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EUROPEAN POLICY ON FUTURE ROAD MOBILITY - TECHNOLOGY NEUTRALITY RIGHT OF WAY OR HEADED IN THE WRONG DIRECTION?

Ralph Pütz [1]*

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RESEARCH ARTICLE

ABSTRACT: The EU policy with the compulsion towards electromobility in the road and off-road vehicle sector and with an exclusive focus on driving operation (Tank-to-Wheel) and neglecting of the relevant processes of vehicle production (Cradle-to-Gate), energy supply (Well-to-Tank) as well as recycling (End-of-Life) leads to an ideological ecological distortion ignoring the boundary conditions of a free market economy. Parallel options for propulsion and fuel/energy systems have to be admissible. A return of the policy towards technology openness and scientific facts is essential.

KEY WORDS: *E-vehicle, technology-neutrality, EU policy*

EVROPSKA POLITIKA O BUDUĆOJ MOBILNOSTI NA PUTEVIMA - TEHNOLOŠKA NEUTRALNOST ISPRAVAN PUT ILI SE KRENULO U POGREŠNOM PRAVCU?

REZIME: Politika EU isforsirano okrenuta ka elektromobilnosti u sektoru drumskih i terenskih vozila i sa isključivim fokusom na vožnju (Tank-to-Wheel) i zanemarivanje relevantnih procesa proizvodnje vozila (Cradle-to-Gate), energije snabdevanje (Well-to-Tank) kao i reciklaže (End-of-Life) dovode do ideološke ekološke distorzije koja ignoriše granične uslove slobodne tržišne ekonomije. Paralelne opcije za pogon i sisteme za snabdevanje gorivom/energijom moraju biti prihvatljive. Povratak politike ka tehnološkoj otvorenosti i naučnim činjenicama je od suštinskog značaja.

KLJUČNE REČI: *E-vozilo, tehnološka neutralnost, politika EU*

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EUROPEAN POLICY ON FUTURE ROAD MOBILITY - TECHNOLOGY NEUTRALITY RIGHT OF WAY OR HEADED IN THE WRONG DIRECTION?

Ralph Pütz

INTRODUCTION

Climate change and environmental pollution are an existential threat to the world. A sustainable approach must examine the effects of the respective measures on all ecological fields of action - local and global emissions, energy efficiency and noise emissions (see Figure 1). The political and societal objective is to limit global warming to 1.5°C. The European Union (EU) set ambitious greenhouse gas (GHG) emission reduction targets in the wake of the climate change conferences in Paris in 2015, Marrakech in 2016, Bonn in 2017 and Katowice in 2018. To achieve this challenging global warming limit, the "European Green Deal" has been established by the EU on July, 14th 2021 to reduce global emissions (greenhouse gas emissions) compared to 1990 levels by 55% by 2030 and to ensure no net emissions of greenhouse gases (resp. CO2 equivalent) by 2050. Furthermore, economic growth shall be decoupled from resource use. On this path, every sector – so also the transport sector – has to achieve these challenging goals. By now, transport global emissions represent around 25% of the total greenhouse gas emissions in the EU (and 20% in Germany). In order to achieve climate-neutrality in the EU by 2050, ambitious targets in the transport sector are set by EU emission regulations. This means a 90% reduction (sic!) in transport-related greenhouse gas emissions by 2050.

Passenger cars and vans are respectively responsible for around 12% and 2.5%, trucks and heavy-duty vehicles for 5,4% of the total EU emissions of CO2, which is the main greenhouse gas, see Figure 2.

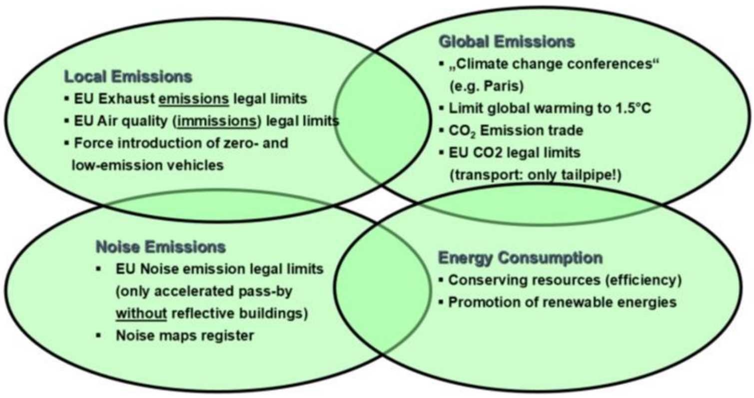

Figure 1. "Holistic" environmental protection as an overriding objective (Source: Pütz, R.)

Starting in the years 2025 and 2030, Regulation (EU) 2019/631 sets stricter EU fleet-wide CO2 emission targets for cars and vans, whereas Regulation (EU) 2019/1242 introduced stricter CO2 fleet targets for heavy-duty vehicles. All these targets

are defined as a percentage reduction from the 2021 starting points:

•Cars: 15% reduction from 2025 on and 37.5% reduction from 2030 on

•Vans: 15% reduction from 2025 on and 31% reduction from 2030 on

•Trucks: 15% reduction from 2025 on and 30% reduction from 2030 on

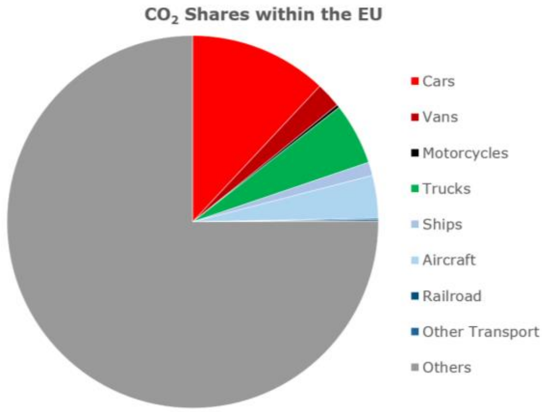

Figure 2. Contribution of the EU Transport Sector to the EU global Emissions in 2022 (Source: Statista)

The annual specific emission targets of each manufacturer will be based on these EU fleet-wide targets, taking into account the average test mass of its newly registered vehicles. If the average CO2 emissions of a manufacturer's fleet exceed its specific emission target in a given year, the manufacturer has to pay – for each of its vehicles newly registered in that year – an excess emissions premium of €95 per g/km of target exceedance. Besides, manufacturers are required to ensure correspondence between the CO2 emissions recorded in the certificates of conformity of their vehicles and the CO2 emissions of vehicles in service.

Heavy-duty vehicles, as trucks, buses and coaches, are responsible for about a quarter of CO2 emissions from road transport in the EU and for about 6% of total EU greenhouse-gas emissions. Due to increasing road freight traffic, these emissions are still rising.

The EU-wide CO2 emission standards mentioned above also include a mechanism to force the introduction of zero- and low-emission vehicles. The explicit weak point of these regulations is that only the operation part (tank-to-wheel) of the several options is covered, whereas a holistic analysis covering also the energy supply (well-to-tank), vehicle production (cradle-to-gate) and recycling/disposal (gate-to-end-of-life) is indispensable for a truly resilient evaluation of environmental impacts of different propulsion options and to hence ensure a technology-neutral way. For a comprehensive ecological and economic evaluation of vehicle fleets of different power drives and fuel types all stations of the lifecycle of transport systems must be included in the analysis, namely:

•Vehicle production (Cradle-to-Gate; CtG) and, if applicable, recovery/disposal,
•Fuel availability (Well-to-Tank; WtT),
•Driving mode (Tank-to-Wheel; TtW) and
•Maintenance

Since the isolated view of only looking at the actual driving operation can lead to completely false conclusions. Only in this way can targeted solutions be identified for transport systems with both low local and global emissions and increased energy efficiency and reduced noise in the context of a holistic ecological integrity (see Figure 2 for example PT bus). The subsystems highlighted in green form the PT system, which allows a comprehensive ecological and economic analysis. In the analysis of emissions, the main locally effective criteria are particulate and nitrogen oxide emissions and the main globally effective criteria are CO2 emissions (CO2 equivalent), the effects of which can be summarised as the ecological profile of a propulsion technology by determining their external costs.

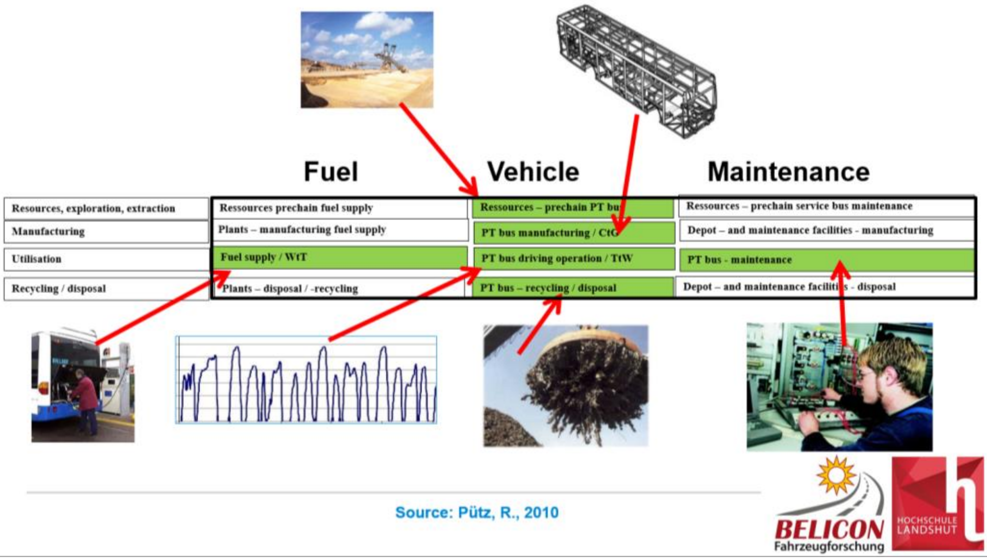

Figure 3. Ecological Systems Approach with Subsystems (example: PT Bus)

In fact, the actual regulations intend to exclusively promote electro-mobility with batteries and/or fuel cells. A further downfall of technology-neutrality is the compulsion to buy quotas of electric buses as laid down in the so-called “Clean Vehicles Directive” (Regulation (EU) 2019/1161). After the amended directive came into force, 45 percent of procurements are initially to consist of "clean vehicles" by 2026, half of which are to be "zero-emission vehicles", and by 2030 as much as 65 percent of procurements are to consist of "clean vehicles". Emission-free vehicles" are defined in the directive as vehicles with no local emissions and no direct emissions of CO2 (see Figure 3). What should be understood by "clean" fuels in connection with this is listed in the EU Directive 2014/94/EU v. 22.10.2014 (Directive on the Development of Alternative Fuels Infrastructure, so-called "DAFI Directive"). In addition, the "Renewable Energy Directive" defines targets for renewable energy quotas in the EU, according to which these should amount to at least 30 per cent at EU level in 2030 and at least 14 per cent in the transport sector.

The same political intention is to be identified in the proposals for EU Regulations on local emissions. A final legislative proposal for Euro 7 (cars) and Euro VII (trucks and buses) is expected in 2022, with introduction targeted for 2025 at the earliest, according to the current status. The aim is to maintain the lowest possible emission values in all conceivable driving situations in real-world operation over a driving distance of 1.2 million km and a lifetime of 15 years. Lowest cold-start emissions of e.g. 100-150 mg NOx/kWh in the WHTC engine type test cycle and permanent on-board emission monitoring supplement these extremely high requirements. In addition, new limit values for nano-particles PN10 and nitrous oxide N_2O will be introduced.

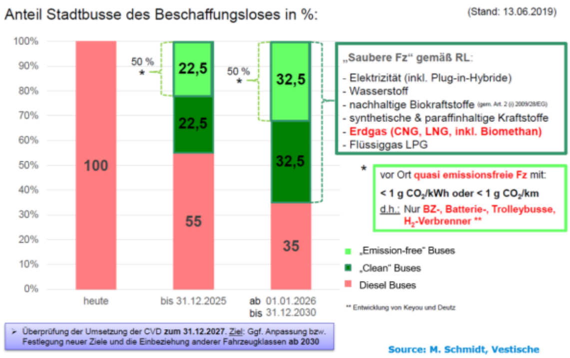

Figure 4. Fixed Quotas for the tendering of new PT buses over time acc. to EU “Clean Vehicles Directive”.

