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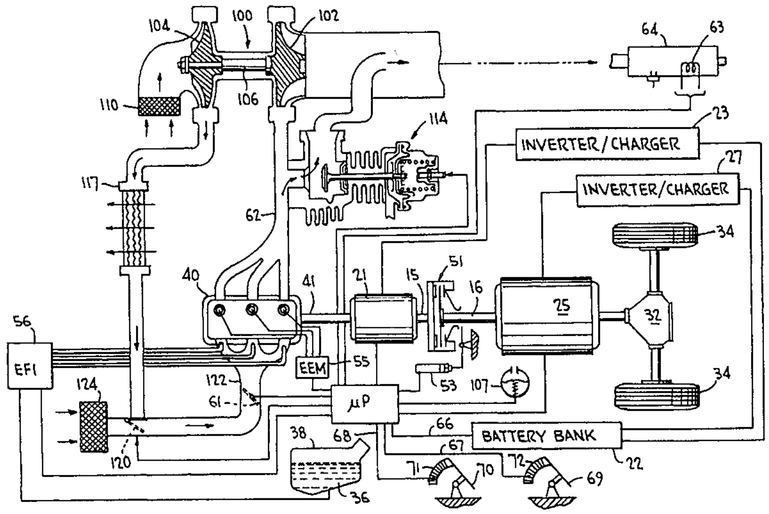

(57) Abstract

A hybrid vehicle comprising an internal combustion engine controllably coupled to road wheels of the vehicle by a clutch, a traction motor coupled to road wheels of said vehicle, a starting motor coupled to the engine, both motors being operable as generators, a battery bank for providing electrical energy to and accepting energy from said motors, and a microprocessor for controlling these components is operated in different modes, depending on the vehicle's instantaneous torque requirements, the state of charge of the battery bank, and other operating parameters. The mode of operation is selected by the microprocessor in response to a control strategy resulting in improved fuel economy and reduced emission. The engine may be fitted with a turbocharger operated in response to a control signal for extended high–load operation.

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HYBRID VEHICLES

Field of the Invention

This application relates to improvements in hybrid vehicles, that is, vehicles in which both an internal combustion engine and one or more electric motors are provided to supply torque to the driving wheels of the vehicle. More particularly, this invention relates to a hybrid electric vehicle that is fully competitive with presently conventional vehicles as regards performance, operating convenience, and cost, while achieving substantially improved fuel economy and reduced pollutant emissions.

Discussion of the Prior Art

For many years great attention has been given to the problem of reduction of fuel consumption of automobiles and other highway vehicles. Concomitantly very substantial attention has been paid to reduction of pollutants emitted by automobiles and other vehicles. To a degree, efforts to solve these problems conflict with one another. For example, increased thermodynamic efficiency and thus reduced fuel consumption can be realized if an engine is operated at higher temperatures. Thus there has been substantial interest in engines built of ceramic materials withstanding higher combustion temperatures than those now in use. However, higher combustion temperatures in gasoline-fueled engines lead to increase in certain undesirable pollutants, typically NO_x.

Another possibility for reducing emissions is to burn mixtures of gasoline and ethanol ("gasohol"), or straight ethanol. However, to date ethanol has not become economically competitive with gasoline, and consumers have not accepted ethanol to any great degree. Moreover, to make an alternate fuel such as ethanol available to the extent necessary to achieve appreciable improvements in nationwide air quality and fuel conservation would require immense costs for infrastructure improvements; not only the entire nation's motor fuel production and delivery system, but also the vehicle manufacture, distribution, and repair system, would have to be extensively revised or substantially duplicated.

One proposal for reducing pollution in cities is to limit the use of vehicles powered by internal combustion engines and instead employ electric vehicles powered by rechargeable batteries. To date, all such "straight electric" cars have had very limited range, typically no more than 150 miles, have insufficient power for acceleration and hill climbing except when the batteries are substantially fully charged, and require substantial time for battery recharging. Thus, while there are many circumstances in which the limited range and extended recharging time of the batteries would not be an inconvenience, such cars are not suitable for all the travel requirements of most individuals. Accordingly, an electric car would have to be an additional vehicle for most users, posing a substantial economic deterrent. Moreover, it will be appreciated that in the United States most electricity is generated in coal-fired power plants, so that using electric vehicles merely moves the source of the pollution, but does not eliminate it. Furthermore, comparing the respective net costs per mile of driving, electric vehicles are not competitive with ethanol-fueled vehicles, much less with conventional gasoline-fueled vehicles. See, generally, Simanaitis, "Electric Vehicles", *Road & Track*, May 1992, pp. 126-136; Reynolds, "AC Propulsion CRX", *Road & Track,* October 1992, pp. 126-129.

Brooks et al U.S. patent 5,492,192 shows such an electric vehicle; the invention appears to be directed to incorporation of antilock braking and traction control technologies into an otherwise conventional electric vehicle.

Much attention has also been paid over the years to development of electric vehicles including internal combustion engines powering generators, thus eliminating the defect of limited range exhibited by simple electric vehicles. The simplest such vehicles operate on the same general principle as diesel-electric locomotives used by most railroads. In such systems, an internal combustion engine drives a generator providing electric power to traction motors connected directly to the wheels of the vehicle. This system has the advantage that no variable gear ratio transmission is required between the engine and the wheels of the vehicle.

More particularly, an internal combustion engine produces zero torque at zero engine speed (RPM) and reaches its torque peak somewhere in the middle of its operating range. Accordingly, all vehicles driven directly by an internal combustion engine (other than certain single-speed vehicles using friction or centrifugal clutches, and not useful for normal driving) require a variable-ratio transmission between the engine and the wheels, so that the engine's torque can be matched to the road speeds and loads encountered. Further, some sort of clutch must be provided so that the engine can be mechanically decoupled from the wheels, allowing the vehicle to stop while the engine is still running, and to allow some slippage of the engine with respect to the drive train while starting from a stop. It would not be practical to provide a diesel locomotive, for example, with a multiple speed transmission, or a clutch. Accordingly, the additional complexity of the generator and electric traction motors is accepted. Electric traction motors produce full torque at zero RPM and thus can be connected directly to the wheels; when it is desired that the train should accelerate, the diesel engine is simply throttled to increase the generator output and the train begins to move.

The same drive system may be employed in a smaller vehicle such as an automobile or truck, but has several distinct disadvantages in this application. In particular, and as discussed in detail below in connection with Figs. 1 and 2, it is well known that a gasoline or other internal combustion engine is most efficient when producing near its maximum output torque. Typically, the number of diesel locomotives on a train is selected in accordance with the total tonnage to be moved and the grades to be overcome, so that all the locomotives can be operated at nearly full torque production. Moreover, such

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