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Elevator with Vertical Vibration Compensation

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ABSTRACT

Elevator with Vertical Vibration Compensation

The present invention provides an elevator comprising a car (1) arranged to travel along guide rails (6) within a hoistway (8) and a main drive (52,54,56,DMC) to propel the car (1). A sensor (30;40) is mounted on the car (1) to measure a vertical travel parameter (V_c;A_c) of the car (1), a comparator (32) compares the sensed car travel parameter (V_c;A_c) with a reference value (V_r;A_r) derived from the main drive (52,54,56,DMC), and an auxiliary motor (24) is mounted on the car (1) to exert a vertical force (F) on at least one of the guide rails (6) in response to an error signal (V_e;A_e) output from the comparator (32).

[Fig. 4]

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COMPLETE SPECIFICATION

STANDARD PATENT

Application Number:

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Invention Title: **Elevator with Vertical Vibration Compensation**

The following statement is a full description of this invention, including the best method of performing it known to us:

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ELEVATOR WITH VERTICAL VIBRATION COMPENSATION

FIELD OF THE INVENTION

The invention relates to elevators and, more particularly, to reducing transient vertical vibration acting on an elevator car.

BACKGROUND OF THE INVENTION

One problem associated with elevators is that of low frequency vertical vibration of the elevator car. This phenomenon is principally due to the inherent elasticity of the main drive system used to propel and support the car within the hoistway; for example, the compressibility of the working fluid used in hydraulic elevators and the elasticity of the rope used in traction elevators. Accordingly, any fluctuation in the force acting on the car will cause transient vertical vibration about a steady-state displacement of the car. The predominant frequency of these vibrations is that of the fundamental mode of vibration which is dependent on the travel height of the elevator and, for a traction elevator, the type of rope used. For a traction elevator having a travel path of 400m and using steel ropes the fundamental frequency can be less than 1 Hz. Vibrations at such low frequencies are easily perceptible to passengers, undermining confidence in the safety of the elevator and generally leading to a deterioration in perceived ride quality.

There are two general sources of vibration, namely:

a) vibrations due to fluctuations in the load of the car caused by passengers embarking and disembarking while the car is held stationary by the drive at a landing; and

b) vibrations during travel caused by car overshoot during jerk phases of the drive, interference with other components within the elevator hoistway (such as wind forces due to passage of the car past shaft doors and neighbouring cars within the hoistway, counterweight crossing, etc.) and movement of passengers within the travelling car.

The effects of the first of these sources of vibration are discussed in and addressed by European patent document EP 1 460 021 A1, which describes friction shoes mounted on the car being brought into contact with guide rails when

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the car is at rest at a landing. Hence, the overall damping ratio of the system is increased and the transient vibrations due to load fluctuations as passengers embark and disembark the car are attenuated more quickly. However, this solution is only applicable to a stationary elevator car and cannot solve the vibration experienced by a passenger while travelling in an elevator car.

Furthermore, if the steady-state displacement of the car from the landing due to the changing load is above a specific value, it may be necessary to perform a conventional re-levelling operation whereby the main drive is employed to make a small trip and thereby bring the car back to the level of the landing. The use of the main drive in this fashion, particularly since the car and landing doors are open, obviously presents an unwanted safety risk to passengers. The steady-state displacement must be determined before the re-levelling operation can commence, hence it necessarily has a slow reaction time. Furthermore, the re-levelling operation itself excites further low frequency vibrations.

One of the sources of vibration while the car is travelling is jerk phases in the travel curve of the drive. When a typical acceleration command generated by the elevator controller is fed directly into the motor of the main drive, there tends to be some overshoot in the car's response producing jerk and unwanted vibrations as shown by the first response curve R1 in FIG. 1. One method of reducing the vibrations in the response is to compensate by rounding of the jerk as show by travel curve trajectory R2. However, this compensation of the response always increases travel time and therefore reduces the transport capacity of the elevator.

Furthermore, such compensation cannot solve the problem of vibrations induced by interference of the travelling car with other components within the elevator hoistway and movement of passengers within the car. In a traction elevator having a traction sheave driving a rope interconnecting the car and a counterweight, the sheave acts as a node in the fundamental mode of vibration particularly when the car is in the middle section of the hoistway and therefore has no influence whatsoever on the amplitude of the predominant fundamental vibrations experienced by the car. Until recently, this problem was not particularly disturbing to passengers travelling in the car, since the ropes were relatively stiff (being made from steel) and therefore the amplitude of these vibrations was

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relatively small. However, with the development and subsequent deployment of synthetic ropes in traction elevators to replace traditional steel ropes, the elasticity of the ropes has approximately doubled and, for a travel path of 400m, the fundamental frequency can be less than 0.6 Hz. This increase in elasticity combined with the decrease in the fundamental frequency makes the car much more susceptible to low frequency vertical vibrations. In particular, vibrations induced by interference of the travelling car with other components within the elevator hoistway and movement of passengers within the car are no longer a problem that can be disregarded since they will be increasingly perceptible to passengers in the future.

There is consequently a need for measure that may help address these and other limitations and, particularly, help reduce vertical vibrations generated in more elevator cars.

SUMMARY OF THE INVENTION

The present invention provides an elevator having a car arranged to travel along guide rails within a hoistway, a main drive to propel the car, a sensor mounted on the car to measure a vertical travel parameter of the car, a comparator to compare the sensed car travel parameter with a reference value derived from the main drive, and an auxiliary motor mounted on the car to exert a vertical force on at least one of the guide rails in response to an error signal output from the comparator. Accordingly, any undesired vertical vibrations of an elevator car while it is stationary at a landing or travelling through the hoistway will produce an error signal from the comparator and the auxiliary motor is driven to exert a vertical frictional or electromagnetic force on the guide rail to counteract the vibrations.

Furthermore, provided that the auxiliary motor has sufficient power, when the car is stationary at a landing, the auxiliary motor can keep the car level with the landing and therefore the conventional re-levelling operation executed by the main drive is no longer required.

