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ECOLOGY - VEHICLE AND ROAD SAFETY - EFFICIENCY

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Giovanni Belingardi[1]
Alessandro Scattina[2]

INTEGRATED UNDERBODY AND BATTERY PACK FOR BATTERY ELECTRIC VEHICLES: CHALLENGES AND SOLUTIONS IN THE DESIGN

KEYWORDS: electric vehicles, battery pack housing, design targets, architectural solutions, passive safety

Evolution toward electric vehicle (the most diffused electrification solutions include Hybrid Electric Vehicles (HEVs), Plug-in Hybrid Electric Vehicles (PHEVs) and fully electric Battery Electric Vehicles (BEVs)) appears to be nowadays the mainstream in the automotive and transportation industry. The evidence of climate change effects has finally pushed governments all over the world to act in order to reduce Greenhouse Gases (GHGs) emissions and the transportation sector is one of the relevant sources for this type of emissions. Therefore, in the next twenty years, the transportation sector is expected to face a deep transformation in order to meet the required emissions targets. This choice, that is expected to have beneficial impact on the climate changes and on the pollution of the air, especially inside towns, asks for feasible, effective solutions to some challenging engineering problems. The mobility industry is asked to provide innovative solutions to reach these objectives.

At first, naturally, the innovated power transmission system and its control, the vehicle autonomy (that is related to the dimension of the on-board battery pack) and the rapidity in battery recharging operation, further the new vehicle drivability and the passengers comfort: all these are relevant engineering problems.

The main concerns regarding BEVs are today currently associated to the battery pack and its medium energy storage capability. The energy density of the battery pack is not comparable with the one of the fuels. This leads to severe limitation in the driving range and rather long time for recharging operations. Moreover, there is a relevant increment of the vehicle weight due to the heavy battery pack: to reach the requested ranges, due to the limited battery energy density, BEVs weight on average 24% more than Internal Combustion Engine Vehicles (ICEVs) and this may also affect the dynamic behaviour of the vehicle.

The underbody architecture of a vehicle has many functions and requirements. For the topic of this paper the attention is focused on the structural and safety functions. Dealing with the structural function, the static and dynamic strengths and stiffnesses are of crucial importance for the dynamic and NVH performance of the vehicle. Regarding the safety function, the underbody must contribute on one hand to the appropriate protection of the occupants, as it is an essential part of the passenger compartment, and more in general, to distribute the energy absorbed during impact (both frontal and lateral) events. In the specific case of the BEVs, the safety function requires also appropriate protection of the battery pack to avoid fire or explosion hazards of this component.

The general target is to design a light and stiff frame because it is a fundamental part of the whole vehicle body, and it can be also used for different vehicles in the same marketing segment. The body static stiffness (both bending and torsional) should be the highest possible, both for passengers comfort and for drive precision, while keeping the mass as low as possible.

For what concerns the safety function, the general concept is to ensure the integrity of the passenger compartment, by dissipating as much as possible of the vehicle kinetic energy through progressive deformation of dedicated crumple zones. In the case of BEVs, the side impact is the most critical loading scenario because not only the passengers but also the battery pack have to be adequately protected. The side impact regulations take into account

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two possible loading scenario: the impact against another vehicle, or the impact against a pole (or similar, like a tree). This last condition is particularly severe because the loads are concentrated in a smaller part of the body in white, compared to the first test condition, where a larger part of the vehicle side structure is involved.
Typically, the vehicle sides and doors have room just for a limited crash absorbing structure and, in case of the BEVs, the vehicle deck should remain nearly undeformed and therefore does not contribute to the energy dissipation.
In this square, the body structure of the BEVs needs important architectural modifications compared to the ICEVs body in white, mainly to give a proper location and protection to the battery pack. In the BEVs the required battery is not a relatively cheap component located in the engine compartment, but it is a pack structure made up of several cells, which have to satisfy different functions: structural stability, underbody stiffness, crash protection, thermal management.
Considering the weight of the battery pack required for the new BEVs, in order to avoid a relevant change in the position of the vehicle centre of gravity that in turn could affect the vehicle drivability, the battery pack is usually located below the passenger compartment floor. This is an interesting solution for easy serviceability and maintenance, but the battery pack has to be carefully protected in case of lateral impact.
Therefore, the BEVs architecture has usually the central portion of the underbody occupied by a large and mostly flat battery pack constituting an ideal board (Figure 1a). This solution reduces the impact on the vehicle packaging and ensures a low centre of gravity. The crucial aspect of this type of architecture is the integration of the underbody structure with the battery pack in a sort of sandwich structure that guarantees high static, dynamic and safety performances. It is a simple architecture concept that offers more flexibility to the design of the vehicle.
To meet the required safety standard, the different car makers implemented several solutions. The rocker (that is the lower longitudinal side member of the body in white) should be stiffer and stronger than the usual one. To this aim, often its cross section put in evidence an additional internal structure made up of extruded longitudinal bars, Figure 1b (or stamped metal sheets). This solution enhances the rocker strength and its energy absorption capability in case of lateral impact. Moreover, the front longitudinal beams (main rail) have a larger cross-section, because of the wider space available in absence of the ICE and a complex gearbox. In this way they can manage higher amount of the impact energy. The floor is flat, with no or low-profile central tunnel, no underfloor rails are present. Since no exhaust system is present, it is possible to place a cross-member at the front part of the floor below the firewall. This cross-beam may be either part of the body structure or be included into the battery pack frame. Furthermore, the two front torque boxes (that connect the front side members to the door sills) and the two lateral rockers, are often reinforced with respect to the previous ICEVs design. Sometimes, the vehicle structures tend also to exploit the volume under the rear seats with a battery pack protrusion that is typically dedicated to host the electronic circuits for the battery management. Smaller contributions to the energy absorption in case of side impact come also from the B-pillar and from the door structure but the main amount of energy is absorbed by the rocker and the sandwich structure that is constituted by the passenger compartment floor and the underbody shield. In some cases, the battery pack could ensure a small contribution if its structure is specifically designed to this aim.
As a consequence, the global dynamic behaviour of the BEVs during a side crash is different with respect to the usual ICEVs. Being the lower longitudinal member stiffer, the vehicle tends to have higher rolling rotation around the longitudinal axis, because there is less deformation of the lower structure. Consequently, the upper part of the structure (in particular the B-pillar and the upper beam that constitutes the roof longitudinal member) is involved in the impact going in contact with the pole. As expected, the choice of the geometries and materials of the novel structure solutions, is very influencing the global behaviour of the vehicle. This choice depends on the design philosophy of the different car manufactures. For an excellent design these parameters should be defined with optimization processes. For instance, the position and the thickness of the extruded beams inside the rocker heavy influence the lateral loads distribution to the different parts of the underbody (upper floor, lower floor or battery case). It has to be avoided that, during the side impact, the loads will be rigidly transmitted to the battery pack.
In this work some engineering analysis has been presented together with an overview of sketches of some adopted possible solutions for the above listed topics. The paper proposes also some more detailed considerations related to the impact protection of the battery pack, with particular reference to the standard side impacts.

