CONCEPT AND DEVELOPMENT STATUS OF A DUO-BUS/TROLLEY BUS MODULAR CONSTRUCTION SYSTEM.

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1. DEVELOPMENT STATUS OF THE DUO-BUS

1.1 The concept behind the DUO-Bus

Development of the DUO-Bus goes back to 1974, a time which was affected by the first oil crisis and the resulting occasional bans imposed on passenger cars.

As in all other economic fields - or rather especially - in the field of public transportation, in which more than 50 % of the transport performance is achieved by diesel buses, the search began for a substitute for petroleum as the primary source of energy by other suitable sources of energy, more readily available in the Federal Republic of Germany. The goal was not to replace diesel drive in the short term with alternative drive systems, but rather to look for and find technological possibilities or alternatives in order to have suitable, tested solutions available at the right time.

In this context, electrical energy, which can be produced by many primary energy sources had and has considerable significance.

However, trolley bus development in the Federal Republic had come to a halt. Only now are the German bus and electro industries beginning to develop suitable trolley buses for domestic use. (e.g. Solingen, Kaiserslautern). Quite apart from the question of availability of suitable trolley bus vehicles, a diesel bus operation cannot be instantly changed to a trolley bus operation. This requires several phases for the construction of the necessary trolley bus infrastructure. For this reason, not to mention the "fixed routes" determined by the trolley wires, a pure trolley bus system is not desirable to most operators.

The basic idea behind the DUO-Bus concept is the combination of two types of drive which enables the bus to drive on highly frequented routes under a trolley wire as well as totally independently of trolley wires in less frequented, widely spread out areas. Aside from a pure DUO-Bus system, a combination of trolley bus, DUO-Bus and diesel buses in one service area can provide a reasonable and economic alternative.

1.2 DUO-BUS TRIALS

Since 1st January 1980, buses with bi-modal propulsion systems have been under test in passenger service in the Federal Republic of Germany (Esslingen a.N.). The two versions being tested are:

- the trolley/battery DUO-Bus and
- the trolley/diesel DUO-Bus.

The first version is equipped with only one kind of drive, an electric motor. In trolley bus mode, the motor is supplied with current from the trolley wire via a vehicle battery which is charged, at the same time, for operation without trolley wires.

In the second version, the vehicle is equipped with two complete propulsion systems, one electric and one diesel drive, which power the vehicle alternately via an automatic switching mechanism. In the electric mode, the vehicle operates as a trolley bus supplied with current by trolley wires and in operation without trolley wires as a conventional diesel bus.

The operational trials of the

2 trolley/battery buses (2-axles)

finished on 31st July 1981 and the trials of the

3 trolley/diesel buses (two 2-axle and 1 articulated)

are still in progress.

1.3 RESULTS OF THE TESTS OF THE TWO TROLLEY/BATTERY BUSES

In order to permit these buses to operate, a special licence was needed, limited to line haul service in Esslingen a.N., allowing a total weight of 18,800 kg and a rear-axle load of 12,400 kg. These values are 2,800 kg above currently permissible total weight, and 2,400 kg above currently permissible axle loads. These values are still too high for series introduction of the vehicles.

Passenger service with the DUO-Bus had to be started without the vehicles having undergone sufficient driving and functional tests, as the companies of the DUO-Bus group had no suitable test route with trolley wires available. Even though the passenger service was introduced to the public as a "trial service", it was a disadvantage for the system that the whole start up and test phase had to take place in full public view. Situations arose which, on the one hand complicated operations and on the other hand were often unjustly put down as disadvantages of the system.

A longer trial period without passengers was not possible, as the DUO-Buses were urgently needed by the Esslinger transport company as replacements for old trolley buses which had to be taken out of service.

The average operational availability of both buses throughout the entire test period, amounted to just barely 50 %, both with regard to days of operation as well as daily mileage. The slightly better results were achieved by vehicle no. 302 during the first 6 months of the trial with an availability of 66 % (days of operation) and 77 % (daily mileage). When the technical problems recognized during the trial operation are solved, future buses of this type will be able to achieve availability results equivalent to conventional diesel buses, of nearly 90 %. The problem lies in the high degree of servicing required by the batteries to achieve this level of availability.