Preferably the elevator is a traction elevator where the main drive has an elevator controller, a main motor and a traction sheave engaging a traction rope interconnecting the car with a counterweight. The present invention is particularly

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beneficial for a traction elevator wherein the traction rope is synthetic since such installations are inherently more susceptible to low frequency vertical vibration. However, the invention is also applicable to traction elevators using belts or steel ropes, particularly when the installation is of the high-rise type.

Advantageously the error signal is fed into an auxiliary controller which outputs a force command signal to a power amplifier providing energy to the auxiliary motor. The auxiliary controller provides the necessary conditioning of the error signal to ensure effective vibration damping. The auxiliary controller may comprise a band-pass filter to suppress components of the signal having a frequency less than the fundamental frequency of the elevator to prevent any build up of steady state errors. The upper cut-off frequency of the filter can be determined by the dynamics of the control system so as to prevent high frequency jitter. Furthermore the auxiliary controller preferably contains a proportional amplifier to produce a behaviour commonly known as skyhook damping. Additionally, the auxiliary controller may also comprise a differential amplifier, an integral amplifier and/or a double integral amplifier to add virtual mass to the car and virtual stiffness to the system.

Preferably the car is guided along the guide rails by roller guides, each roller guide comprising a plurality of wheels engaging with the guide rail and wherein the auxiliary motor is arranged to rotate at least one of the wheels. Many elevators already use roller guides to guide the car along the guide rails and driving one of the wheels of the roller guides with the auxiliary motor is an efficient, relatively low-cost and lightweight way of implementing the present invention.

Preferably a shaft of the driven wheel is rotatably mounted at a first point of a lever which is pivotably secured to the car at a second point and a shaft of the of the auxiliary motor is aligned with the second point with a transmission belt arranged around the shaft of the driven wheel and the auxiliary motor ensuring simultaneous rotation. With this arrangement the auxiliary motor is in a fixed position with respect to the car and accordingly the motor is not required to move with the wheel which can be subject to vibration.

In order to reduce the energy demand of the system, the auxiliary motor is preferably of a synchronous, permanent magnet type so that energy can be

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regenerated when the motor is decelerating the car and working as a generator and not as a motor. Ultracapacitors can be incorporated in the power amplifier to store this recovered energy for subsequent use.

The present invention also provides a method for reducing vibrations exerted an elevator car, the method having steps of providing a main drive to propel the car along guide rails within a hoistway, measuring a vertical travel parameter of the car, comparing the measured car travel parameter with a reference value derived from the main drive to give an error signal, and driving an auxiliary motor mounted on the car to exert a vertical force on at least one of the guide rails in response to the error signal. Accordingly, any undesired vertical vibrations of an elevator car will produce an error signal from the comparator and the auxiliary motor is driven to exert a vertical friction force on the guide rail to counteract the vibrations.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a diagrammatic overview of conventional travel curve responses for an elevator.

Figure 2 is a schematic representation of an elevator according to the present invention.

Figure 3 is a perspective view of the elevator car of Figure 1.

Figure 4 is a cross-section view of the roller guide of Figure 3 incorporating a speed controller.

Figure 5 is a series of graphical illustrations of a first set of results obtained from simulation.

Figure 6 is a series of graphical illustrations of a second set of results obtained from simulation.

Figure 7 is a series of graphical illustrations of a third set of results obtained from simulation.

Figure 8 is a series of graphical illustrations of a fourth set of results obtained from simulation.

Figure 9 corresponds with Figure 4 but uses an acceleration controller instead of the speed controller.

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DESCRIPTION OF THE PREFERRED EMBODIMENTS

To avoid unnecessary repetition within the description, features that are common to more than one embodiment have been designated with the same reference numerals.

Figure 2 illustrates an elevator according to the present invention. The elevator includes an elevator car 1 which is arranged to travel upwards and downwards within a hoistway 8 of a building. The elevator car 1 comprises a passenger cabin 2 supported in a frame 4. A traction rope 52 interconnects the car 1 with a counterweight 50 and this rope 52 is driven by a traction sheave 54 located above or in an upper region of the hoistway 8. The traction sheave 54 is mechanically coupled to a main motor 56 which is controlled by an elevator controller DMC. The traction rope 52, the traction sheave 54, the motor 56 and the elevator controller DMC constitute the main drive used to support and propel the car 1 though the hoistway 8. In high-rise elevators the weight of the traction rope 52 is significant and a compensation rope 60 is generally provided to counteract any imbalance of the rope 52 weight as the car 1 travels along the hoistway 8. The compensation rope 60 is suspended from the counterweight 50 and the car 1 and is tensioned by a tensioning pulley 62 mounted in a lower region of the hoistway 8. A dynamic car controller DCC is provided to actuate the car 1 in response to a signal V_c; A_c representative of the car speed or acceleration and a reference signal V_r; A_r from the main drive. As clearly shown, there is a degree of elasticity and damping associated the traction rope 52, the compensation

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rope 60, the mounting of the traction sheave 54, the mounting of the tensioning pulley 62 and the mounting of the passenger cabin 2 within the car frame 4, respectively.

Figure 3 is a perspective view of the car 1 shown in Fig. 2. Two roller guides 10 are mounted on top of the car frame 4 to guide the car 1 along guide rails 6 as it moves within the hoistway 8. Each roller guide 10 consists of three wheels 12 arranged to exert horizontal force on the associated guide rail 6 and thereby the car 1 is continually centralised between the opposing guide rails 6. As will be appreciated by the skilled person, a further pair of roller guides 10 can be mounted beneath the car 1 to improve the overall guidance of the car 1. A significant difference between the roller guides 10 used in the present invention and those of the prior art, is that at least one of the wheels 12 can be driven to exert a vertical frictional force F against the guide rail 6.

