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(72) Inventor JOHN FREDERICK EASTHAM



(54) AN ELECTRIC BATTERY DRIVEN VEHICLE

(71) We, K. G. ENGINEERING LABORATORIES LIMITED, a British Company, of Kennedy Tower, St. Chads Queensway, Birmingham B4 6EL, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an electric battery driven vehicle.

Although many forms of power source for an electric car have been suggested, the conventional lead/acid battery developed over many years has proved itself to have the ruggedness and reliability necessary for a car drive system and is also capable of being recharged and of being relatively cheaply produced despite its high level of sophistication. It is therefore a preferred choice as a source of electrical power, at least at the present time, despite its weight and size.

Most battery car drive systems use direct current (d.c.) series motors. These machines are, of course, commutator motors and hence require regular brush maintenance. In addition, the rotor carries an insulated coil winding in its slots which limits the peripheral speed. This in turn restricts the output from a particular frame size. The machine also produces a system disadvantage in that regeneration, from an overhauling load, is difficult to arrange in that it requires a change in circuit configuration.

The use of a squirrel cage induction motor as a drive means is capable of avoiding the above-mentioned disadvantages as the squirrel cage rotor can have a robust winding consisting of a set of cast aluminium bars with integral end-rings. Such rotors can spin at high speed without damage and do not require a commutator or brush gear. The induction motor can, in addition, provide a system advantage in that regeneration is possible without a change in the main power connections. However, an induction motor inherently requires a polyphase alternating current (a.c.) supply and this means that an

inverter is necessary in order to provide an alternating current supply from a d.c. source such as a battery.

When energised, the stator coils of a poly-phase induction motor produce a rotating field pattern. The rotational speed (Ω_s) depends on the number of pole pairs ($2p$) produced by the winding and the frequency (f) of the current supplied. The speed of an induction motor is relatively close to the synchronous speed which is expressed by the equation

$$\Omega_s = \frac{60f}{p}$$

r.p.m.

The output torque against rotor speed characteristic of a typical induction motor is shown in the accompanying Figure 3A from which it will be noticed that the torque is positive when the rotor speed is below the synchronous speed and negative for all speeds above. In the positive torque region, power is supplied to the mechanical output of the motor from the electrical input. In the negative torque region, power is taken from the mechanical system and absorbed electrically so as to give rise to regenerative braking. The ability of an induction motor to brake regeneratively is important in a battery-driven car because a limiting factor on the car range is the battery charge which can be conserved to some extent by making use of regenerative braking to return some of the power to the battery. This enables the car range to be increased without requiring a heavier, large and more costly battery.

Unfortunately, it is difficult to arrange an induction motor to have its maximum torque at standstill without impairing its high speed running efficiency.

Also when an induction motor is providing positive torque, its efficiency is given by

$$\frac{\Omega_r}{\Omega_s}$$

where Ω_r is the rotor speed. In other words, for efficient use of an induction motor the rotor speed must be close to the synchronous speed. Although by varying the synchronous speed one could maintain a relatively high efficiency of operation of the induction motor one is still left with the problem that its torque output when controlled this way is approximately constant with speed whereas the torque requirements of a car vary with the terrain and the desired acceleration.

An object of this invention is the provision of an improved electric battery driven vehicle.

According to the present invention there is provided an electric battery driven vehicle having drive wheels connected through a gear box and a clutch to a rotor of an induction motor, an inverter whose output is connected to the induction motor and a battery to which the inverter is connected, a control circuit connected to the inverter to control its frequency by a control signal, an accelerator member, a transducer which is responsive to the position of the accelerator member and whose output is connected to the control circuit and a tachogenerator which is coupled to the induction motor and whose output is connected to the control circuit. Preferably the battery is rechargeable through the inverter by energy extracted from the motor such as when braked regeneratively to decelerate the vehicle. Preferably the inverter output frequency is so controlled that the motor delivers a called-for torque at a relatively high efficiency.

The slip speed is defined as the difference in speed between the field and the rotor. By relatively high efficiency is meant an efficiency which in all but the lowest speed ranges corresponding to a vehicle speed of less than 2—3 mph does not fall beneath 80% or thereabouts.

Preferably a mechanical braking system is provided and also a regenerative braking system which comprises a transducer which responds to depression of a braking pedal by supplying a signal to the control circuit so that regenerative braking of the induction motor takes place by feed back of power through the inverter to the battery.

