TRIALS OF BATTERY-POWERED BUSES WITH AUTOMATIC CHARGER COUPLING FOR BRIEF BOOSTER CHARGING DURING REGULAR STAGE SERVICES

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SUMMARY

A new battery charging technique offers the possibility of developing the battery-powered bus to a genuine alternative to the diesel-engined bus. Brief periods of booster charging during longer, timetable waiting periods, mainly at route ends, make it possible to run regular stage services with electric buses for a full day without changing batteries. The booster charging is carried out by an automatic coupling with stationary contacts above the vehicle.

STARTING SITUATION

Environmental and energy considerations led at the beginning of the 1970's to investigation of the possibilities not only of electrifying private cars, light vans and special vehicles but also of using battery stored electrical energy for local bus services. The trolley bus, the traditional form of electric bus, had lost more and more ground to the more flexible and economical diesel bus, on account of the limitation of the trolley bus to its tracks and the costs of laying and maintaining the tracks. This investigation was thus a new start into electric propulsion, which is low-pollutant and independent of oil, under the influence of the oil crisis and the worldwide ecological discussion.

Compared to the trolley bus concept, battery-powered buses offer more flexibility in operation and require a less costly support infrastructure. The operational utility is however limited, particularly in comparison to the diesel bus, by the low energy density of the storage medium carried. To achieve an adequate run range or daily range for regular local stage services, some form of recharging must be provided. This recharging can either be on the vehicle, by means of a diesel generator, or on the route, by means of a support infrastructure either at points or along lines. These considerations led to three different design concepts for battery-powered buses, which were developed and put to trial in parallel.

The hybrid bus is one which carries its own diesel generator for recharging the traction battery. In this way, run ranges of up to 100 km can be achieved with the diesel engine running for around 50% of the operating time.

The duo bus, in the variant with combined mains and battery powered electric drive, is designed so that the vehicles can travel in cycles, whereby for part of the cycle they are in contact with overhead wires and for the remainder they operate from batteries. This does however make them partially trackbound.

The concept of the purely battery-powered bus aims to enable the bus to be used flexibly for regular stage operation by providing suitable recharging facilities for the traction battery at certain fixed points, without needing any recourse to other sources of energy.

The future prospects for the new types of electric bus and the extent to which they are competitive with the diesel bus are decisively dependent on advances in battery technology. So long as the worldwide intensive research effort here still does not achieve a breakthrough, the use of battery-powered buses will remain limited to specialized applications. This is all the more true insofar as the well-proven diesel technology has such a large economic advantage that this cannot be counterbalanced by energy-source and environmental policy benefits alone.

Despite this, it is necessary to test alternative forms of propulsion, and particularly electrical ones, in order to be well prepared for cases of need which could arise through a new oil crisis or through new developments in batteries.

CLASSIFICATION WITHIN EXISTING TYPES OF BUS

Fig. 1 shows how the battery-powered bus compares with existing types of regular stage bus as regards type of propulsion and method of energy supply.

Line c, on the far right of the picture, shows the diesel bus, not trackbound, which can be utilized in a wide variety of ways in local public transport services with negligible route-bound infrastructure. Its especial operational advantage is that it can be deployed extremely flexibly; its disadvantages, on the other hand, are that its engine is completely dependent on mineral oil which is becoming scarcer and scarcer, and that it produces noise and fumes which are experienced as nuisance, particularly in heavily built-up areas.

A low-noise system with no exhaust gases, operated by electricity and independent of oil, has existed for a long time in the form of the trolley bus (Line a). The fact that it is trackbound to its overhead wires is however a major disadvantage, since firstly it means the bus cannot be flexibly deployed and secondly this extensive, route-bound infrastructure of overhead wires must be erected. Nevertheless the trolley bus, a well-proven engineering system, remains suitable for specialized applications, for reasons including its low pollution and its independence from oil.