Of the 6 types of service period:

- daily, - every 3 days, - monthly
- 1/4 yearly, - 1/2 yearly, - annually,

the expenditure is greatest for servicing every 3 days, which only needs to be carried out on the trolley/battery bus and not on the trolley or diesel buses.

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The 3-day cycle is necessary for battery maintenance and includes the following work: "Extracting the battery troughs, checking the density and temperature of the electrolyte and the fluid level of the electrolyte in each cell as well as topping up with water, checking insulation values and examining all systems before finally replacing the battery troughs in the vehicle".

The 173 hours per year required for this is already in excess of the total maintenance time for the trolley bus, diesel bus or any comparative bus.

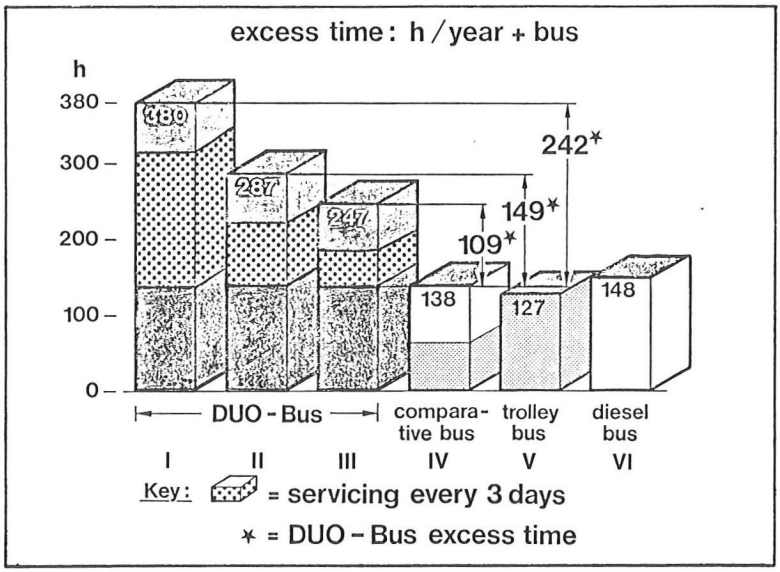

Fig. 1: Expenditure of time for servicing trolley/battery buses.

Fig 1; I & IV: The "comparative bus" takes a comparison of the DUO-Bus system and a trolley bus/diesel bus system into account, which is to say, it is comprised 50 % of the time expenditure for trolley buses and 50 % for diesel buses.

The above displayed time expenditure for servicing every 3 days results from manual extraction and replacement of the battery trough and when each and every cell is checked, as in Esslingen (servicing time totals 2 hours/check).

If we assume that the batteries are changed semi-automatically and only every second cell is checked, time expenditure is reduced to 1 hour/check or 80 hours/year
(Fig. 1; II).

If the batteries are changed semi-automatically and random cell checks are made, the time can be reduced to 1/2 hour/check or 40 hours/year
(Fig. 1; III).

In this final case, however, we are still left with an excess of more than 109 hours/year or about 80 % compared to the "comparative bus".

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Despite the good characteristics of the trolley/battery DUO-Bus concept namely

- independence from petroleum
- very quiet
- totally exhaust free (these characteristics have led to the system being positively judged by both passengers and drivers),

its application in practice is unsatisfactory. The batteries are still too heavy, require too much maintenance and are too inefficient and expensive for general introduction into public transportation.

It remains to be seen whether there will be a decisive break-through in battery research. In the near future of the DUO-Bus, however only the trolley/diesel concept can be considered.

1.4 RESULTS OF THE TESTS OF THE 3 TROLLEY/DIESEL BUSES

As already mentioned, the operational testing of these buses is still in progress so that no final statistics are as yet available.

The following four sources of malfunction have so far lead to operational breakdown:

- noises in the five-joint cardan shaft caused by rotational oscillation in electrical operation
- switching impulses during braking in electrical operation caused by differing rotational masses of electric and diesel motors
- switching of the transfer gears from diesel to electrical operation and
- controlling power collection in the automatic power collector.

Of the above mentioned malfunctions, the problems of the switching of the transfer gears has been completely solved.

The other malfunctions have been greatly improved although not totally eradicated.

The dynamic synchronization of the electrical drive with the switching of the automatic transmission remains a problem.