The structure of the roller guides 10 is shown in greater detail in Figure 4. For clarity, the middle wheel of the roller guide 10 has been removed. Each wheel 12 has an outer rubber tyre 14 engaging the guide rail 6 and has a central shaft 26 which is rotatably supported at a first point P1 on a lever 16. At its lower end, the lever 16 is pivotably supported at a second point P2 on a mounting block 28 which is fastened to a base plate 18. The base plate 18 in turn is secured to the top of the car frame 4. A compression spring 19 biases the lever 16 and thereby the wheel 12 towards the guide rail 6

The dynamic car controller DCC of Fig. 2 will be explained with reference to the wheel 12 positioned on the right of Fig. 4. This wheel 12 is capable of being driven by an auxiliary motor 24. The auxiliary motor 24 is mounted to the base plate 18 it is aligned with the second point P2 of the lever 16. The wheel 12 further comprises a gear pulley 20 integral with its central shaft 26. A transmission belt 22 is arranged around the pulley 20 and a second pulley (not shown) on the shaft of the auxiliary motor 24 ensuring simultaneous rotation. Preferably the gear ratio is one, however a higher gear ratio can be used to enable a reduction in the size of the auxiliary motor 24.

Although it is feasible to mount the auxiliary motor 24 directly to the shaft 26 of the guide wheel 12, this arrangement would have several disadvantages with respect to the preferred arrangement shown in Fig. 4 and described above. Firstly, such an arrangement would add further mass to the wheel 12 and consequently would impair the ability of the roller guide 10 to effectively isolate vibration between the car 1 and the guide rails 6. Furthermore, the auxiliary motor 24 itself would be subject to strong and harmful

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vibrations. Lastly, the arrangement would necessitate the provision of flexible wiring to the moving auxiliary motor 24.

A speed encoder 30 attached to a shaft 26 of a wheel 12 that is not driven by the motor outputs a signal V_c representative of the speed of the car 1. The car speed signal V_c is subtracted from a speed reference signal V_r derived from the main drive at a comparator 32. A speed error signal V_e resulting from this comparison is fed into a speed controller 34 mounted on the car 1. The speed error signal V_e is initially passed through a band-pass filter 34a. The lower cut-off frequency of filter 34a is less than the fundamental frequency of the elevator to compensate for rope slippage in the traction sheave 54 and to prevent any build up of steady state errors. The upper cut-off frequency of the filter 34a can be determined by the dynamics of the control system so as to prevent high frequency jitter. After filtering, the speed error signal V_e is amplified in the speed controller 34. Proportional amplification k_P is predominant in the speed controller 34 and results in a behaviour commonly known as skyhook damping which is analogous to having a damper mounted between the car 1 and a virtual point which moves at the reference speed V_r such that any deviations V_e of the car speed V_c from the reference speed V_r result in the application of a force opposite and proportional to the speed deviation V_e. Additionally, the speed controller 34 can provide a certain amount of differential k_D and integral k_I amplification. Differential amplification k_D adds virtual mass to the car 1 while integral amplification k_I adds virtual stiffness to the system.

A force command signal F_c output from the controller 34 is supplied to a power amplifier 36 which in turn drives the auxiliary motor 24 establishing a vertical frictional force F between the wheel 12 and the guide rail 6 to compensate for any deviation V_e of the car speed V_c from the reference speed V_r. Accordingly, any undesired vertical vibrations of an elevator car 1 will produce a speed error signal V_e from the comparator 32 and the auxiliary motor 24 will be driven to exert a vertical friction force F between the wheel 12 and the guide rail 6 to counteract the vibrations. Furthermore, when the car 1 is stationary at a landing, the auxiliary motor 24, provided it has sufficient power, will keep the car 1 level with the landing and therefore the conventional re-levelling operation executed by the main drive is no longer required.

In order to reduce the energy demand of the system, the auxiliary motor 24 is preferably of a synchronous, permanent magnet type so that energy can be regenerated when the motor 24 is decelerating the car instead of accelerating. Ultracapacitors 38 in a dc

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intermediate circuit of the power amplifier 36 store this recovered energy for subsequent use. Accordingly, power drawn from the mains supply need only compensate for energy losses. These losses are proportional to the loss factor ($1/\eta - \eta$) where η is the combined efficiency factor of the motor 24, transmission belt 22, friction wheel 12 and power amplifier 36. For η = 0.9, 0.8 and 0.7, the loss factor is 0.21, 0.45 and 0.73, respectively. Hence, the combined efficiency should be maintained as high as possible.

The performance of the system was evaluated using the elevator schematically illustrated in Fig. 2. The simulation was carried out for two different installations; the first having a travel height of 232 m using four aramid traction ropes 52, and the second having a travel height of 400 m employing seven aramid traction ropes 52. In both cases, the speed controller 34 employed zero integral gain k_I, the lower cut-off frequency of the filter 34a was 0.3 Hz, and the vertical frictional force F developed between the driven wheel 14 and the associated guide rail 6 was limited to about 1000 N. A numerical summary of the results obtained is provided in Table 1. A more detailed analysis of the results showing car acceleration and ISO filtered car acceleration (modelling human sensation to the vibration as defined in ISO 2631-1 and ISO 8041) of the conventional system against that recorded for a dynamic car control DCC system according to the invention is shown in the graphical representations of Figures 5 to 8 together with the force produced and the power and energy consumption of the dynamic car control DCC system.

Travel height (m)		232		400	
Rated speed (m/s)		6		10	
Rated load (kg)		1150		1600	
DCC proportional gain		10'000		15'000	
DCC differential gain		2'000		3'000	
Travel sequence		Long Trip	Short Trip	Long Trip	Short Trip
Figure No.		5	6	7	8
ISO-Acceleration Peak R.M.S. (milli-g)	No DCC	11.1	20.8	11.8	32.1
	With DCC	8.9	15.5	9.9	11.8
ISO-Acceleration R.M.S. (milli-g)	No DCC	2.7	8.5	3	14.5
	With DCC	2.7	7.5	2.6	5.4
DCC Peak Force on Car (N)		350	660	930	1080
Motor Peak Power (kW)		2.2	0.6	10.2	1.2
Motor R.M.S. Power (kW)		0.29	0.18	1.33	0.49

Table 1

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The results clearly illustrate that the dynamic car controller DDC reduces the amplitude of any vibrations exerted on the car 1 during travel and also shortens the time take to extinguish those vibrations, especially for short trips (Figs. 6 and 8) which inherently are more susceptible to low frequency vibration and excitation of the fundamental mode of vibration.