The battery-powered bus supported by frequent battery changes is shown in Line b. This type of bus carries its own energy supply on board, and can be sent wherever the routes and the timetable permit the batteries to be mechanically changed;

it also offers the advantages of using electricity as its propulsion energy. The supply at the stationary points does however require substantial expense.

As regards its aim of combining the advantages of the diesel bus with those of electric propulsion, the brief booster charging method (Line e) is a further onward development from the method of frequent battery changes. The battery carried on the vehicle here largely replaces the extensive network of overhead lines of the trolley bus and removes the rigidity of route which this imposes. Compared with the frequent battery changes method however, the brief booster charging method with automatic coupling is substantially cheaper and offers operational flexibility much closer to that of the diesel bus.

Lines e, f, g, and h show the various duo bus and hybrid bus variants as mentioned above.

EXPERIENCE WITH THE BATTERY-POWERED BUS

In a model trial, 20 electric buses have been used on daily stage services since late 1974. The mileage covered was approximately 6 million kilometres, and has demonstrated that battery-powered buses, using the method of frequent battery changes, can meet the requirements of full-day stage services in a similar way to the diesel bus.

The battery-powered buses were used on a country route of approx. 40 km round-trip length in Mönchengladbach and on an 11 km circular city route in Düsseldorf.

The total mileage of the twenty vehicles used averaged 280 000 km per vehicle. The maximum was 350 000 km for one of the buses in Düsseldorf. The maximum run range proved to be about 60 km. Taking into account the factors affecting battery life, the batteries were however changed every 40 km in practice, for reliability reasons (fig. 2).

The amount of energy used from the mains supply was on average 10.19×10^6 joules per km (2.83kWh/km). The energy recovered by regenerative braking was on average 15%. These figures should be compared with figures of 9.36×10^6 joules per km (2.60 kWh/km) for the trolley bus and of 14.35×10^6 joules per km (3.99 kWh/km) for the diesel-engined bus.

The maintenance interval for the batteries was initially from 15 to 20 use cycles, i.e. after running for 600 to 800 km. This maintenance interval was subsequently extended to 50 use cycles (2000 km) by using batteries with mechanical stirrers for the acid.

The battery life was initially 1100 use cycles (46 000 km), subsequently increased to 1500 use cycles (60 000 km). As regards the energy throughput, this represents an increase from 306 x 10^9 joules (85 000 kWh) to 403 x 10^9 joules (112 000 kWh). When this is related to the annual mileage, the battery life is approximately one year.

A pilot project for testing the automatic charging coupling concentrated primarly on investigating the battery's capacity to accept charge during halt periods of different lengths as determined by the route timetable, and on how high a charging current could be used. The results showed that a mean charging current almost double that used on the frequent battery changing method is necessary. The normal discharge time is 5 hours: at a charging current four times this current, this represents a rate of charging not previously applied to traction batteries (fig. 3). Fig. 4 shows an example of the typical alterations in battery charge during a working day of more than 16 hours.

In early 1979 a prototype bus was used by the Düsseldorf local transport authority (Rheinische Bahngesellschaft) for regular stage services. In the trial period of 18 months this vehicle has successfully run around 60 000 km. The most important results to emerge from this trial can be summarized as follows:

1. It is advantageous to use an automatic coupling (arm-mounted contact) in the interests of maximum possible utilization of the halt periods for charging the batteries.

2. The battery life is relative good, similar to that achieved by the frequent battery change method.

3. Heat conduction away from the battery must be increased to cope with the heavy losses during the brief intensive charging periods.

4. The system found good acceptance with the bus drivers.

The experience and results from the pilot project are the basis for the design and execution of the operating trials in Düsseldorf.

OPERATING TRIALS WITH AUTOMATIC CHARGER COUPLING

The most important aims of the operating trials started in Summer 1982 with 20 batter-powered buses recharged by brief booster charging are as follows:

1. To prove that full-day use on regular stage services without other sources of energy is possible.

2. To prove that the newly developed automatic charger coupling functions properly.

3. To reduce the costs for the stationary energy supply equipment, coupled with a marked reduction in overall costs and improved flexibility in changing routing.

