earlier with reference to FIG. 5*c*.

The pulling down of front contact *a* of relay R3 will cause a circuit to be completed from the B battery terminal over front contact *a* of relay R3, lead 137, diode 138, lead 139, lead 140, relay R9, to the N battery terminal, thereby energizing relay R9 and closing front contacts *a* and *b* of relay R9. It will be noted that front contact *b* of relay R5 is closed due to the prior noted energization of relay R5. Hence, a holding circuit for relay R9 is completed from the B battery terminal over front contact *b* of relay R5, lead 143, front contact *a* of relay R9, diode 142, lead 141, lead 140, relay R9 to the N battery terminal. Since front contact *b* of relay R9 is closed, lead 144 will be energized via the B battery terminal over front contact *b* of relay R9 as long as relay R9 is held energized which is until relay R5 becomes deenergized. Here again it should be noted that the functional effect on the system of energizing lead 134 has been discussed earlier with reference to FIG. 5*c*.

The pulling down of front contact *a* of relay R4 causes the lead 148 to be energized via the B battery terminal over front contact *a* of relay R4. Once again reference is made to FIG. 5*c* and the description pertaining to the functional effect on the system when lead 148 is energized.

The pulling down of front contact *a* of relay R5 causes lead 152 to be energized via the B battery terminal over the front contact *a* of relay R5 to lead 152. It will be noted that lead 152*a* is deenergized, thereby deenergizing Mode III relay R12, which relay is employed in the coast mode of operation for the propulsion unit 81 of car X.

The pulling down of front contact *a* of relay R6 will cause lead 155 to be deenergized, thereby ensuring the deenergization of brake actuation relay BR.

In summary, with a speed error of less than −4 miles per hour, namely, −15 miles per hour, leads 129, 134, 144, 148, and 152 are energized which results in series operation as it may be termed for both propulsion units 81, 82 of cars X and Y, respectively. Simultaneously, leads 152*a*, 163, 164 and 155 are deenergized which results, respectively, in coast Mode III relay R12, coast Mode III relay R15, and brake relay BR being deenergized.

Accordingly, since leads 129, 134 and 144 are energized, so is relay R10, and since leads 148 and 152 are energized, so is relay R11. Hence, as was before noted, propulsion unit 81 has both Modes I and II in operation, Mode III not being in operation due to the deenergization of lead 152*a*, and car X is in its series mode of operation. Furthermore, since lead 129 is energized, so is relay R13 and as a result so is lead 160, and since leads 129, 148 and 160 are energized, so is relay R14. Hence, as was noted previously, propulsion unit 82 has both its Modes I and II in operation, Mode III not being in operation due to the opening of back contact *c* of relay R13 and back contact *b* of relay R14, and car Y is in its series mode of operation. Since both cars X and Y are in their series modes of operation they provide a combined tractive effort which is reflected by the train propulsion and performance curve 12 of FIG. 3.