Figure 9 illustrates an alternative embodiment of the present invention. Instead of speed, the vertical acceleration A_c of the car 1 is measured by an accelerometer 40 mounted on the car 1. The signal A_c from the accelerometer 40 is subtracted from an acceleration reference signal A_r derived from the main drive at the comparator 32. An acceleration error signal A_e resulting from this comparison is fed into an acceleration controller 44. As in the previous embodiment, the acceleration error signal A_e is conditioned by a band-pass filter 44a and after filtering is amplified in the acceleration controller 44. The acceleration controller 44 has proportional k_P, integral k_I and double integral k_{II} amplification. Hence, it functions in a similar manner to the speed controller 34 of the previous embodiment but the quality of the signal is different and to account for this the level of filtering and amplification must be changed.

As before a force command signal F_c output from the controller 44 is supplied to the power amplifier 36 which in turn drives the auxiliary motor 24 establishing the vertical frictional force F between the wheel 12 and the guide rail 6 to compensate for any deviation A_e of the car acceleration A_c from the reference acceleration A_r. Accordingly, the auxiliary motor 24 will be driven to exert a vertical friction force F between the wheel 12 and the guide rail 6 to counteract vibrations.

Furthermore, when the car 1 is stationary at a landing, the auxiliary motor 24, provided it has sufficient power, will keep the car 1 level with the landing and therefore the conventional re-levelling operation is no longer required.

The dynamic car controller DCC, whether in the form of a speed controller 34 or an acceleration controller 44, need not be fixed to the car 1 as in the previously described embodiments but can be mounted anywhere within the elevator installation. Indeed, further optimization is possible by integrating the dynamic car controller DCC with the elevator controller DMC in a single multi input multi output (MIMO) state space controller.

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As is becoming increasingly common practice within the elevator industry, the traction ropes 52 can be replaced by belts to reduce the diameter of the traction sheave 54. The invention works equally well for either of these traction media.

Furthermore, the auxiliary motor 24 of the previously described embodiments of the invention can a linear motor. In such an arrangement a primary of the linear motor is mounted on the car 1 with the guide rail 6 acting as a secondary of the linear motor (or vice versa). Accordingly, the electromagnetic field produced between the primary and the secondary of the linear motor can be used not only to guide the car 1 along the guide rails 6 but also to establish the required vertical force to counteract any vibrations of the car 1. This embodiment is less advantageous since currently available linear motors have low efficiency, are relatively heavy and energy recuperation is not possible.

Although the invention has been described in relation to and is particularly beneficial for traction elevators incorporating synthetic traction ropes 52 or belts, it will be appreciated that the invention can also be employed in hydraulic elevators. In such an arrangement the main drive comprises an elevator controller and a pump to regulate the amount of working fluid between a cylinder and ramp to propel and support the elevator car 1 within the hoistway 8.

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THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. An elevator having:

a car travelling along guide rails within a hoistway; and

a main drive for propelling the car;

a sensor mounted on said car for measuring a vertical travel parameter of the car;

a comparator for comparing said sensed car travel parameter with a reference value derived from the main drive to generate an error signal; and

an auxiliary motor mounted on the car for exerting a vertical force on at least one of the guide rails in response to the error signal output from the comparator to reduce vibrations exerted on the car.

2. An elevator according to claim 1 wherein the main drive has an elevator controller, a main motor and a traction sheave engaging a traction rope interconnecting the car with a counterweight.

3. An elevator according to claim 2 wherein said traction rope is formed of a synthetic material.

4. An elevator according to any one of the preceding claims, wherein the error signal is fed into an auxiliary controller which outputs a force command signal to a power amplifier providing energy to the auxiliary motor.

5. An elevator according to claim 4, wherein the auxiliary controller has a band-pass filter and at least one of a proportional amplifier, a differential amplifier, an integral amplifier and a double integral amplifier.

6. An elevator according to claim 4 or claim 5, wherein the car is guided along the guide rails by roller guides, each roller guide having a plurality of wheels engaging with the guide rail and wherein the auxiliary motor is arranged to rotate at least one of the wheels.

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7. An elevator according to claim 6, further having a transmission belt arranged around a shaft of the driven wheel, wherein the shaft of the driven wheel is rotatably mounted at a first point of a lever which is pivotably secured to the car at a second point and a shaft of the auxiliary motor is aligned with the second point, and the auxiliary motor ensuring simultaneous rotation.

8. An elevator according to claim 6 or claim 7, wherein the auxiliary motor is one of a synchronous permanent magnet motor, an asynchronous motor and a dc motor.

9. An elevator according to claim 8, wherein the power amplifier has one or more ultracapacitors.

10. A method for reducing vibrations exerted on an elevator car the method having steps of:

propelling a car along guide rails within a hoistway using a main drive;

measuring a vertical travel parameter of the car;

comparing the measured car travel parameter with a reference value derived from the main drive to generate an error signal; and

driving an auxiliary motor mounted on the car to exert a vertical force on at least one of the guide rails in response to the error signal.

11. An elevator car substantially in accordance with any one of the embodiments of the invention described herein with reference to the accompanying drawings.

12. A method of reducing vibrations exerted on an elevator car substantially in accordance with any one of the embodiments of the invention described herein with reference to the accompanying drawings.

INVENTIO AG

WATERMARK PATENT & TRADEMARK ATTORNEYS

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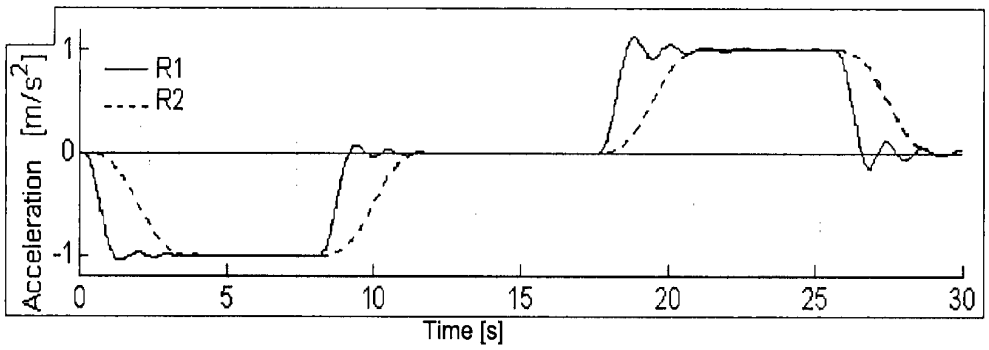