4. To optimize the utilization of batteries, in respect of battery life, size, and stockholding of batteries.

In order to assess the effect of different types of route with differing passenger characteristics, these vehicles are being tested on two routes of differing character. The most important parameters of these routes are as follows:

Route 779: Ring route, 11 km long.
7 full-day duties, 4 peak-hour duties
Mean service frequency approx. 13 minutes
Mean halt time at end stop approx. 10 minutes
Wholly urban route.

Route 788: Length of route 28.2 km
3 full-day duties, 3 peak-hour duties
Mean service frequency approx. 16 minutes
Mean halt time at end stop approx. 16 minutes
Mixed urban and rural route

These two routes meet at one end stop, the Benrath station (fig. 5), which is also a station for the railway, for bus routes, and for urban and inter-urban trams. This point was chosen for the booster charging point, since at this point both routes can use the same charger coupling system.

To meet the timetable requirements of these two routes, seventeen buses were equipped for the new booster charging system. Three of the originally used battery buses, equipped for the frequent battery changing system, which can only be charged by being plugged in at the bus garage, are available as operating reserves for the peak-hour services.

Five booster charging equipments are provided at the Benrath station, with automatic coupling (fig. 6).

During the operating trial, which is initially planned for a period of 18 months, all operating and traffic data relevant to the assessment of the coupling system will be recorded. To supplement and confirm these findings, special measurement runs under precisely defined test conditions will also be carried out. On completion of the experiment it should be possible to use the data obtained to compare electrically-powered buses of differing energy supply types with each other and with the diesel bus in respect of energy balance-sheet, cost/benefit relationship, reliability and spectrum of applications.

AUTOMATIC COUPLING by H. Gerndt

TECHNICAL DESCRIPTION OF THE SYSTEM

The vehicles used are standard VÖV electric buses manufactured by M.A.N.(Maschinenfabrik Augsburg Nürnberg AG), taken over from operation on the frequent battery change method. These are standard production models, some fitted with series-wound motors (Siemens), some with externally-excited shunt-wound motors (Bosch). Both these variants have regenerative braking.

To retain the passenger capacity of the buses and to avoid costly modifications, the batteries (Varta), weighing 6 tonnes, are located on a two-wheel trailer. This makes it easier to test various different battery designs.

The new charger coupling device is built onto the bus roof, free to swivel, above the front axle (fig. 7). The contact arm is raised and lowered by a pneumatic cylinder and two tensions springs parallel to it. At the end of the contact arm, which is 2.30 metres long, are four electric contacts: two movable main contacts, one earthing contact to equalize the voltage, and one control contact for monitoring the system (fig. 8).

Contact arm:	length of jib	2.30 m
	weight	120 kg
	press force (max.)	275 N
	2 main contacts	
	1 earth contact	
	1 auxiliary contact	
	lateral tolerance for vehicle	± 0.35 m
	powered by compressed air and mechanical springs.	
Mating contact:		
	length	1.80 m
	width	0.70 m
	height	0.60 m
	weight	90 kg
	2 main contacts	
	1 earth contact	
	1 auxiliary contact	
Electrical data:		
	max. charging current	400 A
	max. voltage	500 V.

In contrast to the trolley bus, where costly double insulation is used, in this system an earth wire system provides the necessary safety against persons touching dangerous voltage parts. The electrical control system for the movement of the contact arm is located in an electrical cabinet in the free space behind the driver's seat (fig. 9).

The stationary mating contact, 1.80 m long, is fixed at 4.25 m height to a mast. It is shaped like a gable roof and contains the four mating contacts to those on the arm on the bus (fig. 10). The contact is made partly smoothly sliding, partly frictionally, and thus it can be anticipated that the contacts will be self-cleaning.

