ANALYSIS OF LONGITUDINAL VEHICLE CONTROL SYSTEMS WITH MINIMISED EMISSIONS AND OPTIMISED DRIVING COMFORT

Dipl.-Ing. Dirk Neunzig, Dipl.-Ing. Karsten Breuer
Institut für Kraftfahrwesen Aachen (ika), RWTH Aachen, Steinbachstr. 10, D-52074 Aachen
Tel: +49/241/80-5615, Fax: +49/241/8888-147
neunzig@ika.rwth-aachen.de, breuer@ika.rwth-aachen.de

SUMMARY, INTRODUCTION

For a minimization of emissions of road traffic, today mostly two approaches are followed: By means of comprehensive technical measures the pollutant emissions of the engine are further reduced on the one hand and on the other hand driving resistances effecting vehicles are lowered, e.g. by lightweight construction. Apart from purely technical optimisation measures a significant potential for reducing emissions lies in the adjustment of vehicle operation and the driver's way of driving to the respective traffic situation. For an analysis of this potential the Institut fuer Kraftfahrwesen Aachen (ika) handles the project FORFAHRT on behalf of the German Ministry for Education and Research. Aim of FORFAHRT is the development of a vehicle concept and a concept for longitudinal vehicle control which enable a considerable emission minimization by a forward-looking and therefore smooth way of driving over the short or medium term. This papers describes the concept and the results of the FORFAHRT project.

STATUS OF RESEARCH, EXAMPLES

By a calm driving style emission reductions (for CO2, air pollutants and noise) are possible that could by far exceed today's predictable technical reduction potential [4]. Fig. 1 shows this fact by the example of comparative drives with upper middle class vehicles that are equipped with an Otto engine of the emission class Euro 2. Other sources confirm the above named investigation. For example in [1] is presented that, in respect to the test-procedure, consumption minimization potentials can be achieved of approximately 10% by the vehicle's weight, 20% by the engine and 10% by the drivetrain, without limitation of the vehicle's performance. In contrast to this, the driver's influence amounts to a reduction of 25% on the average with existing automotive technique. For this investigation driving courses with the same average speed on a given stretch profile were evaluated.

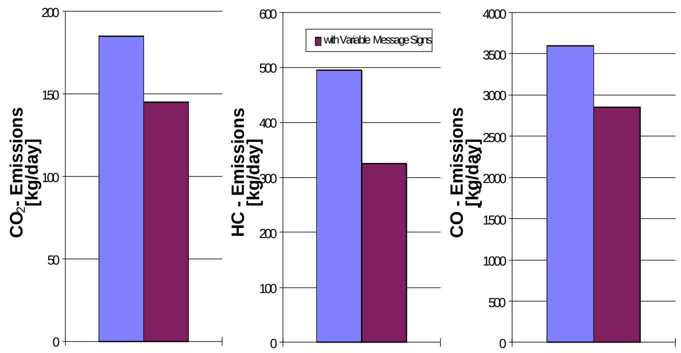

Fig.1: Influence of driving style on pollutant emission of an upper middle class vehicle with Euro 2-engine [5]

Similarly big effects can also be achieved with non-automotive technical measures from the field of traffic engineering. In this context to be named are particularly traffic management systems or in inner-city traffic- optimised traffic light control. As example for the effects of traffic management systems the variable message signs on the highway A 9 in the north of Munich can be named. On this stretch changing traffic signs for accident reduction were installed that enable for example a traffic-depending transmission of speed limits or traffic jam warnings. A side effect of the introduction of this line influencing facility lies in a reduction of pollutant emissions and fuel consumption on this road section [3]. The emission reduction, represented of up to 40% is most of all due to a reduction of the Stop&Go share of approximately 90% and to a reduction of the speed share of 0-30 km/h in favour of higher speeds. In urban areas, comparable emission reductions can be achieved by means of throughput-optimised control of traffic lights. Through simulation this could be proofed for a suburban area of Aachen by the Institut fuer Kraftfahrwesen Aachen [2].

An even and therefore emission-reducing traffic can thus be achieved by so-called traffic management facilities or by an assisting system installed in the vehicle. In case of the collective influencing of traffic flow, the reduction of emissions represents today only a minor motivation apart from road capacity and increase of traffic safety, which actual effect on immission reduction is heavily discussed [4]. Furthermore, traffic influencing facilities are connected with high investments and cannot be installed at every stretch section (particular in urban traffic).