Fig. 1

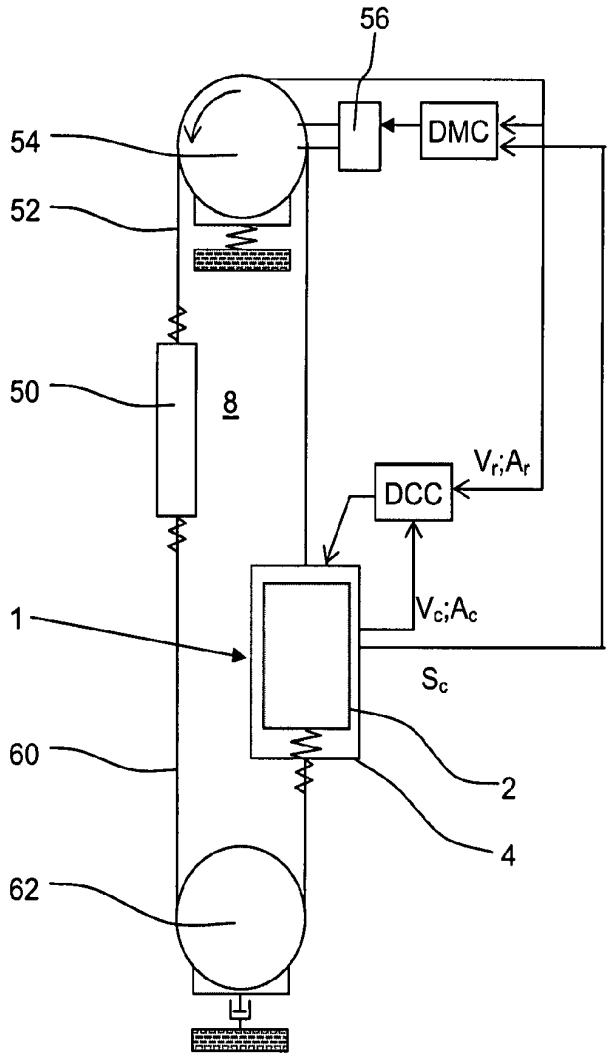


Fig. 2

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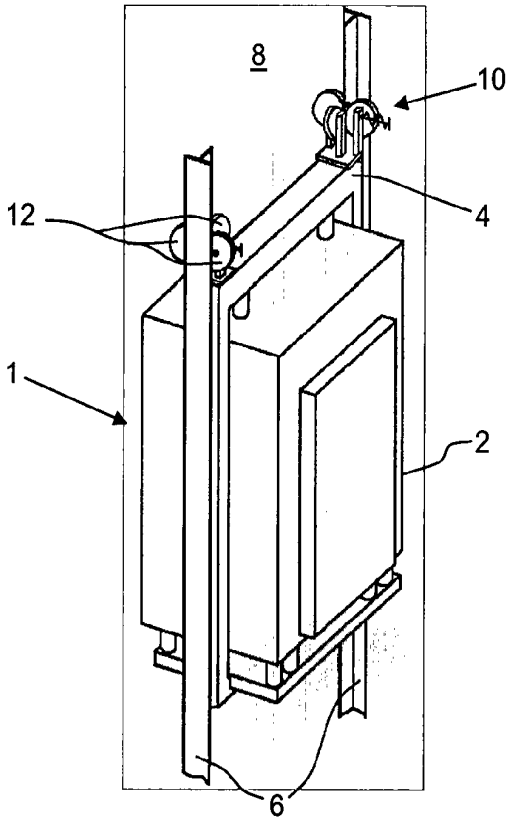