The advantage of such a vehicle drive system is that it utilises well-tried components and overcomes the previously mentioned disadvantages inherent in conventional drive systems. It also enables the induction motor to operate indefinitely in conditions when there is a high torque demand at a low speed such as when the vehicle is climbing a steep hill. A normal d.c. motor or an induction motor without a gear box would rapidly burn out under such conditions unless provided with a separate cooling fan and, additionally, the slip of the induction motor under such conditions would be

so large that the efficiency would be very poor. By using the gear box the induction motor speed can be maintained at a value at which it can maintain itself cool.

The called-for torque may be positive or negative depending on whether the vehicle is to be accelerated or decelerated. The gear box enables the torque output of the induction motor to be controlled to give acceptable accelerating and hill-climbing characteristics and the frequency control ensures that at all speeds a relatively high efficiency is obtained together with a satisfactory high torque.

Embodiments of this invention will now be described, by way of example, with reference to the drawings accompanying the Provisional Specification (Figures 1 to 5) and the accompanying drawings (Figures 6 and 7) of which:—

Figure 1 is a diagrammatic circuit lay-out of a car;

Figure 2 shows an inverter circuit as used in Figure 1;

Figures 3A, 3B and 3C are plots of torque against speed to explain operation of the system;

Figure 4 shows movement of an accelerator pedal;

Figure 5 shows plots of certain voltages against motor speed;

Figure 6 shows in diagram A a first modification of the circuit of Figure 1 where potentiometric transducers are replaced by electromagnetic transducers, diagrams B and C showing graphically operating characteristics obtained by these transducers respectively; and

Figure 7 shows a second modification in which a charging facility for the battery is provided by way of the inverter.

Referring to Figure 1, a car denoted by the broken outline 1 is provided with road wheels 2, 3 of which the former are driven by way of a gear box 4 which receives drive by way of a pedal operated clutch 5 from a two-phase squirrel cage induction motor 6. A tachogenerator 7 is connected to the induction motor shaft and provides an analogue voltage, proportional to the motor speed, to an adder 8 which receives a second analogue voltage from a slider of a potentiometer 9 whose position is controlled by an accelerator pedal 10. The two analogue signals are aggregated in the adder 8 to provide a control voltage which is applied to a solid state inverter 11 to control the frequency and voltage of its electrical output which is fed to the induction motor 6. The inverter receives power from a battery of lead/acid cells 12 shown diagrammatically and across which the potentiometer 9 is partially connected. The negative terminal of the battery 12 is connected to the chassis of the car.

The inverter which is shown in more detail in Figure 2, could take any one of a number

of forms. Its most essential requirement is that it must be capable of allowing power flow in either direction. This means that feed-back rectifiers must be included across each of a number of switching elements which may comprise either thyristors or transistors. Figure 2 shows one phase of a two-phase inverter and it will be understood that the second phase is the same as the first but switching signals to the switches S1 to S4 of the second phase are so controlled that the output voltage it produces is in quadrature with phase shown in Figure 2. The inverter operates by means of pulse-width control in order to vary the voltage output and to achieve this the switches S1 and S2 are opened and closed in turn at the basic required output frequency, whilst the switches S3 and S4 are opened and closed alternately at a higher frequency of, say, eight times the basic frequency. In this way a control of the mark-to-space ratio of the switches S1 and S4 modulates and therefore controls the level of the output voltage.

The analogue voltage obtained from the potentiometer 9 to produce the desired output torque is a signal proportional to the described slip speed of the induction motor and is signified by the position of the accelerator pedal 10. Figure 3B illustrates the intended action by means of an example. The chain line in Figure 3B represents the rotor speed at 1,000 r.p.m. which produces a tachovoltage of 10 volts in the example under consideration. If a positive torque level corresponding to 100 r.p.m. of slip is required, then one volt from potentiometer 9 is added to the tachovoltage in the adder 8 and the resultant control voltage is applied to the inverter frequency control input. It is arranged that the field speed produced by the inverter supply bears exactly the same relationship to the analogue signals as the tachogenerator voltage output bears to the rotor speed. Therefore, the field speed provided by the inverter for a control voltage of 11 volts is 1,100 r.p.m. This results in the torque characteristic *a* shown in full outline and therefore a positive torque *T_p* is produced. Conversely, if a negative torque corresponding to regenerative braking is required from the induction motor when the rotor speed is 1,000 r.p.m., then a 1 volt signal is subtracted from the tachovoltage in the adder 8. The control voltage fed to the inverter 11 then corresponds to a motor speed of 900 r.p.m. and the torque curve *b* shown in broken outline is produced which, at the speed under consideration of the vehicle, produces a negative torque and consequently regenerative braking.

