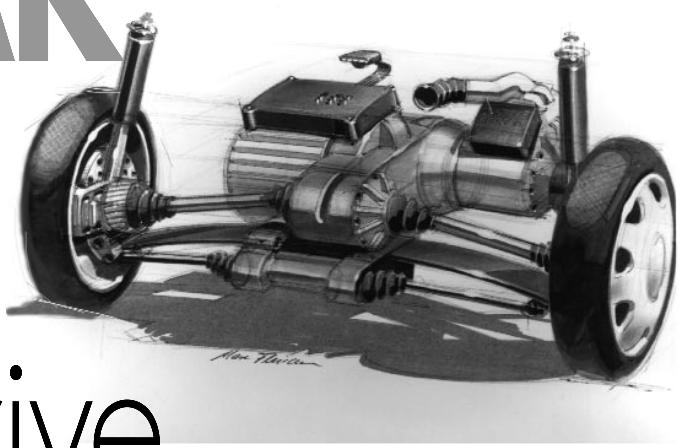
TWIN TRAK – a compact hybrid drive



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Hybrid drivetrains offer one route to providing the range needed in everyday use, along with the zero emissions capability in urban driving. A new drive system, TWIN TRAK, is under development that is light and compact. The system combines the principles behind series and parallel hybrids and features a simpler and more compact design

TWIN TRAK™ is a new compact lightweight hybrid-drive concept developed by Esoro AG in a research and development project that is co-funded by the BEW (Swiss Federal Department of Energy). After patent application, a prototype was successfully completed at the end of 1994. The TWIN TRAK II programme is currently proceeding according to schedule, and is expected to come to a close by the summer of 1997.

The whole hybrid drivetrain, including all components (excluding batteries),fits easily into the engine compartment of compact cars and weighs only97kg. This is less than a conventional drivetrain with an average power output of 40kW.

The prototype is produced in the smallest power size of about 40kW (over the whole driving range). The system has been designed so that it can be scaled up to a maximum of 100kW to meet potential customer needs. This upgraded version will increase weight by less than 30 per cent and volume by less than 10 per cent.

The patented Esoro TWIN TRAK drive is a combination of the advantages of series and parallel hybrids with simplified mechanical complexity. In fact, using current technology, it is not possible to build a hybrid drive with fewer – and smaller – components than the TWIN TRAK system. It features a powerful AC induction motor that allows the car to drive on electric power in a similar way to any well-designed EV (up to 130km/h). Driving below 60km/h will always be electrically powered only. The driver can pre-select between electric or hybrid mode. In the hybrid

mode, a downsized, two-cylinder, four-stroke aluminium engine will add power to the motor for speeds above 60km/h.

This strategy allows comfortable, emission-free driving in urban areas and gives a range of 500km or more on highways.

WHY HYBRID?

Electric propulsion

Back in 1899 the Belgian Camille Jenatzy achieved a new speed record of 100km/h with his torpedo-like electric vehicle '*La jamais contente*'. The car was not electrically powered for environmental reasons. The reason was because of the good performance of electric motors.

Only 10 years later, gasoline engines took over. As soon as stored energy need not be carried – as in any railway or stationary application – electric propulsion is the first choice. It is only due to the very low energy density and very slow recharge rate of batteries that cars do not use electricity today.

The outstanding advantages such as constant high torque, recuperation, very high efficiency at full and partial load, quiet and emission-free operation, are the main reasons for making electric motors the first choice for propulsion in urban areas.

Internal combustion engines

IC engines, on the other hand, have been developed near to perfection over the past hundred years and it is just their successful history (i.e. too many of them) that causes problems now. Neither cities or politicians can any longer accept the pollution they cause and any new emission or efficiency regulation creates additional development costs and the need for peripheral components.

Even if the development potential remains high, with zero emission regulations IC engines will be out of the race in certain markets and urban areas.

Hybrid

Perhaps hybrids could offer a way out of this dilemma. The quality and market potential of hybrids is fully dependent on the strategy of this combination: how to realise a combination of the advantages from both propulsion systems without summing their disadvantages, and saving at the same time on weight, space and cost – the three critical tasks of a double-propulsion system.