There are also concrete plans in the EU to no longer allow new cars with combustion engines from 2035. The latest decisions do fortunately provide for an exemption for internal combustion engines that run on synthetically produced regenerative fuels, so-called e-fuels (or respective e-gases). But in general, a rather tendentious EU transport policy focusing explicitly on e-mobility seems to neglect the propagated and necessary technology-neutrality in the form of effective regulations and instead reveals a technology dictate which is not appropriate and not acceptable for a free market economy.

In order to achieve its ecological objectives, the EU policy provides for coupled political measures as so-called "transitions", which, in addition to the necessary "energy transition" towards the exclusive use of renewable energy, also considers a "mobility transition" (avoidance of traffic, shifting individual transport to public transport) and a "propulsion transition" (exclusive use of electric mobility) to be necessary (see Figure 4). But is a propulsion transition objectively really necessary? In the following, the actual status of local and global emissions from combustion engines in real driving cycles are discussed against the background of the EU´s emission policy. In line with the author's research focus, the emphasis here is on heavy-duty commercial vehicles and mobile machinery.

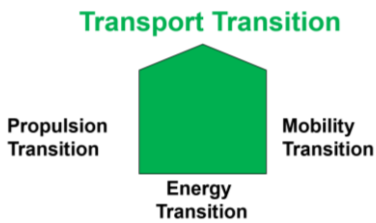

Figure 5. Derived coupled policy measures: "Drive, Energy and Mobility Transitions”

1. ANALYSIS OF THE FIELDS OF ACTION FOR LOCAL EMISSIONS

The EU political focus just on local tailpipe emissions ignores the provision of raw materials and energies for vehicle production including propulsion systems and storages (cradle-to-gate), the production of final energy including distribution – that means provision of fuel and electricity (well-to-tank) – and recycling and disposal (gate-to-end of life), but these subsystems are also very relevant and must be taken into account for a resilient holistic ecological (and economical) balancing. Whereas the intended elimination of pollutants like particles (particulate mass PM and particulate numbers PN) and nitrogen oxides (NO, NO_2, N_2O) is absolutely reasonable, the elimination of CO_2 from the tailpipe is completely irrelevant because global emissions work globally and it´s merely irrelevant if CO_2 is emitted tank-to-wheel or well-to-tank or cradle-to-gate and gate-to-end of life (see Figures 2 and 5). Furthermore, it is indispensable to consider and compare all technical measures within a holistic view because any ecological improvement must also be reflected in the required costs and its social influences – that means every technological measure must also be affordable (see Figure 6).

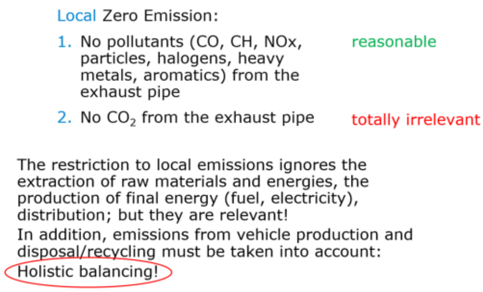

Figure 6. Target: Tailpipe emission-free driving only for pollutants reasonable.

Figure 7. Indispensable: All measures require a holistic view (Source: Bosch)

Concerning particulate emissions, Figure 7 shows for a PT Diesel bus of stage Euro VI with DPF that the intake air (here dirty ambient air) contains significantly more particles than the exhaust gas. Ambient air is thus actually cleaned in the process, a. positive effect which is not possible with battery or fuel cell propulsion.

Figure 8 shows the measured values from the real operation of articulated PT buses in urban traffic with ‘stop-and-go operation’ for a line with demanding topography. On the left, the emission ratio of a Euro V and, on the right, a Euro VI articulated bus are shown respectively. The rise in the exhaust gas temperatures profiles (in green) after about 20 minutes of operation reveal a steep incline of the road. The Euro V articulated bus shown on the left generates high NO emissions after the cold start, which settle down after less than 10 minutes. The Euro VI articulated bus shown on the right emits lower emissions than the operation-ready Euro V articulated bus even at cold start. With the Euro VI articulated bus shown on the right, nitrogen oxide emissions are already at ambient air level after just 10 minutes due to effective SCR exhaust gas after-treatment. Incidentally, the same also applies to Diesel engines in heavy tractors, see Figure 9.

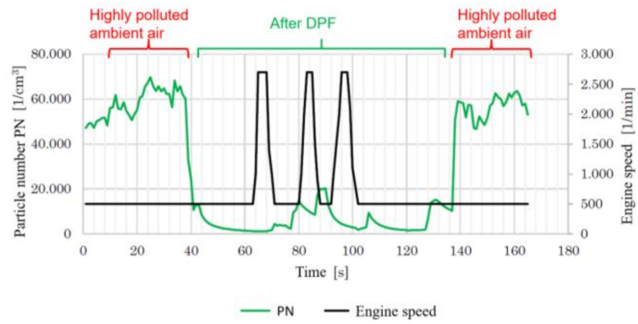

Figure 8. Particulate Emission of a Euro VI Diesel bus before/after Diesel Particulate Filter (DPF) (Source: Löw, J./Pütz, R.)

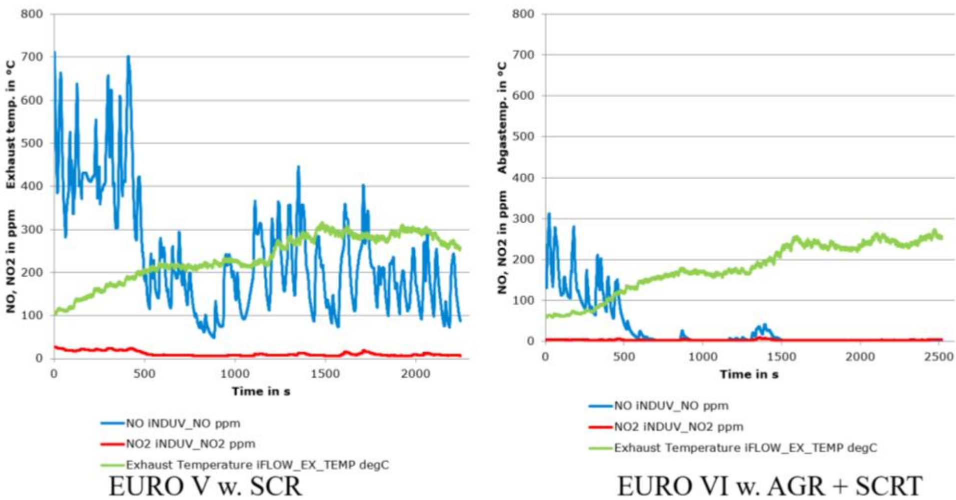

Figure 9. Comparison of NOx Emissions in Euro V/EEV and Euro VI articulated Diesel Buses after cold start on a very demanding city route with steep inclination (Source: BELICON/Pütz, R.)

Even if the ecological assessment with the systems approach shown in Figure 2 reveals for only the locally effective emissions in driving operation for the time horizon "today" advantages in favour of the alternative electric drive options due to the local zero emissions onsite, however, this advantage must be put into perspective in view of the "near-zero emissions" achieved with the Euro VI level for conventional internal combustion engine drives. The local emissions from driving operations today only account for around 4 to 5 percent of the total environmental profile for a Euro VI bus fleet under the above-mentioned boundary conditions, see Figure 10. To sum up, the local pollutant emissions of modern, exhaust-gas after-treated Euro VI (CV) and 6d (cars) combustion engines are already uncritical and negligible even in very demanding driving situations.

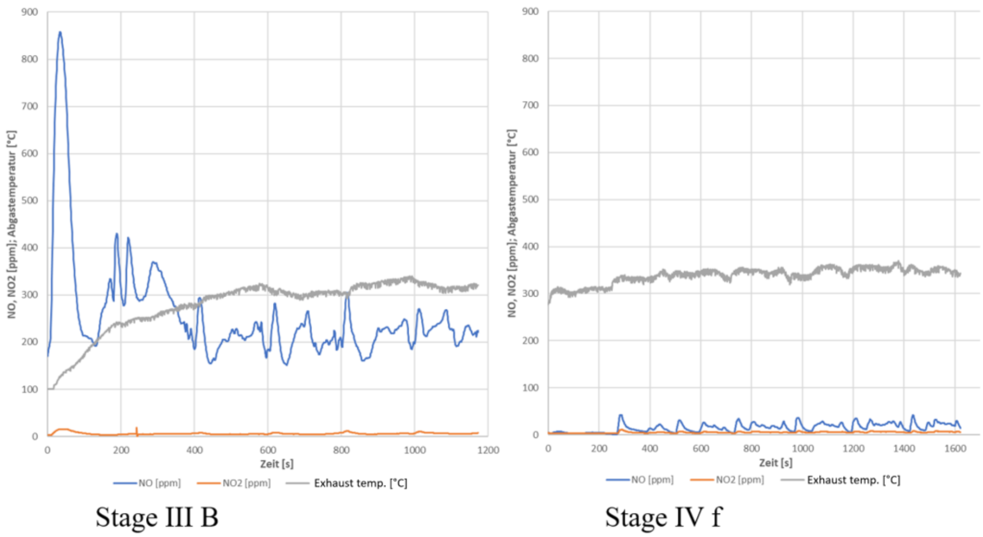

Figure 10. Comparison of Stage III B and Stage IV f tractors: Nitrogen oxide emissions in heavy arable farming (Source: Strixner, M./Pütz, R.)

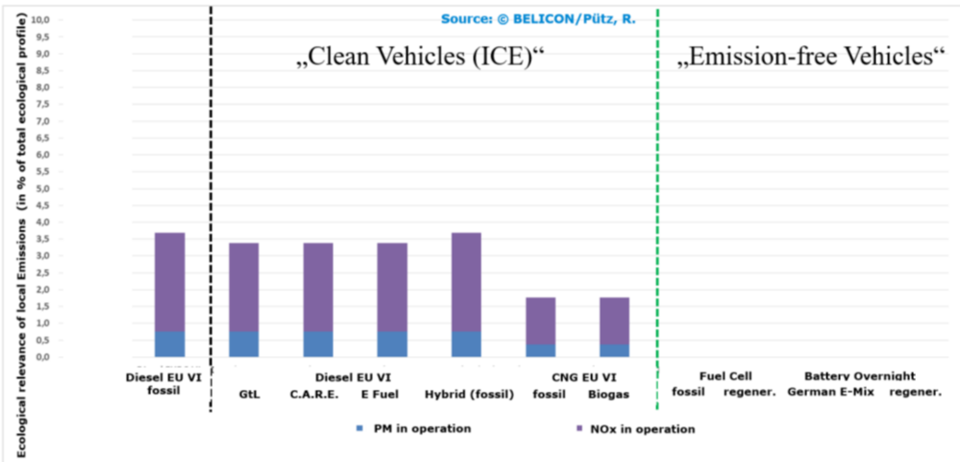

Figure 11. Local environmental relevance in the operation of a real bus fleet (time horizon "today") (Source: BELICON/Pütz, R.)

2. ANALYSIS OF THE FIELD OF ACTION FOR GLOBAL EMISSIONS

Global net anthropogenic GHG emissions have continued to rise during the last decades. Encouragingly, the global CO_2 intensity decreased by 0.3% per year between 2010 and 2019 which is a positive sign. The latest report of the political organization IPCC (International Panel on Climate Change) leaves no doubt about the urgent necessity to dramatically cut GHG emissions. To limit earth's warming to 1.5°C GHG emissions need to be cut by 45% by 2030, compared to 2019 levels. The EU´s "New Green Deal" even goes beyond this recommendation and set the goal to reduce its global emission levels by 55% by 2030. Against the background of the intended ban on highly clean combustion engines, it makes sense to first analyze the global share of anthropogenic CO_2 emissions and hereby those from the transport sector, which is done in Figure 11. In 2020 the contribution of the transport sector has been about 0,6 % of the worldwide CO_2 equivalent which amounts to 14% of the total anthropogenic contribution which itself accounts for only 4.2% of total global CO_2 emission equivalent. Since the EU sees itself as a pioneer in global climate protection it is necessary to quantify the EU´s "leverage effect". This requires a look at the world's largest CO_2 emitters, see figure 12. It can be seen that the largest CO_2 emitter within the EU – Germany – contributes only 1,85% of global CO_2 emissions (the second largest CO2 emitter within the EU is Italy with 0,93% of global CO_2 emissions. Against this background, the EU's ideological goals on climate change seem to be almost ineffective.

