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(54) Title: SUPERCHARGER SYSTEM FOR STOP/START HYBRID OPERATION OF AN INTERNAL COMBUSTION ENGINE

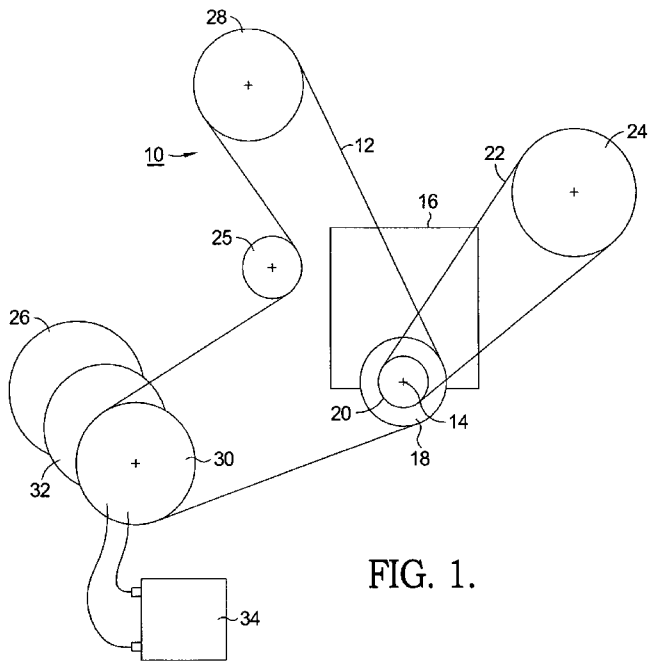


FIG. 1.

(57) Abstract: A supercharger system for supplying compressed air to an internal combustion engine, including a supercharger; an active clutch operationally connected to the engine that can be selectively opened and closed; a motor/generator operationally connected to the supercharger; an energy storage device operationally connected to the motor/generator; and a secondary drive element connecting the supercharger, the clutch, and the motor/generator to permit synchronous rotation thereof, the clutch being disposed either directly on the crankshaft of the engine or on a primary accessory drive element of the engine. Other devices such as an HVAC compressor may be included optionally on the secondary drive element. At low engine speeds, the supercharger is powered by the motor/generator; at high engine speeds, by the engine.

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SUPERCHARGER SYSTEM FOR STOP/START HYBRID OPERATION OF AN INTERNAL COMBUSTION ENGINE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/126,626, filed May 6, 2008.

TECHNICAL FIELD

The present invention relates to supercharging systems for internal combustion engines; more particularly, to such a system that may be driven by a starter/motor/generator and an energy storage device such as a battery at low engine speeds, or by the engine at high engine speeds; and most particularly, to such a system that may be selectively decoupled from the engine to permit continued electric operation of other components such as an A/C compressor when the engine is shut off.

BACKGROUND OF THE INVENTION

Typical prior art internal combustion engines (ICE) employ a starter motor to crank and start the engine and a separate generator or alternator to recharge the battery and power electric accessories. An integration of these functions into one electric machine is now offered by some automotive OEMs, known in the art as an Integrated Starter Generator (ISG). In one prior art arrangement, the ISG is mounted on an accessory drive belt of the engine. This prior art arrangement is known in the art as a Belt Alternator Starter (BAS) system.

Some prior art ICE systems also mount an air conditioning compressor on the accessory drive. With a clutch and/or variable stroke mechanism, the air

conditioning load can be satisfied under widely varying engine speeds. However, such BAS systems with mechanical air conditioning must keep the engine idling to maintain air conditioning performance, which negates much of the efficiency benefit of the BAS system in low speed, stop-and-go driving.

Some prior art diesel ICE systems, and an increasingly large number of gasoline (or alternative fuel) ICE systems, use a turbocharger and/or supercharger to boost the engine torque and power, which can permit use of a smaller, lighter, more nimble engine. See, for example, the Volkswagen twincharger® that uses both a turbocharger and a roots supercharger with a clutch to boost a 1.4-liter four-cylinder engine. In addition to the obvious advantages of a high power-to-weight engine in a vehicle, there are emissions and efficiency advantages for boosted engines, although at the expense of substantial increases in complexity and cost.

Turbochargers are essentially exhaust-driven superchargers, which are attractive in terms of the cost and efficiency of powering the compressor. However, turbochargers are not well matched to engine needs in the sense that the powering exhaust temperature and flow tends to be insufficient at low engine speeds (where more boost would be useful for emissions and driveability) and excessive at high engine speeds. Trying to compensate for these deficiencies gives rise to use of waste gates, variable geometry devices, and even multi-staged boosting, adding considerable cost and complexity.

Supercharging can have more impact on low RPM torque and is a good candidate for improving engine performance in highly downsized engines. It is also being considered for future ICE systems, such as Homogeneous Charge Compression Ignition (HCCI) engines and engines fueled by gases such as Compressed Natural Gas (CNG) or hydrogen. Component suppliers have developed prototype electric superchargers and prototype turbochargers with integral high speed electric motor/generators; however, none of these have been introduced into volume production.