A study of FIG. 3 will reveal that once the cars X and Y of the train are commanded into their series modes of operation, the automatic nature of the existing train propulsion units or motors comes into effect and the train initially will attempt to follow the performance curve 11, which is the switching curve. A change in velocity will automatically cause the incremental addition or subtraction of resistances to the windings of the propulsion units 81, 82 to allow, as has been described earlier, the vehicle to move at a maximum accelerating rate up to the curve 12. Once the vehicle has automatically removed these resistances to the point where all incremental resistances have been removed, the train must then follow the train performance curve 12. Therefore, the train will continue to accelerate as the tractive effort presented by the train performance curve 12 is greater than the train resistance as illustrated by the train resistance curve 17. The train's velocity, accordingly, will increase toward the set speed of 15 miles per hour and follow the curve 12 downwardly past the point 76 on the curve, and, as has been noted in the description of FIG. 3, when the point 61 is reached on the curve 12, the arbitrarily selected speed of a −1-mile-per-hour velocity error will cause the total tractive effort of the train's cars X and Y to be reduced by approximately one-half. The car X will be operating in its series mode, while the car Y will be operating in its coast mode, and therefore car Y will be supplying some dynamic braking. Before this can happen several observations must be made by once again referring to FIGS. 5*a* and 5*b* in conjunction with FIG. 3. When the tractive effort of the vehicle is at point 76 of performance curve 12 in FIG. 3, it can be seen that there is a velocity error of −4 miles per hour, an error equal to that indicated by velocity error sensor 113, and as we pass the velocity error of −4 miles per hour we will want the train to maintain series operation of cars X and Y until a velocity error of −1 mile per hour is present. Accordingly, when the velocity error of −4 miles per hour is reached, velocity error 113 no longer passes a signal and relay R1 will be deenergized, opening front contact *a* of relay R1. However, it will be remembered that relay R8 still is energized (since relay R4 is still energized), and therefore the lead 129 is still energized, maintaining the energization of relay R10. Also, leads 134, 144, 148, and 152 are still energized, while leads 152*a* and 155 are still deenergized. Hence, since there is not effective change in energization of leads essential that both car X and car Y remain in their series modes of operation, the train will still follow train performance curve 12.

When a velocity error of −3 miles per hour is reached, velocity error sensor 114 no longer passes a signal and relay R2 will be deenergized, thus deenergizing lead 134. Leads 129 and 144 remain energized; relay R10 remains energized as does relay R13. Since, also, leads 148, 152 and 160 are energized, relay R11 remains energized as well as relay R14. Hence the train is still following train performance curve 12 since both cars X and Y remain in their series modes of operation.

Again, when a velocity error of −2 miles per hour is detected by the velocity error detection network 110, specifically by the error sensor 115, the error sensor 115 will no longer pass a signal, and hence relay R3 will be deenergized opening front contact *a* of relay R3, but since relay R9 remains energized (because relay R5 is still energized) lead 144 remains energized. Once again, no effective change in essential lead energization required for series operation has occurred and both cars X and Y remain in their series modes of operation and the train still follows train performance curve 12 of FIG. 3.

It can, therefore, be seen that as the train's velocity error approaches the −1-mile-per-hour error noted earlier, both cars X and Y will maintain their series modes of operation, and the continuity required to provide this train performance is established by the circuits just described.

Accordingly, when a velocity error of −1 mile per hour is reached, i.e., point 61 on train performance curve 12, velocity error sensor 116 will no longer pass a signal, and hence relay R4 is deenergized opening front contacts *a* and *b* of relay R4, thereby deenergizing relay R8, which results in the deenergization of the leads 129 and 148. It will also be recalled that lead 134 had been deenergized when the velocity error passed −3 miles per hour and was heading toward a velocity error of −2 miles per hour. Since lead 144 remains energized (because relay R5 is still energized) relay R10 will remain energized and since lead 152 remains energized, so will relay R11. Hence, car X is still in its series mode of operation. But because lead 129 is no longer energized, relay R13 is no longer energized and contact *c* of relay R13 will make contact with lead 163 while contact *b* of relay R13 opens. Since neither of leads 134, 148, or 160 is energized, relay R14 will become deenergized and contact *b* of relay R14 will make contact with lead 164. Hence, a circuit is completed from the B battery terminal over contact *c* of relay R13, lead 163, contact *b* of relay R14, lead 164, relay R15, to the N battery terminal, thereby energizing relay R15 and, as previously noted, placing car Y in its coast mode of operation. Now, car X is in its series mode of operation, while car Y is in its coast mode of operation and the trac-

tive effort of the train is decreased approximately one-half so that the train will begin to follow train performance curve **32** at point **61***a* which indicates a −1 mile per hour velocity error.