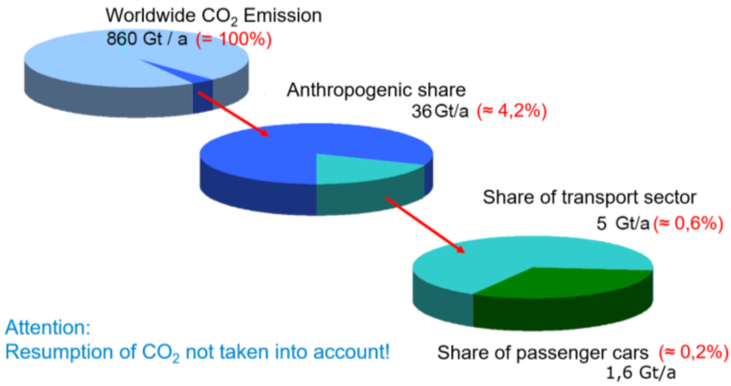

Figure 12. Worldwide annual CO2 emissions in 2020 (Source: UNEP)

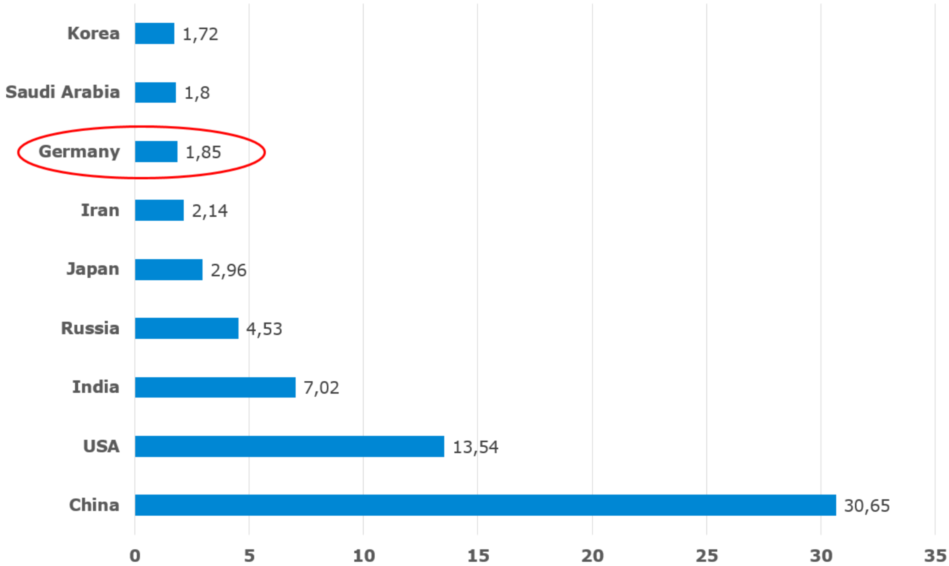

Figure 13. The world's largest CO2 emitters in 2021 (share in %; Source: GCP, Statista)

Today the only need for action is with regard to the use of renewable fuels to significantly reduce globally effective emissions (GHG) and to conserve fossil resources. The ecological assessment of only the globally effective emissions for the time horizon "today" shows a significant dominance of global emissions in the overall ecological profile (external costs) according to the systems approach shown in Figure 2. In terms of global emissions, highly significant improvements compared to the fossil Diesel Euro VI PT bus would be achievable through the use of HVO (C.A.R.E. Diesel), E-Fuels (PtL; Power-to-Liquids) and biogas from waste. With these regenerative fuels in ICE (internal combustion engines) already today also the same GHG emission level as with the alternative drive variants of the spectrum electro-mobility with exclusively renewable energy is achievable, see Figure 13. So the EU political ideology exclusively towards the options of electro-mobility with the elimination of combustion engines is neither comprehensible nor reflects the technology-neutrality which is indispensable in a free market economy.

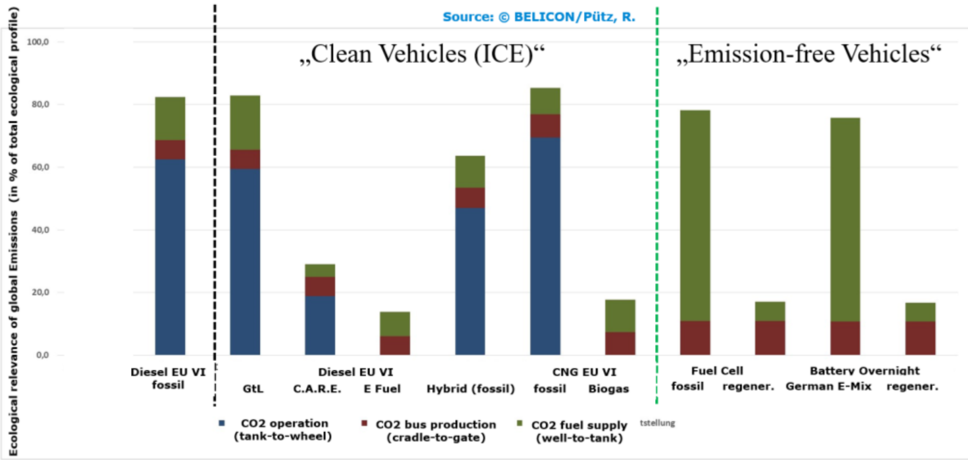

Figure 14. Global environmental relevance of a real bus fleet (time horizon "today") (Source: BELICON/Pütz, R.)

3. ANALYSIS OF THE FIELDS OF ACTION FOR ENERGY CONSUMPTION AND RANGE

A typical Diesel PT bus with a relatively small 350 litre tank has a range of over 1.000 km and only needs to be refuelled every two to three days. In contrast, solo battery buses with a 350 kWh battery and a usable capacity of 300 kWh only reach about 300 km in the best case at around 21°C ambient temperature. In winter times when both battery and passenger compartment have to be heated the range is reduced significantly, see Figure 14. The majority of today's battery buses only manage a range of 160-180 km at best anyway. If the limited passenger capacity due to the high battery weight is also considered, at least two – and in extreme cases four (!) – electrical overnight-charger buses are needed to replace one diesel bus. Figure 15 shows the operational profile of a typical optimized German PT bus fleet. About two thirds of the buses have daily operational ranges of more than 200 km and hardly any stopping time at the terminal stops of the lines. This proves the cost-intensive necessity of additional buses and of course their drivers (the latter amount to half of km cost). These extra cost in the loss-making public transport sector must be provided from public funds. Rhetorical question: Did EU policy take this fact into account in the decisive EU Clean Bus Directive which demands mandatory quotas for E-buses?

Comparable conditions apply to long-haul trucks. While typical long-haul trucks have a range of 3.000 km on one tank of fuel, prototype battery trucks actually have a ranges of only around 500 km and fuel cell trucks reach 1.000 km - with the potential for a 1.500 km range. What is missing today is a sufficient, nationwide energy distribution and refuelling infrastructure for electricity and hydrogen. The cost for their establishment are likely to be immense. In contrast, E-fuels as liquid fuels and methanised E-gases can be used in the existing infrastructure.

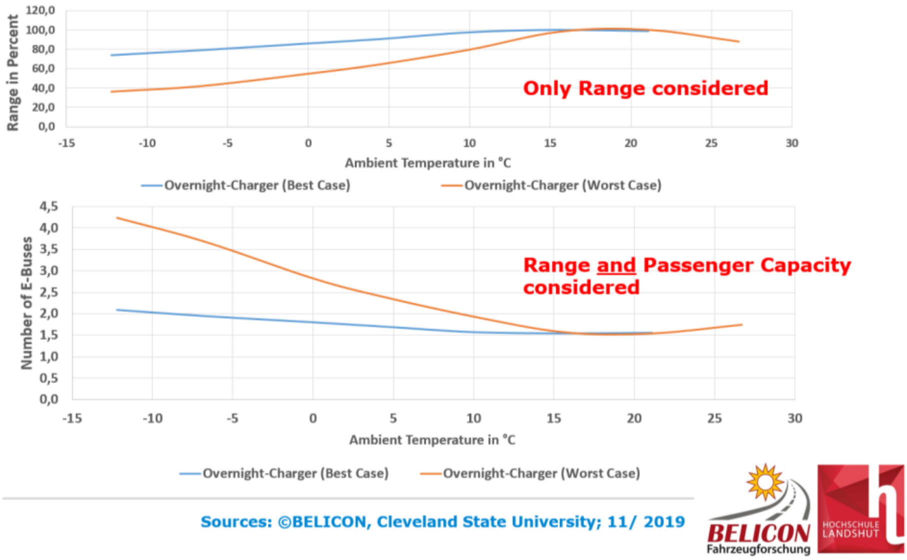

Figure 15. Range depending on ambient Temperature and Passenger Capacity of Overnight-Charger E-Buses (Sources: BELICON/Pütz, R., Cleveland State University)

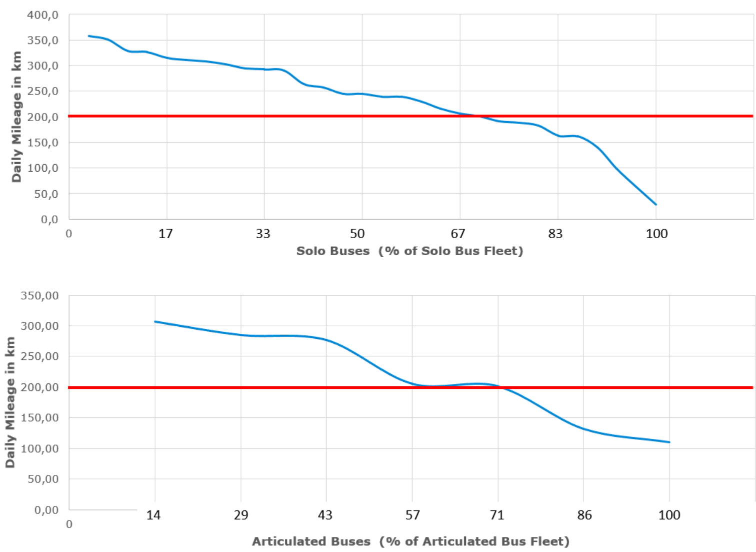

Figure 16. Daily milage on a typical day in school time for a typical German PT bus operator (Source: BELICON/Pütz)

4. ANALYSIS OF THE TOTAL ECOLOGICAL AND ECONOMICAL PROFILES AND OUTLOOK

The overall ecological assessment for the time horizon "today" according the model in Figure 2 shows that for comprehensive sustainability – taking into account local and global emissions as well as energy consumption – the modern Euro VI Diesel fleet is already adequately positioned and today, with the German electricity mix, hardly any to no improvements are achieved through the procurement of alternative electric drive variants, although according to the EU Clean Vehicles Directive all electric vehicles are even declared as "emission-free" regardless of the electricity mix. In the near future and also in the long term, therefore, there would be de facto no ecological need to abandon ICE technology, especially since further ecological potential can be tapped with E-Fuels, see Figure 16. The use of E-fuels (via water electrolysis with regenerative electricity and CO_2 from the air or from power plants; produced in areas with sufficient regenerative primary energy such as North Africa, Southern Europe, etc.) would offer the ecological optimum from today's perspective.