Hybrids can offer a summation of the advantages of each propulsion system – but only in its best configurations. Unfortunately, all too often the opposite has happened.

HYBRID SCENARIOS AND CONSEQUENCES

Unlike pure EVs that will fill niche markets and that may never be a competitor for gasoline-powered cars, hybrids will find themselves positioned in the main market. Performance and range will be comparable to conventional cars – but will the price be?

In the first scenario, no restrictive law will be able to generate a special market, and hybrids will have to offer everything that today's cars can – while maintaining or bettering the costs. This target is still a long way off, but a target worth working towards.

In the second scenario, hybrids face better market conditions due to regulations like local zero-emission laws. In this case customers have to decide between EVs and hybrids, and hybrids are liekly to be their first choice, since they provide unlimited range on long trips. Even a higher price would be acceptable, since no second car is required.

However, in the mid- to long-term view, hybrids will have to become price competitive against conventional cars in any case. Large and complex hybrid propulsion systems – as often presented in the past – will therefore never stand a chance in the market.

Hybrids need to be simple, compact, powerful and lightweight.

SHORT-TERM DEVELOPMENT STRATEGY

Given that hybrids should start to have a growing market share before the year 2000, there will be no time to bring in new technologies. The only option for short-term development is to use existing technology but in a new configuration. To keep up with progress in technology, an 'open layout' will help to replace components in an evolutionary process.

Internal combustion engines

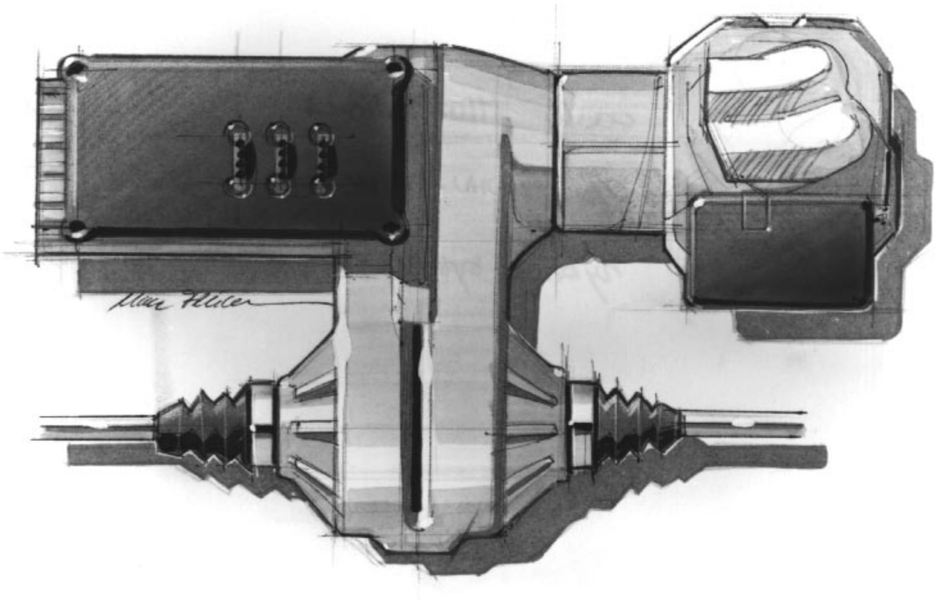
The first engine coming up in discussion concerning hybrids is the diesel engine, as a result of its high efficiency. But modern gasoline engines are getting more and more efficient too. If efficiency is not compared volumetrically but gravimetrically (CO_2 emission adjusted), the gap between the two diminishes considerably. And if low weight, lower cost and comfort is required, the four-stroke gasoline engine will be a better choice.

A two-stroke engine – even if it offers high efficiency and power density – is an additional development risk due to problems concerning emissions not having been definitely solved (over lifetime) and durability.

Multiple fuel machines have many advantages, especially for series hybrids, but most have not proved themselves with regard to size and volume production requirements.

Electric drives

Different electric machines can be used depending on the hybrid concept. Generators for series hybrids are often synchronous or magnet motors. For traction purposes, asynchronous motors



are most often used with synchronous motors or switched-reluctance drives as possible alternatives.