The train now continues to accelerate to the zero velocity error, or set speed, corresponding to a point **62** on train performance curve **32**, This, of course, presumes that the tractive effort afforded by the curve **32** exceeds the train resistance which is represented by the family of curves **17**, **17***a* and **17***b*. It should be kept in mind that the curves **17**, **17***a* and **17***b* are dynamically fluctuating in their movement as grade and wind forces act upon the train.

For purposes of illustration only the description that will ensue will assume for a brief moment that at this point in the description the inertia of the train as well as the effects of grade and wind are such that the train will approach set speed at a slower rate; but that set speed will be reached. Accordingly, when a zero velocity error is attained, velocity error sensor **117** will no longer pass a signal and relay **R5** will be deenergized. The deenergization of relay **R5** causes front contact *a* of relay **R5** to be pulled up and make contact with the lead **152***a*. Thus, a circuit is completed from the B battery terminal over front contact *a* of relay **R5**, lead **152***a*, relay **R12**, to the N battery terminal, thereby energizing relay **R12** which is the Mode III relay of car X and provides the coast function for propulsion motor **81** of car X. The deenergization of relay **R5** also causes front contact *b* of relay **R5** to open, thereby deenergizing relay **R9** and opening front contact *b* of relay **R9**. The opening of front contact *b* of relay **R9** causes the deenergization of lead **144**. Hence, leads **129**, **134**, **144**, **!148**, **152**, and **155** are deenergized, and lead **152***a* is energized. Car X is now in its coast mode of operation. No effective change has occurred in car Y's operation, so car Y remains in its coast mode of operation. With both cars X and Y in their coast modes of operation a dynamic braking effect will occur as well as the decelerating effects due to train inertia. The train will now begin to follow the dynamic braking curve **16** at point **63**. This dynamic braking has been described in detail with reference to FIG. **3** and no further explanation will be entertained at this point in the description. Should the train continue to accelerate, for example, due to a sudden downgrade, an overspeed braking will occur at a velocity error of +½ mile per hour. If this +½-mile-per-hour velocity error is attained, then velocity error sensor **118** will no longer pass a signal and relay **R6** will be deenergized, causing front contact *a* of relay **R6** to pull up and make contact with lead **155**. When this occurs, a circuit is completed from the B battery terminal over front contact *a* of relay **R6**, lead **155**, relay BR, to the N battery terminal, thereby energizing relay BR which results in a mechanical braking to prevent further overspeed of the train.

By the application of actual train brakes coupled with the ever-present inherent dynamic braking when both cars are in coast, the train begins deceleration until it reaches, once again, the zero velocity error, or set speed. In the interim, if overspeed had occurred, but the dynamic and mechanical braking had brought the actual velocity to a point between +½ mile per hour and set speed, it should be noted that the voltage appearing on the lead **111** to velocity error detection network **110** is indicative of a velocity error which is less than the +½-mile-per-hour error indicated by velocity error sensor **118** and relay **R6** would once again become energized, due to the passage of a signal by velocity error sensor **118**, and front contact *a* of relay **R6** would be pulled down, thereby deenergizing the lead **155** and releasing the train brakes.

At a speed error of zero miles per hour both cars X and Y are in their coast modes of operation due to circuitry functions previously described. Should the train further decelerate there will be a need for higher total tractive effort. Accordingly, once a voltage is present on the lead **111**, which is indicative of a velocity error which is less than that indicated by the velocity error **117**, namely, less than zero miles per hour, velocity error sensor **117** will pass a signal and relay **R5** will once again be energized. The energization of relay **R5** will cause front contact *a* of relay **R5** to be pulled down and to make contact with the lead **152**, thereby closing an energization path for lead **152** and concurrently relay **R11**. This being the sole effective change in the preexisting circuits, car X will now be in its Mode II, namely, the switch operation, while car Y remains in its coast mode of operation. Hence, the train will now follow the train performance curve **31**, representative of the existing tractive effort, beginning at the point **64**, which is located infinitesimally to the left of the 15 -mile-per-hour velocity shown in FIG. **3**.