However, the calculation with the average power plant electricity mix, as applied here and in other studies, is merely a whitewash, because the fluctuating residual load must mainly be covered by controllable power plants. In concrete terms, this means that if the demand for charging power increases, only fossil-fuel power plants are ramped up, so that instead of the average power mix, a fossil-fuel power mix is more likely to be used. This worsens the eco-balance of electro-mobility. Figure 17 shows this effect using a typical passenger car as example.

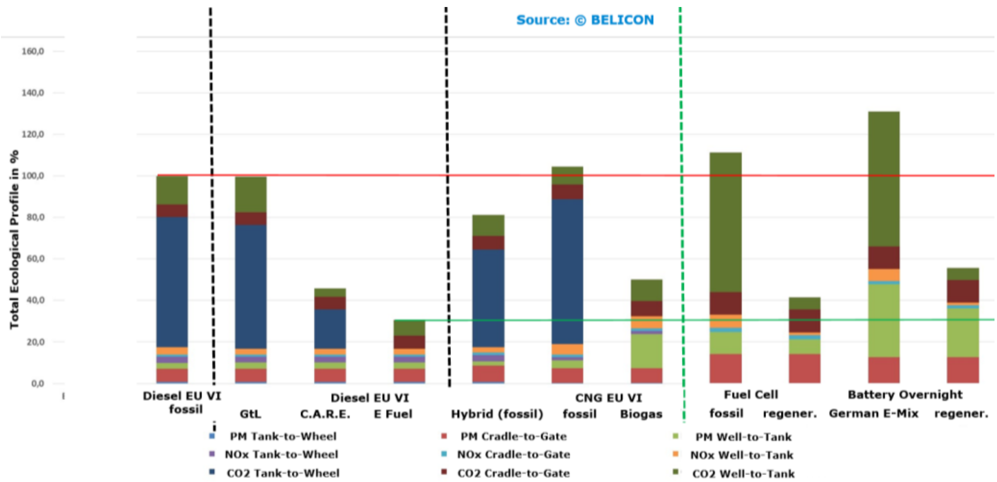

Figure 17. System-related total environmental relevance of a real German PT bus fleet for the time horizon "today" (Source: BELICON/Pütz)

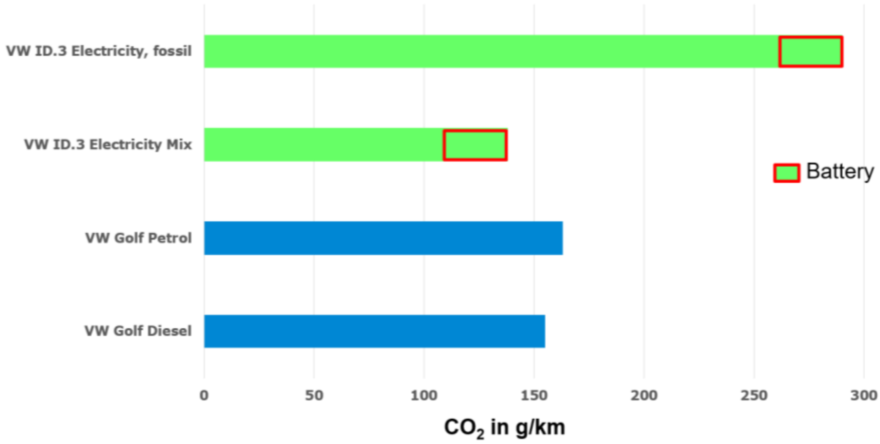

Figure 18. Comparison of CO2 emissions of electric cars using electricity mix and electricity from fossil power plants; electric cars in green (Source: Ruhsert, K.)

In order to objectify the "real" additional cost of the alternative electric options forced by the EU, any vehicle and infrastructure subsidies are disregarded here, as these funding only brings initial relief anyway. The overall economic evaluation of the pure vehicle costs (including infrastructure) depending on the drive technology for the time horizon "today" with an usual depreciation period of 10 years is shown in Figure 18.

It is initially assumed here – against the realities shown in Figures 14 and 15 – that no additional vehicles will be required for battery electric mobility (here: overnight chargers), as it is assumed to be possible to overplan the timetable with possibly lower timetable efficiency. Nevertheless, today the vehicle cost for overnight-charger battery buses have at least to be doubled if not rather tripled, compare with Figure 14. So for overnight-charger buses this means vehicle cost of three to more than five times compared to Diesel buses. Not included here are additional costs due to today in general still lower availability of the electric mobility options (FC hybrid and battery technologies), since according to statements by the German vehicle manufacturers, the same availability as for buses with ICE can be expected in the short term. Also not included are the opefigure 19

rational costs for the necessary transition to daily "refuelling" in the case of FC hybrid and overnight charger battery buses as well as possible additional vehicles when using overnight charging due to the lower passenger capacity (due to the still heavy battery technology) and obligatory electric heating, which can significantly reduce the range in winter as already described.

If among the variety of options only the ecologically targeted options are considered, the use of HVO Diesel fuel (C.A.R.E. Diesel) today requires only slightly more than 3 percent higher vehicle costs, while the use of E-fuels would increase vehicle costs by more than 85 percent. The use of natural gas engines with biogas from waste would increase vehicle cost by more than 22 percent. In contrast, the electromobility options today would require for an overnight charger fleet a significant increase in cost by almost 67 percent. In economic terms, the fuel cell hybrid bus is still far behind, with additional cost of over 140 percent. These "real" market costs make it necessary to massively fund electromobility, which should definitely be continued in the coming procurement years. The use of E-fuels in Diesel engines is already at the cost level of the electromobility options today – regardless of the significant industrialisation potential.

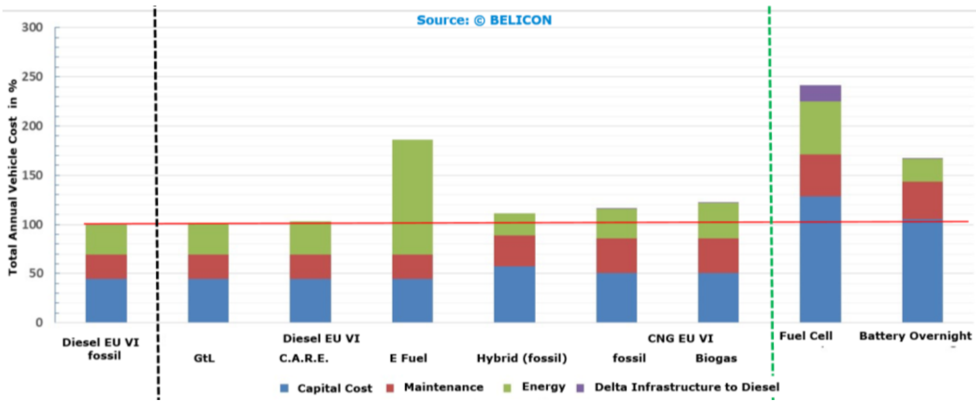

Figure 19. Relative vehicle cost of a real German PT bus fleet "today" - without subsidies (Source: BELICON/Pütz)

The economic evaluation for the time horizon "medium term" (2030) is hardly possible at present, as the Russia-Ukraine war makes a development of fuel prices hardly resilient. For this reason, no outlook can be given here. With regard to the investment costs for electromobility, however, a highly significant cost degression of the energy storage system (batteries) can be assumed, but still a replacement battery over the (up to 18-year) operational service life of the (first) operator in Western Europe is very likely because today, it can be assumed that the service life of batteries in average public transport use is hardly more than "half the life of a bus". A significant cost degression can also be expected for the fuel cell (FC) technology and for E-Fuels. For the latter, production cost of less than one €/l are expected in the medium term. Although electromobility has advantages in terms of energy efficiency compared to the "ICE + e-fuel" approach, this does not play a single role if the excessive availability of renewable energy in regions as North Africa, Patagonia, Australia, Asia etc. is used, see Figure 19. Whereas an on-shore windmill in Germany in average only achieves 1.500 full load hours per year (at maximum 2.500 hours) a windmill in Patagonia achieves up to 5.200 hours per year. The same applies to photovoltaic systems: While in Germany only around 970 full load hours per year can be achieved, in Morocco around 2.350 full load hours can be expected.

In the context of being technology-neutral, the German Energy Agency (dena) anticipates in the long term for Germany a parallel, equal existence of electrical and non-electrical final energy applications within the framework of scenarios for combined energy and power transitions, whose proportional representation in this respect is still completely open (see Figure 20). It is undisputed that the predominant use of regenerative energy must replace the fossil fuel economy soon, but the propulsion technology does not have to be an electric motor. Locally highly clean, reliable and robust ICE have an equal existence – if professional expertise unmasks pure political ideology, see Figure 21. By the way: The increasing share of electricity from fluctuating renewable energies endangers grid stability without countermeasures. Load management should synchronize the load peaks with the regenerative electricity production peaks and make a larger share of the producible green electricity usable. Electric cars do not really help here, they in fact destabilize the grid even more. An example: In order to charge only 3 % of the approximately 50 million cars in Germany simultaneously with only 50 kW charging power, twice of the grid power capacity would be required, which is not feasible in the foreseeable future. With electro-mobility, there is less of an energy problem than a grid problem - and additionally a storage problem. In this context, 50 kW charging power is rather moderate, because most fast-charging stations for cars, e.g. from Tesla, have charging powers between 150 and 250 kW. In the commercial vehicle sector, even charging powers of 500 kW are currently being tested. The grid capacity required for the latter increases the grid problem significantly.

The fossil energy demand in Europe before the start of the Corona pandemic was around 17.100 TWh. In order to be able to replace this demand with renewable energies, more than 2,9 million (sic!) new wind turbines would have to be installed in Europe in addition to the 82.000 already existing. With regard to photovoltaics, the calculation would look similar: The current photovoltaic area of just under 2.100 km^2 would have to be increased to around 230.000 km^2. The decision-makers in the EU should be aware that this would require a fundamentally new electricity grid capacity – as well as the utopia that these figures reflect.

To sum up, the old wisdom that "many roads lead to Rome" should definitely as well be accepted by the EU policy – for the sake of neutrality to technology and a free market economy!

The author as a neutral and for decades experienced scientist takes the perhaps impudent liberty of addressing the following note to the persons responsible for EU transport policy: Quidquid agis, prudenter agas et respice finem!.

Figure 20. Targeted production regions for E-fuels (Source: frontier)

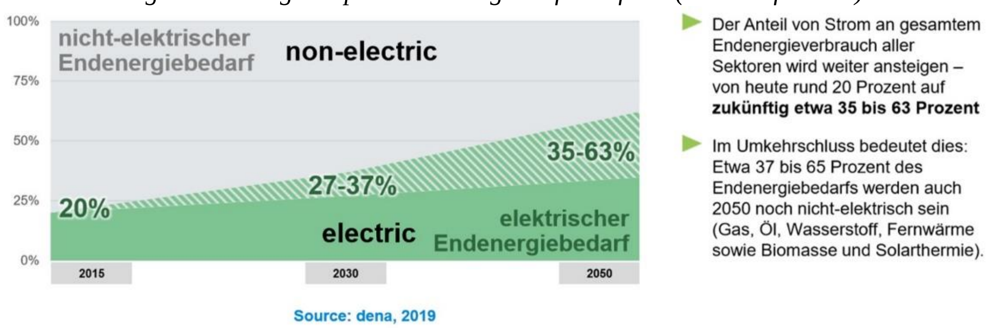

Figure 21. Use of renewable Energies @ end-user over Time (Source: dena)

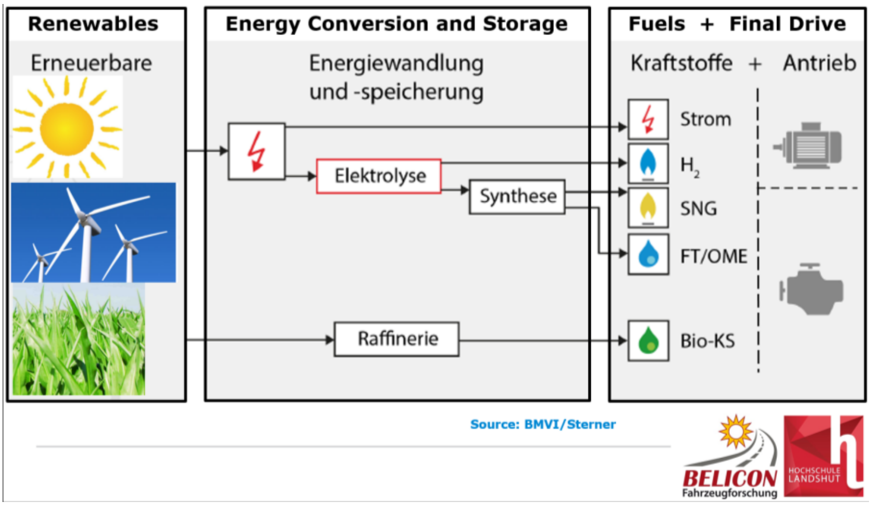

Figure 22. Renewable Energies are the key, but the final drive is still open (Source: BMVI/Sterner)

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ANTI-SLIP WHEEL DEVICES

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RESEARCH ARTICLE

ABSTRACT: Slippage of wheeled and tracked vehicles negatively affects the operation of transmission elements, increased tread wear. Existing methods and means of combating slippage are widely known at the present time: the use of twin and widened wheels, the installation of spikes, putting on chains, lugs, etc. The traction control device proposed by us is activated only at the time of slipping. In normal mode, it is easily placed on the wheel disk, repeating with the lower end the envelope surface of the wheel tread. The weight of the device is 2 kg. Calculations have shown that to ensure the movement of the wheel on loose soil without slipping, the proposed device is placed in an amount of 2 to 6 pcs. in diametrically opposite ends of the wheel, protruding beyond the surface of the tire. Their number can be regulated by pneumatic actuator.

