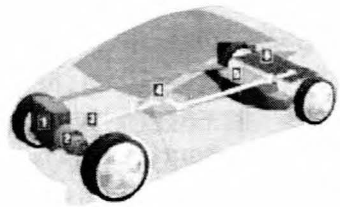

HYBRID VEHICLES: MECHANICAL ALTERNATIVES TO ELECTRICAL HYBRID VEHICLES

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ABSTRACT

The objective of this paper is to outline the major mechanical alternatives to electrical hybrid systems along with their advantages and disadvantages.

1.INTRODUCTION

This paper will be looking at the mechanical alternatives to electrical energy storage for hybrid vehicles. The main mechanical energy storage systems are hydraulic, pneumatic and flywheel. The paper will also look at their advantages and disadvantages compared to electrical systems.

2.DRIVING FACTORS FOR HIBRID VEHICLES

There are a number of driving factors for improving emissions and fuel economy in automotive applications. They include:

- CARB ZEV (zero emission vehicle) emissions regulations.
- The drive to reduce carbon dioxide emissions.
- The drive to improve fuel economy and reduce operational running costs.
- Western vulnerability to fluctuations in the price of oil.
- Emissions legislation outside CARB.

In the short term these can be met by improving engine technology but the improvements are small (10-15%) and the cost for more significant improvements is prohibitive. In the long term (15+ years) technologies such as fuel cell vehicles will provide for these needs. Currently the cost of this technology is expensive and unproven in the wider marketplace. Problems exist with a lack of infrastructure for refuelling. Hybrid vehicles provide the most viable medium term solution to meet the demands of the marketplace.

Hybrid vehicles have two power sources, usually an internal combustion engine and an electric motor. They can provide improvements in fuel economy and emissions for a reasonable cost. The improvements come from a number of factors including more efficient use of the engine and regenerative braking to reclaim some of the energy that would normally be lost to braking. Some systems allow the engine to be turned off during engine idles which improves the overall fuel economy [1]. As hybrid vehicles still use conventional engines as a power source the existing refuelling infrastructure is compatible.

3.HYDRAULIC SYSTEMS

Hydraulic systems are the second main focus of the car manufacturers (after electrical systems). Ford, Jaguar, Permo-Drive and PI technology are some of the companies working on hydraulic hybrid systems.

In a hydraulic system, energy is stored in a hydraulic accumulator using high pressure fluid. A hydraulic accumulator is a reservoir of hydraulic fluid which can store a variable volume of fluid at high pressure. Hydraulic motors and pumps replace the electrical motors and generators. Hydraulic technology is well established in other applications (such as mechanical diggers). The focus of current research is how to adapt and improve the technology for automotive applications.

The following components are added:

- Hydraulic accumulator
- Hydraulic pump/motor
- Hydraulic pump (series only)
- Hydraulic control servos

The following components are deleted:

- Starter motor
- Starter ring
- Large battery (replaced by smaller unit)
- Heavy duty electrical cables (replaced with lower duty cables)
- Gearbox (series only)

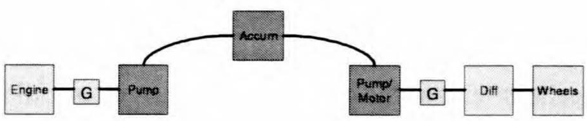

Fig. 1 Series hydraulic hybrid schematic

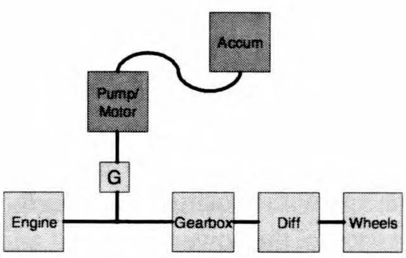

Fig. 2 Parallel hydraulic hybrid schematic

The efficiency of the system is a combination of the accumulator efficiency and the pump/motor efficiencies. Energy is lost from the accumulator as heat. To reduce this the accumulator needs to be insulated, often elastomeric foam is used. With a basic system a single motor is used. More advanced systems use multiple motors to improve the efficiency.

Hydraulic systems have the following advantages compared to electrical systems:

- Less expensive
- Accumulator life is better than battery life. The efficiency, power density and energy density are less affected by use.
- Better energy storage efficiency. Well insulated accumulators can have efficiencies above 95%.
- Better energy and power densities than electrical systems.