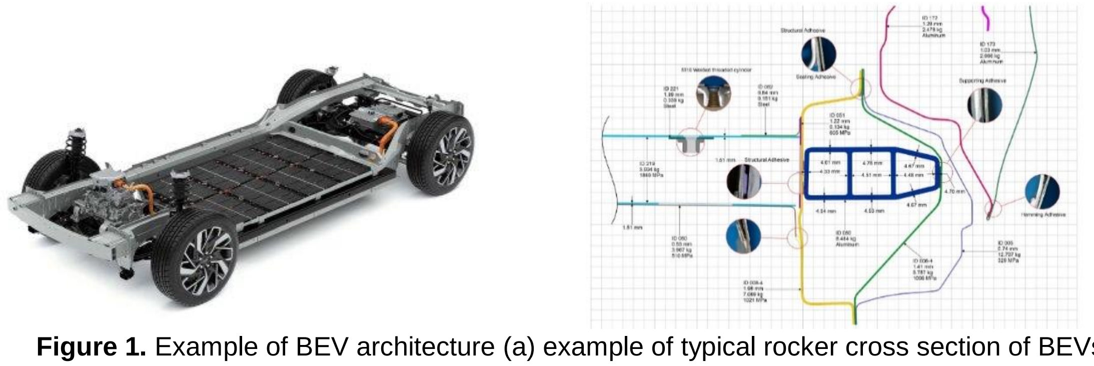

Figure 1. Example of BEV architecture (a) example of typical rocker cross section of BEVs (b).

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Ralph Pütz[1]

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

KEYWORDS: clean road transport, Holistic ecological balancing, EU New Green Deal, technology-neutrality

The Climate change and environmental pollution are an existential threat to the world. A sustainable approach must examine the effects of the respective technology measures on all ecological fields of action - local and global emissions, energy efficiency and noise emissions. 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 on July, 14th 2021 to reduce global emissions compared to 1990 levels by 55% by 2030 and to ensure no net emissions of GHG 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. 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. These new standards also include a mechanism to force the introduction of zero- and low-emission vehicles. The explicit weak point of these EU Regulations is that only the operation part (tank-to-wheel) of the several propulsion 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 and to hence ensure a technology-neutral way. The isolated view at the actual driving operation can lead to completely false conclusions. So the author proposed a method to sum up the main locally effective criteria (particulate and nitrogen oxide emissions) and globally effective criteria (CO2 equivalent) of a propulsion technology by determining their external costs. In this way, a real systems approach delivers an objective and reliable basis for future measures to be taken.
By contrast, the actual EU Regulations mentioned above 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). “Emission-free vehicles" are defined in this directive as vehicles with no local emissions and no direct emissions of CO_2, the latter totally irrelevant as the origin of global emissions – either Tank-to-Wheel, Well-to-Tank or Cradle-to-Gate etc. – does not play a role. The same political intention is to be identified in the proposals for EU Regulations on local emissions for Euro 7 (cars) and Euro VII (trucks and buses), with introduction targeted for 2025. So there are also concrete plans in the EU to no longer allow new cars with combustion engines (ICE) 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.
Therefore, in this contribution the author discusses the actual status of local and global emissions from combustion engines 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. It is shown, that with using DPF the intake 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. Furthermore, a Euro VI articulated bus e.g. emits lower NOx emissions than the operation-ready Euro V predecessor even at cold start and NOx emissions are already at ambient air level after just about 10 minutes due to effective SCR exhaust gas after-treatment. Incidentally, the same also applies to Diesel engines in heavy tractors. Concerning GHG emissions, encouragingly the global CO_2 intensity decreased by 0.3% per year between 2010 and 2019 which is a positive sign. Since the EU sees itself as a

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pioneer in global climate protection it is necessary to quantify the EU´s "leverage effect". 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 CO_2 emitter within the EU is Italy with 0,93%). Against this background, the EU's ideological goals on climate change seem to be almost ineffective.

Today the only need for action is with regard to the use of renewable fuels to significantly reduce GHG emissions 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 mentioned. In terms of global emissions, highly significant improvements would be achievable through the use of HVO Diesel, E-Fuels (PtL; Power-to-Liquids) and biogas from waste. With these regenerative fuels in ICE already today also the same GHG emission level as with the EU promoted alternative drive variants of the spectrum electro-mobility with exclusively renewable energy is achievable. 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.

At last, the overall ecological assessment for the time horizon "today" shows that for comprehensive sustainability – taking into account local and global emissions as well as energy consumption – the modern Euro VI ICE fleet is already adequately positioned and today and, 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.

In order to objectify the "real" additional cost of the alternative electric options forced by the EU, today the vehicle cost for e.g. overnight-charger battery buses have at least to be doubled if not rather tripled compared to Diesel buses. And if the reduced passenger capacity and heating energy in winter times is considered, overnight-charger battery buses show vehicle cost of three to more than five times compared to Diesel buses. 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. 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 vehicles 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. And if the EU´s fossil energy demand shall be replaced 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.

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.