KEY WORDS: *slip, wheel, vehicle, device*

UREĐAJI PROTIV KLIZANJA TOČKOVA

REZIME: Proklizavanje vozila sa točkovima i gusenicama negativno utiče na rad elemenata sistema prenosa snage i povećano habanje gazećeg sloja. Postojeći načini i sredstva za suzbijanje klizanja danas su široko poznati: upotreba dvostrukih i proširenih točkova, ugradnja eksera, stavljanje lanaca, ušica itd. Uređaj za kontrolu proklizavanja koji smo predložili aktivira se samo u slučaju klizanja. U normalnom režimu rada lako se postavlja na disk točka, poravnavajući se sa donjim krajem površine omotača gazećeg sloja točka. Težina uređaja je 2 kg. Proračuni su pokazali da se za osiguranje kretanja točka na rastresitom tlu bez klizanja, predloženi uređaj postavlja sa 2.do6 kom. na dijametralno suprotnim krajevima točka, koji su ispupčeni izvan površine pneumatika. Njihov broj se može regulisati pneumatskim aktuatorom.

KLJUČNE REČI: *klizanje, točak, vozilo, uređaj*

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ANTI-SLIP WHEEL DEVICES

Liubov Sladkova, Aleksandr Siuzev

INTRODUCTION

When moving tracked or wheeled vehicles off-road, due to the low grip of the wheel with the ground or snow, slippage increases, which makes the use of the machine ineffective or completely impossible. Slippage occurs when the traction force exceeds the force of adhesion of the wheel or track to the surface of the road or ground. Slippage can begin after an increase in torque or a decrease in adhesion associated with a change in the properties of the road surface (layer of water, dirt, ice) and wheel load (usually due to maneuvering) (fig. 1).

Figure 1 Towing of wheeled and tracked vehicles

Slippage leads to the failure of the transmission elements. This is due to the fact that when stalling, the engine of the machine works at high speeds, leading to overheating of the flywheel of the engine (clutch) and gearbox (boxes), gearboxes, friction pads (Fig. 2), failure of the cardan shafts (Fig. 3). Given the fact that when slipping, as a rule, the angular speeds of rotation of the wheels are different, there is a failure or failure of the gears of the differential, which are not designed for a large difference in wheel speeds.

Figure 2 Fracture and overheating of the pressure disc with constant slippage of the clutch

Figure 3 Failure of the driveshaft

To bring the machine into a state of motion when stalling, the power of the engine is not enough, so various methods and devices are used to increase the useful power of the engine.

One of the directions for improving the adhesion characteristics of wheeled vehicles (CTS) is the use of various techniques, as well as the modernization of mechanisms and systems in order to increase the installed engine power in useful operation. In addition to this drawback, slipping leads to wear of the tread and its replacement, which entails significant economic costs. For example, for machines widely used in forestry and agriculture [1, 2, 3, 4], arched and twin tires are used [5, 6], or wide-profile tires comparable to a twin wheel are used, installed instead of conventional ones, which increase the permeability of the machine on soils with low bearing capacity, during the spring-autumn mudslide and snow drifts.

With twin tires, the second wheel is installed using a special spacer that provides a gap between the sidewalls of the tires. In addition to such a time-consuming solution, the most common is the method of changing the pressure in the tires, leading to an increase in the spot of contact of the wheel with the road.

Sometimes, to increase adhesion on pneumatic tires, a half-track stroke is installed, the weight is increased by attaching additional cargo (water cylinders, metal) [7]. A theoretical confirmation of this technique is that the grip strength of the PCC depends on the coupling weight of the Gk car, i.e. the vertical load on the drive wheels. (The greater the vertical load, the greater the grip force):

$$P_{fa} = \varphi G_k, \tag{1}$$

whear P_{fa} – the force of adhesion of the wheels to the road, H;

- φ – coefficient of adhesion;
- G_k – coupling weight, N.

The condition of movement without towing of the wheels $P_k < R_{fa}$, i.e. if the traction force Pk is less than the clutch force of the Rsc, then the driving wheel rolls without slipping. If a pulling force greater than the clutch force is applied to the drive wheels, then the car can only move with the drive wheels slipping. As soon as the traction force exceeds the adhesion force, the wheels will rotate around their axis and the vehicle will stand still. This method has the disadvantage associated with the fact that with an increase in mass, the depth of the track and soil compaction increase. To reduce the depth of the track, jacks are used, raising the wheels by the amount of their separation from the soil. The adhesion coefficient is also affected by the tread pattern of the tire [8].

With a complete slip of the tire on the road (slipping of the drive wheels or the south of the braking wheels), the value of the f can be 10 ... 25% less than the maximum. The coefficient of transverse adhesion depends on the same factors, and it is usually taken to be equal to 0.7φ. Average adhesion coefficient values range widely from 0.1 (icy coating) to 0.8 (dry asphalt and cement-concrete pavement). To avoid slipping of the drive wheels when driving in first gear, the following inequality must be met:

$$\frac{M_{max}\eta u_1 u_2 u_3}{G_a r_k} \leq D_{сц} = \frac{m_{p2} G_{a2} \varphi_x}{G_a} \tag{2}$$

where M_{max} – torque on the drive wheels, N·m;

- η – coefficient of efficiency;
- G_a – total weight of the car, H;
- r_k – static radius of the wheel, m;
- u_1 – transmission gear ratios;
- D_{fa} – dynamic factor of the car in grip, m;
- m_{p2} = 1,20…1,35 – coefficient of change of reactions on the rear drive wheels;
- G_{a2} – the weight of the car falling on the rear wheels of the car with a full load, H;
- φ_x – coefficient of adhesion of the wheel to the road.

TECHNIQUES TO REDUCE WHEEL SLIP

Various tricks to reduce wheel slip were taken from the personal experience of drivers. These illustrations are borrowed from Internet resources. To exclude the possibility of slipping when starting from a standstill on deep snow, you should choose in advance a lower gear that would exclude stopping the vehicle. As a rule, to bring the machine out of a state of rest, the force of two three people is used, who, simply put, push the machine out. Or the simplest and most commonly used is digging up the machine with a regular shovel. Often, in order to pull out the machine, the method of a rope-block device is used, where instead of blocks, free-standing trees and a cable are used (Fig. 4).

Figure 4 Method of using the rope-block device

To increase traction, various devices installed on wheel tires (fig. 5) are also widely used, increasing the tread depth (spikes (fig. 5, a), chains (fig. 5, b), linings (fig. 5, c)).

a) b) c)

Figure 5 Devices for increasing adhesion

DEVICES TO REDUCE WHEEL SLIP

The device is already the principle of upgrading the wheels to reduce their slippage. They are removable (Fig. 6) and stationary.

Figure 6 Removable devices to reduce begging

To increase the grip and cross-country ability of the vehicle with ease of manufacture and increase reliability, a wheel with retractable lugs is used (Fig. 7) [9].

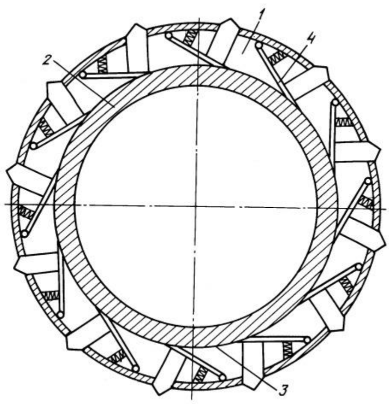
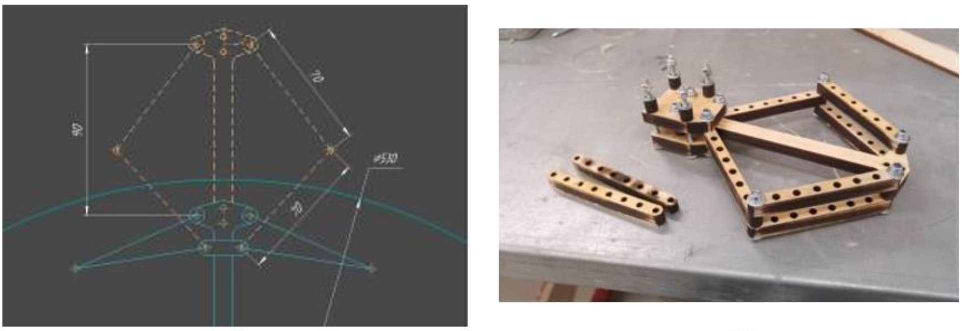


Figure 7 Device to increase the adhesion and cross-country ability of the vehicle

In the device (Fig. 7), the auxiliary wheel 1 with retractable hooks is made in the form of a hollow equiradial drum type wheel 2 of a light alloy material, which is attached to the main wheel 3 and contains hinged shoulder arms 4 hinged at points on the inside of the outer periphery of the wheel, spring-loaded at point 1/3 of the total length. Between the pneumatic chamber and the shoulder arms of the lugs is installed a protective metallized rubberized ring with a thickness of at least 1.5 cm with a width corresponding to the width of the working drum of the wheel. The rim of the wheel and lugs are equipped with holes in which studs are inserted to fix the hooks. The working part of the lug can be made in the form of spikes of various profiles (balls, cones, cylinders, etc.). They are usually located on the periphery of the clip installed on the rim of the wheel. When the wheel moves on loose ground, the value of the shear and cut forces increases. Obviously, when the driving wheel moves, its lugs shift and cut the ground in the direction opposite to the movement. Stopping the lugs in the ground, shearing and cutting are possible only with the full use of frictional forces, i.e. when there is a slippage of the wheel. We offer a traction control device, presented in Fig. 8.



a) *b*)

Figure 8 Traction control device offered by the authors

The device offered by us refers to the chassis on a pneumatic course and is designed to reduce wheel slip. A pneumatic cylinder is fixed to the wheel hub, to the piston of which a fixed guide is attached in the piston cavity, moving freely through the hole, and on the guide there is a hub rigidly fixed to the guide, to which the rods are attached with free ends and, the other free ends of which are connected respectively by hinges and with rods and, the free ends of which are connected by a hinge to the guide, and on the guide in the piston cavity between the inner the base of the hydraulic cylinder a and the piston are an elastic element. It is activated only at the time of stalling. In normal mode, it is easily placed on the wheel disk, repeating with the lower end the envelope surface of the wheel tread. Weight of the device – 2 kg. Consider the operation of the lug when slipping. At the moment of slipping during the transmission of the driving torque, the axle of the wheel moves some distance back, which leads to a decrease in the translational speed of the wheel. The reason for this is the direct movement of the points of the wheel on the supporting surface of the soil when the lug leaves it and moves to the surface of the wheel. At this point, the lugs are located in the ground at different depths, which leads to uneven ground shear forces under the lugs.