Fig. 3

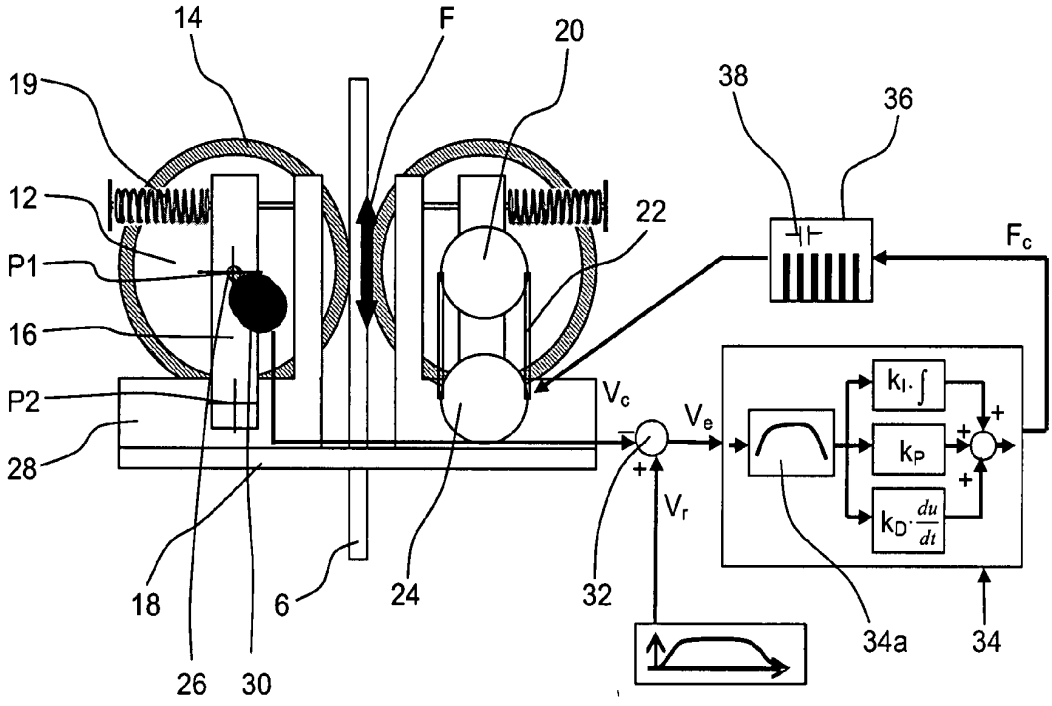


Fig. 4

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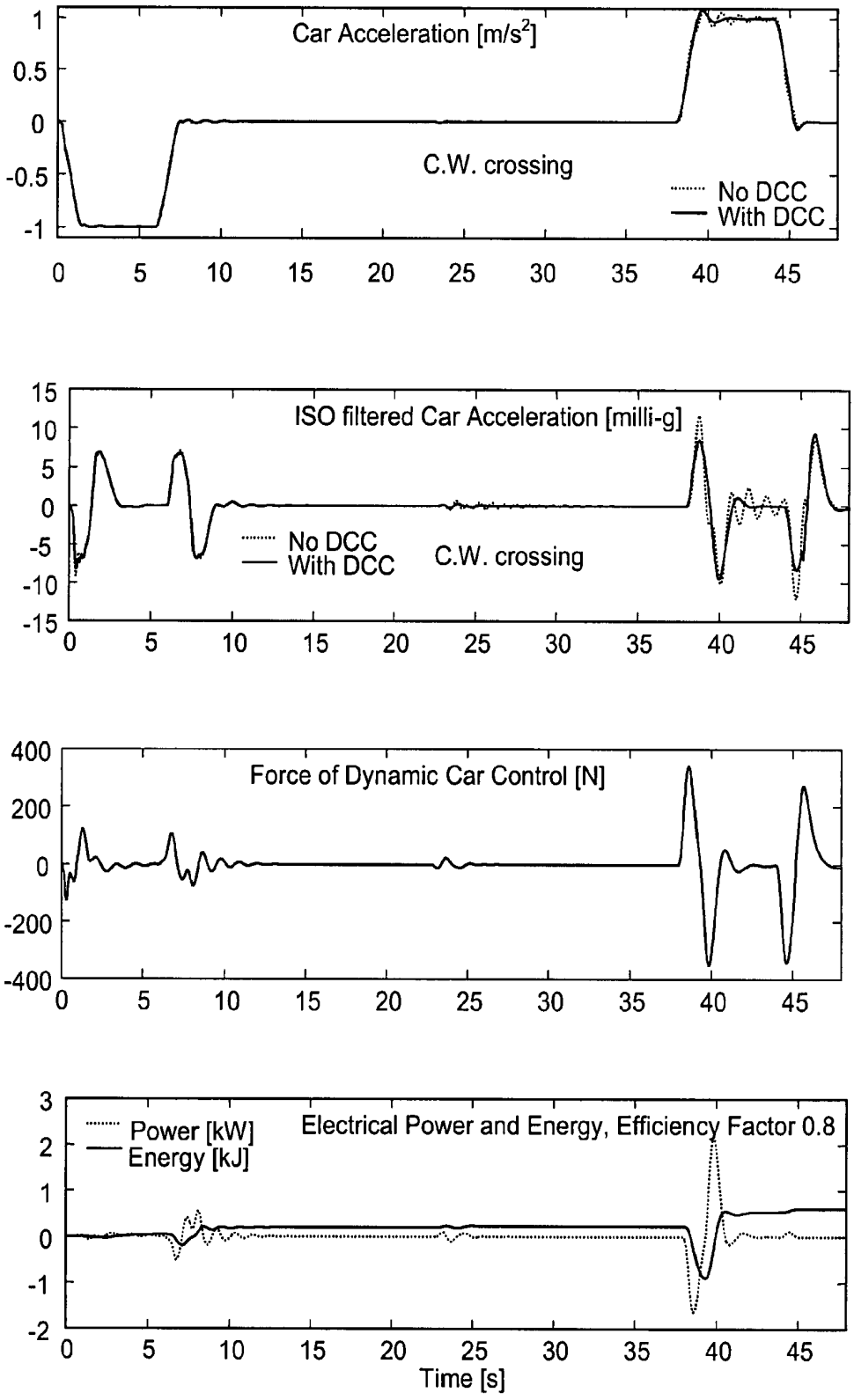