SECTION A

Power Train Technology

- SI Engines
- CI Engines
- Alternative Fuel Engines
- Hybrid & Electrical Power Systems
- Fuel Cell Systems
- After treatment Systems
- Transmission Systems

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THE STUDY OF THE PROCESSES THAT TAKE PLACE IN GASOLINE INJECTION ENGINES

KEYWORDS: total displacement, minimum cylinder volume, maximum cylinder volume, compression ratio, dosage, fuel mass, injection duration, indicated diagram

The fuel supply scheme used in the model of the system proposed by the authors is presented, the engine chosen, with the technical characteristics, the type of injection system adopted, the basic principle of electronic gasoline injection, the calculation cycle proposed for gasoline injection.
Based on their own model, the authors performed an analytical calculation of the indicated diagram. The indicated diagram was also erected on an experimental stand in p-V coordinates. Using the equations from the characteristic points, the state parameters from the characteristic points of the engine cycle will be calculated.
The diagram for the analytical calculation of the pressure in the inlet manifold and the inlet pressure is presented, the variation of these parameters according to the speed and the ambient temperature is represented.
The calculation algorithm of the state parameters of the working gas in the characteristic points of the engine cycle is presented. The logical scheme for analytical calculation is presented [5].
The calculation program is structured on 10 procedures and functions. On the constants declared at the beginning of the program, the engine initial data, assumed to be known arbitrarily chosen from the statistical data of the S.I. cycle, is also valued: Ta0=322 K, Tz0=2530 K, Tu0=2660 K., kc0=1.3, kv0 =1,3, ku0=1.2, kd0=1.3 and ke0=1.3. Without them, all other parameters that characterize the engine cycle cannot be calculated in general. Thus, these initial data will play the role of parameters, variables being explicitly the temperature between these evolving thermal processes. These temperatures are closely dependent on the adiabatic coefficients which, in fact, are stabilized by completing the engine cycle several times until these coefficients become constant with an error of 0.000009. The decision to exit the cycle for a certain rotational speed this time by decreasing the constant error of the intake temperature (Ta) below the value of 1.5 K. [5]
For the calculation of intake manifold pressure p_{ga} and intake pressure p_a, considering the intake process, if the density of the engine fluid is variable, the Bernoulli gas flow equation, written for the intake section 0-0 and section 2-2, applies [1].
Bernoulli's relation is written between sections 0-0 and 1-1 to determine the pressure in the intake manifold pga, and then between sections 0-0 and 2-2, in which case the intake pressure pa is determined [3] and [4]
Calculation of the model for the p – V cycle thermodynamic diagram
The mathematical equation for the transformation that makes the cycle of thermodynamics by who runs Spark Plug Engines The study of lightning are: [7];[8]
The (p, V) diagram of the ICE (enlarged portion) and the calculated Indicated diagram are shown
General configuration of a test bench for measuring the parameters of an S.I. motor.
The transducers and experimental devices are from:
- resistive type – their verification was done with testers to check the resistance according to the temperature of the coolant and the temperature of the intake air;
- an inductive type, where a magnetic field created by a permanent magnet has good magnetic conductivity.
The variation of the magnetic field induces in the electromagnetic coil an electric current of voltage (V), which is directed through a cable to the electronic control unit.

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Object Engine type: 106-20, characteristics: 1557 cm^3 engines transverse placement ε= 9.25 power supply/ignition with Bosch Mono-Motronic M.A. 1.7
Purpose: Contributions to gasoline injection molding on the 106-20 type engine. The function of defining injection timing and ignition advance maps and correction diagrams to ensure the movement of cars. [5]
The model for the gasoline injection system was proposed, the author used the Bosch Mono-Motronic M.A.1.7 system, adapted to the Dacia Logan car engine. The study was carried out to choose the optimum coefficient of excess air for the operation of gasoline injection engines. [5]
The modelling the SI engine with gasoline injection proposed by the author consists in presenting the initial data of the calculate on program; calculating and correlating the expressions of the parameters of the SI engine with the injection of gasoline for the implementation of the calculation programs in Annexes A and B. The calculation cycle of the proposed gasoline injection SI engine is an auxiliary cycle for the computer simulation of the gasoline injection. [5]. The computer simulation allows the determination of the proposed theoretical technical-economic parameters: the proposed theoretical mechanical work corresponding to the rounded diagram, the proposed theoretical pressure, the proposed theoretical efficiency, the proposed specific theoretical consumption. The pressures of mechanical and pumping losses are calculated, with the help of which the effective theoretical technical-economic parameters of the engine are calculated. [5]
By changing the conditions of the environment, the intake process is affected, there are changes in the combustion process, because the state conditions of the initial mixture change. As a result, the volumetric efficiency, the excess air factor, the indicated and efficient efficiency, ie all the factors that decide the level of power and specific fuel consumption will suffer deviations from their optimal values. In order to determine the optimal values for measurements, the atmospheric and altitude conditions under which these measurements are made and the net calorific value of the fuel must be taken into account.
The practical application of this calculus involves, on one hand, the perfectioning of the physical-mathematical model, so that it will be as close as possible to the real development of the gasoline injection process. This means the reduction of the theoretical assumption and the calibration of some of the computation parameters, based on the experimental values. A theoretical model to compute with sufficient precision the thermal processes that take place in a SI engine can be useful for the development of new propulsion systems for road vehicles.
Many think that the transition to the full electric vehicles is a hybrid propulsion system. A variant is the inline hybrid propulsion system. In this case, the thermal engine should provide the energy to power the traction electric motor. The main advantage is the fact that the thermal engine can function at a single regime. This means that the adjustments that are necessary for the functioning at different regimes are no longer necessary. [10]
If it is possible the development of a model for the study of the ICE functioning at low or medium loads, it will be possible to determine the parameters that ensure minimum fuel consumption and polluting emissions at a specific functioning regime. So, the model proposed in this paper, which proved to have a very good precision (and that can be improved) can be used to study the functioning of SI engines in different conditions.
The program was used for the study of other normally aspirated SI engines with gasoline injection.
The authors intend to use this model for turbocharged engines also. [10]
The logic diagram for analytical calculation, determination of engine parameters is presented. The data obtained by calculations are compared with those obtained by measurements, and the obtained results show that the errors obtained are almost insignificant.