Hybrid electric vehicles are also experiencing significant interest in the automotive industry, with stop/start "mild" hybrids becoming standard architecture for many OEMs. For example, Toyota® sold a mild hybrid system in their domestic

(Japan) market from approximately 2001 to 2006. This system was intended as a limousine/taxicab and its stop/start enabled much improve fuel economy in congested traffic duty cycles. The system included a clutched accessory drive with the alternator upgraded to a 42/36-volt starter/motor/generator, power steering, and A/C compressor, which could be operated from a battery with the engine off, to maintain power steering and A/C operation. This system did not include a supercharger or turbocharger on the secondary belt drive.

What is needed in the art is a compact, low cost, and efficient means to boost performance of an internal combustion engine independently of the exhaust temperature and flow rate, with an emphasis on low speed boosting, where it is most needed.

What is also needed in the art is the ability to operate accessories such as air conditioning independently of the engine.

What is further needed in the art is the ability to start and stop the engine quickly and smoothly, for fuel economy under start and stop driving conditions, while maintaining continuous operation of non-engine-related functions such as power steering assist, HVAC including an A/C compressor, and power braking assist.

It is a principal object of the present invention to combine a stop/start system with a hybrid drive (electrical and mechanical) supercharger to allow variable boost at low engine speeds independent of RPM and mechanical supercharging by the engine at high RPM.

SUMMARY OF THE INVENTION

Briefly described, a stop/start hybrid supercharger system in accordance with the invention comprises a secondary drive element such as a belt, chain, or direct coupling that is operationally connected to the crankshaft of an internal combustion engine. The secondary drive element may be operationally connected to the front of the engine (for example, via an accessory drive element or directly on the front of the crankshaft) or to the rear of the engine (for example, geared to the flywheel or to a rotating element synchronized to the output shaft of the engine or to input shaft to

the transmission). The secondary drive element may be driven by a primary drive element such as a primary belt, pulley or chain via an active clutch, preferably a two-speed clutch wherein the second (higher) speed is active and wherein the first (lower) speed is optionally passive via a so-called overrunning clutch. This allows the operation of the system in electric and mechanical (high speed) modes and also (optionally) in a mechanical (low speed) mode. This allows the accessories (including the supercharger, which tends to be the highest peak power device) to be powered primarily mechanically, by the crankshaft, above a predetermined engine speed. The system includes a low-inertia starter/motor/generator having a wide speed range, coupled to the secondary drive element, and a supercharger driven by the starter/motor/generator, either directly (preferred) or via an intermediate linkage as described below. The starter/motor/generator may be electric, hydraulic, or pneumatic but is electric in a presently-preferred embodiment. The supercharger may be a turbo-compressor (centrifugal, axial or mixed flow), "Roots" blower, twin screw "Lysholm" compressor, scroll compressor etc.. In the case of the turbo-compressor, a gear or traction drive must be used to boost from accessory drive speed to compressor shaft speed. With the other compressor types, it is possible to use direct drive or a more modest drive ratio, accommodated by a pulley ratio or single gear set. The system also includes one or more rechargeable energy storage devices, such as an electric battery, ultracapacitor, or hydraulic or pneumatic accumulator (a battery in the presently preferred electric embodiment) and optionally additional accessory devices such as a mechanical A/C compressor, hydraulic power steering pump, and hydraulic or vacuum pump for power brakes and an air compressor. These accessories tend to have performance demands independent of engine speed. Via the secondary drive element, the single starter/motor/generator may operate all the apparatus in the supercharger system, thus saving the cost, weight, and complexity of providing separate motors for each item.

In operation of the system for engine startup, the secondary drive element is coupled to the engine by closing the active clutch to allow the engine to be started by the starter/motor/generator. This supplies modestly compressed air to the ICE from

the supercharger driven by the starter/motor/generator, thereby increasing the temperature of the air and improving the volumetric efficiency of the ICE.

After engine starting, the accessory drive can be operated mechanically by the crankshaft or electrically by the starter/motor/generator. For example, the HVAC can operate with enhanced cooling performance by temporarily running the A/C compressor electrically and thus at a higher speed relative to the engine when the engine is operating at low speed. The A/C compressor can also be operated mechanically at a high engine speed when the active clutch is engaged. Similarly, during peak acceleration, the starter/motor/generator draws power from the battery to drive the secondary drive element which drives the supercharger at high speed, providing high engine boost during initial acceleration from idle. This is markedly superior to the boost provided by prior art engine-coupled superchargers and/or turbochargers.

During a continued peak acceleration, the active clutch must be closed in order to transition from electric power to full or partial mechanical power for the supercharger. This is because at a certain predetermined engine speed, the starter/motor/generator has insufficient power capacity to provide the full engine boost. At engine speeds above this point, the starter/motor/generator may be used as a generator, to supply electrical loads and recharge the battery, and the supercharger and A/C compressor may be fully driven by the engine. In a transient condition or where the energy store is over-full relative to a target level, the supercharger and other accessories may continue to be partially powered by the starter/motor/generator to supplement the torque of the engine. In cruise conditions, wherein supercharger boost is not needed and wherein continuous accessory or battery charging needs are easily met (for example at mid to high engine speeds), the clutch is preferably a two-speed clutch that allows the secondary drive element to operate at a first (substantially lower) speed ratio. This serves at a minimum to reduce the parasitic losses of the bypassing and freewheeling supercharger to a low level. It may also allow a modest amount of energy recovery by allowing the supercharger to act as an expander. When running as an expander, the motor/generator can set the speed of the supercharger independently of the engine,

