An air hybrid vehicle is powered by a downsized internal combustion engine (16 see fig 1) equipped with a rotary air charger (10 see fig 1) which may be a supercharger and/or a turbocharger for pressure charging the engine while having selectable means for loading and unloading the air charger. At times when there is access to a high pressure compressed air source (100 see fig 1), the compressed air source is connected to an air accumulator (110 see fig 1) in the vehicle for delivering into the accumulator a charge of high pressure compressed air which is stored in the air accumulator, and at times when there is no access to a high pressure compressed air source and the vehicle is driven on load by the engine (16) the air supply to the engine (16) is selectable by one of at least three routes: a) naturally aspirated when boost is not required and the rotary air charger (10) is unloaded, b) pressurised air is delivered from the air accumulator (110) to the engine (16) when boost is required while the rotary air charger is unloaded, and c) pressurised air is delivered from the rotary air charger(10) to the engine (16) when boost is required and the rotary air charger is loaded. The vehicle achieves fuel saving and high performance by not having to drive the rotary air charger when the engine (16) is supplied with pressurised air according to route b) pre-charged in the air accumulator (110). Mains electricity is used to power the high pressure compressed air source (100) so that the vehicle benefits from energy displacement by indirectly using mains electricity instead of on-board fuel to power the boosting of the engine (16).
Fig. 2a

Fig. 2b
PLUG-IN AIR HYBRID VEHICLE

Field of the invention

The present invention relates to a hybrid vehicle using air energy as well as fuel energy on board the vehicle.

Background of the invention

It is known that engine downsizing significantly reduces the fuel consumption of a motor vehicle by providing a small capacity engine operating near its maximum efficiency under naturally aspirated conditions just big enough to meet the most frequently used low and medium load demands of the vehicle, and then catering for the occasional high load demands by boosting the engine with pressurised air supplied from a turbocharger or supercharger. Such a downsized engine will be lighter and produce the same or even higher maximum torque and power than a bigger and heavier naturally aspirated engine, and a vehicle equipped with this engine will have good performance, fun-to-drive as well as good fuel economy.

It is also known that a regenerative hybrid vehicle can achieve significant reduction in fuel consumption (hence CO₂ reduction) by recovering some of the kinetic energy of the vehicle during deceleration or braking of the vehicle and transforming it into another form of energy which can be stored and later re-used.

One example is the electric hybrid vehicle in which the braking energy is transformed into electric energy and stored in an electric battery for future use. Another example is the inertia hybrid vehicle in which the braking energy is transformed into inertial energy and stored in a spinning flywheel for future use. A further example is the pneumatic hybrid vehicle in which the braking energy is
transformed into pneumatic energy and stored in a compressed air tank for future use.

It is further known that a plug-in hybrid electric vehicle can be powered separately or in combination by an internal combustion engine and an electric motor both on-board the vehicle. When there is access to mains electricity the electricity is used to charge the battery in the vehicle sufficiently to drive the vehicle using only the electric motor during an average daily journey so that the battery is the main source of energy and needs to be re-charged on average once per day while the vehicle still has full backup of high performance and long travel range by switching over to the engine whenever it is required. In this way, the vehicle benefits from energy displacement by using mains electricity instead of on-board fuel to drive the vehicle in the average daily journeys and saves on-board fuel by using the engine as little as possible.

Aim of the invention

The present invention aims to achieve a high efficiency plug-in air hybrid vehicle.

Summary of the invention

According to the present invention, there is provided an air hybrid vehicle powered by an internal combustion engine equipped with a rotary air charger for pressure charging the engine while having selectable means for loading and unloading the air charger, the vehicle characterised in that at times when there is access to a high pressure compressed air source, the compressed air source is connected to an air accumulator in the vehicle for delivering into the accumulator a charge of high pressure compressed air which is stored in the air accumulator, and at times when there is no access to a high pressure
compressed air source and the vehicle is driven on load by
the engine the air supply to the engine is selectable by one
of at least three routes: route a) naturally aspirated when
boost is not required and the rotary air charger is
unloaded, route b) pressurised air is delivered from the air
accumulator to the engine when boost is required while the
rotary air charger is unloaded, and route c) pressurised air
is delivered from the rotary air charger to the engine when
boost is required and the rotary air charger is loaded, the
vehicle achieving fuel saving and high performance by not
having to drive the rotary air charger when the engine is
supplied with pressurised air according to route b) pre-
charged in the air accumulator.