Lead-acid traction batteries are used, rated for 360 V and with a a working capacity of 360 Ah. Within the scope of this trial, which is supported by the German Federal Transport Ministry, six batteries with a new system of stirring the electrolyte are also being tested under the support of the German Federal Ministry for Research and Technology.

The main method used for conducting away the waste heat generated in the battery is a higher performance version of the air/water cooling system well proven in the trials with the frequent battery change method. This type of cooling is simple and effective. Another form of cooling has been created by inserting a refrigerating unit in the existing cooling water circuit. This solution, more complicated from an engineering point of view, nevertheless offers the advantages of being able later to utilize the heat for heating the passenger compartment and of enabling the battery to be operated within its optimum temperature range.

The booster chargers at each terminus use thyristor chargers in a fully-controlled three-phase bridge circuit. The power these take from the mains supply is a maximum of 240 kVA. On the DC side they are designed for 400 V and 500 V. The charging characteristic is of the same type as an IUIa characteristic. At the overnight bus garage, the batteries are fully charged overnight using comparable chargers but of lower power. The electrical contact in this case is made through existing plug-in charger connections.

MEASUREMENT PROGRAMME AND RESULTS OF TRIALS

(will be supplemented orally, since final checked results not yet available)

FUTURE PROSPECTS

Considering the intense efforts being made to develop batteries capable of holding a higher energy density, such as the high-power sodium-sulphur battery being supported by the Federal Research and Technology Ministry, it can be expected that the system of brief booster charging with automatic coupling for regular stage services will further increase in importance within the near future.

A higher energy storage capacity on board the vehicle permits firstly a greater run range for the vehicle and thus a marked reduction in charging times, in the number of booster charges and the number of booster charging stations. The increased range of applications thus resulting from this low-pollutant system which is also independent of oil supplies could also lead to a more intensive use of the charger stations which would provide noticeable savings in the capital costs for the infrastructure, quite apart from the lower unit costs of producing the vehicles in volume.

Secondly, raising the energy density could also permit the batteries to be made smaller, enabling them to be more easily accomodated within the vehicle. A reduction in weight and being able to dispense with the trailer for the batteries would improve the running characteristics of the bus.

Independent of which of the two available directions is given priority for future development, it can be expected that the electric bus system with brief booster charging which has been presented here will, in the not too distant future, be representing a genuine alternative to existing bus operating methods.

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Elektrobusse mit Kurzzeitzwischenladung durch Automatische Ankopplung im Linienbetrieb
Paper presented at "Statusseminar IX Nahverkehrsforschung '82"

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Erfahrungen mit Kurzzeitzwischenladung an batterie-elektrischen Linienbussen
Paper presented at DRIVE ELECTRIC Amsterdam '82

PICTURES

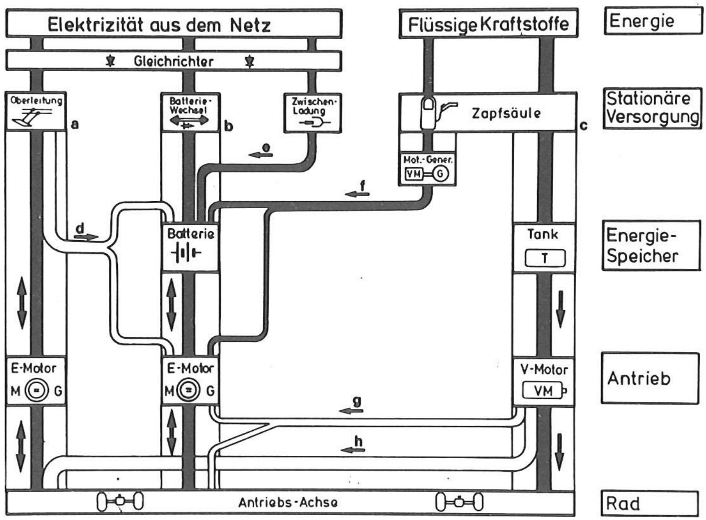

Fig. 1: Urban Transport Busses and their supply (by GES)