or, with typically higher accessory loads, the over-running clutch engages to keep the accessories running at a desired minimum speed ratio, relative to the engine. In order to use a roots supercharger as an expander, it is necessary to reduce the speed by a factor of between 3.0 and 4.0 compared to the normal speed for mechanical supercharging. These numbers may vary somewhat further based on the target boost pressure (when supercharging) vs. the target vacuum level (when using the supercharger as an expander). Also, the optimal ratio will vary with other supercharger types. In aggregate, this would define a useful range of 2.0 to 5.0 for specification of the ratio between high and low speeds of the two-speed clutch. While the supercharger may act somewhat inefficiently as an expander, it is often useful to run it as an expander to maintain the intake manifold pressure at somewhat below atmospheric pressure. For example, this allows exhaust gas recirculation and evaporative canister purge to function. For another example, it may be useful to operate the intake at an increased level of vacuum for a period of time after cold start to improve the vaporization of fuel (with a beneficial effect on emissions and driveability). Thus, energy recovery from using the supercharger as an expander in cruise and idle conditions may reduce cruise fuel consumption. During regenerative braking of the vehicle, the clutch is returned to the second (higher) speed to enable maximum regenerative and engine braking.

In stop/start mode of vehicle operation, when the vehicle is stopped, the engine is shut down. The clutch is opened, allowing the peripheral functions such as HVAC to continue to operate via battery power, which is particularly useful in hot or cold climates.

The following benefits are provided by a supercharger system in accordance with the present invention:

1. Flexible boosting which enables high engine torque from idle to red-line.

2. Fast response (very short lag during transients).

3. Capable of low emissions because of fast warm-up (no thermal mass of turbocharger in the exhaust).

4. Reduced parasitic energy loss of supercharger under engine cruise conditions.

5. Ability to boost the engine and run the starter motor at high speed allows improved engine starts: less torque required through the clutch, better fuel vaporization through adiabatic air heating in the supercharger, and high starter motor speed reduces the required dynamic range for the starter/motor/generator and positive pumping work through the engine. This may allow elimination or derating of other cold start devices such as glow plugs or fuel, coolant, and air heaters or a redundant conventional starter motor.

6. Single electric machine allows single power electronics with relatively low power level (2-5 kW) typical for a light duty passenger vehicle (or modestly higher for a commercial system) because supercharging power requirement at higher engine speeds is met by mechanical linkage to the engine.

7. Torque and power capability similar to that provided by the Volkswagen twincharger system but the cost and complexity of the turbocharger system is replaced by the starter/motor/generator stop/start function. This allows gains in low speed, stop-and-go efficiency with the hybrid function and with the possibility of "expander" energy recovery in low power conditions, offset with a modest efficiency penalty in high speed/high power conditions. The system also allows more substantial downsizing of the ICE, with equivalent low RPM torque. For many drivers, this will result in higher real world fuel efficiency.

8. Enhanced air conditioning and heating (with the engine "OFF") and enhanced HVAC performance using electric or high speed mechanical operation (with the engine "ON").

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

FIG. 1 is a schematic drawing of a first embodiment in accordance with the present invention; and

FIG. 2 is a schematic drawing of a second embodiment in accordance with the present invention.

Corresponding reference characters indicate corresponding parts throughout the several views. The exemplification set out herein illustrates one preferred embodiment of the invention, in one form, and such exemplification is not to be construed as limiting the scope of the invention in any manner.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIGS. 1 and 2, a stop/start hybrid supercharger system 10 in accordance with the present invention comprises a secondary drive element 12 such as a belt, chain, or direct coupling that is operationally connected to the crankshaft 14 of an internal combustion engine 16. Secondary drive element 12 may be driven directly via a clutch 18 to permit automatic selective drive of the secondary drive element 12 by the engine crankshaft above a predetermined minimum engine speed. Preferably clutch 18 comprises at least an active (on/off) clutch, and preferably also a passive (so-called "over-running") clutch. In FIG. 1, clutch 18 is mounted directly on the end of crankshaft 14, along with a pulley damper 20 for driving a primary drive element 22 such as a primary belt or chain at a fixed ratio to engine speed. In FIG. 2, clutch 18 is mounted for being driven by primary drive element 22.

An "over-running" clutch refers to a clutch between two rotatable elements that latches and unlatches with relative rotation of the input and output elements. If the input element (in the present case connected to engine 16 either directly as in FIG. 1 or via primary drive element in FIG. 2) is at the speed of the output element (connected to supercharger secondary drive element 12) the clutch latches. If the engine is turning slower than secondary drive element 12, the clutch freewheels, allowing secondary drive element 12 to run faster than synchronous with engine 16. Thus, for engine 16 to be driven by system 10 as in starting mode, an additional, on/off clutch is required (also referred to herein as an "active" clutch). The two clutches are not in series but may be on different elements of a planetary gear set, as is known in the prior art.

In the present discussion, the term "primary" should be taken to mean comprising apparatus 24 either necessary to the functioning of the engine or which

needs to rotate at a fixed ratio to the engine speed, e.g., a water pump. "Secondary" should be taken to mean comprising apparatus either non-essential to the functioning of the engine or which needs to rotate at a speed independent of engine speed, e.g., supercharger 26, A/C compressor 28, or power steering (not shown) and power brakes (not shown) which may be optionally included in system 10.