The rotary air charger may be a supercharger or a
turbocharger driven mechanically or by exhaust gases
respectively supplying pressurised air the engine, or a
combined supercharger and turbocharger connected in series
supplying the engine. The terms loading and unloading the
air charger are herein defined such that in the case the air
charger is a supercharger, the supercharger is loaded by
mechanically coupling the supercharger to the engine to be
driven by the engine or by coupling the supercharger to an
electric motor to be driven by the electric motor while
supplying pressurised air to the engine, and is unloaded by
relaxing the delivery pressure of the supercharger via an
air bypass system with or without the supercharger being
driven by the engine or by the electric motor. In the case
the air charger is a turbocharger, the turbocharger is
loaded by directing the exhaust gases from the engine to
drive the turbine of the turbocharger, and is unloaded by
diverting a large proportion of the exhaust gases to bypass
the turbine of the turbocharger. This may be achieved by
opening a large size waste-gate in the turbocharger. The
turbocharger may also be unloaded by relaxing the air
delivery pressure via an air bypass system across the turbo-
blower of the turbocharger.
In either case, when the air charger is loaded, energy is consumed by the air charger for producing pressurised air. When the air charger is unloaded, little or no energy is consumed as the air charger will be idling or disengaged.

The present invention draws priority from GB0800720.5 and is a sister invention with GB0803024.9 for an air hybrid vehicle, and is predicated upon the realisation that producing the pressurised air for boosting the engine would require energy that could be derived at least in part from the regenerative braking energy of the hybrid vehicle and from other energy sources external to the vehicle. The more aggressively the engine is downsized, the more frequently the boosting is called upon to meet the dynamic driving demand of the vehicle, and the greater the fuel saving from using the regenerative braking energy or the external energy source to produce the pressurised air for boosting the engine, especially under urban driving conditions. So preferably in the present invention, the engine is an aggressively downsized supercharged and/or turbocharged internal combustion engine.

The present invention focuses on the external energy source that could be used for producing pressurised air for boosting the engine in an air hybrid vehicle with or without regenerative braking. Whilst regenerative braking such as the one described in GB0803024.9 for an air hybrid vehicle yields significant on-board fuel saving through energy recovery, the present invention provides further fuel saving through substitution of energy or energy displacement using mains electricity instead of on-board fuel to power the boosting of the engine.

Preferably the high pressure compressed air source is a reciprocating air compressor driven by an electric motor on board the vehicle and the air accumulator is charged by
connecting the electric motor to an electricity mains supply in the vicinity of the vehicle where the vehicle is parked.

Alternatively the air accumulator may be charged from a high pressure reciprocating air compressor driven by a mains powered electric motor in the vicinity of the vehicle where the vehicle is parked.

As a further alternative, the air accumulator may be charged from a high pressure air storage reservoir in the vicinity of the vehicle where the vehicle is parked and the air storage reservoir is pre-filled by a mains powered reciprocating air compressor.

The charge pressure in the air accumulator may be several 100s of bars of pressure in order to store a large quantity of air within a small space of the accumulator.

In the design of the plug-in air hybrid vehicle the air accumulator preferably has a storage capacity for sufficient air to be stored to supply boost to the engine as required in urban driving conditions during an average daily journey so that the air accumulator is the main supply for boost and needs to be re-charged on average once per day while the vehicle achieves on-board fuel saving by energy displacement substituting mains electricity for on-board fuel to power the boosting of the engine in the average daily journeys.

An average journey is herein defined as a journey representative of typical use derived from statistical data taken from a large population of vehicle journeys in a representative urban setting. It is therefore a statistically valid set of driving conditions that could be used for optimising the design of the air hybrid vehicle.

Thus the air hybrid vehicle may be tailored according to the statistical driving style and usage pattern of a
targeted group of drivers by selecting an air accumulator of the appropriate storage capacity for the vehicle. For example a plug-in air hybrid vehicle matched for average daily journeys of 20 miles travel distance will have a smaller air accumulator than another plug-in air hybrid vehicle matched for average daily journeys of 40 mile travel distance. In this way, the vehicle benefits from having boost for as much as needed in the average daily journeys produced substantially from mains electricity while the rotary air charger is used as little as possible for boosting the engine but is always available as backup when the air accumulator is depleted.

In the present invention, by boosting the engine from the air accumulator with the rotary air charger unloaded, the engine not only saves fuel in not having to drive the rotary air charger but also has higher power output because the boosted torque from the engine is produced requiring no power overhead from the rotary air charger. This gives the vehicle higher performance than a standard pressure charged vehicle, or for the same performance lower fuel consumption.

Depending on the frequency and level of boost required for a downsized engine to drive a vehicle on an average journey comprising an average number of accelerations and decelerations, there is an optimum combination of the engine and the vehicle where the pressurised air required for boosting the engine would match the compressed air stored in the air accumulator in which case the maximum fuel displacement would have been achieved. Thus a good guide for selecting a downsized pressure charged engine to drive a vehicle with a suitably sized air accumulator in an average journey in urban setting comprising an average number of accelerations and decelerations is that the total quantity of compressed air stored in the air accumulator should exceed the total quantity of pressurised air required for boosting the engine, in which case the engine will be
boosted entirely with compressed air produced from mains electricity and the rotary air charger will not be used at all for boosting the engine during the journey.

In supplying pressurised air suitable for boosting the engine, the high pressure air accumulator is preferably connected to an intermediate air chamber via a pressure regulating valve set to a predetermined boost pressure in the chamber of typically less than 2 bar gauge pressure, and the intermediate air chamber is connected to the intake system of the engine controlled by another valve.