Should the train continue to decelerate it will follow train performance curve **31** until it reaches a point **65** directly above the 14-mile-per-hour indication. At the instant the voltage on the lead **111** is indicative of a velocity error which is less than that indicated by the velocity error sensor **116**, the velocity error sensor **116** will pass a signal, thereby energizing relay **R4**. The energization of relay **R4** will cause front contact *a* of relay **R4** to close providing an energization path for the lead **148**. With lead **148** energized and front contact *a* of relay **R16** making contact with lead **149***b* (due to the deenergization of relay **R16**), an energization path is provided for relay **R14**. The energization of relay **R14** opens its front contact *b* ensuring that the Mode III operation, namely, coast, of car Y is interrupted. Thus, car Y is now placed in its switch mode of operation, and since no effective change has occurred with respect to car X, car X remains in its switch mode of operation. Both cars X and Y being in their switch modes of operation, the train follows the next higher tractive effort curve, namely, train performance curve **11**, beginning at point **66** thereon in FIG. **3**.

Should the train decelerate further, it will follow train performance curve **11** until the voltage on the lead **111** is indicative of a velocity error which is less than that indicated by velocity error sensor **115**, namely, less than −2 miles per hour, shown by point **67** in FIG. **3**. Once this occurs, velocity error sensor **115** will pass a signal thereby energizing relay **R3**. The energization of relay **R3** will cause front contact *a* of relay **R3** to close completing a circuit from the B battery terminal over front contact *a* of relay **R3**, lead **137**, diode **138**, lead **139**, lead **140**, relay **R9**, to the N battery terminal, thus energizing relay **R9**. The energization of relay **R9** causes front contact *b* of relay **R9** to close, and, once again, an energization path for lead **144** is provided. With lead **144** energized, so is relay **R10**, and since both leads **148** and **152** have once again been energized, so will relay **R11**. Since both relays **R10** and **R11** are energized, car X will now be placed in its series mode of operation. Because lead **144** is energized so is relay **R16**, and thus front contact *a* of relay **R16** is pulled down deenergizing the relay **R14** and causing the contact *b* of relay **R14** to make contact with lead **164**, thereby energizing relay **R15**. Hence, car Y will now be in its coast mode of operation. Due to a higher tractive effort afforded by car X being in a series mode of operation and car Y in a coast mode of operation, the train will now begin to follow train performance curve **32** at the point **68** in FIG. **3**.

It should be kept in mind that at any point along any particular performance curve, which the train is following, should the train be above the train resistance curve **17**, as is point **68** on train performance curve **32**, the train will once again begin accelerating in accordance with the particular performance curve until it reaches a point where it may follow a lower train performance curve due to a lower requirement in tractive effort. But for purposes of illustration, let us assume that such an occurrence does not happen. In order to trace the remaining circuits it will be presumed that the train resistance is greater than the tractive effort being supplied.

Accordingly, should the train further decelerate, it will follow along train performance curve **32**, beginning from point **68**, to a point **69**, directly above the −3-mile-per-hour velocity error indication in FIG. **3**. At this point **69**, the voltage on the lead **111** begins to indicate a velocity error which is less than that indicated by velocity error sensor **114**, namely, less than −3 miles-per-hour. Hence, the velocity error sensor **114** will pass a signal which, one again, causes relay **R2** to be ener-

gized. With relay R2 energized, front contact *a* of relay R2 is pulled down, thereby allowing the lead **134** to become energized. With leads **134**, **144**, **148**, and **152** energized, car X remains in its series mode of operation. And because lead **134** is energized, relay R14 will once again be energized causing contact *b* of relay R14 to drop out of contact with lead **164**, thus deenergizing coast relay R15. Car Y is, therefore, placed in its switch mode of operation. Since car X is in its series mode of operation and car Y has been placed out of its coast mode of operation into its switch mode of operation, the train is producing a higher total tractive effort and begins to follow train performance curve **33** at the point **70**, as shown in FIG. **3**.