System 10 further includes a low-inertia starter/motor/generator 30 having a wide speed range, coupled to the secondary drive element 12. Supercharger 26 is driven by starter/motor/generator 30, either directly (preferred) or via an intermediate linkage such as an additional belt (not shown). If supercharger 26 includes a turbo-compressor, a high-speed transmission 32 may be inserted between starter/motor/generator 30 and supercharger 26. The starter/motor/generator 30 may be electric, hydraulic, or pneumatic but is electric in a presently-preferred embodiment. The system also includes an energy storage device 34, such as a battery, ultracapacitor, hydraulic or pneumatic accumulator, or combinations thereof.

Clutch 18, having 2 speeds (active, plus passive over-running) selectively operates in the following modes:

1. at a fixed multiple of engine speed (when the engine is "ON" and the overrunning clutch latches), for example when the engine is in "cruise" mode.
2. at a fixed higher multiple of engine speed (when the active clutch is "ON"), for example, when the engine is being supercharged.
3. at a variable speed, independent of the engine, when the active clutch is "OFF" and the engine is "OFF" or running at a lower speed than the supercharger system.

The second embodiment 10 shown in FIG. 2 packages these devices on the primary drive element 22 of the engine 16. The simplest short term integration is to mount the starter/motor/generator 30, A/C compressor 28, supercharger 26, and a belt tensioner 25 on secondary drive element 12. The two- speed, overrunning clutch 18 can latch, lock, or freewheel according to the operating conditions with primary drive element 22 that is linked to crankshaft 14 and any other accessories 24 that remain (such as the water pump, power steering pump, cooling fan etc.).

The supercharger device 26 may be a turbo-compressor (centrifugal, axial, or mixed flow, i.e. the cold side of a turbocharger) or a Roots blower, or scroll or Lysholm compressor. In the case of a turbo-compressor, a high ratio drive 32 is required to spin the compressor at a very high speed (compared to the secondary drive element 12). This may be with a gear set or a roller traction drive. In the case of the other supercharger technologies, a more moderate step up drive may be used or the device may run at the same speed as its secondary drive.

The system has a large cost benefit, by using a single starter/motor/generator 30 (and associated controls) to do multiple functions. For example, in the case of an electric starter/motor/generator 30, this starter/motor/generator 30 can provide:

- engine starting (both for initial cold start and subsequent stop-start cycles),
- steady state (low power) generating to run accessories and keep a battery charged,
- hybrid electric functions (torque assist and regenerative braking) using the ultracapacitor or other high power energy storage 34 to source or sink the required power,
- engine independent boosting, and
- engine independent air conditioning.

The system has a number of secondary benefits that may not be obvious:

Engine Starting: By supercharging the engine during cranking, the engine is provided with air that is compressed relative to atmospheric and thus does negative pumping work (with the ICE acting as an expander), thereby reducing the torque that must be transmitted via the active clutch. The boosted air also is warmed by adiabatic compression, improving the ability of the engine to start in cold weather conditions wherein fuel vaporization rate is often a limiting factor. In cranking the engine via active clutch 18, the speed of the starter/motor/generator 30 is relatively high, allowing a beneficial compromise between the design of a starter motor (which tends to be heavy in the prior art in order to produce high torque at very low motor speeds) and a lighter, high-speed lower-torque machine for the generator, hybrid electric, engine boosting, and electric air conditioning functions.

By starting the crank sequence by spinning up the starter/motor/generator 30 and supercharger before the active clutch is engaged, the dynamic torque of the

spinning supercharger system when the clutch becomes engaged helps to overcome the static friction and inertia of the stationary engine crankshaft. This improves the ability to start in extreme climatic conditions and also allows larger displacement engines or diesel engines to adopt this system (as well as small gasoline engines which, by definition, take less power to crank).

Of course, in some applications, such as large truck diesel engine systems, starting may still be performed conventionally with a separate starter motor independent of the supercharger system. However, even in such instances, it is still beneficial to have the supercharger system operating at high speed, with active clutch open and the over-running clutch freewheeling, before engaging the starter motor, for reasons described above.

Engine Boosting: By configuring the boost system as a hybrid system, the required power level of the starter/motor/generator 30 is consistent with the requirements for the other functions. At higher engine speeds, where the boost power is very high, the supercharger system can be substantially or 100% mechanically driven via the drive system and the active clutch. Thus, a relatively small electric machine (for example approximately 3 kW) can supply substantial boosting at low engine speeds (for example below 1800 rpm for a 2.0L gasoline engine). At very high engine speeds, for example, in climbing a mountain or towing a trailer, the much higher power level required for supercharger boosting (for example > 15 kW) may be supplied mechanically by the engine, allowing full boost up to the red line of the engine. In contrast, some prior art electric superchargers use a dedicated electric motor to try to cover the entire range of demanded boost, which motor is then either too low in power to have any impact except at low engine RPM or too large and expensive to be practical.