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THE INDICATED DIAGRAMS IN p-V COORDINATES CALCULATED AND MEASURED ON THE ENGINE STAND

KEYWORDS: the thermodynamic cycle, the indicated diagrams, engine stand, the characteristic points, the speed of rotation, the low pressure, the high pressure

This paper presents the numerical results of a simulation of the thermodynamic cycle for in gasoline injection engine in normal external conditions (T_0=293 K; p_0=10^5 Pa) and revolution n=5500 rpm, at full charge. The simulation took in account the constrain for λ=1, for air pollution reduction whit combustible gases. [1] The indicated diagram was calculated in p-V coordinates, and in p-α coordinates. Equations for thermal processes that take place in the engine were determined and then entered into a computer program. Using these equations, the state parameters were calculated at the characteristic points of the engine cycle. The research was conducted in order to obtain information that could be used improving the characteristics of an engine S.I. The operating mode of the engine is defined by the speed of rotation and load,cooling fluid temperature, intake air temperature, exhaust temperature, altitude corrections and so on).[1]. The logic diagram of the calculation program is presented. The calculation program for determining the indicated diagram is done in mathcad, both for the low pressure area and for the high pressure. The engine stand and the pressure transducer with their characteristics are presented. The diagram shown in p-V and p-φ coordinates is shown. The diagrams indicated in p-V coordinates are calculated, calculated with the presented program and measured on the engine stand and the errors between them are calculated. The model calculation for cycle thermodynamic diagram p – V.
The mathematical equations of transformation that make up the thermodynamic cycle after which spark-ignition engines run are: [2]; [6] the polytrophic compression a-c; the isochors burn c-z; the polytrophic relaxation z-u; the polytrophic relaxation u-d; the freely evacuation d-d_1; the forced evacuation d_1-r ; the adiabatic extend to evacuation r-r_1; the admissible at constant pressure r_1-a. It is proposed to use the calculation model of the engine SI with gasoline injection, when modeling multipoint electronic injection systems. The SI engine cycle modeling proposed by the authors is done by running a computer program. The engine cycle proposed by the authors for the analytical calculation is presented. The logical scheme for the analytical calculation is presented [3]; [4]. The simulate on computer and numerical result, to can to describe a thermodynamics cycle that is give us for before equation (1 - 9), we must to know the value his n_u, n_c, n_d, k_e, α, δ. This size is estimate for normal conditions of temperature and pressure (T_o=293 K; p_o=10^2 kPa) and of revolution of n= 5500 rpm at λ=1, who show the medley character from gaze that are give to burn with pollution products minimum quantitative and qualitative.[4]
The proposed experimental model. The main task of the system is to establish the correlation between the engine's intake air mass and the injected fuel mass per cycle, forming a mixture of maximum economy for each engine operating regime. For electronic injection systems, the dependence between the amount of petrol injected per cycle at each engine operating mode and the injector opening time is determined in advance at the test stand, with manually operated control units, according to the criteria of the actual minimum specific fuel consumption, the maximum effective engine torque and the minimum pollutant emissions (carbon monoxide, hydrocarbons, nitrogen oxides), after which it is stored in the computer of the injection equipment, tabular or in the form of curves of variation of the opening time of the injector depending on the speed having as a variable parameter either the depression in the intake manifold or the position of the shutter damper, therefore the pressure transducer existing in these installations must be of special precision.

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The adjustment of the amount of petrol injected per cycle for different engine operating modes is based on the amount of air drawn in by means of an air flow meter provided with a transducer which transmits information on the air flow to the computer. Replace the air flow meter with vane and transducer element with a Karman-Vartex type air flow meter based on ultrasonic waves, which improves engine performance. A study is made to choose the excess air coefficient λ; the pressure regulator is modeled; the pressure regulator constant is determined; the electromagnetic injector is modeled and the injection duration ratio is calculated. The three-dimensional maps were made on the computer according to the information provided by different translators and processed on the abscissa, the pressure in the intake manifold (throttle angle) and the ordered speed of the engine, the third dimension being the enrichment of the mixture. (injection time) for mapping. injection and ignition advance for the ignition mapping below. Renix electronic multi-point injection system equipping adapted Dacia Logan Renault engines. The electronic unit is digital and combines two essential functions: ignition and gasoline injection. Ignition points and injection timing are calculated using the same information (engine speed and absolute intake manifold pressure), it makes sense to use a single computer to control the two functions. Among other things, the ignition can benefit from additional corrections (water/air temperature) without the use of private translators. In this way, most transducers (speed, pressure, temperature) can be used together for 2 functions, which allows a high degree of reliability at no cost compared to two separate computers. The amount of gasoline injected depends on the absolute pressure in the intake manifold and the engine speed (crankshaft pressure-speed system). Ignition and injection are determined using information provided by different translators and processed by traversing two three-dimensional maps, with abscissa (pressure), ordinate (velocity), the third dimension is: mixture enrichment (or injection time) for injection mapping, figure 7; or ignition advance for ignition mapping, figure 8. For each mapping there are, for example, 9 regularly distributed pressure inputs and 13 engine speed inputs that do not require equal distribution. In total, therefore, 9 x 13 = 117 theoretical adjustment points are arranged. By writing (9-1) x (13-1) = 96 the elementary surface is made on the computer with a double interpolation, with a weighting of each point a defined polygon. The theoretical values of the ignition advance and the duration of the injections are then modulated by correcting parameters: air pressure, air temperature, water temperature, battery voltage, acceleration, noise, etc. The real indicated diagram the general configuration of a test bed for the measurement of the parameters of a S.I. engine: The test bed on which the experimental data were acquired is provided with an electric machine with eddy currents of a W130 Shenk type. The modeling of the SI engine cycle proposed by the authors consists in the presentation of the initial data of the calculation program, the calculation and the correlation between the engine parameters for the realization of the calculation programs. The proposed model is an aid cycle to simulate gasoline injection.The computer simulation allows the determination of the technical-economic theoretical parameters: the mechanical work corresponding to the rounded diagram, the indicated average pressure, the indicated yield and the indicated specific fuel consumption. [1]; [4]. After calculating the mechanical and pumping losses, the effective technical-economic parameters of the engine can be calculated. Using the model proposed in this paper, it is possible to calculate the mass of fuel injected per cycle, depending on the rotation speed at full load, the fuel flow through the electronic injector, achieving the intended goal, determining the injection duration depending on the rotation. speed, at full load. If it is possible to develop a model for the study of ICE operation at low or medium load levels, it will be possible to determine the parameters that ensure minimum fuel consumption and pollutant emissions at a certain operating regime. So, the model proposed in this paper, which has been shown to have very good accuracy (and it can be improved) can be used to study the operation of SI motors under different conditions. The program has been used to study other normally aspirated AND gasoline injected engines. The most conclusive gain for Dacia Logan's petrol injection engine is the depollution of the engine. Pollutant emission tests carried out in the Bosch laboratories at Schwieberdinger (under the control of UTAC-France representatives as homologation authority) have already confirmed that the Dacia Logan complies with the depollution rules in force. The Renix multi-point injection system, which equips Renault engines with 4-cylinder Dacia cars, has been adapted to increase engine performance, reduce engine size, reduce fuel consumption, reduce fuel consumption and reduce pollution. Experienced gasoline injection engines are superior to carbureted engines in reducing fuel consumption and pollutant emissions, as well as dynamic performance of construction and operation. [5]. The temperature values calculated at the characteristic points of the engine cycle were according to statistical data. The calculated values were observed to be within the recommended ranges.