2. ALTERNATIVE DRIVE CONCEPTS

In the search for further suitable drive concepts, the question must first be answered as to which basic vehicle (carrier vehicle) should be used.

2.1 CONSIDERATION ABOUT THE CARRIER VEHICLE

In the Federal Republic of Germany there are only 3 trolley bus companies operating today. Their requirements for new vehicles in numbers is uninteresting for development of a DUO-Bus/trolley bus system. Other applications must, therefore, be found. The most recent investigations have shown that the largest spectrum for application of a DUO-Bus/trolley bus system lies among the diesel bus and trolley bus/diesel bus operators. 32 diesel bus companies have been chosen which are suitable for a change over to an electric or partially electric bus system.

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A prerequisite for the introduction of trolley buses in diesel bus operations is always the installation of power transmission systems. Therefore only those route sections which justify such high capital investment due to their high level of passenger demand or short headways can be considered.

Route sections with high passenger density lend themselves especially well to the economic use of articulated buses. As far as trolley buses and especially DUO-Buses are concerned, the costs for equipping the vehicles/passenger place are considerably more favourable or lower for articulated buses than for single units (2-axle).

Based on these considerations, only the articulated bus can be considered as an economical carrier vehicle for trolley buses and especially for DUO-Buses.

The installation and development of power transmission networks is always carried out step by step; less densely used route sections in the outer city areas are also not electrified for economic reasons: In this area the best and most reasonable chances for the introduction of DUO-Buses can be seen although every transit operator is left to decide for himself the extent to which overhead power networks are developed and whether to establish a pure trolley bus system or a combined trolley bus/DUO-Bus system.

Demand for a modular construction system arises out of the possibility of parallel operation of diesel bus, trolley bus and DUO-Bus, consisting on the one hand of the same carrier vehicles and on the other hand of, as far as possible, uniform equipment components.

2.2 CONSIDERATIONS ABOUT THE DUO-BUS DRIVE CONCEPTS

A total of 15 drive concepts and variants have been defined, investigated and compared with one another. The concepts which have shown the best results in the comparison tests are described briefly in the following (the bus against which comparisons were made is the diesel articulated bus).

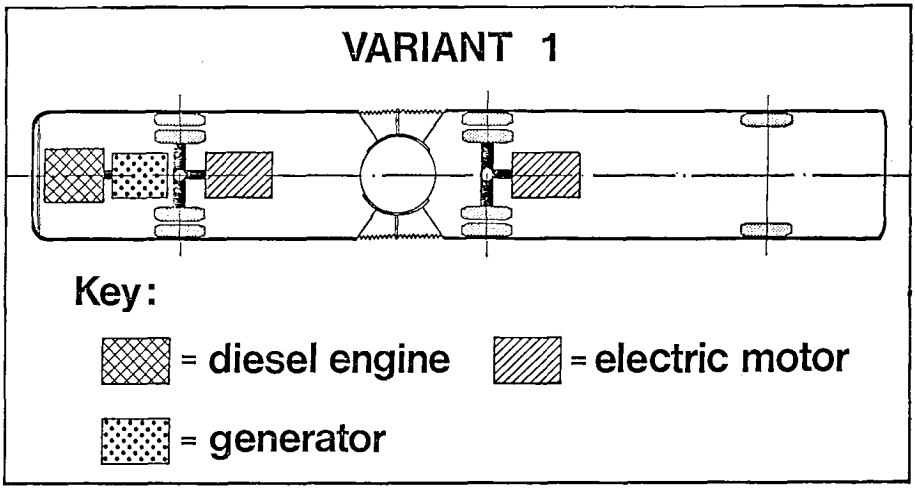

Fig. 2: DUO-Bus, 2-axle drive (trolley/diesel-electric)

The advantages of "Variant 1" are:

- very good traction characteristics with 2-axle drive and
- possibility of modular construction system "DUO-Bus/trolley bus".

The disadvantages are:

- very high total weight of vehicle (approx. + 3 tons)
- high axle overload (approx. 1.5 tons) and
- relatively high vehicle production costs.