VEHICLE MANAGEMENT AND AUTOMATION OF LONGITUDINAL VEHICLE CONTROL

On part of technical measures for consumption and emission reduction a significant reduction of driving resistances could be achieved in recent years by lowering air resistance as well as by reduction of roll resistance. However, this development was partly neutralized by the simultaneous increase of vehicle weight. A significant reduction of weight and thereby caused reduction of pollutant emissions could up-to-now only be rarely realized in series vehicles. The emission of vehicles are therefore mainly reduced by an improvement of the engine and a more efficient catalyst after treatment of exhaust gas. A combination of these measures with the use of renewable and low-carbon energy carrier promises a further reduction potential for vehicle emissions in future.

The measure groups „Traffic Flow Manipulation“ and „Reduction of Pollutant Engine Emission“ are however connected with high development expenses and costs as well as with significant requirements at the infrastructure. Clear effects for the minimization of traffic emissions by these measures are from today’s point of view to be expected over the medium or long term. Aim of the presented project lies therefore in conception, analysis and later realization of technologies from two complementary measure groups, in order to reach a significant reduction of pollutant emission already in a few years.

Both measure groups can thereby achieve their reduction potential by combination of adjusted single components and base on existing (that is available today or in the next years) technology. Optimisation of driving operation should thereby be realized by a particularly forward-looking driving style of the vehicle itself with a driving course as even as possible. The emission-minimized operation of combustion engines can follow by selection of the respectively optimal operational point. The availability of a sufficient information amount concerning the current traffic situation in direct environment of the vehicle and on the route ahead represents an essential precondition. The information can then be converted by suitable drivetrain elements (such as, e.g., a CVT-transmission) and an adjusted driver assistance system (e.g. an extended ACC-controller [7]).

In a first step the necessary information about the local traffic situation (starting from stop & go up to „free driving") is determined by the driver assistance system itself. Such an approach does however only reach it's full performance capacity, if a forward-looking driving style is enabled, based on centrally registered traffic data.

In the course of the project it is analysed, how the share of emission-unfavourable acceleration phases can be reduced by employment of innovative drivetrain technique and traffic information, without simultaneously deteriorating stretch throughput and travel time of the overall traffic. Thereby it is of particular interest, whether consumption and emissions of the non-equipped vehicles are positively influenced by an reduction of the driving course dynamics of the equipped vehicles. The technologies to be analysed for the processing of traffic situation information can be basically divided into two groups: Vehicle-autonomous systems which register all relevant data in the vehicle itself and infrastructure-based systems which get their information of surrounding vehicles from a suitable communication channel or sensor systems or control devices. Completely vehicle-autonomous systems (e.g. Stop&Go control on the basis of ACC) possess the advantage that in combination with drivetrain systems such as CVT-drives and integrated starter-alternator systems they can already soon be introduced in series vehicles. Furthermore, they enable an engine control in a wide operation range. Over the medium term the emission minimization potential of these systems can still be greatly increased by processing of infrastructure data (e.g. traffic light approaching control for controlled engine starting / stopping, neutral position etc.).

Drive Train Concept

Starting point of the analyses represents a selection of the drivetrain technologies to be investigated. For an upper middle-class vehicle suitable latest EURO 3 and EURO 4 engines are to be selected and to be reproduced in simulation. The focal point lies thereby on direct injection engines. If the respective engine specifications are not available, it is relied on an estimation of consumption and emission characteristics, being derived from current publications.

Aim of the drivetrain control lies in an optimal and emission-reducing adjustment of engine operational point and drive transmission to the current driving situation and speed. For controlling the emission-favourable engine operational point the respective transmission must be adjustable, if possible. In case of a conventional transmission this can lead to an extremely high amount of gears. Additionally, the task requires an automation of the drivetrain, in order to relief the driver of necessary and frequent transmission changes. The requirement range is at first only fulfilled by CVT-transmissions. This kind of transmission enables a free choice of the gear ratio with simultaneously good effectiveness. Basically, the CVT-transmission seems to be best suited for emission-reducing drivetrains. However, it can still not be predicted, whether the expected consumption savings and expected low costs of this transmission can be realized in praxis. Therefore, also automatic transmissions and particularly automated manual transmissions must be included in an analysis of the drivetrain conception. If a complete decoupling of engine operational point and driving situation has to be achieved, the above named transmission can be combined with an integrated starter-alternator-damper (ISAD).