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A CONTRIBUTION TO INVESTIGATION OF OSCILLATORY LOADS OF DRIVING AXLES IN ORDER TO CREATE CONDITIONS FOR LABORATORY TESTS OF TRUCKS

KEYWORDS: motor vehicle, axles, oscillatory loads, laboratory tests

Motor vehicles are complex dynamic systems with large number of influences and disturbances. Dynamic phenomena, especially vibrations, cause fatigue of the driver and passengers, reduce the life cycle of the vehicle etc. In general, the movement of motor vehicles is done on uneven roads (terrain) and curvilinear paths in flat roads. Oscillatory movements cause loading of vehicle parts, but also negatively affect human health. Therefore, special attention must be paid to the harmonization of the mutual movement of the vehicle subsystem, and in particular, the suspension system.

The aim of this work was to establish the oscillatory movements of axles in operating driving conditions in road for vehicle, in order to create conditions for laboratory testing. The subject of research is a vehicle FAP 1118, with 4x4 drive formula and load capacity of 4t and maximum mass of 11000 kg.

The measuring chain for measuring the dynamic parameters of the vehicle consisted of the following elements: Kistler Correvit S-350 sensors for vehicle dynamic values, HBM Quantum MX 840B universal measuring acquisition system connected to a QuantumX CX22B-W computer, B-12 acceleration sensor, placed in the center of gravity of the rear truck bridge and SST 810 dynamic inclinometer, placed in the center of gravity of vehicle axles. With it, angle, velocity and acceleration was measured around the X, Y and Z axes and all measured quantities are being processed by using HMB Catman easy software. Based on previous experiences at the Military Academy, it was considered expedient to test the vehicle while driving in real operational conditions, on an asphalt regional road near Belgrade (maximum speed, 67 km/h – design vehicle limited speed 80 km/h).

Figures 1. and 2. show the time history of vehicle velocity and the linear movements of the front axle. In order to determine the character of the registered signals, using the Software Analsigdem, autocorrelation functions were calculated and shown in Figure 3. Analysis partially given at Figure 3. shows that autocorrelation functions decrease with increasing time delay and that they oscillate slightly around zero so registered oscillatory values can be treated as stationary. The probability of occurrence of the observed values by levels (histogram, %) was calculated, using the same software.

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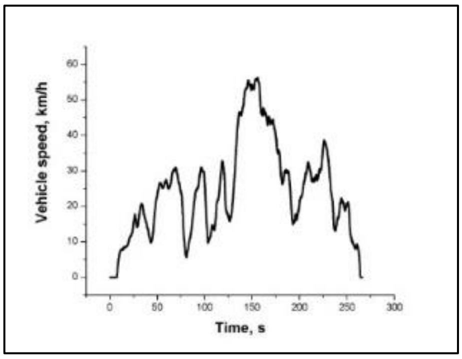

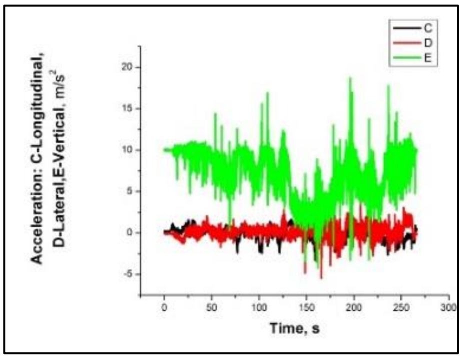

Figure 1. Vehicle velocity change during drive. **Figure 2.** Longitudinal, lateral and vertical.

First, the minimum and maximum value of each variable was calculated using the aforementioned software. Then the interval between those values was divided into 500 fields and the number of occurrences of the variable within the limits for each field was automatically determined (histogram, %). The calculated values are, for the sake of illustration, partially shown in figure 4.

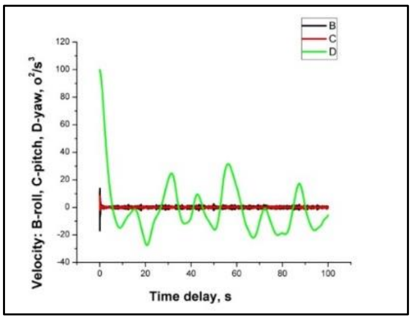

Figure 3. Autocorrelation function of roll, pitch and yaw velocity of vehicle's rear drive axle.

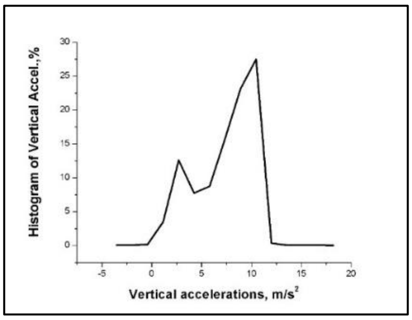

Figure 4. Front axle vertical acceleration distribution histogram of the vehicle's front drive axle.