An air throttle valve or non-return valve is also provided in the intake system of the engine and located downstream of the rotary air charger and upstream of the air connection to the intermediate air chamber. When pressurised air is delivered from the intermediate air chamber into the intake system of the engine for boosting the engine, the air throttle valve is closed or the non-return valve automatically closes to prevent any back flow of air from escaping through the rotary air charger which is unloaded.

The above air throttle valve or non-return valve will serve a similar function for guarding the air exit of the rotary air charger. The non-valve valve has the advantage of being automatic, driven by the pressure difference across the valve so that it will close as soon as there is a back flow into the rotary air charger in a direction reverse to the normal supply flow direction of rotary air charger. The air throttle valve, on the other hand, will have to be controlled by an actuator in response to pressure difference across the air throttle valve, but it could be opened and closed more fully and more quickly than the non-return valve.

As mentioned earlier, the air hybrid vehicle of the present invention can operate with or without regenerative
braking. In the case the air hybrid vehicle operates with regenerative braking having another air storage tank for storing the pressurised air produced using energy derived from braking of the vehicle, the engine may be boosted from either the intermediate air chamber or the air storage tank during acceleration or cruising of the vehicle with the rotary air charger unloaded.

When the vehicle comes to a stop after a deceleration the engine may be temporarily switched off and just before the vehicle is launched the engine is re-started by a starter motor while pressurised air is directed from the intermediate air chamber to the engine for assisting the cranking of the engine working as an air motor and the rotary air charger is unloaded. The vehicle therefore achieves further fuel saving by using the pressurised air pre-charged in the air accumulator to power the assisted starting of the engine.

The pressurised air in the intermediate air chamber supplied from the high pressure air accumulator via the pressure regulating valve is in exactly the right pressure range for boosting the engine when route b) is selected, i.e. between 0 and 2 bar boost pressure depending on the dynamic driving demand of the vehicle. When used to assist cranking of the engine during stop/start operation, the engine could receive the pressurised air and produce 1-2 bar IMEP (indicated mean effective pressure) working as an isobaric air motor, which is more than adequate for rapidly cranking up the engine.

In the case an air intercooler is provided between the rotary air charger and the engine, the intermediate air chamber is preferably connected to the intake system of the engine downstream of the air intercooler.
The present invention requires modification to the vehicle only with a high pressure air accumulator while the downsized engine with the rotary air charger having selectable means for loading and unloading the air charger is conventional and well known to a person familiar with the state of the art. Compared with a non-hybrid vehicle powered by an engine already equipped with a rotary air charger as the baseline, the present invention converts it to a plug-in air hybrid vehicle with only a few additional components, thus providing the added function at low extra cost. It also has no adverse effect on the performance and driveability of the vehicle while the energy usage is shifted at least to a useful proportion from on-board fuel to mains electricity.

In displacing the energy for boosting the engine using mains electricity instead of on-board fuel, less exhaust emissions will be emitted by the engine of the air hybrid vehicle of the present invention. The mains electricity may be derived from renewable or nuclear energy sources so that the present invention could yield a significant saving in the use of fossil fuels or bio-fuels.

Of course at any time the driver of the vehicle demands a higher boost pressure than could be supplied from the intermediate air chamber according to route b), the air supply to the engine will be switched to route c) very quickly and the driver will not feel any response delay coming from the rotary air charger because the boost in the engine is already established from route b).

Brief description of the drawings

The invention will now be described further by way of example with reference to the accompanying drawings in which Figure 1 is a schematic layout of an air hybrid vehicle of the present invention which also operates
with regenerative braking according to GB0803024.9, and

Figures 2a and 2b are diagrammatic illustrations of the air hybrid concept of the present invention in a self-explanatory manner.

**Detailed description of the preferred embodiment**

Figure 1 shows an internal combustion engine 16 driving the wheels 18 of a road vehicle. The engine 16 is equipped with a rotary air charger 10 supplying pressurised air to the engine 16 via an intercooler 12 and intake manifold 14. Exhaust gases from the engine 16 is discharged via an exhaust manifold and exhaust pipe 20. The rotary air charger 10 may be a supercharger or a turbocharger driven mechanically or by exhaust gases respectively in the conventional manner the details of which are not shown in Figure 1 in order to avoid unnecessary complexity in the diagram. The rotary air charger 10 may also be a combined supercharger and turbocharger connected in series supplying the engine 16.

The rotary air charger 10 has selectable means for loading and unloading the air charger the details of which are also not shown in Figure 1 for the same reason since they are conventional components including clutch, air bypass, waste-gate etc. In so far described, the setup of the air charge system 10, 12, 14 for supplying air to the engine 16 and the exhaust system 20 for discharging gases from the engine 16 is conventional and is suitable for application in a downsized internal combustion engine matched for low fuel consumption, high performance and good driveability for the vehicle.