Hydraulic systems have the following disadvantages compared to electrical systems:

- There are some minor safety concerns with regard to ensuring a safe failure mode, for the hydraulic accumulator, during a crash.
- Does not qualify for CARB ZEV credits.

4. PNEUMATIC SYSTEMS

Research into pneumatic hybrid systems is relatively new and it is the technology that has been least developed by the main car manufacturers. One of the reasons for this is that most of the systems require a fully variable valvetrain. As the cost of these systems reduce with time/mass production the pneumatic systems will become more and more viable.

Pneumatic systems store energy in the form of compressed air. Two types of system can be used. The first operates in a similar way to hydraulic systems but instead of hydraulic pumps and motors, pneumatic compressors and pumps are used. There is little research into using these for hybrid systems due to their poor efficiency and bulk compared to hydraulic systems.

The second system uses a modified internal combustion engine as the pump/motor. An air storage tank is connected, through an additional valve, directly to the cylinder or through a switching air intake system. The majority of systems have fully variable electro-hydraulic valvetrains. The valves must be able to open/close with sufficient speed and be able to work with the high forces created by the pressurised system.

The air is stored in a large tank. The tank can be insulated or filled with elastomeric foam to reduce the energy lost as heat. Some systems flow exhaust gas around the air tank to control the pressure and temperature of the gas in the tank. If the air is too hot it can cause detonation when the engine is operating in modes using the compressed air during a combustion cycle. Figure 3 shows a schematic of a pneumatic system.

The following components are added:

- Air tank and piping.

- Electro-hydraulic valve system.

The following components are deleted:

- Starter motor.
- Starter ring.
- Cam system.
- Large battery (replaced by smaller unit).
- Heavy duty electrical cables (replaced with lower duty cables).

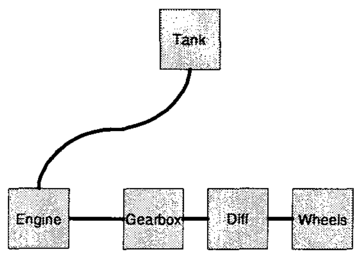

Fig.3 Pneumatic hybrid schematic

The engine can operate in a number of modes:

- Conventional running.
- Air pump mode/Compression braking.
- Air motor mode.
- Air power assist mode.
- Supercharged.
- Undercharged.

With electro-hydraulic valves the engine can operate all the modes as two or four stroke cycles.

The pneumatic system/electro-hydraulic valves also allow the following functions: mixed modes, cylinder deactivation, secondary air injection and internal EGR. Pneumatic systems benefit from the same advantages due to starter motor deletion as hydraulic systems.

4.1. Conventional Running

When running conventionally the engine runs exactly as it would in a normal vehicle. The introduction of a camless valvetrain increases the performance, fuel economy and emissions compared to a conventional engine with a cam driven system [1]. The fully variable valves allow the engine to operate in two or four stroke modes, deactivate cylinders and reduce the pumping losses.

4.2. Air Pump

When the vehicle is braking, the engine is operated in a compression braking mode. The engine produces a negative torque by compressing the air and storing it in the air tank. Air is drawn into the cylinder from the atmosphere, compressed and exhausted to the air tank. Depending on the torque required the engine can be run in both four and two stroke modes. No fuel is injected while operating in air pump mode.

4.3. Air Motor

When operating in air motor mode compressed air from the air tank is introduced into the cylinder provided the driving torque. The air is exhausted into the air intake or the exhaust depending on the specific design. No fuel is injected when operating in air motor mode. The air motor mode cannot provide as much power as air assist mode [3].

4.4. Air Power Assist

With the air power assist mode (four stroke) the engine runs with a positive pumping loop which provides some of the power. The air is added from the tank and exhausted (when combusted) into the exhaust system. If the system has a valve directly into the cylinder then a direct injection system is needed.

4.5. Supercharged

When short periods of high power are required during conventional operation the engine can be supercharged by adding high pressure air during the induction part of the cycle. This has the same benefits as conventional supercharging but without the need for additional components or power losses. It is limited to short periods of operation only due to the limited amount of compressed air stored. By adding the air later the pumping losses can be reduced [4].

4.6. Undercharged

When operating at part load during conventional operation the undercharged mode can be used. When operating in undercharged mode some of the air compressed prior to combustion is diverted into the air tank.