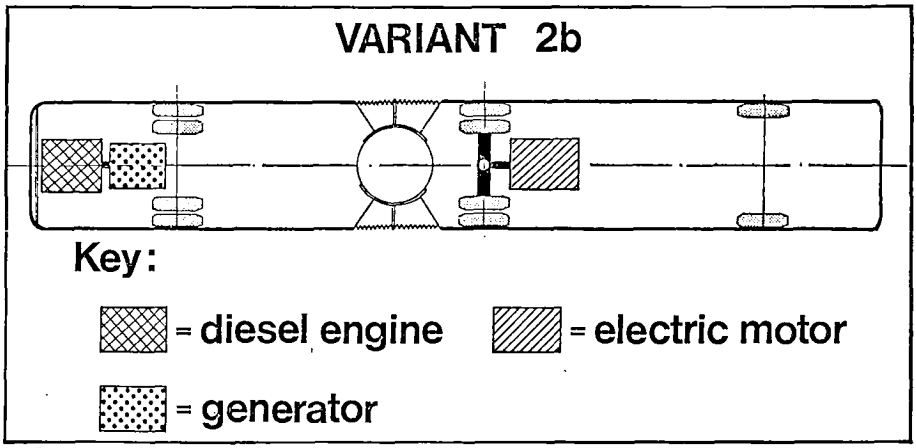

Fig. 3: DUO-Bus single axle drive (trolley/diesel electric)

"Variant 2b" is lighter and cheaper than "Variant 1". It is, however, still

- too heavy (approx. + 2.5 tons) and
- too expensive.

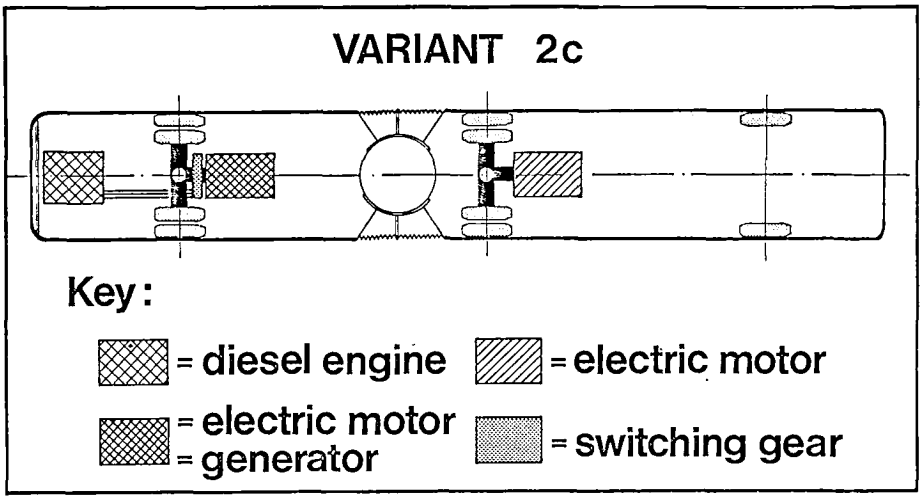

Fig. 4: DUO-Bus double/single axle drive (trolley/diesel electric)

"Variant 2c" (see Fig. 4) can be placed between "Variant 1" and "Variant 2b" (the generator in operation without the trolley wire is switched to a second drive motor in trolley wire operation).

Advantages:

- traction characteristics during trolley wire operation are very good due to the 2-axle drive and
- possibility of modular construction system "DUO-Bus/trolley bus".

Disadvantages:

- high total weight of vehicle (approx. + 2.3 tons)
- axle overload on one axle (approx. 1.25 tons) and
- additional clutch and switching device to change from 'motor' to 'generators' and vice versa.