Gearbox

If at all possible a complicated gearbox should not be used in parallel hybrids since this will once again increase weight and complexity. While conventional automatic transmissions have high losses, continuous variable transmissions (CVT) offer better efficiency, but are still complicated and heavy. By sharing dynamic urban driving (electric) and constant highway driving (hybrid-electric), it will be possible to use a simple reduction gear offering comparable functions with less weight, complexity and cost.

Batteries

Batteries present the main problem for EVs as well as hybrids. Like EVs, hybrids need a very high peak power density (not decreasing lifetime) to bring about an energy buffer function. In addition, the capacity has to be high enough to produce the desired range in zero emission areas.

Sometimes hybrid solutions are proposed for the battery itself to overcome the power density problem (conventional batteries combined with flywheels or super capacitors). But this solution is the exact opposite of a 'simple is beautiful' strategy.

Fuel

Alternative fuels such as methanol and others are sometimes proposed for hybrids, but the lack of infrastructure is a serious penalty. For short-term and worldwide market applications, gasoline may be the best choice.

HYBRID SYSTEMS OVERVIEW

Only today's standard technologies are used for this comparison (IC engines are conventional piston machines). Those hybrids can be divided into the following classes:

- SIC – classic series hybrid, no recharging;
- SIR – series hybrid with range extender function, to be recharged;
- PHT – transient parallel hybrid, to be recharged;
- UNI – universal hybrid, to be recharged;
- TWIN TRAK – Esoro hybrid system, to be recharged.

Series hybrid

Series hybrids are powered at all times by the electric motor only. The (full size) electric motor therefore has to deliver all of the power required by the vehicle.

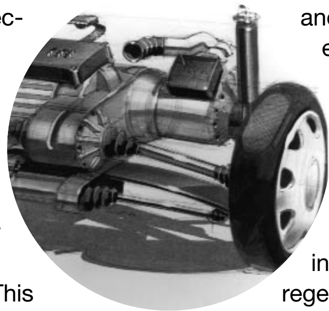
A mechanically completely independent 'generator unit'– made up of an IC engine and a generator – charges the battery. If designed to work without recharge from grid, this unit must again be full sized.

If no recharging is planned, a series hybrid will host (and the customer will pay) three times the power available for driving (1 x steady state engine – 1 x generator – 1 x electric motor). Series hybrids based on conventional technology can be the most inefficient, heaviest and most expensive.

However, major advantages are the downsizing of the battery pack and the low emissions (except CO_2). Especially if machines of continuous combustion are used, near zero emission may be reached.

Parallel hybrid

In parallel hybrids both motors have a mechanical connection to the wheels, and their power can be combined. Most existing parallel hybrids are based on IC engines working as a main motor. The electric motor only serves as secondary subordinate propulsion. This results in very poor electric performance, with bad acceleration even on flat roads, and causes significant problems during hill climbing. In any of these instances the IC engine has to support the electric motor, which can cause cold start problems and uncomfortable noise.



Conventional parallel hybrids often have very poor electric performance and unsatisfactory range. In this case it may be better to have only an efficient IC engine – in any case it would be cheaper.

WHAT MAKES THE TWIN-TRAK HYBRID DIFFERENT

At first glance, the Esoro TWIN TRAK hybrid seems to be a conventional, small parallel configuration. But there are differences – and it is therefore possible to use some of the advantages of series hybrid as a combination of the two. In addition there is an evolutionary version – not discussed here – working as a compact universal hybrid, featuring any parallel and any series function.

As simple as possible – but not simpler

First of all, the TWIN TRAK features a minimum of components and most of them are in their basic form. It is not possible to build a hybrid with fewer – and less complex – components. It features a very small IC engine, a full-size electric motor, an automatic clutch and a single-speed gear with differential. The result is the most compact, cost-effective and lightweight configuration possible using conventional technology. At the same time efficiency has been improved.