Fig. 2: Battery Powered Urban Bus supplied by Battery Changing

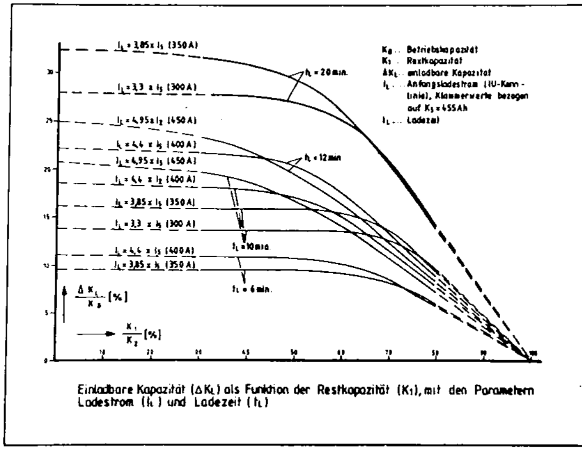

Fig. 3: Chargeable capacity (ΔK_L) as a function of the residual capacity (K_1) with parameters initial charge-current (I_L) and charging time (t_L) (by GES)

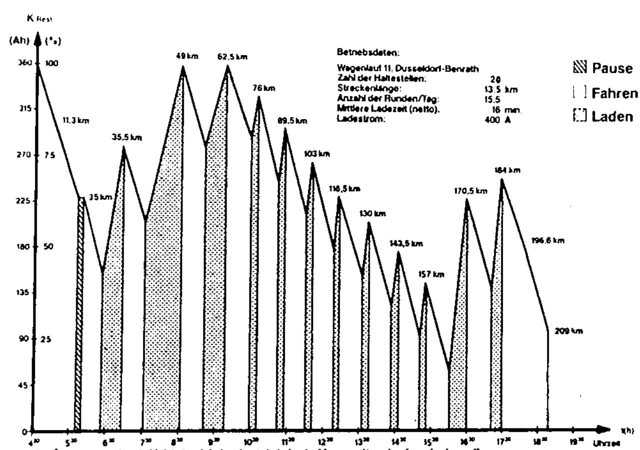

Fig. 4: Capacity diagram of line operation with "Short Term Intermediate Recharging (by GES)

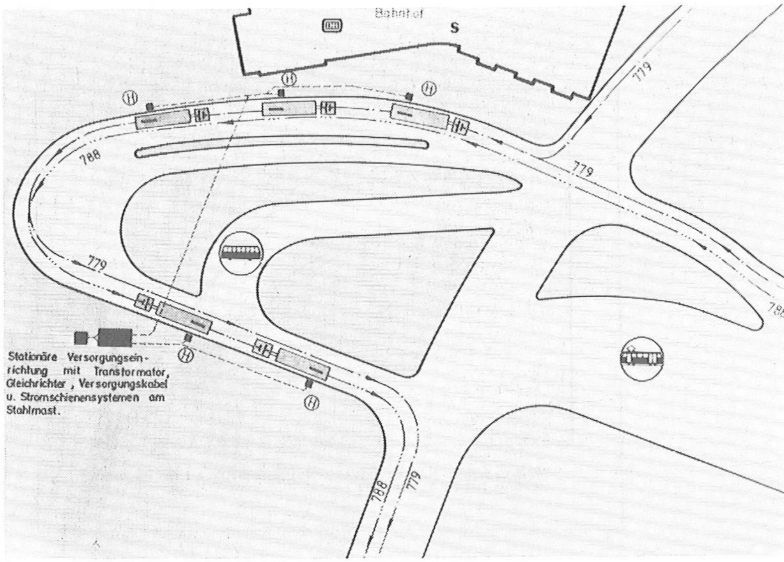

Fig. 5: Battery-Powered Urban Busses and their supply facilities at trafic center "Bahnhof Benrath"