Before describing the plug-in feature of the present invention, Figure 1 shows a road vehicle powered by an internal combustion engine 16 equipped with a rotary air
charger 10 which can be loaded or unloaded at any time on demand. The vehicle can be operated with regenerative braking according to GB0803024.9 by including the following additional components:

1) a back pressure valve 24 for regulating or blocking the exhaust pipe of the engine 16,
2) a first air flow branch 22 connecting from between the engine 16 and the back pressure valve 24 to the air storage tank 34 for diverting pressurised air from the back pressure region 20 of the engine exhaust system into the air storage tank 34 when the back pressure valve 24 is closed,
3) an air filling valve 26 located in the first air flow branch 22 for regulating and sealing the first air flow branch 22,
4) a second air flow branch 32 connecting from the air storage tank 34 to the intake system of the engine 16 between the rotary air charger 10 and the engine 16,
5) an air dispensing valve 36 located in the second air flow branch 32 for regulating and sealing the second air flow branch 32, and
6) an air throttle valve 38 (or a non-return valve 38) located downstream of the rotary air charger 10 and upstream of the second air flow branch 32 for blocking any back flow of pressurised air through the rotary air charger 10 when the pressurised air in the air storage tank 34 is delivered via the second air flow branch 32 to the engine 16 and the rotary air charger 10 is unloaded.

The above additional components allow the vehicle to be programmed to operate in different air hybrid modes by switching to different operating strategies affecting the use of the rotary air charger 10 as follow:

A') at times when the engine 16 is driven by the vehicle during deceleration or coasting of the vehicle the intake air flow to the engine 16 is open and the engine back pressure is maintained at a predetermined equilibrium value by simultaneously applying a flow restriction 24 in the
engine exhaust system and controlling the filling rate of pressurised air diverted from the back pressure region 20 of the engine exhaust system into a separate air storage tank 34 in the vehicle with the result that the braking torque generated within the engine 16 is increased derived from the increased back pressure and the pressurised air is transferred to the air storage tank 34 and stored in the air storage tank 34, B') at times when the engine 16 is driving the vehicle during acceleration or cruising of the vehicle the engine back pressure is released while the air supply to the engine 16 is selectable by one of at least three routes:

route a') naturally aspirated when boost is not required and the rotary air charger 10 is unloaded,

route b') pressurised air is delivered from the air storage tank 34 to the engine 16 when boost is required while the rotary air charger 10 is unloaded,

route c') pressurised air is delivered from the rotary air charger 10 to the engine 16 when boost is required and the rotary air charger 10 is loaded, and

C') during stop/start operation, the engine 16 is re-started from rest by a starter motor while pressurised air is directed from the air storage tank 34 to the engine 16 for assisting the cranking of the engine 16 working as an air motor and the rotary air charger 10 is unloaded.

The vehicle achieves fuel saving by not having to drive the rotary air charger 10 when the engine 16 is supplied with pressurised air via route b') produced and stored earlier during deceleration or coasting of the vehicle. It also achieves further fuel saving by using the pressurised air produced and stored earlier during deceleration or coasting of the vehicle to power the assisted starting of the engine 16.

In so far described, the air hybrid vehicle with regenerative braking shown by way of example in Figure 1
will be used as the basis for incorporating the plug-in air hybrid feature of the present invention.

Thus Figure 1 shows an air hybrid vehicle powered by an internal combustion engine 16 equipped with a rotary air charger 10 for pressure charging the engine 16 while having selectable means for loading and unloading the air charger 10. According to the present invention, the plug-in air hybrid vehicle is characterised in that:

A) at times when there is access to a high pressure compressed air source 100, the compressed air source 100 is connected to an air accumulator 110 in the vehicle for delivering into the accumulator a charge of high pressure compressed air which is stored in the air accumulator 110,

B) at times when there is no access to a high pressure compressed air source and the vehicle is driven on load by the engine 16 the air supply to the engine 16 is selectable by one of at least three routes:

route a) naturally aspirated when boost is not required and the rotary air charger 10 is unloaded,

route b) pressurised air is delivered from the air accumulator 110 to the engine 16 when boost is required while the rotary air charger 10 is unloaded,

route c) pressurised air is delivered from the rotary air charger 10 to the engine 16 when boost is required and the rotary air charger 10 is loaded,

C) during stop/start operation, the engine 16 is re-started from rest by a starter motor while pressurised air is directed from the air accumulator 110 to the engine 16 for assisting the cranking of the engine 16 working as an air motor and the rotary air charger 10 is unloaded.

The vehicle achieves fuel saving and high performance by not having to drive the rotary air charger 10 when the engine 16 is supplied with pressurised air according to route b) pre-charged in the air accumulator 110. It also achieves further fuel saving by using the pressurised air in
the air accumulator 110 to power the assisted starting of the engine 16.