Pneumatic systems have the following advantages compared to electrical systems:

- The emissions and fuel economy are improved during conventional running due to the variable cam system. [1]
- The engine size can be reduced as the supercharged, air power assist and two stroke modes produce more power. This enables lighter, cheaper and more efficient engines to be used.
- No additional propulsion source needed [1]
- Pneumatic systems are the simplest and lightest of the hybrid systems [1, 5, 6].
- Pneumatic systems are cheaper than electrical systems. They are the cheapest of all the hybrid solutions and, if the vehicle has an existing variable valve system, they can actually be cheaper than the original vehicle (due to starter motor deletion).
- Better energy and power densities than electrical systems.

Pneumatic systems have the following disadvantages compared to electrical systems:

- If air is sent down the exhaust system, it will have a negative impact on the emissions due to catalyst cooling. In addition to this the catalyst will be oxygen rich, which will have a negative impact on NOx, but will improve hydrocarbon emissions when the engine returns to conventional running.
- There could be problems with robustness of switching valves in the high temperature/corrosive environment of the exhaust [1].
- There must be sufficient force for the valve to hold closed while the system is pressurised [5].
- Electro-hydraulic valve systems have higher energy consumption than a conventional cam system but the overall benefits of the system outweigh this.
- There are some safety concerns, regarding the venting of the compressed air, in the event of a crash.
- A large volume air tank is needed to store the energy.
- Pneumatic systems have poor energy density and control [5].
- The durability of the engine being used as a pump needs to be proved [6]
- Does not qualify for CARB ZEV credits.

5. FLYWHEEL SYSTEMS

Flywheel systems were a main area of research in the 1970s by companies such as Leyland trucks and buses. For a number of commercial and technological reasons flywheel systems were never fully introduced at this time. Developments in control methodology and materials technology mean that flywheel systems are once again viable hybrid options. The US department of defence and science applications international corporation are some of the companies currently working on flywheel hybrid systems.

In a flywheel system energy is stored in a rotating flywheel. The majority of current work in this area focuses on composite flywheels, as part of electrical devices. Flywheels can also be used in a purely mechanical system, using CVT (continuously variable transmission) or IVT (infinitely variable transmission) transmissions.

Figures 4 and 5 show typical flywheel hybrid schematics.

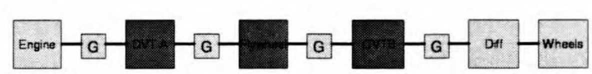

Fig.4 Series flywheel hybrid schematic

The following components are added:

- Flywheel.
- Bearing.
- Vacuum pump.
- Flywheel casing.
- CVT/IVT.

The following components are deleted:

- Gearbox (series only).

For maximum efficiency the flywheel needs to operate in a vacuum chamber. The overall efficiency of the system is limited by the CVT/IVT efficiencies.

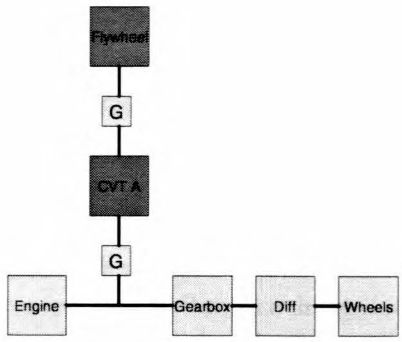

Fig.5 Parallel flywheel hybrid schematic

Pure flywheel systems have the following advantages compared to electrical systems:

- Less expensive
- Flywheel life is better than battery life. The efficiency, power density and energy density are less affected by use.
- Better energy storage efficiency. Efficiencies above 98% can be achieved.
- CVT/IVT have better efficiencies than electrical generators/motors.
- Better energy and power densities than electrical systems.

Pure flywheel systems have the following disadvantages compared to electrical systems:

- Energy dissipates between trips.
- Starter motor deletion is not possible.
- There are safety concerns with regard to ensuring a safe failure mode, for the flywheel, during a crash/failure.
- Does not qualify for CARB ZEV credits.

6.CONCLUSIONS

Hybrids are the medium term solution to meet the legislative and commercial needs in the marketplace. Mechanical systems are not as developed as electrical systems and do not qualify for CARB ZEV credits but they offer cost weight and efficiency benefits compared to electrical systems.

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__Andrew Barr__ was born in Worcester (England, U.K.), in 1978. He obtained his Masters degree in Automotive Engineering from the University of Bath in 2000. His final year project was the development of a computer simulation of a Formula SAE race car.

He is currently a research engineer at the University of Warwick on the Engineering Doctorate program. His area of research is focused on the simulation and development of mechanical hybrid vehicles.