Fig. 6: MAN-Battery-Powered Urban Bus suplied by "Short Term Intermediate Recharging"

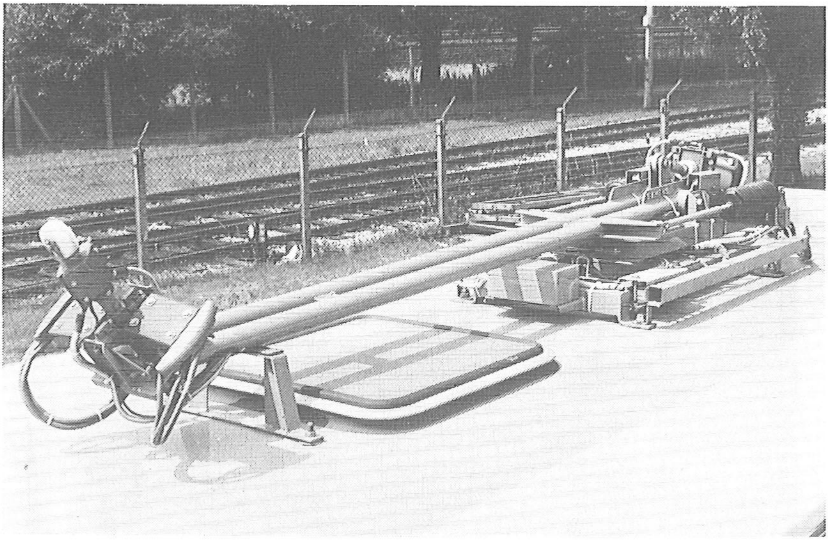

Fig. 7: Current collector

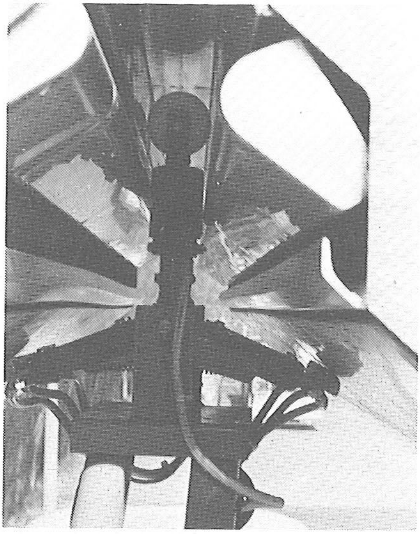

Fig. 8: Coupled contact-head

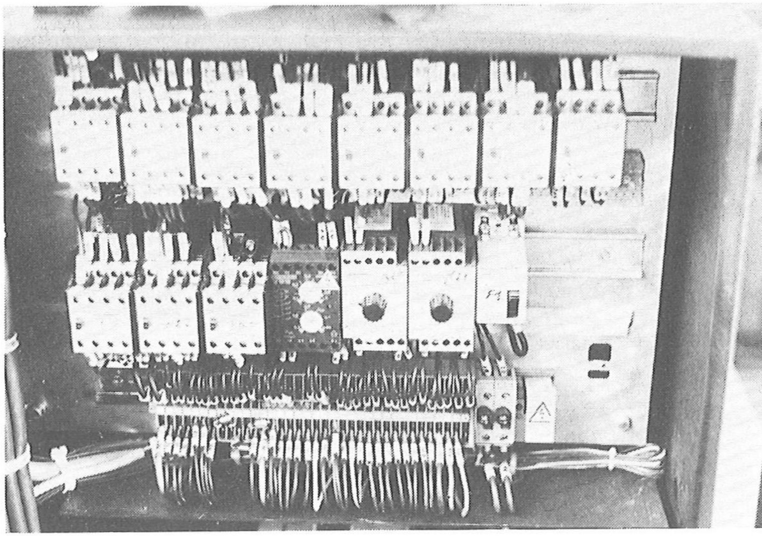

Fig. 9: Controlling means behind the drivers seat

Fig. 10: Stationary coupling-system