Should the train further decelerate, it will follow along train performance curve **33** to the point **71**, directly above the −4-mile-per-hour velocity error indication in FIG. **3**. The instant that the voltage present on the lead **111** is indicative of a velocity error which is less than −4 miles per hour, the velocity error sensor **113** will pass a signal. Hence, relay R1 will again be energized causing front contact *a* of relay R1 to close completing a circuit from the B battery terminal over front contact *a* of relay R1, lead **121**, diode **122**, lead **123**, lead **124**, relay R8, to the N battery terminal, again energizing relay R8. With relay R8 energized, front contacts *a* and *b* of relay R8 are closed. The closing of front contact *b* of relay R8 allows the lead **129** to, once again, become energized. With the leads **129**, **134**, **144**, **148**, and **152** energized, both relays R10 and R11 remain energized and car X remains in its series mode of operation. Due to the energization of lead **129**, relay R13 again becomes energized via lead **130***a*, and since relay R14 remains energized, car Y will now be in its series mode of operation. With car X in its series mode of operation and car Y being placed in its series mode of operation from its switch mode of operation, a higher overall tractive effort will be produced. Accordingly, the train will now follow the tractive effort curve **12** beginning at point **76**. Keeping in mind that the previously mentioned holding circuits are again in effect (due to the energization of relays R4 and R5) it will be seen that the entire speed control process will now recycle.

It will be appreciated that while the specific vehicular operation shown and disclosed is directed to only a portion of the family of performance curves, shown in the aforementioned preferred embodiment of the invention by FIG. **2**, said portion illustrated in FIG. **3**, the underlying inventive concept extends itself to the entire family of curves associated with said preferred embodiment, although not shown herein. Further, it is to be understood that the number of operational curves comprising the family of curves inherent in the vehicular system, depends upon the number of propulsion units included in the vehicular system, and upon the number of propulsion modes per propulsion unit as shown previously.

From the foregoing teachings it is apparent that, while the invention is described in a preferred embodiment of a train propulsion system, there are other areas where the teachings are equally applicable. For example, where there is more than one motor available to drive a given variable load and the motors all have more than one mode or operating state, then motor control logic similar to the propulsion control logic may be employed to provide smoother control over the variable load.

In addition, the teachings of the invention will find equally applicable use in propulsion systems of the future here the technology is advancing with reference to the use of solid-state devices. It is becoming increasingly apparent that propulsion systems will not experience a sudden metamorphosis to produce total changeover to solid-state control of propulsion motors. The change ill be one of evolution wherein more solid-state devices will be employed in the system control but this will not obviate the basic economics which call for the continued use of many of the proven control techniques. It is to this evolution the current teaching provides the economic salve to ease the change.

While the invention has been shown and described with reference to a preferred embodiment thereof, it will be understood by those skilled in the art that other embodiments may be made therein without departing from the spirit and scope of the invention.

Having thus described my invention, what I claim is:

1. A vehicular propulsion control system having at least two propulsion unity for causing vehicular movement along a predetermined path at a preselected speed relatively free from accelerating and decelerating effects, said system comprising:

a. one propulsion unit having a plurality of selectable operating modes,

b. at least one other propulsion unit having a plurality of selectable operating modes,

c. propulsion control logic means operatively coupled respectively to said propulsion units, said propulsion control logic includes

d. vehicular speed command control means,

e. vehicular speed measuring means,

f. speed comparator means, said speed comparator means coupled respectively to said vehicular speed command control means and said vehicular speed measuring means to thereby provide an output indicative of a change in velocity,

g. performance curve selection logic which is controlled by said velocity change output,

said propulsion units simultaneously controlled by said propulsion logic means to select a predetermined number of combinations of said modes of operation from said propulsion units, said predetermined number of said combination modes available exceeding the number of modes available for any one of said propulsion units, said selected combination of modes closely approximating the propelling effort required to maintain said preselected vehicular speed free from accelerating and decelerating effects.