Extension of lugs is possible due to an additional pneumatic drive device when air is discharged from the wheel. Calculations have shown that in order to ensure the movement of the wheel on loose soil without slipping, the proposed device is placed in an amount of 2 ... 6 pcs. in diametrically opposite ends of the wheel, protruding beyond the surface of the tire.

CONCLUSIONS

To combat towing of wheeled vehicles, the most effective means are additionally installed on the wheel removable or stationary traction control devices, manufactured at the suggestion of the authors and allowing to increase adhesion to the ground and bring the machine out of the stalling mode.

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THE INFLUENCE OF STEP SHAPED ROAD SURFACE ON SAFETY WHEN DRIVING IN A BEND ON THE ROAD

Franci Pušavec [1], Janez Kopač [2], Krsto Mijanović [3]*

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RESEARCH ARTICLE

ABSTRACT: The influence of the difference in the height of the road junctions e.g. when crossing the viaduct (dilatation), it can cause de-balancing of a vehicle, especially in the corners/bends. In practice, this differences in height can reach amplitudes (high of differences two asphalt planes) from 1 cm to 3 cm, or even more. However, anything larger than 1 cm can already represents the critical vertical movement of the vehicle that in combination with the vehicle speed, bend radius, the roughness of the asphalt, dry / wet roads, etc. can lead in catastrophic accident – especially by trucks. This paper, thus present analysis of tests and simulation of such vehicle behaviour, and correlate them with the observations from real occurred traffic accidents, related to this topic. Also concrete cases are shown.

KEY WORDS: *driving in bend road, speed limit in curve, side friction coefficient, vertical step on road, traffic accident*

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UTICAJ STEPENASTIH ISPUPČENJA NA POVRŠINI PUTA NA BEZBEDNOST VOŽNJE U KRIVINI

REZIME: Uticaj razlike u visini putnih čvorova npr. pri prelasku preko spojnica (dilatacija) može izazvati disbalans vozila, posebno u krivinama. U praksi, ove razlike u visini mogu dostići amplitude (velike razlike dve asfaltne ravni) od 1 cm do 3 cm, pa i više. Međutim, sve više od 1 cm već može predstavljati kritično vertikalno kretanje vozila koje u kombinaciji sa brzinom vozila, radijusom krivine, neravninama puta, suvim/mokrim asfaltom i sl. može dovesti do katastrofalne nezgode – posebno kamiona. U ovom radu je predstavljena analiza testova i simulacija ovakvog ponašanja vozila i dovedena u korelaciju sa zapažanjima iz stvarno nastalih saobraćajnih nezgoda, vezanih za ovu temu. Prikazani su i konkretni slučajevi.

KLJUČNE REČI: *vožnja u krivini, ograničenje brzine u krivini, koeficijent bočnog prijanjanja, vertikalni skok na putu, saobraćajna nezgod*

THE INFLUENCE OF STEP SHAPED ROAD SURFACE ON SAFETY WHEN DRIVING IN A BEND ON THE ROAD

Franci Pušavec, Janez Kopač, Krsto Mijanović

INTRODUCTION

Centrifugal force in the bend/turn, $F_c = m \cdot a_r\_r = m \cdot v^2/r = m \cdot (\omega \cdot r)^2/r$, is depending on the radius of the curve (r), the mass of the vehicle (m), and radial acceleration i.e. speed through the corner. This causes the constant radial force on the wheel grip with road (perpendicular to the driving direction), throughout the corner. Any change in the height of the road surface, like a step, dilatation, bump, etc. can initiate the vertical movement of the car and thus on normal force that car acts on the road surface. Normal force of wheels on the road surface is assuring the sufficient friction between the tyre and the road that side movement of the car is prevented. With lowering the normal force, also the friction force is decreased [1]. In critical situation, when the tire for a moment loses contact, this means the normal force to the road surface will be zero and no friction will be assured. If this happens during driving through the corner/turn, the friction force cannot oppose the centrifugal force and the car will start uncontrollably moving radially from the corner/turn [2,3]. A sample case of such road surface has been analysed with the measurement of accelerations when driving through the in the corner. Results of the measurement are shown on Figure 1. The vertical step on the road surface, on the viaduct dilatation, can be recognised by a vertical amplitude in the signal (the diagram where the oscillation is recorded transversely to the direction of travel - at a time of 43.5 sec and close to 49 sec). From the other two graphs we can see that no impulse can be seen in the direction of the driving. However, in lateral direction, at a jump (periodic vertical bouncing of suspension) the slight peak can also be seen. At that moment, the car has driven over the vertical bumper on the road and caused the lateral movement. In this case higher periodic vertical amplitudes are observed after this excitation. Acceleration observed in vertical direction represents the decrease of the friction (that acts against the centrifugal force) for 50% ($F_{fr} = m \cdot g \cdot \mu = m \cdot (g - a_{vertical}) \cdot \mu$). Thus, from practical case we can see that the centrifugal force and lateral acceleration, as a result of cornering dilation, can cause the vehicle to skid and start to drift out of the corner. This is even more problematic in the situations where friction coefficient is, due to the weather conditions, significantly reduced (wet road, snow on the road) [4,5].

1. ACCIDENT CASE STUDY

On a wet road, where the friction coefficient decreases from 8 m/s^2 to e.g. 5 m/s^2, when the driver is already driving at a critical speed, the vehicle start skids in a corner even sooner [6,7]. This has happened in real situation accident of the track trailer driving over the viaduct/bridge. Additionally, we have to take into account the possible scenario of slipping of tires. When wheels/tires slip on a wet road, for a few moments, static friction changes to much lower dynamic one. This one is smaller and the vehicle can even faster come to situation that cannot resist the centrifugal force in the corner. Especially if the driving speed is too high or the corner radius is too small.

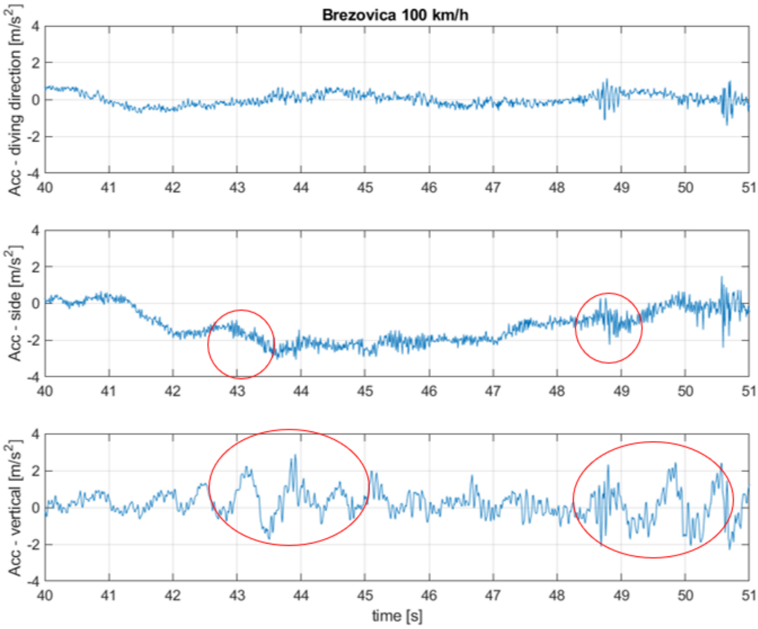

Figure 1 Accelerations acting on the car when driving through the corner with R = 300 m, and vertical dilatation step of 3 cm

The example that is show presents a traffic accident when an empty truck was moving downhill in a right-hand bend/turn with R = 100 m and on a wet road (Figure 2). The calculated speed exceeded the speed limit. The vehicle slipped while transporting the dilatation with a certain height difference out of the bend (centrifugal to the left), where it collided with the cabin in the opposite direction of a moving full truck. The empty vehicle bounced back to the right, over the bridge, through the railing and fell to a depth of 8 m.

Figure 2 Accelerations acting on the car when driving through the corner with R = 300 m, and vertical dilatation step of 3 cm

For the analysis, accelerations were measured in the corner and, as a result, due to the dilatation height drop, also transverse accelerations has been acting on the trailer. The results can be seen from the diagrams. It was found that this dilatation level difference also contributed to the vehicle slipping in the bend. Further, a critical situation arises when the sum of different factors cross composed limit value, where the vehicle comes to unstable region of behaviour, leading to radial slip or rollover. Overturning is largely influenced by the height of the centre of gravity. This is often the critical case for trucks, trailers, semi-trailers and tankers. If there is an additional lateral force in those situations, the balance is destroyed and the vehicle is evacuated centrifugally from the roadway. One of such examples can be show in Figure 3, where the truck is driving through the corner, close to the limit conditions (according to speed in a corner). In such a situation, a passenger car drifted into the front of the truck. Even though the passenger car has significantly lower weight, the impact was sufficient enough to de-balance the truck and cause that the tuck slide out of the bend, broke the concrete guardrail and fell to a depth of 15 m.

Figure 3 Centrifugal force (in turn) and radial hit force (by car) acting on a truck resulting on a catastrophic accident

2. RESULTS AND CONCLUSIONS

Based the shown analysis, it has been confirmed that the speed limitations have to be carefully defined. And at defining the right speed limit, the critical situation have to be predicted, and based on this defined the values that assure safety in everyday traffic. Contrary, even if the drivers are critical to those defined speed limits, they should follow them and not really judge whether they are appropriate. Those values are covering wide range of every day conditions (from most favourable to the most critical ones, i.e. wet road, high dilatations, bumps, dirt on the road, snow, etc.). Not following the recommendations, can cause as a consequence side skid of a car, etc. But of course, the base is the radius of the curve road, which is the primary reason for the lateral magnitude of the centrifugal force.

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SELECTION OF SHAFT MATERIALS USING A MULTICRITERIA APPROACH

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RESEARCH ARTICLE

ABSTRACT: The aspiration of modern mechanisms is to achieve the highest possible speed of work. The same requirements apply to transmission shafts, so a precise dynamic analysis of the stability of these elements is very important. It is known that the frequency of oscillation is directly proportional to the elasticity of the body, and inversely proportional to the mass of the body. The essence of the work is in the selection of the optimal shaft material in order to avoid the occurrence of resonance that can lead to different types of shaft destruction. Aluminum and composite carbon fiber shafts in combination with epoxy resin were analyzed. The paper proposes a multicriteria approach (MCDM) for the selection of the optimal transmission shaft material. It is emphasized how suitable this method is for analyzes of this type because it includes the influence of numerous qualitative and quantitative properties of materials in the selection.

KEY WORDS: *multi-criteria decision making, shaft, material, composite*

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IZBOR MATERIJALA VRATILA VIŠEKRITERIJUMSKIM PRISTUPOM

REZIME: Težnja savremenih mehanizama je postizanje najveće moguće brzine rada. Isti zahtevi važe i za prenosna vratila, pa je precizna dinamička analiza stabilnosti ovih elemenata veoma važna. Poznato je da je frekvencija oscilovanja direktno proporcionalna elastičnosti tela, a obrnuto proporcionalna masi tela. Cilj rada je izbor optimalnog materijala vratila kako bi se izbegla pojava rezonancije koja može dovesti do različitih oštećenja osovine. Analizirana su vratila od aluminijuma i kompozitnih karbonskih vlakana u kombinaciji sa epoksidnom smolom. U radu se predlaže višekriterijumski pristup (MCDM) za izbor optimalnog materijala prenosnog vratila. Istaknuto je koliko je ova metoda pogodna za analize ovog tipa jer u izbor uključuje uticaj brojnih kvalitativnih i kvantitativnih svojstava materijala.