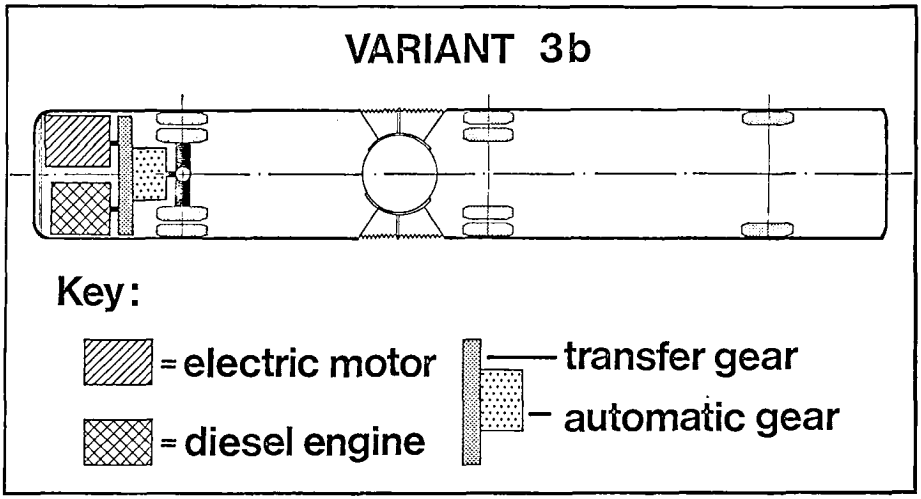

Fig. 5: DUO-Bus single axle drive (trolley/diesel)

"Variant 3b" represents the model being currently tested in Esslingen (with automatic transmission).

Its advantages are:

- lightest of the DUO-Bus variants (approx. + 1.2 tons) and
- relatively low vehicle production costs.

Its disadvantages are:

- a concept-dependent high axle overload (approx. 1.15 tons) and
- no possibility of a modular construction system for DUO-Bus/trolley bus due to the complete difference of electrical equipment (unless, the automatic transmission concept could be improved to such an extent that it could be used to govern a pure trolley bus drive).

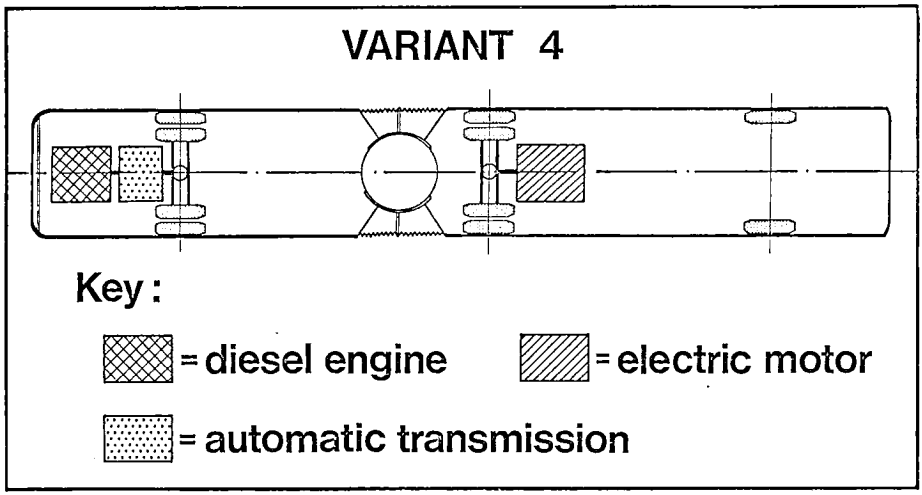

Fig. 6: DUO-Bus alternate axle drive (trolley/diesel)

"Variant 4" represents the technically simplest concept with its mainly conventional equipment components. In the grouping of alternate drive systems, it demonstrates the lowest axle overload and offers good possibilities for a "DUO-Bus/trolley bus" modular construction system. Its disadvantage is that in each case only one axle can be driven.

"Variant 6" (see Fig. 7) with its hydraulic intermediate transmission and a hydro-accumulator comes off best with regard to vehicle production costs and possibilities of regeneration for both forms of propulsion.

As a result of regeneration, both propulsion motors can be designed at a lower performance level which results in the lowest axle overload compared to all the other variants (less than 1.0 ton).