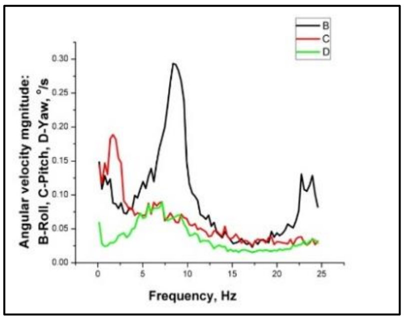

Figure 5. The magnitudes of the spectrum of the roll, pitch and yaw velocity of rear axle.

Analyzing the histogram of all registered values, it was observed that the maximum values are close to the domain of mean values. Bearing in mind that the mean values are not always positive, it was considered useful to perform hypothesis tests with Gaussian, Laplace and Cauchy distributions. Analyzes have shown that the assumed probability density functions do not meet the so called Romanovsky criterion, so they do not belong to any of the observed distributions. Frequency analysis was performed using the Analsigdem software with 8192 points and a sampling step of 0.02 s, which enabled reliable analysis in the range 0.061 to 25 Hz (the DC components are turned off for frequency analysis). Having in mind that the phases of the calculated spectra do not enable the analysis of the energy carried by the signal, it was considered useful to observe only the magnitudes of the calculated spectra, which is, for illustration, shown in Figure 5.

Analyzes of the all calculated spectrum magnitudes, partially given in Figure 5, have shown that the largest amplitudes are not unambiguous: they depend on the axle (front, rear), as well as on the registered value. Namely, with the front axle (all observed values) and with the rear axle (linear accelerations), the maximum values occur at very low frequencies. However, when it comes to the angular velocities of the rear axle, this is not the case. Therefore, it was found useful to determine the magnitudes of the spectra at resonant frequencies. It is noted that the analysis does not include resonances originating from the sprunged mass, drive group, etc.

We can conclude that tests performed on the FAP 1118 truck with 4x4 wheel formula showed that the observed measured values belong to the group of random processes, so the following methods were used for their identification: time, amplitude and frequency identification of parameters.

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3D PRINTING OF HYDRODYNAMIC COUPLING FOR SCHOOL EDUCATION

KEYWORDS: hydrodynamic coupling, 3D printing, education, teaching

The application of 3D printing technologies in the industry is growing as new possibilities for their application are discovered, which take advantage of their functionalities. Also, today more and more 3D technology is used for educational purposes. Incorporating of 3D printing in the form of production of three dimensional shapes into the teaching process improved the understanding of geometry. 3D printing technology in developed countries has already entered the field of education, in primary and secondary school, as well as at the university, and has become a powerful tool for "intelligent manufacturing". The application of 3D printing at universities enables the acquisition of knowledge through the creation of 3D models during the creation of project tasks. Integration of 3D printing skills development into curricula is done through inclusion in existing courses. 3D printing is very important for learning at the university level. The application of 3D printing in education has several goals: training students and teachers about 3D printing, supporting new technologies in teaching, creating models that contribute to better learning, skill development and increased engagement of students and teachers in the subject. At technical faculties, almost all areas of engineering can be understood better through 3D printed models. Also, 3D printers in Universities have greater applicability and possibility for use in engineering and applied science [1]. Students can print models to simplify and understand complex theories and learn about new technology, while teachers can create models to teach subjects that are difficult to explain in 2D. Also, the equipment used for 3D printing within the teaching purposes is relatively cheap [2].

3D printing is the process of making 3D solid objects from a digital file by building up layer by layer of material. This type of manufacturing process has a many of advantages over traditional manufacturing: 3D printed designs do not become more expensive due to complexity, it is very cheap to customize the design, and shapes that are impossible to produce through manufacturing techniques can be printed [3]. Also, 3D printers are more environmentally sustainable than other manufacturing techniques because they use fewer raw materials, create fewer by-products, and represent a less energy-intensive process [4, 5].

Hydrodynamic couplings works on the hydrodynamic principle, which takes place based of the indirect principle of operation. The pump wheel transfers the introduced mechanical energy into the kinetic energy through the fluid flow. The fluid of higher energy flows centrically from the pump wheel to the turbine wheel, where re-conversion to mechanical energy takes place. The calculation of the geometric parameters of the working spaces of the hydrodynamic coupling is based on a one-dimensional flow model and the similarity theory. This method implies the averaging of current parameters by flow sections, taking as reference the values of these quantities in the meridian surface. The calculation was done in the MathCAD software. After the calculation, the 3D model of the hydrodynamic

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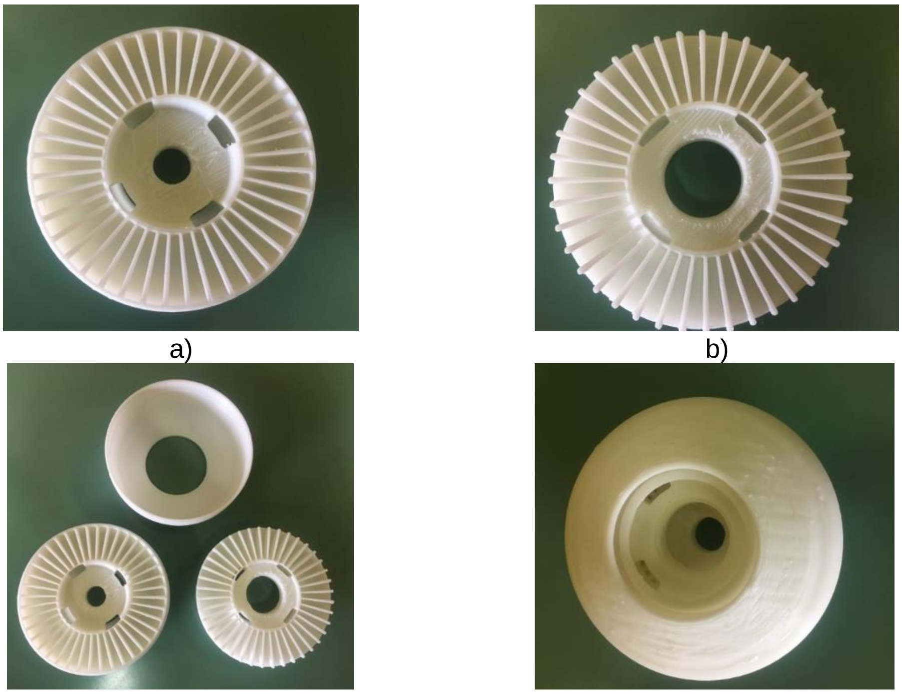
coupling was created in the Autodesk Inventor software package, and after that, 3D print is accessed (Figure 1). 3D printer supports .STL files which are obtained in any 3D modelling program. Before printing, it is necessary to set a number of parameters such as: plastic melting temperature, substrate temperature, printing speed, speed of movement of the printer head when passing from one place to another, percentage of filling of objects, support material etc.



a) b)

c)

Figure 1. 3D printing of hydrodynamic coupling a) pump wheel, b) turbine wheel and c) assembly.