It is clear from the above that the characteristics of the plug-in air hybrid vehicle is entirely compatible with the characteristics of the regenerative braking air hybrid vehicle so that the two could work in close cooperation with each other in the same vehicle and the resultant fuel saving is substitutive with one or the other. Thus for a given journey, a plug-in air hybrid vehicle with regenerative braking will require a smaller charge in the air accumulator to provide the same quantity of air boost compared with another plug-in air hybrid vehicle without regenerative braking.

The present invention focuses on the external energy source that could be used for producing the pressurised air for boosting the engine 16 in an air hybrid vehicle with or without regenerative braking. Whilst regenerative braking such as the one described in GB0803024.9 for an air hybrid vehicle yields significant on-board fuel saving through energy recovery, the present invention provides further fuel saving through substitution of energy or energy displacement using mains electricity instead of on-board fuel to power the boosting of the engine.

In Figure 1 the high pressure compressed air source may be a reciprocating air compressor 120 driven by an electric motor 130 on board the vehicle and the air accumulator 110 is charged by the compressor 120 via a self-sealing valve 112 by connecting the electric motor 130 to an electricity mains supply 140 in the vicinity of the vehicle where the vehicle is parked.

Alternatively the air accumulator 110 may be charged from another high pressure reciprocating air compressor 120a
driven by a mains powered electric motor 130a in the vicinity of the vehicle where the vehicle is parked.

As a further alternative, the air accumulator may be charged from a high pressure air storage reservoir 150 in the vicinity of the vehicle where the vehicle is parked and the air storage reservoir 150 is pre-filled by a mains powered reciprocating air compressor 120b, 130b.

The charge pressure in the air accumulator 110 may be several 100s of bars of pressure in order to store a large quantity of air within a small space of the accumulator 110.

In the design of the plug-in air hybrid vehicle, the air accumulator 110 preferably has a storage capacity for sufficient air to be stored to supply boost to the engine 16 as required in urban driving conditions during an average daily journey so that the air accumulator 110 is the main supply for boost and needs to be re-charged on average once per day while the vehicle achieves on-board fuel saving by energy displacement substituting mains electricity for on-board fuel to power the boosting of the engine 16 in the average daily journeys.

An average journey is herein defined as a journey representative of typical use derived from statistical data taken from a large population of vehicle journeys in a representative urban setting. It is therefore a statistically valid set of driving conditions that could be used for optimising the design of the air hybrid vehicle.

Thus the air hybrid vehicle may be tailored according to the statistical driving style and usage pattern of a targeted group of drivers by selecting an air accumulator of the appropriate storage capacity for the vehicle. For example a plug-in air hybrid vehicle matched for average daily journeys of 20 miles travel distance will have a
smaller air accumulator than another plug-in air hybrid vehicle matched for average daily journeys of 40 mile travel distance. In this way, the vehicle benefits from having boost for as much as needed in the average daily journeys produced substantially from mains electricity while the rotary air charger 10 is used as little as possible for boosting the engine but is always available as backup when the air accumulator 110 is depleted.

In the present invention, by boosting the engine 16 from the air accumulator 110 with the rotary air charger 10 unloaded, the engine 16 not only saves fuel in not having to drive the rotary air charger 10 but also has higher power output because the boosted torque from the engine 16 is produced requiring no power overhead from the rotary air charger 10. This gives the vehicle higher performance than a standard pressure charged vehicle, or the same performance at a lower fuel consumption.

In supplying pressurised air suitable for boosting the engine 16 in Figure 1, the high pressure air accumulator 110 is preferably connected to an intermediate air chamber 116 via a pressure regulating valve 114 set to a predetermined boost pressure in the chamber 116 of typically less than 2 bar gauge pressure, and the intermediate air chamber 116 is connected to the intake system of the engine 16 controlled by a valve 118.

The same air throttle valve 38 or non-return valve 38 used in the vehicle with regenerative braking is also used in the plug-in air hybrid vehicle of the present invention. The valve 38 is provided in the intake system of the engine 16 and is located downstream of the rotary air charger 10 and upstream of the air connection to the intermediate air chamber 116. When pressurised air is delivered from the intermediate air chamber 116 into the intake system of the engine 16 for boosting the engine 16, the air throttle valve
38 is closed or the non-return valve 38 automatically closes to prevent any back flow of air from escaping through the rotary air charger 10.

Thus in the operation of the plug-in air hybrid vehicle, at times when the engine 16 is driving the vehicle and the air supply to the engine is selected according to route a), the control valve 118 is closed and the air throttle valve 38 is opened (or the non-return valve 38 automatically opens). In this case, naturally aspirated air is delivered to the engine 16 through or bypassing the rotary air charger 10.

At times when the engine 16 is driving the vehicle and the air supply to the engine is selected according to route b), the rotary air charger is unloaded while the control valve 118 is opened and the air throttle valve 38 is closed (or the non-return valve 38 automatically closes). In this case, pressurised air is connected from the intermediate air chamber 116 to the engine 16 to boost the engine 16. The vehicle achieves fuel saving by not having to drive the rotary air charger 10 when this pressurised air is used to supply the engine 16.