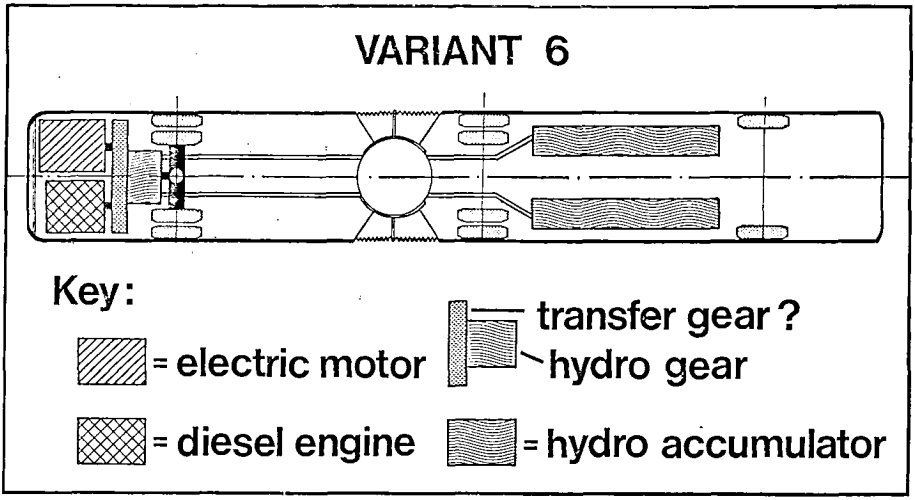

Fig. 7: DUO-Bus single axle drive (trolley/diesel with hydro transmission/ energy accumulator)

The disadvantages are that this technology has not yet reached its final level of development and that a modular construction system with conventional trolley bus propulsion is not representable, unless this technology can also in future, be used to control a pure trolley bus drive.

3. CONCEPT OF A DUO-BUS/TROLLEY BUS MODULAR CONSTRUCTION SYSTEM

The three Federal German trolley bus operators urgently require new trolley buses. Reliable DUO-Buses are needed short-term for the comparative test project "Automatic laterally guided buses" in Essen in which buses together with trams should drive through a tunnel to make use of the existing infra-structure and for the DUO-Bus operation in Esslingen a.N.

In order to work out common acquisition standards for a DUO-Bus/trolley bus system, these transport operators have formed a work group. This work group is currently working out the draft of an appropriate construction system, on the basis of which, both DUO-Buses and trolley buses can be manufactured without changes to the floor components and superstructure of currently produced diesel articulated buses.

Due to the urgent requirements for vehicles, all members of the work group agreed to select one propulsion variant composed of the best tested and most reliable components. For this reason the already mentioned "Variant 4" was selected. For the modular construction system, the following 4 solutions to the propulsion question can be considered:

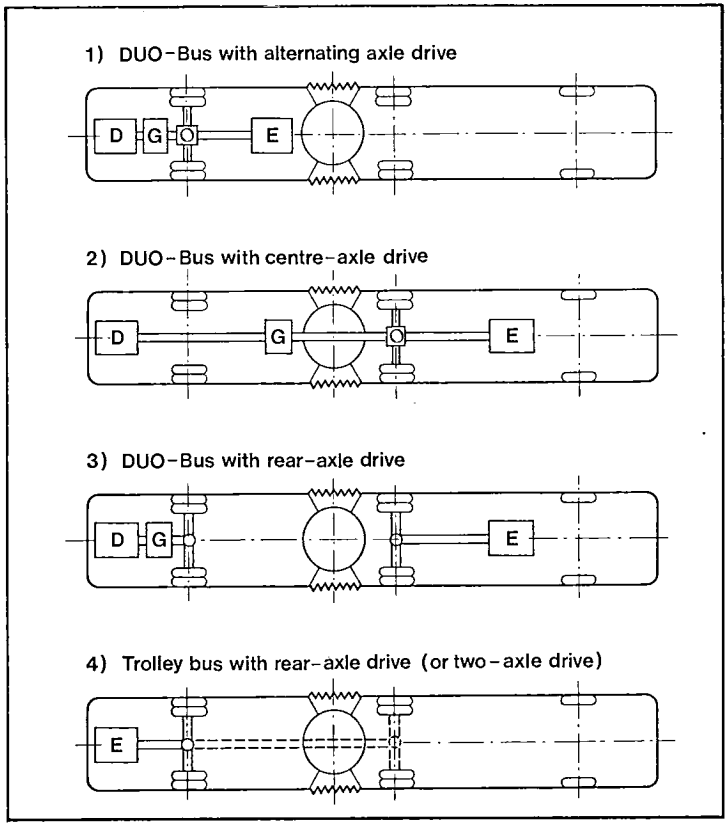

Fig. 8: DUO-Bus/Trolley bus drive layouts

The DUO-Bus solution is faced with the problem of installing the electric motor under the floor, as the rear of the bus is already taken up with the diesel engine. The result is a problem of floor height.