For the example given above it will be apparent that full torque control up to the peak available from the motor can be obtained simply by varying the bias voltage

from potentiometer 9 between positive and negative limits and that this control can be exercised at any speed. Figure 3C shows the torque output which can be expected at different fixed bias voltage settings.

In practice, the motor voltage requirements will depend on its design but in general the voltage applied should be approximately proportional to the frequency and this is a feature inherent in the inverter design.

Figure 4 shows the accelerator pedal 10 in an intermediate position, its two extreme positions being referenced 10a and 10b. The pedal 10 is depressed against the bias of a spring 20 and it travels through a negative bias arc α before reaching the positive bias arc β . These two bias arcs α and β are shown in Figure 1 and the way in which the torque level applied to the vehicle is varied will be understood with reference to Figure 5 in which the ordinate represents the voltage and the abscissa the speed of the motor.

Operation

The operational sequence on starting the car is as follows. The power is first switched on to the inverter with the gear box in neutral and the accelerator pedal at its position 10a. The speed signal from the tachogenerator 7 is then zero and the inverter control voltage signal is obtained wholly from the negative portion of the potentiometer 9 and is therefore negative. It is arranged that all control voltage signals under a predetermined level indicated by the horizontal line X—X in Figure 5, produce a minimum inverter frequency. This may be obtained by using a suitable "catching" circuit. For rotor speeds below the line A—A the field speed, held at its minimum value by the catching circuit, is arranged to be greater than the motor speed and a positive torque is produced. The motor would therefore run up to the line A—A which corresponds to the motor idling speed.

The car can now be put in gear with the clutch 5 depressed. The effect of engaging the clutch with the accelerator pedal 10 at its upper limiting position 10a is to place a load on the induction motor 6 causing the tachogenerator output speed signal to fall slightly and the car would run at a speed below A—A in Figure 5. If the pedal is now depressed to give a positive bias signal corresponding to the broken line B—B then the car would accelerate at the corresponding torque level. The operations have been described separately, however, in practice of course the clutch would be engaged and the accelerator pressed simultaneously as in normal driving technique.

The gear changing to the next ratio is accomplished by first de-clutching and releasing the accelerator. The motor then

quickly slows down as a result of the pedal 10 being released into its negative bias arc α and the motor would brake regeneratively to return energy through the inverter to the battery 12. The next gear can then be engaged and the sequence of acceleration continued.

It will therefore be apparent that when the accelerator pedal 10 is released one gets dynamic braking through the transmission as long as the clutch is engaged as in a conventional motor-driven car utilising engine braking. However, the energy released during this braking is returned to supplement the charge on the battery instead of being dissipated as heat.

In practice, the full measure of regenerative braking would not be built into the accelerator pedal 10 since in any case a mechanically operated brake is provided. The amount of negative bias voltage available from the accelerator pedal should however be sufficient to slow the motor down quickly during upward gear changing. This is obtained by controlling the minimum frequency level corresponding to the output of the "catching" circuit.

To provide regeneration during normal braking occurring when a brake pedal 21 is depressed (see Figure 1) a third input is provided to the adder 8 from a second potentiometer 20. This is connected across a battery providing negative bias which increases when the slider of the potentiometer is moved by the brake pedal 21 which also controls a master braking cylinder of an hydraulic braking system in conventional manner. During braking of the car by means of the brake pedal 21, the first part of the travel of the brake pedal provides only a supplementary negative bias signal to the adder 8 to reduce the inverter output frequency so that the induction motor 6 is braked regeneratively to a greater extent than is possible with the accelerator pedal 10. The hydraulic braking system is not at this time effective. After the first part of the travel of the brake pedal is completed, the full mechanical braking system takes over to bring the car to a standstill by conventional friction braking and throughout this braking the maximum negative bias signal is applied to the adder 8. A lost-motion linkage (not shown) allows the potentiometer 20 to remain in its maximum negative bias position throughout mechanical braking and irrespective of the position of the brake pedal 21.

In the first modification shown in Figure 6A the parts identical to those shown in Figure 1 are correspondingly referenced. However in place of the potentiometer devices 9 and 20, electromagnetically operated transducers 30 and 31 are provided. Each of the transducers 30, 31 provides a

direct current output giving the slip speed signal and regenerative braking signal, respectively, to the adder 8 which provides the control voltage to the inverter 11 as formerly. The direct current output in each case varies linearly with the displacements of the respective associated pedals 10 and 21. The advantage of using electromagnetic transducers is that they can be more sturdily constructed than resistive potentiometer devices. Each may incorporate its own conversion circuits for changing alternating current to direct current and vice-versa. Movement of the pedals 10, 21 from their respective rest positions is resisted by respective springs 32, 33.