At times when the engine 16 is driving the vehicle and the air supply to the engine is selected according to route c), the control valve 118 is closed and the air throttle valve 38 is opened (or the non-return valve 38 automatically opens). In this case, pressurised air from the rotary air charger 10 is delivered directly to the engine 16 to boost the engine 16.

When used during stop/start operation and the engine 16 is re-started from rest, the control valve 118 is opened and the air throttle valve 38 is closed (or the non-return valve 38 automatically closes). After the engine 16 has started and reached a predetermined speed, the control valve is
closed while the air throttle valve 38 is opened (or the non-return valve 38 automatically opens). In this case, some pressurised air is connected from the intermediate air chamber 116 to the engine 16 during starting of the engine 16 followed by ambient air is drawn directly into the engine 16.

The pressurised air in the intermediate air chamber 116 supplied from the high pressure air accumulator 110 via the pressure regulating valve 114 is in exactly the right pressure range for boosting the engine 16 when route b) is selected, i.e. between 0 and 2 bar boost pressure depending on the dynamic driving demand of the vehicle. When used to assist cranking of the engine 16 during stop/start operation, the engine could receive the pressurised air and produce 1-2 bar IMEP (indicated mean effective pressure) working as an isobaric air motor, which is more than adequate for rapidly cranking up the engine.

Figure 1 also shows an air intercooler 12 located between the rotary air charger 10 and the engine 16. Preferably the intermediate air chamber 116 is connected to the intake system of the engine 16 downstream of the intercooler 12.

Figures 2a and 2b show in a self-explanatory manner the air hybrid concept of the present invention in which the air accumulator is pre-charged with high pressure compressed air from a compressed air source when there is access to mains electricity in the vicinity of the vehicle where the vehicle is parked. The vehicle achieves energy displacement by substituting mains electricity for on-board fuel by not having to drive the rotary air charger when pressurised air pre-charged in the air accumulator is used to boost the engine with the rotary air charger unloaded.
Depending on the frequency and level of boost required for a downsized engine to drive a vehicle on an average journey comprising an average number of accelerations and decelerations, there is an optimum combination of the engine and the vehicle where the pressurised air required for boosting the engine would match the compressed air stored in the air accumulator in which case the maximum fuel displacement would have been achieved. Thus a good guide for selecting a downsized pressure charged engine to drive a vehicle with a suitably sized air accumulator in an average journey in urban setting comprising an average number of accelerations and decelerations is that the total quantity of compressed air stored in the air accumulator should exceed the total quantity of pressurised air required for boosting the engine, in which case the engine will be boosted entirely with compressed air produced from mains electricity and the rotary air charger will not be used at all for boosting the engine during the journey as illustrated in Figure 2a.

The present invention requires modification to the vehicle only with a high pressure air accumulator while the downsized engine with the rotary air charger having selectable means for loading and unloading the air charger is conventional and well known to a person familiar with the state of the art. Compared with a non-hybrid vehicle powered by an engine already equipped with a rotary air charger as the baseline, the present invention converts it to a plug-in air hybrid vehicle with only a few additional components, thus providing the added function at low extra cost. It also has no adverse effect on the performance and driveability of the vehicle while the energy usage is shifted at least to a useful proportion from on-board fuel to mains electricity.

In displacing the energy for boosting the engine using mains electricity instead of on-board fuel, less exhaust
emissions will be emitted by the engine of the air hybrid
vehicle of the present invention. The mains electricity may
be derived from renewable or nuclear energy sources so that
the present invention could yield a significant saving in
the use of fossil fuels or bio-fuels.

Of course at any time the driver of the vehicle demands
a higher boost pressure than could be supplied from the
intermediate air chamber 116 according to route b), the air
supply to the engine 16 will be switched to route c) very
quickly and the driver will not feel any response delay
coming from the rotary air charger 10 because the boost in
the engine 16 is already established from route b).

Finally the engine 16 in Figure 1 need not be a
down sized engine. In the case a large capacity engine is
used in a high performance vehicle, the present invention
will give the vehicle a performance boost when pressurised
air is supplied to the engine according to route b) with the
rotary air charger 10 unloaded and not absorbing power from
the engine 16. On the other hand, the energy displacement
benefit for this vehicle will be relatively small compared
with one with a downsized pressure charged engine because of
the infrequency of demand for boosting the engine.
CLAIMS

1. An air hybrid vehicle powered by an internal combustion engine equipped with a rotary air charger for pressure charging the engine while having selectable means for loading and unloading the air charger, the vehicle characterised in that at times when there is access to a high pressure compressed air source, the compressed air source is connected to an air accumulator in the vehicle for delivering into the accumulator a charge of high pressure compressed air which is stored in the air accumulator, and at times when there is no access to a high pressure compressed air source and the vehicle is driven on load by the engine the air supply to the engine is selectable by one of at least three routes: route a) naturally aspirated when boost is not required and the rotary air charger is unloaded, route b) pressurised air is delivered from the air accumulator to the engine when boost is required while the rotary air charger is unloaded, and route c) pressurised air is delivered from the rotary air charger to the engine when boost is required and the rotary air charger is loaded, the vehicle achieving fuel saving and high performance by not having to drive the rotary air charger when the engine is supplied with pressurised air according to route b) pre-charged in the air accumulator.