Exactly the opposite strategy

A major difference is created by using exactly the opposite strategy to that of conventional parallel hybrids: not the IC engine as the main motor, but the electric motor as the 'master' and more powerful motor while the IC engine is just sized to maintain any speed between 60 and 130km/h. In other words the IC engine runs in a 'quasi steady state' mode – as known from series hybrids – with the advantage of a permanent high load operating point. It therefore has excellent efficiency and it is easier to manage emissions.

By modulating the electric motor over this 'band energy' delivered by the IC engine, it is possible to have perfect acceleration and hill-climbing performance as well as regenerative braking at any point desired. The result is very high overall efficiency, since the induction motor has nearly the same high efficiency atpartial or full load, and the IC engine runs permanently at good efficiency loads.

In addition, it is possible to have nearly constant torque over the whole speed range, and this is without any torque interruption caused by gear change.

Of course, the driver does not need to worry where power comes from – torque is demanded (or negative torque) by the drive-by-wire acceleration pedal (or brake pedal) and is delivered. Once the driver pre-selects either hybrid or electric-only driving, everything works exactly as in any car with automatic transmission – or even better. The system has several advantages:

- Ease of construction;
- Shortest possible efficiency chain in any direction;
- Less components;
- Low weight;
- Low cost;
- Compact dimensions;
- Installed power can be added and substituted;
- Electric performance comparable to a good EV;
- No emissions in urban areas;
- Good IC engine efficiency thanks to permanent high load point;

- No cold starts necessary (preheat);
- Option: universal hybrid.

INSTALLING TWIN TRAK

The whole hybrid drivetrain including all components – except the batteries – fits easily into the engine compartment of a compact car and weighs only 97kg. This is less than a conventional drivetrain with an average power of 40kW (the size fitted in best selling compact cars).

IC engine

A newly developed two-cylinder, four-stroke boxer engine is used. The smallest version of this aluminium engine has a capacity of 360cc and features four valves, fuel injection and a weight less than 30kg. Maximum torque is 35Nm and top speed 6,000rpm. The specific consumption is below 255g/kWh at the best point and below 275g/kWh in most of the used load points.

Electric motor

A very advanced AC induction motor is used, delivering 34kW maximum power in its air-cooled version, and a maximum torque of more than 70Nm. Since this motor is in mechanical contact with the wheels at all times, it can charge in any situation, converting most of the braking and downhill energy into stored battery energy. With its controller the efficiency is 89 per cent at the best point and 85 per cent in most load points. The motor and controller together weigh 42kg.

Gearbox

A single speed 10:1 (electric motor) and 5:1 (IC engine) reduction gear works very well for the TWIN TRAK hybrid. An automatic clutch connects the IC engine to the single speed reduction if hybrid mode is selected.

Battery

A 230kg NiCd battery pack delivers about 9kWh energy at a system voltage of 180V. It takes four hours to recharge the battery from a conventional outlet. During highway driving at 120km/h, the battery can be recharged from 30 per cent to 80 per cent in about two hours, if this is required.

TWIN TRAK HYBRID IN A LIGHT-WEIGHT CONCEPT CAR

To give an example of what could be achieved, TWIN TRAK was built into a very efficient compact car of the future – the Esoro H301. For this car, even the smallest TWIN TRAK is oversized, with an average of 40kW over the whole driving range.

As indicated before, TWIN TRAK can also be scaled up to an average of 100kW for customised application in larger cars. In this event, the weight of the system will increase by only 30 per cent and will therefore result in a very high power density. ●

Vehicle data
Dimensions (lxbxh) 3.0mx1.5mx1.43m
Seats 4
Curb weight 710kg
Fuel 21 litres
Frontal area 1.8m^2
Drag coefficient 0.24
Rolling resistance 0.08

Acceleration
Electric or Hybrid 0-50km/h < 5 sec
Electric or Hybrid 0-80 km/h < 9 sec

Range
Electric 70-100km
Hybrid@90km/h >800km plus electric range
Hybrid@120km/h >500km plus electric range

Efficiency
Urban cycle ECE-electric <14kWh (0 l/100km)
@ 90km/h 2.6l/100km (0kWh/100km)
@ 120km/h 3.9l/100km (0kWh/100km)