Traffic Information and Drive Train Control
For the capacity of the driver assistance system, infrastructure data, integrated into the strategies for emission-minimal operation of the vehicle, are of particular importance. By means of infrastructure information the vehicle for example can react early to traffic jams or traffic lights on the route ahead. For this end, comprehensive data is necessary that is not available today. Thus, a communication between a traffic light control and an approaching vehicle has to be made possible that eventually will enable an approach with switched-off motor in case of red light. Furthermore, the functionality of an extended vehicle-navigation system has to be integrated into simulation, in order to register detailed information concerning stretch (e.g. incline, curves or traffic signs) on the route ahead. In particular, data about the traffic situation ahead („dynamic navigation“) should be taken into consideration.

Aim of this work package is the analysis of traffic data that is absolutely necessary for an effective operation of the drivetrain control. Furthermore, it has to be presented, how high the emission minimization potential of the processing of this additional traffic data is. A further goal lies in the preparation of an optimal control strategy for the drivetrain and therefore for a selection of the optimal engine operational point by means of an analysis of the traffic data. On the other hand a driving strategy has to be developed that enables an even and therefore emission-optimal way of driving, without disturbing traffic flow.

RESULTS

This section will give a summary of the actual results of the here described project FORFAHRT. It focuses on the strategy development for driver assistance systems by analysing the fuel consumption during acceleration as well as on the potential of different drivetrain structures. The section finally points out how a driver assistance system and therefore automation of the longitudinal vehicle control can reduce the consumption and emission in traffic. The project FORFAHRT is currently running and will be finished in October 2000, therefore only preliminary results will be presented. The results were achieved with ika’s simulation tool PELOPS.

The Simulation Tool PELOPS [2]
The idea of PELOPS is a combination of highly detailed sub-microscopic vehicle- and microscopic traffic technical models, that permits investigations concerning the longitudinal dynamics of vehicles as well as an analysis of the course of traffic [8]. The advantage of this combination is the opportunity to take all interactions into consideration that occur between driver, vehicle and traffic. An important basis for the realisation of this idea is the fact, that computer capacity was significantly optimised during last years. Without this capacity the required degree of detail with a simultaneous consideration of all influencing factors would be unthinkable.

PELOPS is orientated towards the fundamental elements of traffic, namely route and environment, driver and vehicle (Fig. 2). The route model is based on the description of the altitude profile with gradients, further on the presentation of the curves with straight stretches of road, arcs of a circle and transitions from a straight route to a curve, as well as the number of lanes with their respective lane widths. In addition to the geometrical course of the road, the sign postings and the environmental conditions define the state of the route. The route-model covers the entire range from motorways to urban roads, including for example intersections and traffic-lights. The initial conditions of the traffic situation are given by the number of vehicles driving on a stretch of road with a defined length (traffic density) as well as from their starting speeds and their distances (traffic flow). To simulate certain courses of traffic or to instruct vehicles with calculated load profiles, single driver-vehicle-units may also be moved according to specific driving speed profiles. With regard to investigations on single vehicles this can be realised by means of standardised driving cycles, like ‘EUDC’, ‘FTP-75’, etc. or in traffic investigations by means of e.g. breaking in panic or constant driving.