2. An air hybrid vehicle as claimed in claim 1, wherein the high pressure compressed air source is a reciprocating air compressor driven by an electric motor on board the vehicle and wherein the air accumulator is charged by connecting the electric motor to an electricity mains supply in the vicinity of the vehicle where the vehicle is parked.

3. An air hybrid vehicle as claimed in claim 1, wherein the air accumulator is charged from a high pressure reciprocating air compressor driven by a mains powered
electric motor in the vicinity of the vehicle where the vehicle is parked.

4. An air hybrid vehicle as claimed in claim 1, wherein the air accumulator is charged from a high pressure air storage reservoir in the vicinity of the vehicle where the vehicle is parked and the air storage reservoir is pre-filled by a mains powered reciprocating air compressor.

5. An air hybrid vehicle as claimed in any preceding claim, wherein the air accumulator has a storage capacity for sufficient air to be stored to supply boost to the engine as required in urban driving conditions during an average daily journey so that the air accumulator is the main supply for boost to the engine and needs to be recharged on average once per day while the rotary air charger is used as little as possible for boosting the engine but is always available as backup when the air accumulator is depleted, the vehicle thereby achieves on-board fuel saving by energy displacement substituting mains electricity for on-board fuel to power the boosting of the engine in the average daily journeys.

6. An air hybrid vehicle as claimed in any preceding claim, wherein a downsized pressure charged engine is selected to drive the vehicle with a suitably sized air accumulator in an average journey in urban setting comprising an average number of accelerations and decelerations such that the total quantity of compressed air stored in the air accumulator exceeds the total quantity of pressurised air required for boosting the engine.

7. An air hybrid vehicle as claimed in any preceding claim, wherein the air accumulator is connected to an intermediate air chamber via a pressure regulating valve set to a predetermined boost pressure in the chamber, and
wherein the intermediate air chamber is connected to the intake system of the engine controlled by another valve.

8. An air hybrid vehicle as claimed in claim 7, wherein an air throttle valve or non-return valve is provided in the intake system of the engine and located downstream of the rotary air charger and upstream of the air connection to the intermediate air chamber, and wherein when pressurised air is delivered from the intermediate air chamber into the intake system of the engine for boosting the engine, the air throttle valve is closed or the non-return valve automatically closes to prevent any back flow of air from escaping through the rotary air charger which is unloaded.

9. An air hybrid vehicle as claimed in any preceding claim, wherein the vehicle also operates with regenerative braking having another air storage tank for storing the pressurised air produced using energy derived from braking of the vehicle, and wherein the engine is boosted from either the intermediate air chamber or the air storage tank during acceleration or cruising of the vehicle with the rotary air charger unloaded.

10. An air hybrid vehicle as claimed in claim 7 or 8, wherein when the vehicle comes to a stop after a deceleration the engine is temporarily switched off and just before the vehicle is launched the engine is re-started by a starter motor while pressurised air is directed from the intermediate air chamber to the engine for assisting the cranking of the engine and the rotary air charger is unloaded, the vehicle achieving further fuel saving by using the pressurised air pre-charged in the air accumulator to power the assisted starting of the engine.
Amendment to the claims have been filed as follows

CLAIMS

1. An air hybrid vehicle powered by an internal combustion engine equipped with a rotary air charger for pressure charging the engine while having selectable means for loading and unloading the air charger, the vehicle characterised in that at times when there is access to a high pressure compressed air source, the compressed air source is connected to an air accumulator in the vehicle for delivering into the accumulator a charge of high pressure compressed air which is stored in the air accumulator, and at times when there is no access to a high pressure compressed air source and the vehicle is driven on load by the engine the air supply to the engine for combustion is selectable by one of at least three routes: route a) naturally aspirated when boost is not required and the rotary air charger is unloaded, route b) pressurised air is delivered from the air accumulator to the engine when boost is required while the rotary air charger is unloaded, and route c) pressurised air is delivered from the rotary air charger to the engine when boost is required and the rotary air charger is loaded, the vehicle achieving fuel saving and high performance by not driving the rotary air charger when the engine is supplied with pressurised air according to route b) pre-charged in the air accumulator.

2. An air hybrid vehicle as claimed in claim 1, wherein the high pressure compressed air source is a reciprocating air compressor driven by an electric motor on board the vehicle and wherein the air accumulator is charged by connecting the electric motor to an electricity mains supply in the vicinity of the vehicle where the vehicle is parked.

3. An air hybrid vehicle as claimed in claim 1, wherein the air accumulator is charged from a high pressure reciprocating air compressor driven by a mains powered
electric motor in the vicinity of the vehicle where the vehicle is parked.