Normal (unboosted) driving: In normal cruise operation, the active clutch is "open" and over-running clutch 18 may latch providing a minimum speed ratio for the accessories of system 10 relative to the ICE. This reduces the parasitics of operating the accessories fast (at light load or stand-by conditions) as is the case with prior art accessory arrangements. For example, many aftermarket supercharged ICE systems are driven at fixed ratio to the engine speed. Under low

load conditions, a by-pass valve short circuits the supercharger (relieving the pressure), but the supercharger still rotates at high speed (at a fixed multiple of engine speed) such that some mechanical and pneumatic losses continue. The present system rotates the supercharger at a much lower speed, such that these losses are much reduced. With appropriate design of the low speed ratio and supercharger type and porting (especially if the supercharger is a roots blower), the supercharger may actually act as an expander, recovering a small but useful amount of energy which would otherwise be lost in throttling the engine with a conventional throttle valve. Under this "expander" operation, the speed can be determined by the latched over-running clutch or by the torque balance of the accessory load (generator, A/C compressor etc.) vs. the expander power. When the active clutch is latched, a fraction of the accessories are powered by the expander. When the clutch over-runs, all of the accessory loads are supplied by the expander.

Regenerative braking: By switching to the high relative speed (using the second high speed clutch), the starter/motor/generator 30 can provide a high level of regenerative braking, even at relatively low engine speeds. Thus, the pneumatic load of the supercharger also contributes to the braking power. This reduces the wear on brakes and reduces the level of vacuum in the intake manifold (which can be problematic in terms of oil consumption, particularly for diesel engines). When a pneumatic accumulator is provided, this pneumatic energy may also be stored for future use in engine starting and/or transient boosting.

While the present supercharger system 10 is very capable in terms of performance, fuel efficiency and emissions compliance, some applications may use both system 10 as described and a turbocharger (not shown). In such cases, the ability to variably boost the engine at low RPM allows the turbocharger be biased towards high speed/high power driving conditions. It also should allow the cost, complexity, and losses associated with variable geometry turbocharger actuation to be substantially reduced while still providing high levels of boost in transient conditions with "lag" controllable to a small fraction of a second. The overall result is to offer a range of solutions that can be applied to relatively small displacement engines, thereby avoiding the historical marketing logic of offering several optional

higher-displacement engines which tend to be less fuel efficient. For example, a standard engine/vehicle system might be a start-stop hybrid without supercharging, and the novel system disclosed herein would cover the up-option supercharged system as well as the most capable and efficient stop/start supercharged and turbocharged embodiment.

While the invention has been described by reference to various specific embodiments, it should be understood that numerous changes may be made within the spirit and scope of the inventive concepts described. Accordingly, it is intended that the invention not be limited to the described embodiments, but will have full scope defined by the language of the following claims.

CLAIMS

What is claimed is:

1. A supercharger system for an internal combustion engine, comprising:

a) a supercharger for delivering compressed air to said engine;

b) a clutch operationally connected to said engine, said clutch including an active clutch portion that can be selectively opened or closed;

c) a starter/motor/generator operationally connected to said supercharger;

d) an energy storage device operationally connected to said starter/motor/generator; and

e) a drive element connecting said supercharger, said clutch, and said starter/motor/generator to permit synchronous rotation thereof,

wherein said clutch is disposed in a position selected from the group consisting of directly on the crankshaft of said engine, on an accessory drive element of said engine, and on a rotating element in the drive line which is normally connected to the output shaft of said engine,

wherein said system is coupled mechanically to said engine when said active clutch portion is closed, and

wherein said system is decoupled mechanically from said engine and may be driven by said starter/motor/generator when said active clutch portion is open.

2. A supercharger system in accordance with Claim 1 wherein said starter/motor/generator and said energy storage device are each selected from the group consisting of electric, hydraulic, and pneumatic.

3. A supercharger system in accordance with Claim 1 wherein said clutch is a two-speed clutch having a first speed defined by a second clutch and a second speed defined by said active clutch, wherein said first speed is lower than said second speed.

4. A supercharger system in accordance with Claim 3 wherein said second clutch comprises a passive, over-running clutch..

5. A supercharger system in accordance with Claim 1 further comprising a high-speed transmission disposed between said starter/motor/generator and said supercharger.

6. A supercharger system in accordance with Claim 1 further comprising an A/C compressor disposed on said drive element.

7. A supercharger system in accordance with Claim 1 wherein said drive element is selected from the group consisting of belt, chain, and direct coupling.

8. A method for controlling a supercharger system for starting a stopped internal combustion engine in an Engine Start Mode, the supercharger system including a supercharger for supplying compressed air to the engine, a clutch operationally connected to the engine, said clutch including an active clutch portion that can be selectively opened or closed, a starter/motor/generator operationally connected to the supercharger, an energy storage device operationally connected to the starter/motor/generator, and a drive element connecting the supercharger, the clutch and the starter/motor/generator to permit synchronous rotation thereof,

the method comprising the following steps:

a) energizing said starter/motor/generator from said energy storage device to drive said drive element; and

b) closing said active clutch portion to operationally connect said system mechanically to said engine to cause said engine to rotate at a starting speed.

9. A method in accordance with Claim 8 wherein said drive

element has a first rotational speed to cause said engine to rotate at said starting speed and a second rotational speed higher than said first rotational speed wherein said drive element is brought to said second rotational speed prior to said closing step.

10. A method for controlling a supercharger system for operating an internal combustion engine in an Electrically-driven Supercharger Boost Mode, the supercharger system including a supercharger for supplying compressed air to the engine, a clutch operationally connected to the engine, said clutch including an active clutch portion that can be selectively opened or closed, and an over-running clutch portion having a first rotational element directly connected to an output drive of said engine and a second rotational element directly connected to a drive element, a starter/motor/generator operationally connected to the supercharger, an energy storage device operationally connected to the starter/motor/generator, and said drive element connecting the supercharger, the clutch, and the starter/motor/generator to permit synchronous rotation thereof,

the method comprising the following steps:

a) opening said active clutch portion to decouple said supercharger system mechanically from said engine; and

b) operating said starter/motor/generator and said drive element at a speed wherein a rotational speed of said second rotational element is greater than a rotational speed of said first rotational element and wherein said second rotational element over-runs said first rotational element.

