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Electric Hybrid Drive Systems for Passenger Cars and Taxis

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Abstract

Various hybrid drive configurations are described and their advantages and disadvantages for application in passenger cars are discussed; specifically, these are the series hybrid, the parallel hybrid, hybrid drives with added torque and speed, single and two-shaft hybrids.
The Volkswagen and AUDI group has developed different vehicles with hybrid drive for various applications. These vehicles are described and test results are presented on their energy consumption, emissions and driving performance. In conclusion, some considerations are pursued concerning their chances on the market in different scenarios.

1. INTRODUCTION

A hybrid drive, comprising both electric drive and internal combustion engine, can, if suitably designed, combine the advantages of the conventional vehicle drive system (large cruising range, good performance) with those of a purely electric drive (low noise and exhaust emissions, conservation of petroleum resources).

Vehicles equipped with such drive systems are thus far more flexible than electric vehicles; they are often just as versatile as vehicles with an internal combustion engine and consequently are not confined from the outset to the "second car" market.

Hybrid drives thus have far more extensive potential applications than electric drives; higher production rates could in principal therefore be achieved, leading to low manufacturing costs.

Surprisingly, there is a wealth of possibilities for realizing such hybrid drives. Some of these possibilities are outlined below and the advantages and disadvantages of these different designs are investigated by considering vehicles already manufactured.

2. SYSTEM ANALYSIS OF HYBRID DRIVES

2.1 SERIES HYBRID DRIVE - Taking the purely electric drive as a starting point, it is simple to conceive of a hybrid drive: the batteries of the electric vehicle are recharged when driving as required via generator driven by an internal combustion engine. This is not only simple in concept, but also in practice; several VW Electric Transporters, fitted with a suitable motor/generator assemply in the loading area, have been transferred from Wolfsburg to Essen. In actual fact, not only improvised vehicle drives have been built according to this principle, but also real drives, e.g. by Daimler Benz (l)* for a city bus.

The main advantage of the series hybrid:

It is possible to operate the internal combustion engine at a fixed operating point within its engine-speed/torque map. This point can be selected so that the engine functions with the greatest efficiency or produces particularly low emissions.

Nevertheless, the efficiency of the entire drive is not satisfactory. As the structure of this so-called series drive in Fig. 1 clearly shows, the 3 components V (internal combustion engine), G (generator) and E (electric motor) are arranged in series: the mechanical energy generated by the petrol

*Numbers in parentheses designate references engine is converted into electrical energy by the generator and this is again converted back into mechanical energy in the electric motor. Each process of conversion is afflicted with losses resulting in relatively bad efficiency. This is also confirmed by test results from a fleet of hybrid buses which were operated in Esslingen.

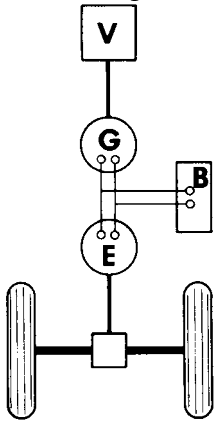

Fig 1 Structure of the series hybrid drive

A further disadvantage of this series hybrid drive is its heavy weight.

If power P_{max} is required at the drive axle e.g. for the maximum speed, the electric motor must be designed to produce this power P_{max}. If the driver wishes to drive long distances at this maximum speed, the power, which the battery could contribute, can be disregarded so that both, the generator and the internal combustion engine must be designed for the power P_{max} (because of the conversion losses in the electric motor and the generator, the power to be employed by the internal combustion engine would be even greater). A total power of over 3 P_{max} is required to drive at P_{max}. That makes this drive difficult to use in a universal vehicle (e.g. passenger cars) and expensive - particularly due to the two electric components.

For a vehicle, which only travels in the city, e.g. a delivery van or city bus, it may suffice, if the internal combustion engine and generator of the series hybrid are designed for average performance, since the battery could then provide for the power peaks. If this average performance is set at 1/2 P_{max}, it can be seen that, even in these urban vehicles, engines would have to be installed with power of more than 2 P_{max}.

Only if the combustion engine and the generator are very small compared to the electric motor - e.g. like in a range extender for electric vehicles (2), the series hybrid structure may be acceptable because additional weight, volumes and costs are small.

The problem of energy efficiency is neglectable in this case because most of the driving energy comes as electricity from the public network over the battery and the electric motor to the wheels and only a small amount comes out of the fuel tank over the IC-engine, the generator and the electric motor.

Another situation would be given, if the efficiency of the generator and the electric motor together are as good as the efficiency of the conventional gearbox. In this case, not only a series hybrid could make sense, but even a generator-motor-set instead of the mechanical gearbox. Some companies hope to be able to do this by using high speed synchronous generators and motors with new permanent magnets having a very high magnetic energy density (3).

But regarding Fig 2 showing that the efficiency of a mechanical gearbox is in a wide range over 90 %, it seems to be a long way to the "electrical gearbox".