By using an electric motor of 510 mm in diameter, already in series production for trams, and a slightly limited floor clearance of 250 mm, there is already a floor height of 800 mm. Floor height for the new generation of diesel buses should, however, only be 710 mm. There are two possible solutions to this problem:

1) Using the available motors of 510 mm diameter and suitable ramping of the floor. Disadvantage: Additional production expenditure through alteration to the floor construction; (see Fig. 9).

2) Development of an electric motor with a suitably small diameter (450 mm). Disadvantage: Risk of developing a new motor.

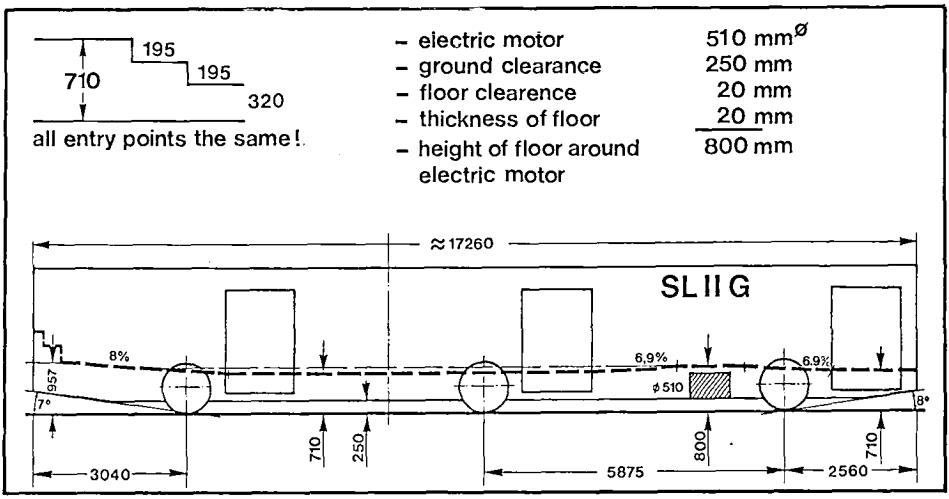

Fig. 9: Floor height with an electric motor of 510 mm in diameter

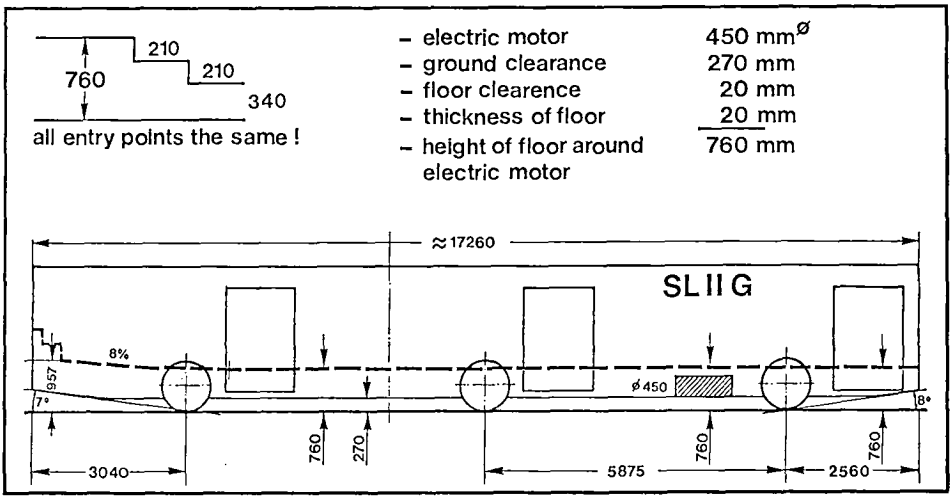

Fig. 10: Floor height with an electric motor of 450 mm

Both alternatives are currently being developed. A vehicle prototype with a motor of 510 mm in diameter and floor ramping as well as a prototype with a motor of 450 mm in diameter and level floor are to be put into operation in Essen this year within the framework of the project "Automatic laterally guided buses". Two further prototypes of the variant with a motor of 450 mm diameter will be introduced in Esslingen a.N. in the autumn of this year.

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