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ANALYSIS OF POWERTRAIN'S WORKLOAD DURING THE TURNING PROCESS OF A HIGH-SPEED TRACKED VEHICLE

KEYWORDS: high-speed tracked vehicles, powertrain workload analyses, tracked vehicle dynamics, tracked vehicle experimental testing, power balance analyses

High-speed tracked vehicles have a great advantage over wheeled vehicles when it comes to overcoming hard condition terrains. In order to maintain high mobility in low adhesion and high moving resistance conditions, these vehicles have robust powertrain components and complex turning mechanisms, which can withstand high torque, while producing a respectful velocity at the same time. This means that the power source, IC engine, has to produce enough power to satisfy all of these requests. Unlike with wheeled vehicles, the selection of the IC engine for a high-speed tracked vehicle is calculated according to the power requirements for the lowest turning radius achieved with the highest vehicle velocity, turning towards the hill of a maximum gradient. To analyze the efficiency of a high-speed tracked vehicle powertrain, it is necessary to understand the powertrain workloads in specific working regimes. Experimental tests are conducted on a specific high-speed tracked vehicle, in various terrain conditions, in order to obtain accurate workload data and isolate the maximum workload regimes. The vehicle is driven on soft soil and in dry conditions, varying turning and rectilinear moving scenarios, with gear and vehicle velocity changes. In order to analyse the power losses during the turning mechanism slip, a scenario where the vehicle is driven with a relatively constant engine input velocity, in specific gear, with field condition change reduced to minimum is selected, varying only the activation pressure of the auxiliary clutch.

The turning process of a high-speed tracked vehicle is evidently the most complex moving scenario, influenced by a large number of variables such as vehicle mass and dimensions, construction of the powertrain and turning mechanism, vehicle velocity, engagement state of the powertrain components, adhesion conditions, moving resistance etc. Given that, special attention is given to analysing the results from power balance point of view. The obtained results indicate that the slip of the turning mechanism friction elements greatly influences the character of the power balance change. For 30% of auxiliary clutch maximum activation pressure value, power delivered to the outer track is 25% lower than when the clutch is fully engaged. When the clutch activation pressure is 60% of the maximum value, the power losses are reduced to 10%. It is obvious that, the lower the activation pressure of the auxiliary clutch, the greater the power loss due to slip, so the logical conclusion is to avoid these working regimes and turn the vehicle with auxiliary clutch fully activated. Unfortunately, these vehicles are most commonly driven in such working regimes, where the vehicle is slightly turned just for trajectory correction. Rarely is the vehicle turned with the lowest values of the turning radius (calculated radius). This means that, for the most of the vehicle usage, the vehicle is turned with great power losses in turning mechanism friction elements.

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The problem of power loss on friction elements can be overcome by modifying the powertrain, in such a way, that the existing turning mechanisms with friction elements are replaced with hydrostatic or electric components, which would provide a continuous trajectory change, with an infinite number of calculated turning radii and no power loss.

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THE INFLUENCE OF THE FUEL STRATIFICATION ON THE IC ENGINE WORKING CYCLE WITH THE COMPRESSED NATURAL GAS

KEYWORDS: fuel stratification, prechamber, main space, combustion process, experimental investigation

The air pollution is global problem which negatively influences on the environment and people health. The new produced vehicles have less fuel consumption, and because of this emit less harmful combustion products. However, the great number of people still drive older vehicles, and because of this it is necessary to focus on the measures which will provide the reduction of the harmful products from the combustion process, and one of the measures can be the adaptation of vehicles, to use gas fuels. The gaseous fuels use can be very convenient from the economic aspect and ecology aspect.

The experimental investigation of how the fuel stratification influences on the IC engine working cycle, was conducted on the experimental test spark ignition engine, in the laboratory for the IC engines and fuels, at the Faculty of engineering. In order to achieve the fuel stratification, it was made the separation of the engine working space, on the area where the mixture will be always rich, and on the area where the mixture will be always lean. This was achieved by engine upgrade with the prechamber. With this approach, the mixture in the prechamber will be always rich, while the mixture in the main space will be always lean. Fuel stratification allows the spark ignition engine work with the globally lean mixture and in this way, increases the engine efficiency. In order to see how the fuel stratification influences on the IC engine work, it was created a mathematical model based on the ideal gas law, for the calculation of air-fuel ratio in the main space and air-fuel ratio in the prechamber. It was found that the combustion can be separated into the two parts.

The first part of the combustion (the highest intensity combustion) is highly related to the combustion which happened into the prechamber, where the mixture is ignited. That is, this part of the combustion illustrates the flow of gases from the prechamber to the main space.

The second part of the combustion, which is connected to the fuel stratification, it looks like the late combustion at diesel engine. This part of the combustion, is actually the combustion which continues from the prechamber into the main space. During this part of the combustion, in some cases appears specific shape which reminds to the hump. If the mixture is very lean in the main space (main space air-fuel ratio over the 2.5), combustion process almost stops in on moment and then continues.

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The very lean mixture in the main space is specific for the regimes with low load. Regimes at low engine load (where combustion at the moment almost stops) are followed with low efficiency, that is, the efficiency increment demands mixture enrichment in in the main space (air-fuel ratio in the main space should be between the 1.5 and 2). For future researches, it is good to think about the usage of prechamber with smaller volume, in order to provide the exit of the greater amount of gas into the main space, and in this way to enrich the mixture in the main space.