Fig. 5

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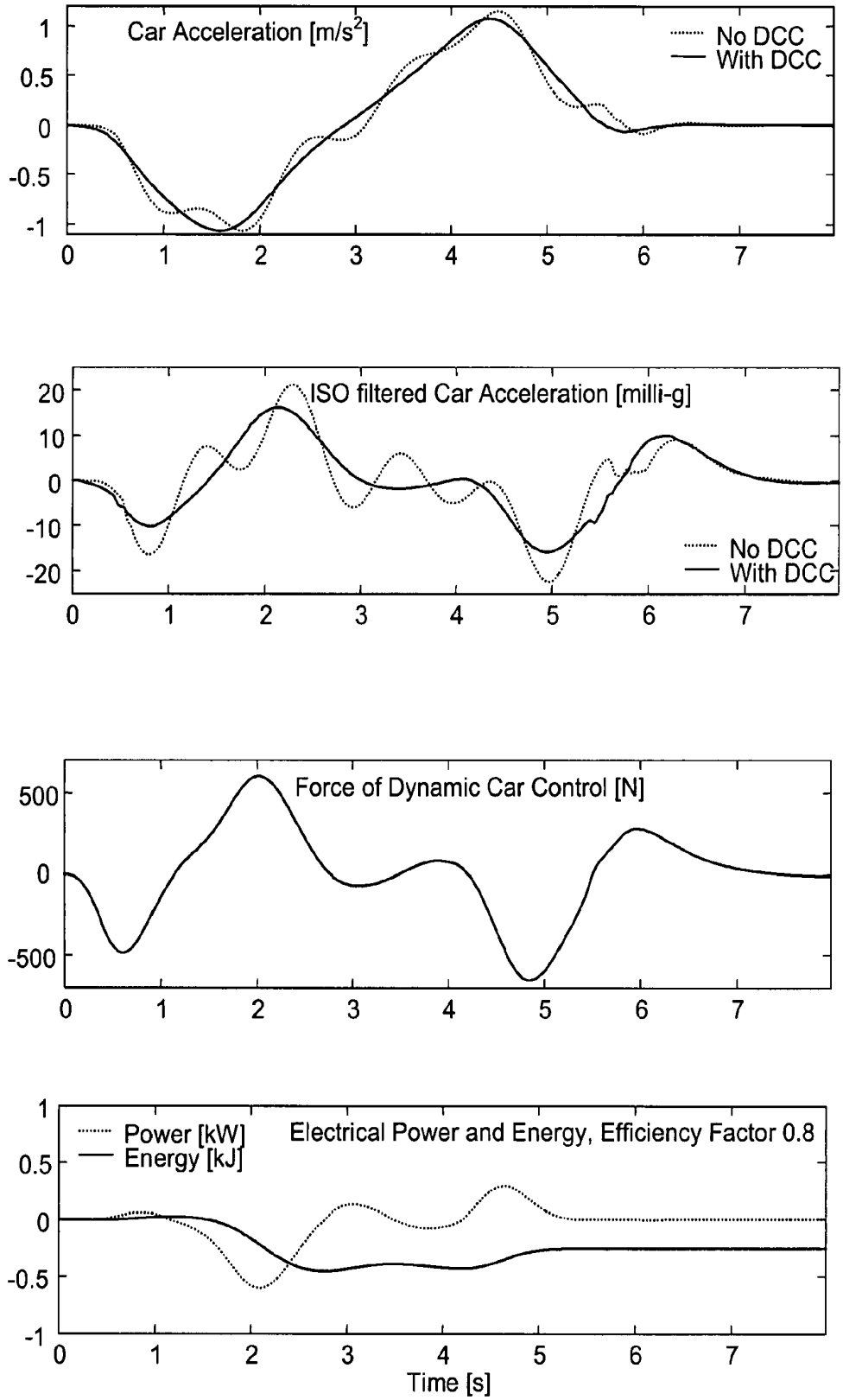


Fig. 6

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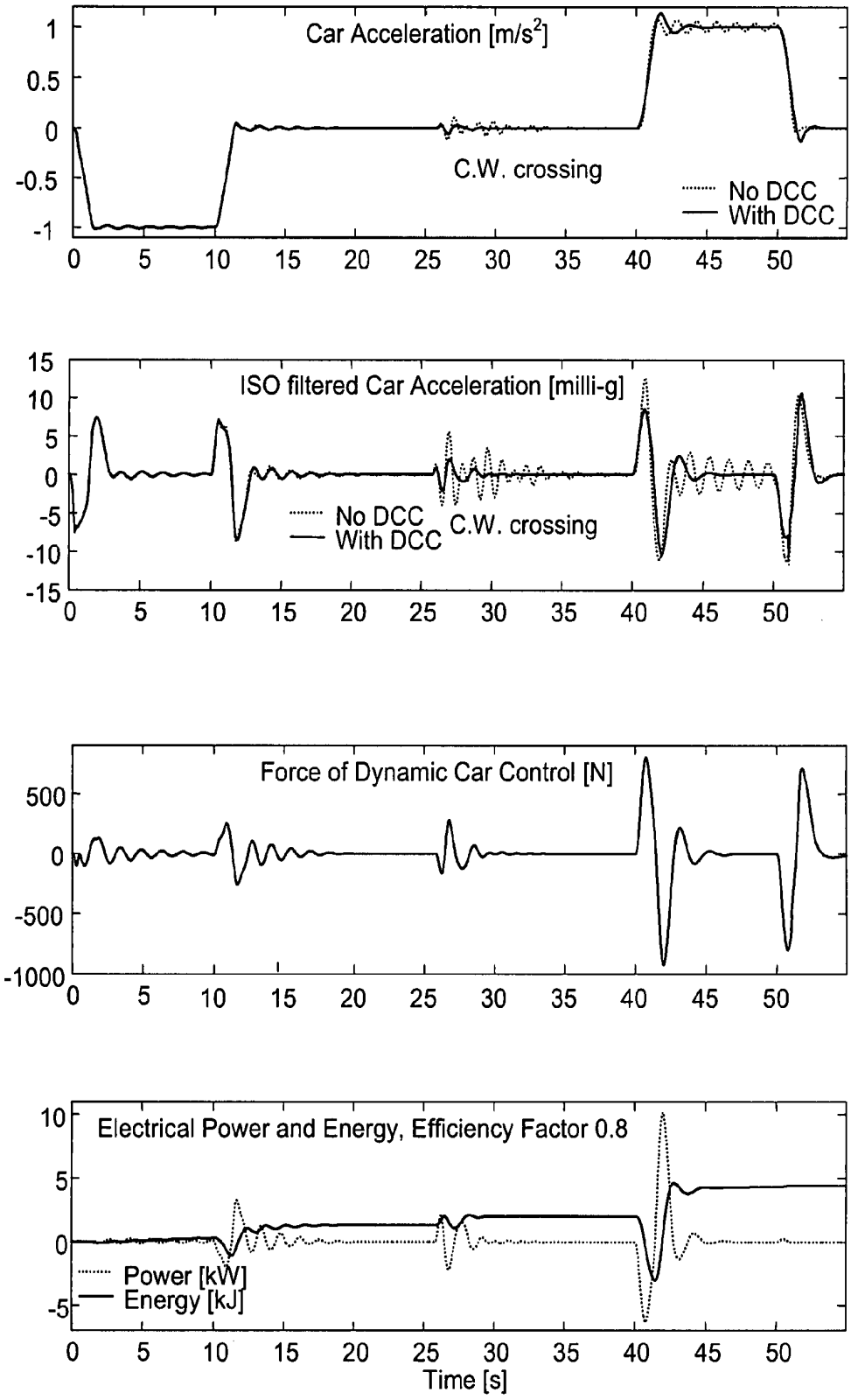