11. A method in accordance with Claim 10 wherein, in said operating step, said operating speed of said starter/motor/generator is selectively varied, and wherein an operational speed of said supercharger is varied synchronously.

12. A method in accordance with Claim 11 wherein said over-running clutch portion includes a latch point when said rotational speed of said first rotational element equals said rotational speed of said second rotational element, wherein, in

said operating step, a minimal operational speed of said supercharger relative to said engine output drive is established by said latch point.

13. A method for controlling a supercharger system for operating an internal combustion engine in a Mechanically-driven Supercharger Boost Mode, the supercharger system including a supercharger for supplying compressed air to the engine, a clutch operationally connected to the engine, said clutch including an active clutch portion that can be selectively opened or closed, a starter/motor/generator operationally connected to the supercharger, an energy storage device operationally connected to the starter/motor/generator, and a drive element connecting the supercharger, the clutch, and the starter/motor/generator to permit synchronous rotation thereof,

the method comprising the following steps:

a) closing said active clutch portion to couple said supercharger system mechanically to said engine; and

b) operating said supercharger, said starter/motor/generator and said drive element at a speed synchronous with the speed of said engine.

14. A method for controlling a supercharger system for operating an internal combustion engine in a Regenerative Braking Mode, the supercharger system including a supercharger for supplying compressed air to the engine, a clutch operationally connected to the engine, said clutch including an active clutch portion that can be selectively opened or closed,a starter/motor/generator operationally connected to the supercharger, an energy storage device operationally connected to the starter/motor/generator, and a drive element connecting the supercharger, the clutch, and the starter/motor/generator to permit synchronous rotation thereof,

the method comprising the following steps:

a) closing said active clutch portion to couple said supercharger system mechanically to said engine;

b) operating said starter/motor/generator as a high power generator.

15. A method in accordance with Claim 14 further including the step of operating said supercharger to compress air.

16. A method in accordance with Claim 15, wherein said compressed air is a stored for subsequent boosting of said engine, for braking functions or for emission control functions.

17. A method for controlling a supercharger system for operating an internal combustion engine in a High Power Accessories Mode, wherein a clutch is operationally connected to the engine, said clutch including an active clutch portion that can be selectively opened or closed, a supercharger, a starter/motor/generator and an optional A/C compressor, and a drive element connecting the clutch to the supercharger, starter/motor/generator and A/C compressor to permit synchronous rotation thereof,

the method comprising the following steps:

a) closing said active clutch portion to couple said supercharger system mechanically to said engine at a second higher speed; and

b) operating at least one of said starter/motor/generator as a high power generator or said A/C compressor at a high power level.

18. A method for controlling a supercharger system of an internal combustion engine wherein a clutch is operationally connected to the engine, said engine including an output drive, said clutch including an active clutch portion that can be selectively opened or closed wherein said clutch is a two-speed clutch having a first output speed defined by a second passive over-running clutch and a second output speed higher than said first output speed, said second output speed defined by said active clutch, a supercharger for delivering compressed air to said engine, a starter/motor/generator operationally connected to the supercharger and a A/C compressor, an energy storage device operationally connected to said starter/motor/generator and a drive element connecting the clutch to the

supercharger, starter/motor/generator and A/C compressor to permit synchronous rotation thereof,

the method comprising the step of selectively operating said drive element at one of a low speed or a high speed relative to a rotational speed of said engine output drive.

19. A method in accordance with Claim 18 wherein at least one of said A/C compressor or said supercharger is drive at one of a low speed or a high speed by said drive element.

20. A method for controlling a supercharger system for operating an internal combustion engine in a Cruise Mode, the supercharger system including a supercharger for supplying compressed air to the engine, a clutch having a first output speed and a second output speed operationally connected to the engine, said clutch including an active portion that can be selectively opened or closed, said active portion defining said second output speed when said active portion is closed, said second output speed being higher than said first output speed, a starter/motor/generator operationally connected to the supercharger, an energy storage device operationally connected to the starter/motor/generator, and a drive element connecting the supercharger, the clutch and the starter/motor/generator to permit synchronous rotation thereof,

the method comprising the following steps:

a) opening said active clutch portion wherein said supercharger is driven by said first output speed; and

b) operating said drive element, said A/C compressor and said supercharger at a lower speed than would otherwise be defined by the second output speed.

21. A method in accordance with Claim 20 , wherein, in the operating step, said lower speed is between 2 and 5 times lower than a speed that would otherwise be defined by said second output speed.

22. A method in accordance with Claim 20 wherein, in said operating step, said supercharger is operated as an expander.

23. A method in accordance with Claim 20 further including a bypass valve coupled to said supercharger wherein said bypass valve causes at least a portion of supercharger air pressure to be relieved, the method further comprising the step of selectively operating said bypass valve to selectively relieve said air pressure.