2. The vehicular control system of claim **1** wherein said propulsion units are electric motors.

3. The vehicular control system of claim **2** wherein said electric motors are DC series-connected motors.

4. The vehicular control system of claim **3** wherein said plurality of operating modes are equivalent to series-connected electric motor performance curves.

5. The vehicular control system of claim **1** wherein each of said propulsion units has equal number of propulsion modes of similar propulsion effort.

6. The vehicular control system of claim **1** wherein each of said propulsion units is positioned on a separate vehicle.

7. The vehicular control system of claim **6** wherein said vehicles are connected in tandem relationship.

8. The vehicular control system of claim **1** wherein said combination of modes available is determined by the following equation:

$$\text{number of propulsion combination modes} = \frac{(n+1)(n+2)\cdots(n+[m-1])}{(m-1)!} \quad \begin{matrix} n \geq 2 \\ m \geq 2 \end{matrix}$$

where

n = the number of propulsion units and both m and n are integers

m = the number of propulsion modes per propulsion unit.

9. A vehicular propulsion control system having at least two propulsion units for causing vehicular movement along a predetermined path at a preselected speed relatively free from accelerating and decelerating effects, said system comprising:

a. one propulsion unit having a plurality of selectable operating modes, said one propulsion unit being a series-connected DC electric motor,

b. at least one other propulsion unit having a plurality of similar selectable operating modes, said one other propulsion unit being a series-connected DC electric motor,

c. propulsion control logic means electrically coupled

respectively to said propulsion units, said propulsion control logic includes

d. vehicular speed command control means,

e. vehicular speed measuring means,

f. speed comparator means, said speed comparator means coupled respectively to said vehicular speed command control means and said vehicular speed measuring means to thereby provide an output indicative of a change in velocity,

g. performance curve selection logic which is controlled by said velocity change,

said series-connected DC electric motors of said propulsion units simultaneously controlled by said propulsion control logic means to select a predetermined number of combinations of said modes of operation from said propulsion units,

said predetermined number of said combination modes available exceeding the number of modes available for any one of said propulsion units,

said selected combination of modes approximating the propelling effort required to maintain said preselected vehicular speed,

said selection of said combination mode of operation being a function of the combined effects of acceleration, deceleration and change in velocity whereby said selected combination mode of operation closely approximates said propelling effort required to maintain said vehicular speed free from accelerating and decelerating effects.

10. The vehicular control system of claim **9** wherein said plurality of operating modes are equivalent to series-connected electric motor performance curves.

11. The vehicular control system of claim **9** wherein each of said propulsion units has equal number of propulsion modes of similar propulsion effort.

12. The vehicular control system of claim **9** wherein each of said propulsion units is positioned in a separate vehicle.

13. The vehicular control system of claim **12** wherein said vehicles are connected in tandem relationship.

14. The vehicular control system of claim **9** wherein said combination of modes available is determined by the following equation:

$$\text{number of propulsion combination modes} = \frac{(n+1)(n+2)\cdots(n+[m-1])}{(m-1)!} \quad \begin{matrix} n \geq 2 \\ m \geq 2 \end{matrix}$$

where

n = the number of propulsion units and both m and n are integers

m = the number of propulsion modes per propulsion unit.

15. A motor control system having at least two motors for causing a combined motor output to drive a variable load at preset velocity, said system comprising:

a. one motor having a plurality of selectable operating modes,

b. at least one other motor having a plurality of selectable operating modes,

c. motor control logic means operatively coupled respectively to said motor,

said motors simultaneously controlled by said motor control logic means in response to a change in velocity to select a predetermined number of combinations of said modes of operation from said motors, said predetermined number of said combination modes available exceeding the number of modes available for any one of said motors, said selected combination of modes closely approximating the effort required to drive said variable load at said relatively constant preset velocity.