4. An air hybrid vehicle as claimed in claim 1, wherein the air accumulator is charged from a high pressure air storage reservoir in the vicinity of the vehicle where the vehicle is parked and the air storage reservoir is pre-filled by a mains powered reciprocating air compressor.

5. An air hybrid vehicle as claimed in any preceding claim, wherein the air accumulator has a storage capacity for sufficient air to be stored to supply boost to the engine as required in urban driving conditions during an average daily journey so that the air accumulator is the main supply for boost to the engine and needs to be recharged on average once per day while the rotary air charger is used as little as possible for boosting the engine but is always available as backup when the air accumulator is depleted, the vehicle thereby achieves on-board fuel saving by energy displacement substituting mains electricity for on-board fuel to power the boosting of the engine in the average daily journeys.

6. An air hybrid vehicle as claimed in any preceding claim, wherein a downsized pressure charged engine is selected to drive the vehicle with a suitably sized air accumulator in an average journey in urban setting comprising an average number of accelerations and decelerations such that the total quantity of compressed air stored in the air accumulator exceeds the total quantity of pressurised air required for boosting the engine.

7. An air hybrid vehicle as claimed in any preceding claim, wherein the air accumulator is connected to an intermediate air chamber via a pressure regulating valve set to a predetermined boost pressure in the chamber, and
wherein the intermediate air chamber is connected to the intake system of the engine controlled by another valve.

8. An air hybrid vehicle as claimed in claim 7, wherein an air throttle valve or non-return valve is provided in the intake system of the engine and located downstream of the rotary air charger and upstream of the air connection to the intermediate air chamber, and wherein when pressurised air is delivered from the intermediate air chamber into the intake system of the engine for boosting the engine, the air throttle valve is closed or the non-return valve automatically closes to prevent any back flow of air from escaping through the rotary air charger which is unloaded.

9. An air hybrid vehicle as claimed in any preceding claim, wherein the vehicle also operates with regenerative braking having another air storage tank for storing the pressurised air produced using energy derived from braking of the vehicle, and wherein the engine is boosted from either the intermediate air chamber or the air storage tank during acceleration or cruising of the vehicle with the rotary air charger unloaded.

10. An air hybrid vehicle as claimed in claim 7 or 8, wherein when the vehicle comes to a stop after a deceleration the engine is temporarily switched off and just before the vehicle is launched the engine is re-started by a starter motor while pressurised air is directed from the intermediate air chamber to the engine for assisting the cranking of the engine and the rotary air charger is unloaded, the vehicle achieving further fuel saving by using the pressurised air pre-charged in the air accumulator to power the assisted starting of the engine.
### Patents Act 1977: Search Report under Section 17

#### Documents considered to be relevant:

<table>
<thead>
<tr>
<th>Category</th>
<th>Relevant to claims</th>
<th>Identity of document and passage or figure of particular relevance</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>1, 3, 4, 5, 6</td>
<td>US4300486 A (LOWTHER) esp fig 5 &amp; col 6 ln 16-24</td>
</tr>
<tr>
<td>A</td>
<td>-</td>
<td>US4240381 A (LOWTHER) esp abstract, fig 2, col 4 ln 32-41, col 9 ln 13-68</td>
</tr>
<tr>
<td>A</td>
<td>-</td>
<td>JP2005147052 A (NISSAN) esp figure 1</td>
</tr>
<tr>
<td>A</td>
<td>-</td>
<td>WO2007/060274 A1 (ROS ROCA) esp fig 1 &amp; abstract</td>
</tr>
<tr>
<td>A</td>
<td>-</td>
<td>US6138616 A (SVENSSON) esp fig 1</td>
</tr>
</tbody>
</table>

#### Categories:

- **X**: Document indicating lack of novelty or inventive step
- **Y**: Document indicating lack of inventive step if combined with one or more other documents of same category
- **A**: Member of the same patent family
- **P**: Document published on or after the declared priority date but before the filing date of this invention
- **E**: Patent document published on or after, but with priority date earlier than, the filing date of this application

#### Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC\(^X\):

- **B7H**: Worldwide search of patent documents classified in the following areas of the IPC
  - B60K; F02B; F02D; F02M

The following online and other databases have been used in the preparation of this search report:

- Online: EPODOC, WPI & TXTEN

#### International Classification:

<table>
<thead>
<tr>
<th>Subclass</th>
<th>Subgroup</th>
<th>Valid From</th>
</tr>
</thead>
<tbody>
<tr>
<td>B60K</td>
<td>0013/02</td>
<td>01/01/2006</td>
</tr>
<tr>
<td>Subclass</td>
<td>Subgroup</td>
<td>Valid From</td>
</tr>
<tr>
<td>----------</td>
<td>----------</td>
<td>------------</td>
</tr>
<tr>
<td>F02D</td>
<td>0023/00</td>
<td>01/01/2006</td>
</tr>
<tr>
<td>B60K</td>
<td>0006/12</td>
<td>01/01/2006</td>
</tr>
</tbody>
</table>