24. A method for controlling a drive system of an internal combustion engine for operating a supercharger for supplying compressed air to said engine and an A/C compressor, the system including a clutch operationally connected to the engine, said clutch including an active clutch portion that can be selectively opened or closed, a starter/motor/generator operationally connected to said supercharger, an energy storage device operationally connected to the starter/motor/generator, and a drive element connecting the A/C compressor, the clutch,and the starter/motor/generator to permit synchronous rotation thereof,

the method comprising the following steps:

a) opening said active clutch portion to decouple said drive element mechanically from said engine; and

b) driving said A/C compressor with said starter/motor/generator when said engine is in one of a low speed or engine off mode.

25. A method in accordance with Claim 24 further comprising the step of driving said supercharger with said starter/motor/generator when said engine is in a low speed mode.

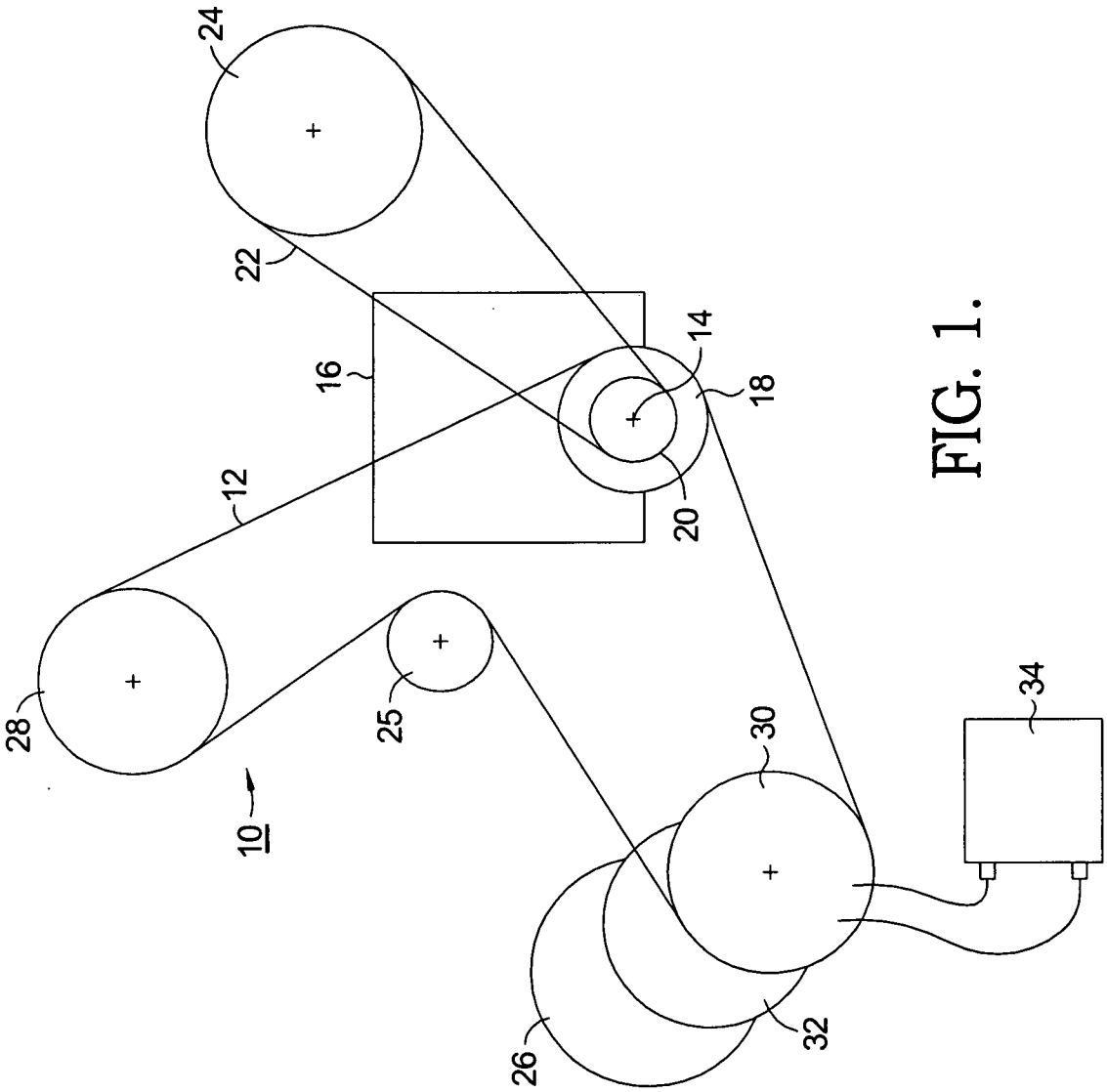


FIG. 1.