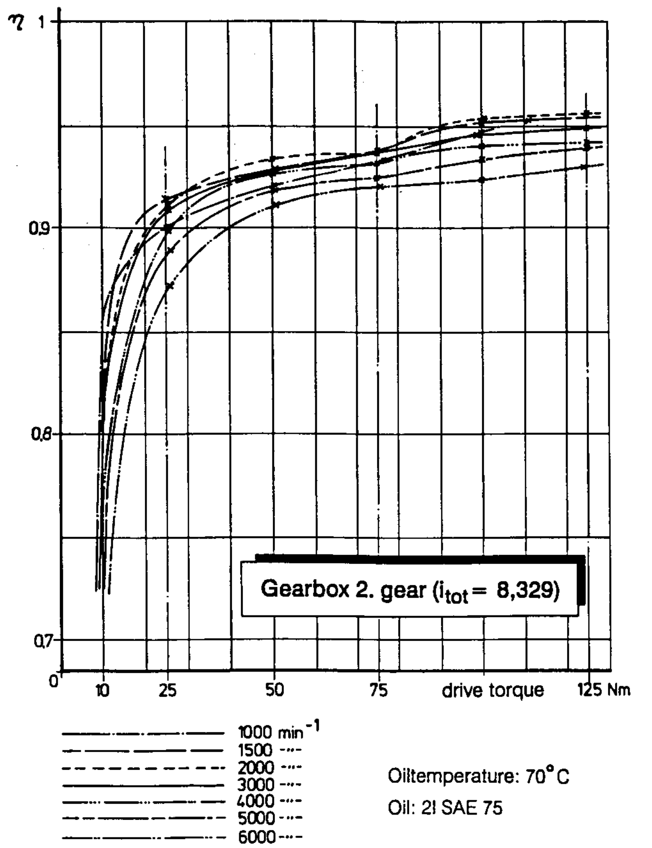

Fig. 2 Efficiency of a typical mechanical gearbox over the torque of the input shaft for different rotation numbers.

2.2 PARALLEL HYBRID DRIVES - Fig. 3 illustrates a parallel hybrid drive. Here, the internal combustion engine V and the electric motor E are not arranged in series (considering their power flow) but in parallel. The power provided by the two motors could be added to the vehicle drive. In this way, the power P_{max} required to drive a city vehicle, could be provided by designing e.g. both the internal combustion engine and the electric motor to give the power 1/2 P_{max} each. (For a series hybrid under the same conditions, at least 2 P_{max} would have to be installed.)

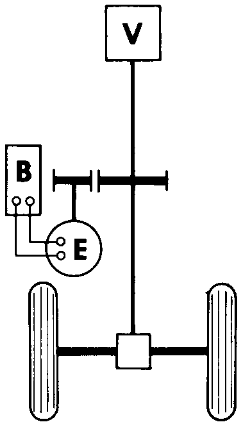

Fig. 3 Structure of a parallel hybrid drive

Whilst the series hybrid requires 2 electric machines, only one is present in the parallel hybrid. Nevertheless, even with the parallel hybrid, neither regenerative braking nor recharging the battery when driving should be disregarded, since the electric motor E can also function as a generator, e.g. if the total power of the internal combustion engine is not required to drive the axles.

Turning to a parallel hybrid for a universal vehicle requires the drive power P_{max} for longer periods, e.g. for long distances on the motorway. In this case, the power of the internal combustion engine must be P_{max}. The power of the electric motor could be selected from this completely independently. If P_{max} is selected for this too, since the series hybrid - if the battery power permits - can drive purely electrically at P_{max}, a total drive power of only 2 P_{max} needs to be installed. For a series hybrid under the same conditions, this would require more than 3 P_{max}.

In reality it is more sensible to select a much lower value for the power of the electric drive in such a parallel hybrid; i.e. a level which permits purely electric inner-city driving with acceptable performance. This is another point in favour of the parallel hybrid. The advantages of the parallel hybrid follows:

- Improved efficiency and thereby lower fuel consumption in the internal combustion engine, since its mechanical energy is directly passed on to the drive axle. (Only if the battery is charged during driving - which should be avoided for reasons of conserving energy - is the same unfavourable efficiency chain present as in the series hybrid.)

- The generator is no longer required

- The weight is lower

- Costs are lower

2.3 STRUCTURES OF PARALLEL HYBRID DRIVES - Parallel hybrid drives can be realized in the most diverse forms, since the two mechanical power plants can be combined in various ways.

The version already discussed is illustrated at the far left of Fig. 4. Because of its two parallel-running drive shafts, we like to call this the two-shaft configuration.

In the next structure both drive units are arranged around a single shaft. As in the two-shaft configuration, the torques are added (or, in generator operation, subtracted), and this provides a free choice, within certain limits, in determining the extent to which the two units contribute to the total drive torque. This provides e.g. the opportunity to compensate for rapid changes in the desired torque with the electric motor torque and to permit only very slow changes in the throttle-valve setting in the internal combustion engine. This sluggishness in the throttle-valve has the effect of reducing exhaust emissions. However, the engine speeds are determined by the gearbox transmission. There is no opportunity for selection here.

The situation is reversed in the third structure illustrated in Fig. 4. Here, the power combination is performed by adding together the speeds of rotation of both drives in a differential gearbox positioned between the two units. There is, therefore, a certain freedom in dividing the speed between the two units, but the torques are fixed by the desired drive torques. In consequence, it is impossible to retard the throttle valve. A further disadvantage arises from the fact that the electric motor torque, on the one hand, and the petrol engine torque, on the other hand, must always be equal, although the torque-speed maps of both units are vastly different. Therefore, it is impossible to utilize e.g. the high torque of the electric motor at low speeds of revolution, which

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