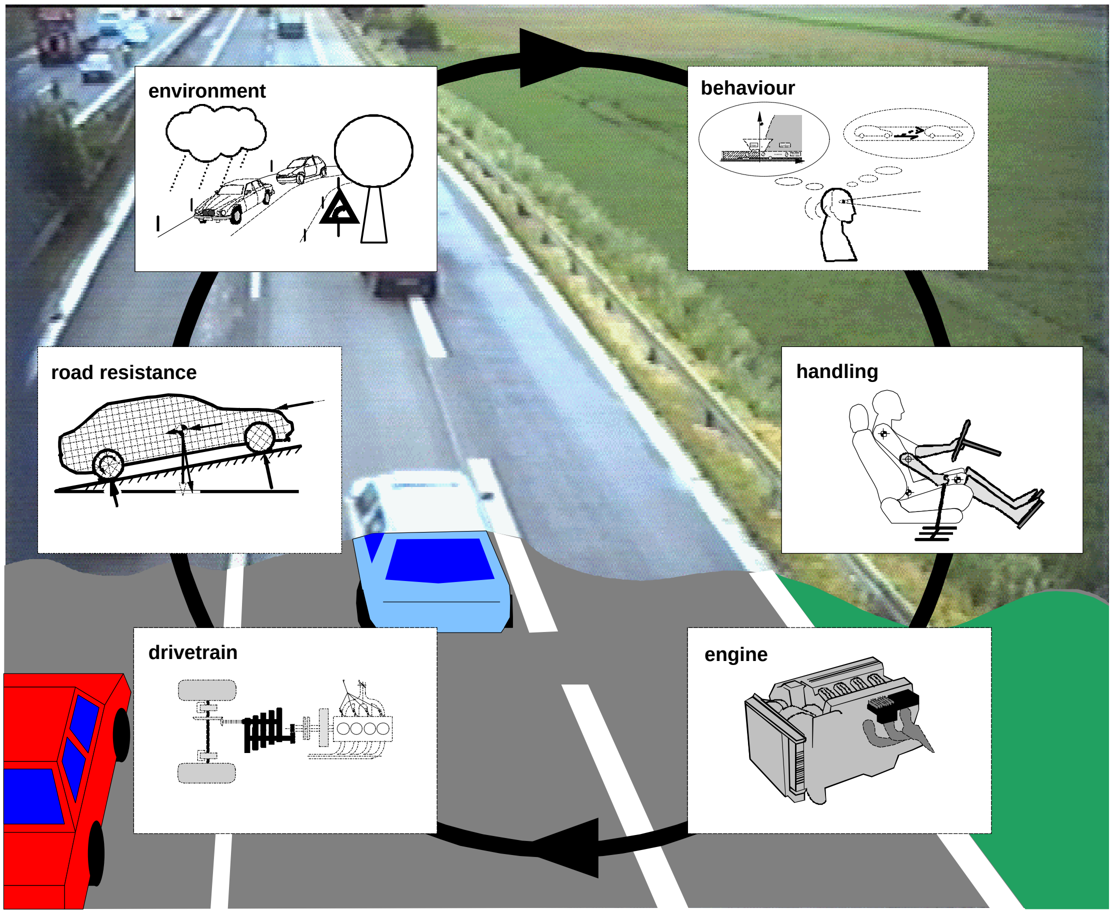

Fig. 2: The Simulation Tool PELOPS

Fuel Consumption And Drivetrain Concept

To compare the influence of different drivetrain structures on the fuel consumption three different transmissions were simulated with PELOPS.

1. conventional 5-speed automatic gearbox
2. conventional 5-speed manual gearbox
3. CVT-transmission with clutch and forward looking strategy

Each drivetrain was simulated in the same upper middle class vehicle with the same engine, same weight, etc. Only the transmission and its control strategy was changed, so that the results can be compared directly and it is possible to see only the effect of the changed transmission. The efficiency map of the CVT drivetrain has to be estimated and is on the same level as the efficiency map of the conventional automatic gearbox.

To get a representative picture of realistic traffic situations driving courses in city traffic and on German highways were simulated with PELOPS for each drivetrain configuration. The simulation results of the CVT transmission with clutch and forward looking strategy represents distinctly the fuel saving potential of new drivetrain technologies in the analysed traffic situations.

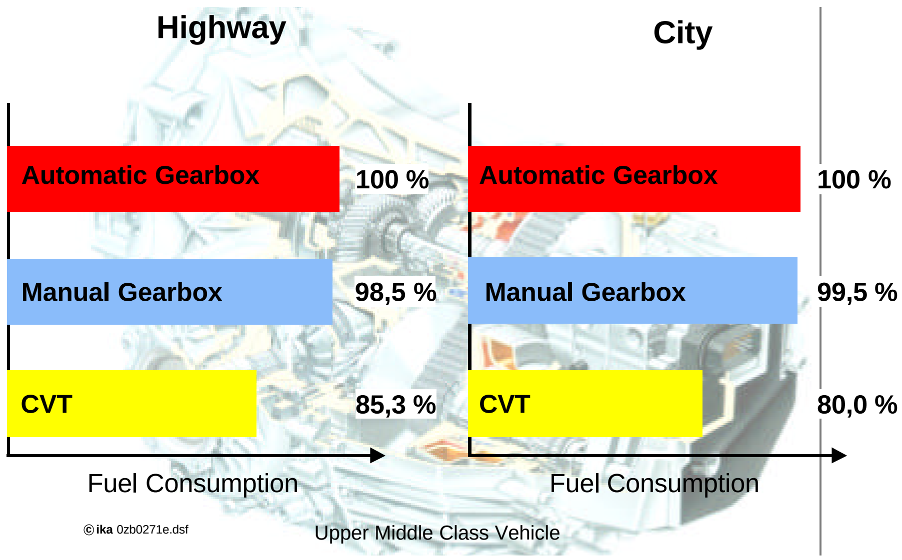

Fig. 3: Fuel Consumption of an CVT-Transmissions with optimised strategy

Fuel-Consumption And Driver Assistance In Urban Areas

In the last part of the here described analysis the focal point lies on the effect of an ACC-system on the fuel consumption in “real” (here simulated with PELOPS) traffic. With the investigated scenarios the effect in urban traffic shall be presented here. A highly frequented, traffic light controlled and one-lane access road in the Aachen suburban area served as investigation ground. Here, measuring was collected in the morning rush hour, in order to register the traffic in terms of macroscopic data (average speed and traffic density, relating to overall traffic) as well as of microscopic data (frequency distribution of distances and velocities, relating to single vehicles).