KLJUČNE REČI: *višekriterijumsko odlučivanje, vratilo, materijal, kompozit*

SELECTION OF SHAFT MATERIALS USING A MULTICRITERIA APPROACH

Saša Jovanović, Zorica Đorđević, Sonja Kostić, Danijela Nikolić, Milan Đorđević

INTRODUCTION

Metal drive shafts can have mass limitations, low critical speeds, and potentially destructive vibrations. Composite drive shafts, thanks to the nature of composites, in which the specific modulus of elasticity is higher (modulus to density ratio) than in metal, can be a good replacement. Composite drive shafts offer excellent vibration damping, reduced wear of drive assembly components, are less susceptible to the effects of stress concentration, reduce installation time, inventory costs, maintenance, etc. [1]. Replacing conventional metal structures with composite structures has many advantages, due to higher specific stiffness and higher specific strength of composite materials [2,3]. The process of filament winding is used in the production of composite drive shafts. And in order to achieve an efficient design, it is done by choosing the appropriate variables, such as the inner radius, the thickness of the layers, the number of layers, the orientation of the fibers, the angle and the order of stacking the layers [4]. In the optimal drive shaft design, these variables are limited by lateral natural frequencies, torsional vibrations, torsional strength, torsion and bending of the shaft, as well as shaft fatigue due to torsion [5-7]. Material has an important role in the design process. Choosing the right material for a particular product is one of the vital tasks for engineers. In order to meet the final requirements of the product, engineers and designers need to analyze the characteristics of different materials and identify the appropriate material. Due to the presence of a large number of materials with different properties, the process of material selection is a complicated and time-consuming task. There is a need for systematization and an efficient approach to select the best alternative material for a given product. The conflicting nature of the material selection evaluation criteria can be resolved using the Multi-Criteria Decision-Making (MCDM) method. The work of Emovon and Oghenenyerovwho (2020) presents a methodological review of the application of MCDM in material selection. The study reviewed a total of 55 papers, published from 1994 to 2019, which were reviewed mainly in high-ranking journals. The results of the analysis showed that the hybrid method combined with two or more MCDM methods is the most applied material selection technique in a particular field of application, and that the MCDM technique is a very useful tool in decision making regarding material selection [8]. The work of Okokpujie et al. (2020) focuses on the implementation of the MCDM for the process of selecting the appropriate material for the development of a horizontal wind turbine blade. The research considers four alternatives, namely aluminum alloy, stainless steel, fiberglass and mild steel. In this paper, a quantitative research approach using AHP and TOPSIS multicriteria decision-making methods was used [9]. Anojkumar et al. (2014) deal with the selection of the optimal material for pipes for use in the sugar industry, from a set of five alternative materials and seven evaluation criteria. The paper discusses different perceptions of methodologies in the problem of material selection, using MCDM. The proposed models FAHP-TOPSIS, FAHP-VIKOR, FAHP-ELECTRE, FAHP-PROMTHEE and VIKOR are simple, practical, precise and efficient tools that help decision makers to choose the right material from alternative materials [10].

The aim of this paper is a multicriteria approach (MCDM) for the selection of the optimal material of the transmission shaft. Aluminum and composite carbon fiber shaft in combination with epoxy resin were analyzed, taking into account seven evaluation criteria: Elasticity modulus E_1 and E_2, sliding modulus, G_{12}, ratio E_1/ρ, weight m, natural frequency f_s, critical speed n_{kr}.

The drive shaft of the car Nissan 350Z series 946-244 was considered. The geometric measurements of the analyzed shaft are: the length of the shaft is 1.5 m, the mean diameter of the shaft is 0.08 m, the wall thickness of the annular cross-section of the shaft is 0.002 m. the shaft is shown in Figure 1.

Figure 1 Nissan 350Z drive shaft [11]

The values of natural frequencies and critical speeds in this work were obtained numerically, using the finite element method. The analysis was carried out using the software FEMAP version 2021.2. The critical speed of the drive shaft of a light-duty passenger vehicle should be greater than 6500 min^{-1}.

1. SELECTION OF OPTIMAL SHAFT MATERIALS USING MCDM

The analysis considered four different materials (Aluminum, USN 150 carbon/epoxy, HS carbon/epoxy, HM carbon/epoxy) for shaft construction and analyzed the impact of seven characteristic values (performance) which are assigned the role of criteria in the multi-criteria decision-making process. The method of additive weighting methods (SAW Simple Additive Weighting Method) was applied in this paper. The SAW method belongs to the relatively simple methods of multicriteria decision-making, but it also belongs to the group of methods that provide relatively reliable estimates of the rank of the considered alternatives. An important element in choosing this method is, in addition to its simplicity, the fact that this procedure takes into account the so-called weighting factors.
Table 1 shows the values of the selected quantities (criteria) for the considered materials. These are also the values (x_{ij}) that form the so-called Decision Matrix.
The procedure of normalization of data from the Table 1 is carried out using the following expressions (1), for max type criteria, and (2), for min type criteria, depending on whether it is a criterion of maximization or minimization type (in the considered example, all selected sizes, ie adopted criteria are of the maximization type, except for the mass of material). One of the criteria planned in the analysis was supposed to be the price of a certain material on the market, but due to the current turbulent economic trends that affect the great instability and comparability of prices, this criterion was omitted. It is planned that, with the calming of events on the world material market, this criterion will be a supplement and part of this analysis:

$$r_{ij} = \frac{x_{ij} - x_j^{\min}}{x_j^{\max} - x_j^{\min}} \tag{1}$$

$$r_{ij} = \frac{x_j^{\max} - x_{ij}}{x_j^{\max} - x_j^{\min}} \tag{2}$$

Table 1 *Values of the considered quantities - criteria for selected materials (x_{ij})*

	Criteria						
	Elasticity modulus E_1, MPa	Elasticity modulus E_2, MPa	Sliding modulus G_{12}, MPa	Ratio E_1/ρ, MPa/kg	weight m, kg	natural frequency f_s, Hz	critical speed n_{kr}, Hz
Aluminum	72000	72000	27000	28	0.6	222.67	13360
USN 150 carbon /epoxy	131600	8200	4500	84.9	0.36	325.46	19527
HS carbon /epoxy	134000	7000	5800	83.7	0.37	335.15	20109
HM carbon /epoxy	190000	7700	4200	118.75	0.37	354.08	21245
type of criteria	max	max	max	max	min	max	max

The values of the normalized data in Table 1 are shown in Table 2.

Table 2 *Normalized values of the considered quantities - criteria for selected materials (r_{ij})*

	k1	k2	k3	k4	k5	k6	k7
Aluminum	0	1	1	0	1	0	0
USN 150 carbon /epoxy	0.505085	0.018462	0.013158	0.626997	0	0.782208	0.782118
HS carbon /epoxy	0.525424	0	0.070175	0.613774	0.041667	0.855947	0.855929
HM carbon /epoxy	1	0.010769	0	1	0.041667	1	1

The weighting coefficients (Wi') of the criteria were determined in two variants using the Saaty procedure [12]. In the first variant, the priority in importance was given to some criteria (sizes) such as k4, k6 and k7, while some were less significant, such as k3. An overview of the Dominant Matrix, for this variant, is given in the Table 3.

Table 3 *Dominant matrix - the first variant*

	k1	k2	k3	k4	k5	k6	k7	Wi
k1	1	1	3	0	0	0	0	5
k2	1	1	3	0	0	0	0	5
k3	0	0	1	0	0	0	0	1
k4	3	3	5	1	2	1	1	16
k5	2	2	4	0	1	0	0	9
k6	3	3	5	1	2	1	1	16
k7	3	3	5	1	2	1	1	16

In the second variant considered, all criteria were equal in importance. The dominant matrix for this variant of the relationship of importance of the criteria is shown in the Table 4.

***Table 4** Dominant matrix - the second variant*

	k1	k2	k3	k4	k5	k6	k7	Wi
k1	1	1	1	1	1	1	1	7
k2	1	1	1	1	1	1	1	7
k3	1	1	1	1	1	1	1	7
k4	1	1	1	1	1	1	1	7
k5	1	1	1	1	1	1	1	7
k6	1	1	1	1	1	1	1	7
k7	1	1	1	1	1	1	1	7

The values of the relative weighting coefficients are shown in the diagram in Figure 2.

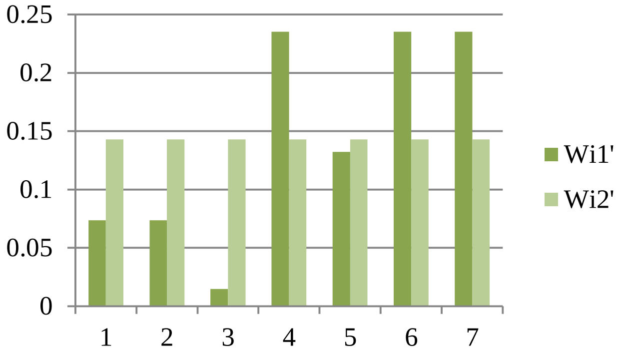

Figure 2 Relative weight coefficients in two variants

Using the procedure implied by the SAW method, the aggregate characteristics for each of the four considered materials were determined for both variants of weight coefficients. The diagram shown in Figure 3 clearly shows that the fourth considered material (HM carbon / epoxy) in both cases has the highest cumulative characteristic, ie the highest score within the conducted multicriteria analysis.

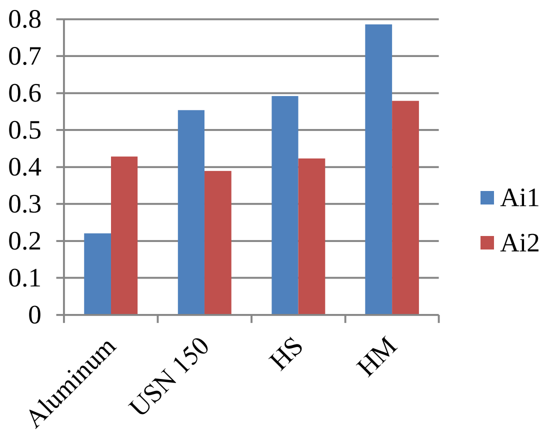

Figure 3 Aggregate characteristics in both considered variants

2. CONCLUSIONS

Ranking and selecting the best material in the product design process is a very important and complex task. The procedure of analysis of composite materials, which was the topic of this paper, is even more complex. Such materials require a multi-criteria approach in the selection. Such an approach provides an opportunity for the designer to change the design of the product already in the design phase and thus achieve an improved version of the same, and all this leads to a reduction in production costs. The aim of this paper was to select the optimal material for the transmission shaft, from the aspect of dynamic stability, for which the SAW method was used as one of the methods of multicriteria decision making. Four different materials (aluminum and three composite materials - USN 150, HS and HM carbon/epoxy) were considered. Based on the presented analysis of the mentioned materials and the evaluation of seven selected characteristics, the shaft made of HM carbon/epoxy showed the best results. The analysis was performed for two variants of weight coefficients and in both cases an identical conclusion was reached.
The next step in the design process would be the analysis of the economic factor (material prices), which will be the subject of future research in this area.

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DEVELOPMENT OF DEVICES FOR TESTING DYNAMIC DURABILITY OF MATERIALS

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RESEARCH ARTICLE

ABSTRACT: Many automotive parts are exposed to complex dynamic stresses during their exploitation. For the design of such elements as shafts, axles, etc., it is necessary to perform fatigue testing in order to obtain permanent dynamic strength of the part. For the purposes of such tests, a device has been developed that provides the possibility of dynamic testing of parts loaded only by torsion, only on bending or parts that are loaded with combined bending and torsional stress. The device provides the possibility of testing cylindrical workpieces. The obtained experimental data show that the maximum error of measuring the dynamic strength of materials at complex stresses is 5%.