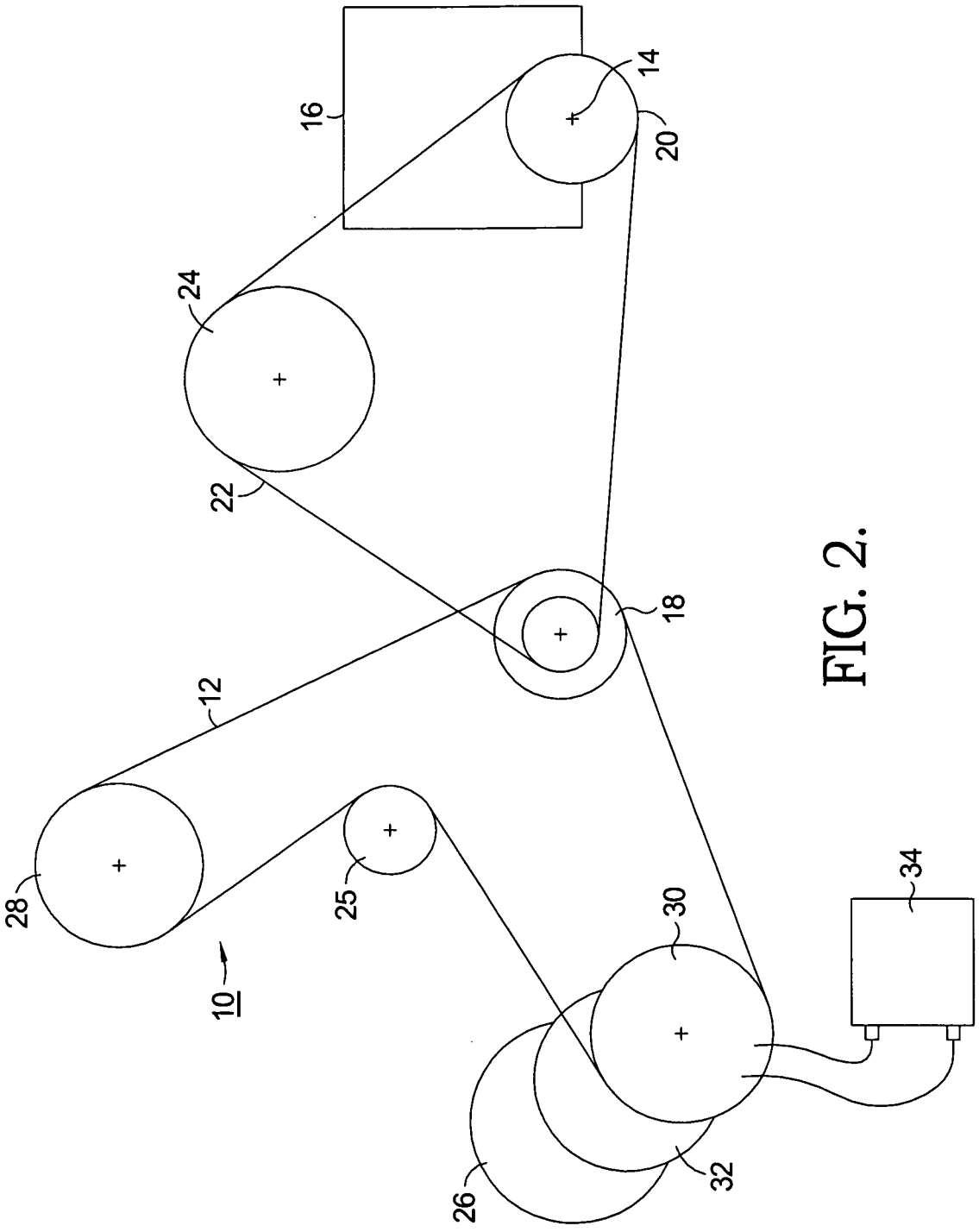


FIG. 2.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US 09/02364

A. CLASSIFICATION OF SUBJECT MATTER
IPC(8) - F02B 33/00 (2009.01)
USPC - 123/559.1
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC(8) - F02B 33/00 (2009.01)
USPC - 123/559.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
USPC - 123/434, 565; 60/598, 597, 605.1 (text search - see terms below)

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
PubWEST(USPT,PGPB,EPAB,JPAB); Google Scholar; Google Patents
Search Terms: supercharger, clutch, starter, motor, generator, energy, storage, two, speed, passive, over-running, A/C, compressor, second, stop, hybrid, operation, stored, compressed, air, expander, bypass, valve

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y	US 2006/0174624 A1 (Grabowski et al.) 10 August 2006 (10.08.2006), Fig 10, para [0027], [0035], [0041], [0047], [0055] and [0057]	1-2, 6-8, 13-15 and 17 --- 3-5, 9-12, 16 and 18-25
Y	US 6,082,340 A (Heimark) 04 July 2000 (04.07.2000), col 3, ln 8-10 and ln 18-23	3-4, 9 and 18-23
Y	US 7,051,824 B1 (Jones et al.) 30 May 2006 (30.05.2006), col 8, ln 16-18	5
Y	US 2006/0180130 A1 (St. James) 17 August 2006 (17.08.2006), para [0030]	4, 10-12, 18-19 and 24-25
Y	US 5,529,549 A (Moyer) 25 June 1996 (25.06.1996), col 4, ln 62-65	16
Y	US 4,802,457 A (Oscarsson) 07 February 1989 (07.02.1989), col 4, ln 38-44	22
Y	US 4,848,086 A (Inoue et al.) 18 July 1989 (18.07.1989), col 1, ln 19-23	23

☐ Further documents are listed in the continuation of Box C. ☐

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier application or patent but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
26 May 2009 (26.05.2009)	11 JUN 2009
Name and mailing address of the ISA/US Mail Stop PCT, Attn: ISA/US, Commissioner for Patents P.O. Box 1450, Alexandria, Virginia 22313-1450 Facsimile No. 571-273-3201	Authorized officer: Lee W. Young PCT Helpdesk: 571-272-4300 PCT OSP: 571-272-7774

Form PCT/ISA/210 (second sheet) (April 2007)