On the basis of this data a simulation with PELOPS was arranged. The parameters were calibrated so that the measured situation could be reproduced. In the following this "Basis-Simulation" serves as reference for simulations with ACC. Different equipment degrees were analysed for the effect of the ACC, in order to demonstrate the effects in different time horizons. The equipment degrees were set to 5%, and 40%. Additionally, a simulation with 100% equipment - meaning that only ACC-vehicles were simulated - was carried out for the assessment of the ACC's potential.

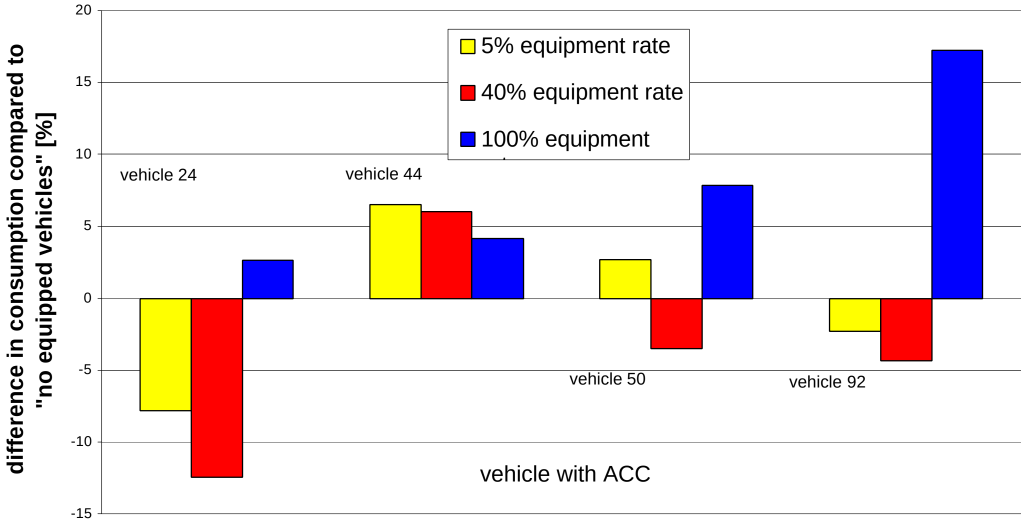

Fig. 4: Fuel consumption of ACC vehicles [10]

The real effect of an ACC-system on the fuel consumption strongly depends on the behaviour of the driver. A very fuel efficient driver may not be surpassed be the assistant system. Additionally it can be seen in the simulations, that the driver assistance system "smoothens" the traffic, strong accelerations are prevented by the system so that a positive effect on the fuel consumption of vehicles, which are not equipped with ACC can be shown.

Conclusion And Outlook

The paper described the course of the project FORFAHRT. The aim of FORFAHRT is the identification and analysis of improved low-emission drivetrain structures for integration into a driver assistance system. The Institut fuer Kraftfahrwesen Aachen (ika) handles the project FORFAHRT on behalf of the German Ministry for Education and Research.

The analysis focuses on "conventional" drivetrain components, not on hybrid or electric propulsion. The analysis is done with the sub-microscopic traffic simulation program PELOPS [5], which was developed at the 'Institut fuer Kraftfahrwesen Aachen' in cooperation with the BMW AG.

The actual results of FORFAHRT presented in this paper show the high fuel saving potential of optimised drivetrain structures using a CVT transmission. Combined with a driver assistance system like an advanced ACC-controller the fuel saving potential may be even increased.

The project FORFAHRT now starts into its last phase. Improved low-emission drivetrain structures for integration into a driver assistance system will be identified and analysed. Part of the assessment will be DI-spark-ignition engines, integrated starter alternator systems as well as automated manual transmissions. The last phase of the project will then examine which amount of traffic data is necessary to realize a smooth traffic dependent driving style.

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