KEY WORDS: *body structures, fatigue strength, devices for testing material, dynamic durability, combined stress*

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RAZVOJ UREĐAJA ZA ISPITIVANJE DINAMIČKE IZDRŽLJIVOSTI MATERIJALA

REZIME: Mnogi automobilski delovi su tokom eksploatacije izloženi složenim dinamičkim naprezanjima. Za projektovanje elemenata kao što su vratila, osovine itd., potrebno je izvršiti ispitivanje na zamor kako bi se dobila trajna dinamička čvrstoća dela. Za potrebe ovakvih ispitivanja razvijen je uređaj koji pruža mogućnost dinamičkog ispitivanja delova opterećenih samo torzijom, samo na savijanje ili delova koji su opterećeni kombinovanim savijanjem i torzionim naprezanjem. Uređaj pruža mogućnost ispitivanja cilindričnih delova. Dobijeni eksperimentalni podaci pokazuju da maksimalna greška merenja dinamičke čvrstoće materijala pri složenim naponima iznosi 5%

KLJUČNE REČI: *strukture karoserije, čvrstoća na zamor, uređaji za ispitivanje materijala, dinamička izdržljivost, kombinovani naponi*

DEVELOPMENT OF DEVICES FOR TESTING DYNAMIC DURABILITY OF MATERIALS

Sonja Kostić, Bogdan Živković, Aleksandra Ivanović, Dragan Džunić, Suzana Petrović Savić, Vladimir Kočović

INTRODUCTION

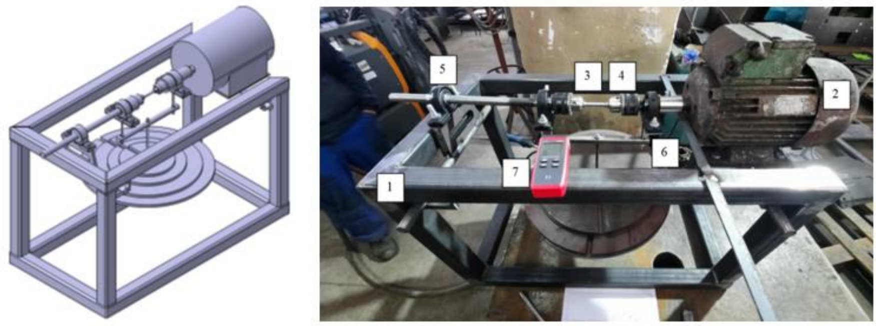
Metal parts that are exposed for a long time to the dynamic effect of a force of variable intensity and direction break even though the intensity of the stress that causes the break is smaller than the force at the yield point of the tested material under static stress. Due to the long-term effect of periodically changing loads, gradual destruction of the material may occur. This phenomenon is called fatigue, and the fracture caused by it is a fracture due to fatigue. Fractures due to material fatigue are very dangerous in practice because they are not preceded by plastic deformation even in tough materials. Initial cracks caused by fatigue are the sharpest natural cracks, which in complex dynamic systems can hardly be detected before the fracture occurs. One of such systems is the car, where not only axles, shafts, crankshafts, transmission levers, screws, etc., but also toothed and chain transmissions, rolling bearings, roller and spherical parts exposed to abrasion are exposed to dynamic, variable loads. Product durability is related to three main factors: structure, load and material. The endurance performance of an automotive product depends not only on the structure configuration, but also on the dynamic load characteristics and fatigue properties of the materials [1]. Due to the fact that automotive vehicle loads are dynamic in nature, one of the main technical challenges for product durability design is how to quantify the fatigue damage sensitivity. Su [1] uses a finite element model and a developed mathematical model to simulate the dynamic stresses of the structural system of car axles, which would simultaneously act on the car on the road. The obtained results show the level of influence on the durability of components under dynamic loading in relation to different design variables.

In the 1950s, fatigue testing devices were introduced, which enabled tests with real loads of samples, components and entire mechanical systems. From then until today, there are numerous literature references on the design of devices for dynamic stress testing of materials, all with the aim of assigning complex and variable loads that occur in real conditions. The life of an automatic weapon is a leading requirement in the field of automatic weapon design. This problem is discussed by Lingl et al. [2] in their work, developing a device for fatigue testing of mechanisms of automatic weapons due to impact loads, thus reducing component manufacturing costs and improving component design reliability. Ghielmetti et al. [3] in their work describe the development of an electromechanical fatigue test machine with force control, as well as the corresponding software, for flat specimen testing. The advantage of this device, taking into account the appropriate accuracy of the obtained results, is its simplicity and low cost. The work of Bhatkar et al. [4] describes the design and production of a dual fatigue testing machine. Currently available devices for fatigue testing of materials have a very high price, and the authors designed an economical, compact and efficient device, which uses two types of mechanisms for fatigue testing of samples of mild steel material (bending with constant or shock loads). In their work, Rajesh and Saravanan [5] develop an economical device for fatigue testing of materials with 95% efficiency. The authors emphasize the simplicity of its modeling of the device and ease of understanding [6-8]. More than one sample can be tested simultaneously on the material fatigue tester. The design of a device for testing two samples of different materials simultaneously was presented by Shreyas et al. [9]. The developed device uses less energy during the test and it is environmentally friendly because it has one motor, shortens the test time, and a comparative analysis of the obtained results for both samples can be done at the same time.

This paper presents the development of a simple and economical device for material fatigue testing, which can be used for educational and research purposes, as well as applied in industry.

1. METHODS AND MATERIAL

The developed device provides the possibility of determining the permanent dynamic endurance during rotational bending of the part. The bending force is realized by weights in the direction normal to the axis of the sample, creating compressive stresses above and tensile stresses below the axis of the sample. As the tested sample rotates around its own axis all the time, compressive and tensile stresses will alternate cyclically in all the fibres of the tested sample. The period of oscillation will solely depend on the set rotation speed of the sample. Figure 1a) shows the 3D model of the device designed in the Catia program.



a) 3D model b) developed device

Figure 1 Material fatigue testing device

The developed device shown in Figure 1b) is composed of standard and specially made parts. The entire measuring system is placed on a stable frame (1), made of steel box profiles. An electric motor (2) with a power of 0.75 kW, with 1450 rpm is attached to the frame via the bogie. Bogie of the electric motor enables elastic deformation of the sample under the action of normal force, which causes torque transmitting shaft rests on three MSC UCP 204 bearings. The bearing (5) is also mounted on the bogie to apply a given normal force to the specimen deformation. The system for setting a normal load consists of a weight carrier (6), on which different weights of 8 kg, 12 kg, 24 kg, 32 kg and 40 kg are placed. As one cycle of stress is completed for one revolution, by measuring the number of revolutions of the specimen until breaking, the number of stress cycles of the specimen is also measured. A UNI-T UT373 digital counter (7) was used to measure the number of revolutions of the sample until it broke. The specimen is placed in the testing device, the load (bending moment) is applied until it breaks, and the number of revolutions that the specimen endured until it breaks is read on the digital counter. Performing a series of tests on identical specimens with different stresses enables the creation of an S-N curve (Weller curve) [10].

The main difference between the axial fatigue test method and the rotational bending method is that the axial fatigue test applies a uniform stress over the entire cross-section of the specimen being tested, while the rotational bending fatigue test is performed under the action of a stress that increases linearly from 0 at the neutral axis to maximum stress on the surface of the specimen.

The specimen used to test the dynamic durability of C10 steel material is shown in Figure 2. Five samples of C10 material were tested, for each given load.

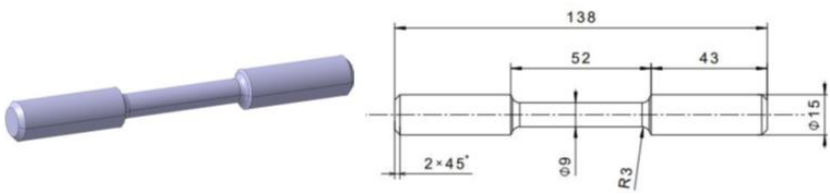


Figure 2 Test specimen made of material C10

The investigation was conducted on the specimen made of unalloyed steel C10 whose chemical composition is: ≤ 0.12 % C, ≤ 0.35 % Si, ≤ 0.5 % Mn, ≤ 0.045 % P, ≤ 0.045 % S. The mechanical and physical characteristics of unalloyed steel C10 are: elastic modulus = 210 GPa, hardness = 610-680 HB, tensile strength = 420-520 MPa, yield strength = 250 MPa, Poisson ratio=0.3 and density=7.8 g/cm3, fatigue strength = 180-240 MPa. In carburized and quenched condition it is used for light-duty structural parts with soft core and hard case, for sample pins, shafts, axles, hubs.

2. RESULTS

Table 1 presents the input data during fatigue testing of materials, for given loads with weights of mass m of 8, 12, 24, 32 and 40 kg, based on which the weight W, i.e. the force acting on the tested samples, can be determined. Based on the shaft length L=346.5 mm on which the load acts and the diameter of the test tube D=15 mm, the moment M and the bending stress σ are calculated.

Table 1 *Input data of testing material C10*

Load m, kg	W=m·g, N	M=L·W, Nmm	$\sigma=32\cdot M/(\pi\cdot D^3)$, MPa
8	78.48	27193.32	82.112
12	117.72	40789.98	123.169
24	235.44	81579.96	246.337
32	313.92	108773.28	328.450
40	392.40	135966.60	410.562

After the test, the results are obtained and shown in table 2. The results are the mean values of measurements of five specimens for each applied load.

Table 2 *Test results of material C10*

Load m, kg	No. of cycles to failure N	Time taken, s
8	80378	3326
12	66700	2760
24	17376	719
32	6960	288
40	3891	161

Figure 3 shows the Weller curve with the obtained results. On the diagram, the red, dotted line shows the exponential trend of the data, because the material testing device has losses that reduce the accuracy of the results obtained.

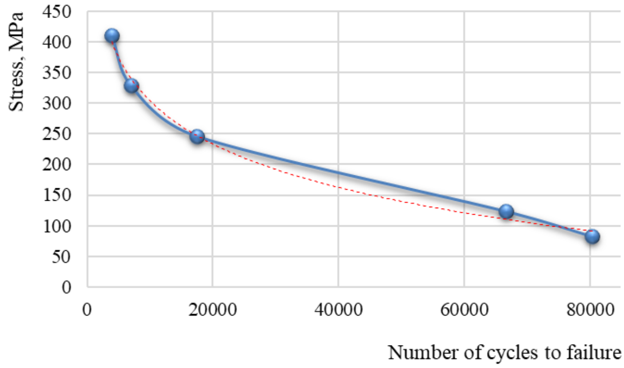
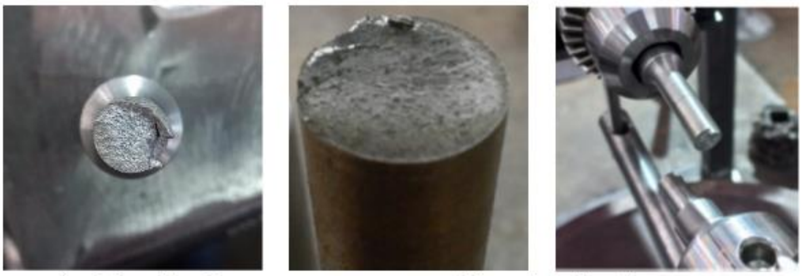


Figure 3 Weller's curve stress-number of cycles S-N

Figure 4 shows the fracture appearance of the specimen after testing with different loads.



a) minimal load b) maximal load

Figure 4 Fracture of the specimen under different loads

The developed device provides the possibility of testing the permanent fatigue strength by applying different types of stress, with minor modifications. In the event that the specimen with a cylindrical cross-section is clamped in both universal clamping heads, then in addition to the bending moment, tensioning stresses in the axial direction also act on the test tube, which occur as a result of bending the specimen. If the chuck (4) is released, the axial component of the force will disappear. In the event that, in addition to the described stresses, the twisting moment of the specimen needs to be varied, it is possible to install some type of brake behind the bearing (5) on the shaft that passes through it, which will achieve the desired resistant torque. In addition to the mentioned methods, it is possible to improve the device in terms of vibration reduction by installing flexible connections between the drive and measuring system as well as between the bogie and the frame.

3. CONCLUSION

Literary sources and the results of conducted experimental research confirm the possibility of applying the developed device for testing the dynamic durability of material samples or finished cylindrical products loaded during exploitation with different types of combined stresses: bending and pressing; tensioning, bending and pressing; twisting, bending and pressing; twisting, tightening, bending and pressing. The specified combinations of stresses during the dynamic durability test enable the testing of a large number of parts used in the automotive industry.

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