Figure 6B shows the variation in electrical output signal with different positions of the acceleration pedal 10 and the linear change together with the two pedal movement ranges α and β during which regenerative braking and acceleration of the induction motor take place, as formerly, are clearly illustrated.

Likewise Figure 6C shows how with gradual depression of the brake pedal 21 through the range α , there is a gradual increase in the regenerative braking signal fed to the induction motor inverter. At the end of the range, denoted by the broken line S-S, mechanical braking commences to supplement the regenerative braking.

Electromagnetic transducer connections suitable for use in such a system are described in "Handbook of transducers for electronic measuring systems" by H. N. Norton (Published by Prentice Hall) between pages 182 and 186.

A further form of transducer which may be used is an electro-optical one. This is provided by a closed chamber containing a light source and a photo-sensitive device therefore such as a photo-electric cell. The quantity of light falling on the photo-sensitive device is controlled by an attenuator which is movable between the two and is positionally controlled by the accelerator pedal position. Such an arrangement has the advantage that no alternating current source such as is necessary with an electromagnetic transducer, is required.

In the second modification shown in Figure 7 and which concerns the inverter, the parts which are identical to those shown in Figure 2 are correspondingly referenced. The alternating output terminals of the inverter which in Figure 2 are connected directly to the induction motor winding are, in Figure 7, taken instead to a double-pole double-throw switch 40 whose two positions (a), (b), are shown respectively in continuous and broken outline. In the former position the inverter is connected to the motor winding 50 for normal running of the car. The switch is moved to the second position when charging of the battery is neces-

sary. In this case the inverter a.c. terminals are connected to the secondary side of a voltage dropping device provided by a transformer 41 whose primary side is connected to socket contacts 42 provided on the car. The socket contacts can have plugged into them a charging lead (not shown) from an a.c. domestic supply. The diodes D_1 — D_4 rectify this supply and feed it to the battery so that a separate battery charger is unnecessary.

Although in the above described embodiments the application of the invention is to a car having a manual gear box and pedal-operated clutch, it is to be understood that the invention is equally usable with an automatic gear change mechanism. In this case deceleration of the motor during periods when it is declutched to enable a lower gear ratio to be selected, may be effected by injecting a suitable component into the inverter control voltage signal to regeneratively brake the motor.

Reference is directed to our copending application No. 35009/72 (Serial No. 1402322) which contains claims directed to the arrangement disclosed in this application.

WHAT WE CLAIM IS:—

1. An electric battery driven vehicle having drive wheels connected through a gear box and a clutch to a rotor of an induction motor, an inverter whose output is connected to the induction motor and a battery to which the inverter is connected, a control circuit connected to the inverter to control its frequency by a control signal, an accelerator member, a transducer which is responsive to the position of the accelerator member and whose output is connected to the control circuit, and a tachogenerator which is coupled to the induction motor and whose output is connected to the control circuit.

2. A vehicle as claimed in claim 1, in which the control signal is an analogue electrical signal and the control circuit is an adder.

3. A vehicle as claimed in claim 1 or claim 2, in which the tachogenerator produces an output signal in the form of an analogue signal.

4. A vehicle as claimed in any preceding claim in which the transducer produces an output signal in the form of an analogue signal.

5. A vehicle as claimed in claim 4, in which the transducer produces an output signal which varies linearly with the position of the accelerator member.

6. A vehicle as claimed in claim 5, in which the transducer is an electromagnetic transducer.

7. A vehicle as claimed in claim 5, in which the transducer is an optical device utilising a light source and a light-sensitive element whose illumination by the light source varies with the position of the accelerator member and which provides an electrical output which varies linearly with the position of the accelerator member.

8. A vehicle as claimed in any one of the preceding claims, in which the inverter utilises pulse width control in order to vary the voltage of its alternating current output.

9. A vehicle as claimed in any one of the preceding claims, including charging terminals connected through a voltage-dropping arrangement to the inverter A.C. terminals whereby the battery is chargeable by way of the inverter.

10. A vehicle as claimed in claim 9, in which a change-over switch is selectively operable to connect to the inverter A.C. terminals, either the windings of the induction motor or the charging terminals.

11. A vehicle as claimed in claim 10, in which the voltage-dropping arrangement comprises a transformer.

12. A vehicle as claimed in any one of the preceding claims, in which the accelerator member is movable through two successive ranges from a rest position corresponding to idling of the motor, the first range entered from the rest position producing an electrical signal fed to the inverter to regeneratively brake the induction motor by feeding power back through the inverter to the battery as long as the clutch is engaged and the second range entered after passing through the first range producing an electrical signal fed to the inverter to accelerate the induction motor.