Fig. 7

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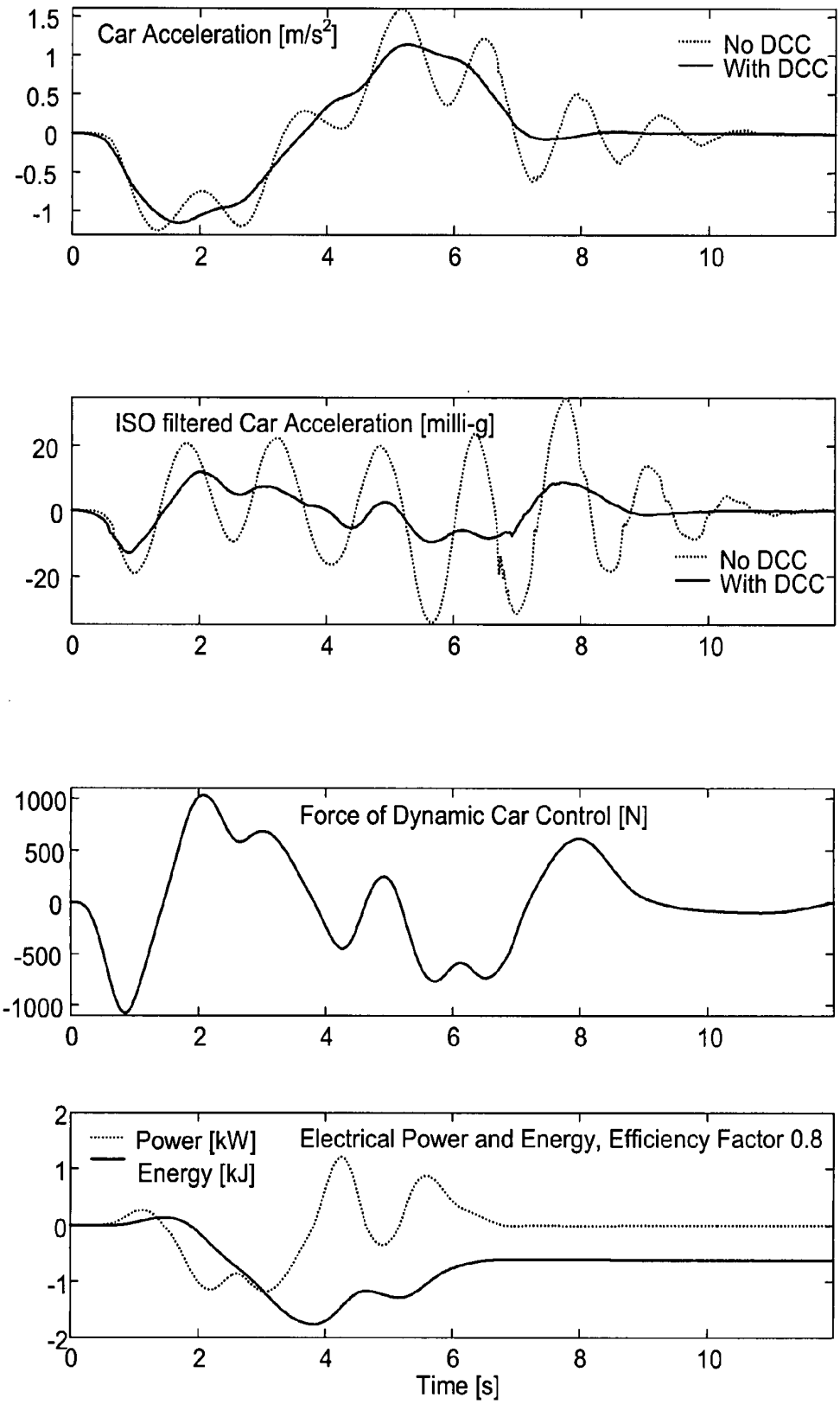


Fig. 8

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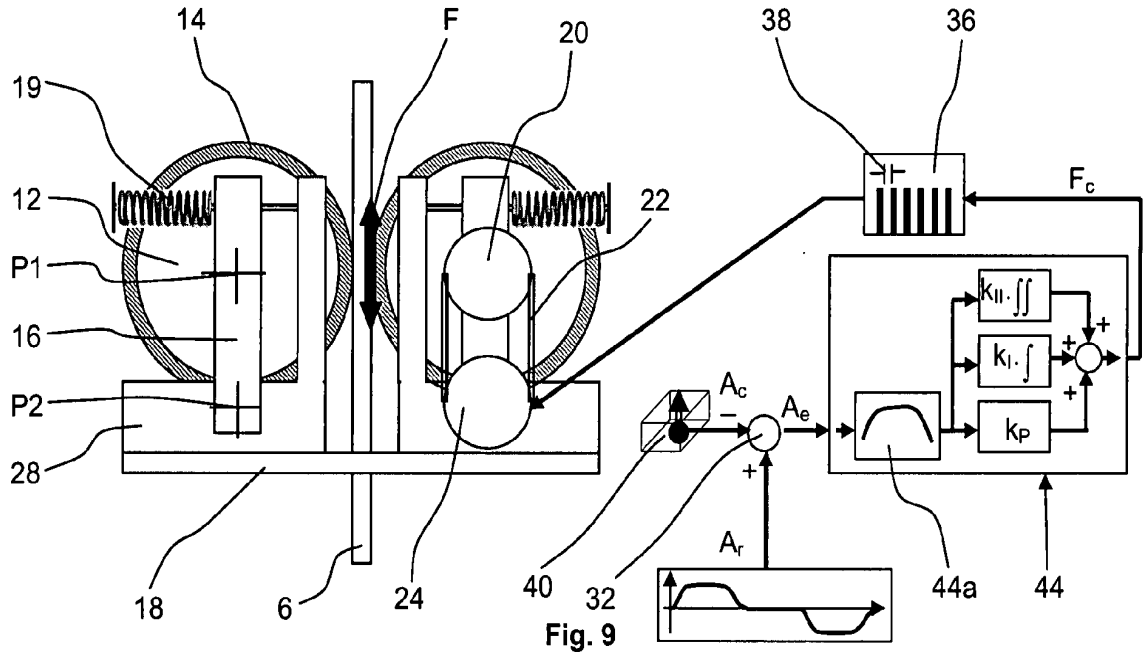


Fig. 9