13. A vehicle as claimed in any one of the preceding claims, in which a mechanical braking system is provided and also a regenerative braking system which comprises a transducer which responds to depression of a braking pedal by supplying a signal to the control circuit so that regenerative braking of the induction motor takes place by feed back of power through the inverter to the battery.

14. A vehicle as claimed in claim 13, in which the braking effect produced by movement of the braking pedal corresponding to gentle braking of the vehicle is solely due to operation of the regenerative braking system.

15. A vehicle as claimed in claim 1, arranged and adapted to operate substantially as described with reference to

sary. In this case the inverter a.c. terminals are connected to the secondary side of a voltage dropping device provided by a transformer 41 whose primary side is connected to socket contacts 42 provided on the car. The socket contacts can have plugged into them a charging lead (not shown) from an a.c. domestic supply. The diodes D_1 — D_4 rectify this supply and feed it to the battery so that a separate battery charger is unnecessary.

Although in the above described embodiments the application of the invention is to a car having a manual gear box and pedal-operated clutch, it is to be understood that the invention is equally usable with an automatic gear change mechanism. In this case deceleration of the motor during periods when it is declutched to enable a lower gear ratio to be selected, may be effected by injecting a suitable component into the inverter control voltage signal to regeneratively brake the motor.

Reference is directed to our copending application No. 35009/72 (Serial No. 1402322) which contains claims directed to the arrangement disclosed in this application.

WHAT WE CLAIM IS:—

1. An electric battery driven vehicle having drive wheels connected through a gear box and a clutch to a rotor of an induction motor, an inverter whose output is connected to the induction motor and a battery to which the inverter is connected, a control circuit connected to the inverter to control its frequency by a control signal, an accelerator member, a transducer which is responsive to the position of the accelerator member and whose output is connected to the control circuit, and a tachogenerator which is coupled to the induction motor and whose output is connected to the control circuit.

2. A vehicle as claimed in claim 1, in which the control signal is an analogue electrical signal and the control circuit is an adder.

3. A vehicle as claimed in claim 1 or claim 2, in which the tachogenerator produces an output signal in the form of an analogue signal.

4. A vehicle as claimed in any preceding claim in which the transducer produces an output signal in the form of an analogue signal.

5. A vehicle as claimed in claim 4, in which the transducer produces an output signal which varies linearly with the position of the accelerator member.

6. A vehicle as claimed in claim 5, in which the transducer is an electromagnetic transducer.

7. A vehicle as claimed in claim 5, in which the transducer is an optical device utilising a light source and a light-sensitive element whose illumination by the light source varies with the position of the accelerator member and which provides an electrical output which varies linearly with the position of the accelerator member.

8. A vehicle as claimed in any one of the preceding claims, in which the inverter utilises pulse width control in order to vary the voltage of its alternating current output.

9. A vehicle as claimed in any one of the preceding claims, including charging terminals connected through a voltage-dropping arrangement to the inverter A.C. terminals whereby the battery is chargeable by way of the inverter.

10. A vehicle as claimed in claim 9, in which a change-over switch is selectively operable to connect to the inverter A.C. terminals, either the windings of the induction motor or the charging terminals.

11. A vehicle as claimed in claim 10, in which the voltage-dropping arrangement comprises a transformer.

12. A vehicle as claimed in any one of the preceding claims, in which the accelerator member is movable through two successive ranges from a rest position corresponding to idling of the motor, the first range entered from the rest position producing an electrical signal fed to the inverter to regeneratively brake the induction motor by feeding power back through the inverter to the battery as long as the clutch is engaged and the second range entered after passing through the first range producing an electrical signal fed to the inverter to accelerate the induction motor.

13. A vehicle as claimed in any one of the preceding claims, in which a mechanical braking system is provided and also a regenerative braking system which comprises a transducer which responds to depression of a braking pedal by supplying a signal to the control circuit so that regenerative braking of the induction motor takes place by feed back of power through the inverter to the battery.

14. A vehicle as claimed in claim 13, in which the braking effect produced by movement of the braking pedal corresponding to gentle braking of the vehicle is solely due to operation of the regenerative braking system.

15. A vehicle as claimed in claim 1, arranged and adapted to operate substantially as described with reference to



Figures 1 to 5 of the drawings accompanying reference to Figure 6 and/or Figure 7 of the 5
the Provisional Specification. accompanying drawings.

16. A vehicle as claimed in claim 15,
modified substantially as described with

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