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INTERNAL COMBUSTION ENGINE TEST PLAN EXECUTION ORDER OPTIMIZATION USING TRAVELLING SALESMAN PROBLEM HEURISTICS APPROACH

KEYWORDS: internal combustion engines, dnamic engine testing, genetic algorithm, travelling salesman problem

For a given internal combustion (IC) engine stationary test plan, significant time savings during its realization could be achieved if the sequence of test points execution is adequately determined. The criterion for stabilizing the engine operating point is determined by the magnitude of the change in the most inert parameter, and in the general case, it is the temperature of the engine exhaust gases. A certain level of prior knowledge about the examined object is necessary to conduct such an analysis. If there are no results from previous tests, simulation models or experiences, the Slow Dynamic Slope (SDS) tests are a great way to quickly gather the necessary information. The idea of the SDS test is based on a slow continuous change of the control parameter. The continuous change of control parameter over time results in deviation (offset) of the measured output of the system in relation to the stationary values that will occur if the test was carried out as a quasi-stationary. The values and position of the offsets will depend on the system's characteristics (system gain, time constants) and the slope of the input. In the ideal case, when increasing the value of the control parameter during a test, we expect this offset to have some constant value, and when decreasing this parameter by the same intensity in the opposite direction, we expect the offset to be symmetrical. By determining the mean value of the response during the ascending and descending control slopes, an approximation is obtained that adequately corresponds to the results of the quasi-stationary test.
The task of finding the optimal sequence for a stationary engine testing plan can be set as Travelling Salesman Problem (TSP). This paper will present the application of one of the heuristic methods for solving the TSP on the example of testing the IC engine, which is a very complex dynamic system. Following this model, it is possible to optimize the stationary test plan for any other dynamic system.
Assuming that a sufficiently good test plan exists, further time savings in its execution can be achieved if a favourable sequence of execution of the operating points is determined. As it was emphasised, the criterion of stabilisation of the operating point is determined by the magnitude of the change of the most inert parameter, and in the general case, it is the temperature of the engine exhaust gases. The basic idea is to find such a sequence of stationary operating modes, during the implementation of which a minor deviation of the engine exhaust gas temperature is obtained. This will result in the shortest stabilisation time for a given series of operating points.

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For an examination plan of p = 45 points, an approximate $N \cong 6 \cdot 10^{55}$ potential combinations of execution order. Solving TSP by exhaustive numerical search belongs to the category of algorithms of factorial dependence of execution duration as a function of the number of parameters. Due to many such combinations, it is impossible to realise (execute) a program that will find the optimal solution through an exhaustive search on an ordinary computer.

Genetic algorithms enable a high level of flexibility in defining the way of changing the path vector, i.e., the previously mentioned mutations. Within the used genetic algorithm [17], mutations of the selected path vector are based on two of the randomly selected indices (points in the path) on which GA: Performs full rotation of path vector elements between specified indices (points); Replaces the value of the path vector at the given indices; Performs a phase shift of part of the path vector with an adequate displacement of one element. In this way, for every parent path, three modified paths are formed, for which the criterion function is determined and the process of further selection is carried out. All mentioned random choices are characterised by a uniform distribution of the probability function.

In the worst case, if the sequence of execution were randomly selected, the average deviation of the exhaust gas temperature would be about 140 °C. If the optimised execution order is determined based on the minimum distance criteria in the Engine Speed - Engine Torque operation space, the mean temperature deviation of exhaust gas temperature would be 34 °C. In the ideal case, for the known stationary test results, the mean value of the exhaust gas temperature deviation is 7.7 °C per operating point. If the models obtained from SDS testing were used to determine the optimal sequence, the mean values of the deviations per operating point would range from 20.5 °C to 9.2 °C, depending on the type and duration of the SDS experiment, which is very close to the ideal case.

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A COMPARISON OF MAIN BEARINGS LOAD OF TWO-CYLINDER "V" AND BOXER MOTORCYCLE ENGINES

KEYWORDS: crankshaft main bearing, bearing load, V-engine, boxer-engine, motorcycle

The paper deals with determining the load of the crankshaft main bearings in two-cylinder motorcycle engines. Two cylinder arrangements, used in two-cylinder motorcycle engines, are considered - the boxer-engine and V-engine. The aim of the research is to determine the influence of cylinder arrangement on the magnitude and circumferential distribution of the bearing load of the engines considered. For this purpose, models of a two-cylinder boxer engine and a corresponding V-engine crankshaft drives were developed using multibody dynamics simulation software. Previously, by using a one-dimensional gas analysis software the engine cycles were simulated in order to determine the cylinder pressure required to simulate piston dynamics. As a result of the dynamics simulations, bearing load diagrams of the boxer- and V-engine were obtained, which were then compared and analyzed.
The schematic view of the calculus procedure leading to the bearing forces is shown in figure 1. The procedure is applied to both boxer-2 and V-2 engines.
First, the crankshaft drives have been modelled by using the CAD software "Autodesk Inventor". In order to obtain the geometry and mass parameters of the mechanisms, BMW GS1200R and Ducati Multistrada engines were taken as examples for boxer-2 and V-2 engines, respectively.
In order to make the comparative analysis of the bearings load as realistic as possible, the piston assemblies and the connecting rods of the CAD models are designed to be of equal dimensions and shapes.
In order to calculate the cylinder pressure during the engine cycle, appropriate one-dimensional gas analysis software was used. The main result of the engine cycle modelling is the p-α (pressure – crank angle) graph. The analysis was performed for 6 engine speeds, representing the entire engine operating range in a satisfactory manner. The engine speeds simulated are 2000, 4000, 6000, 8000, 10000 and 12000 rpm. In order to reduce the number of virtual experiments, only the full engine load has been taken into account, as this is the most unfavourable case regarding the forces on the crankshaft drive components.
Knowing the geometric and mass parameters of the crankshaft drive, as well as the cylinder pressure, it was possible to create dynamic models of both engines. For that purpose, a multibody dynamics simulation software, MSC "ADAMS View", was used.

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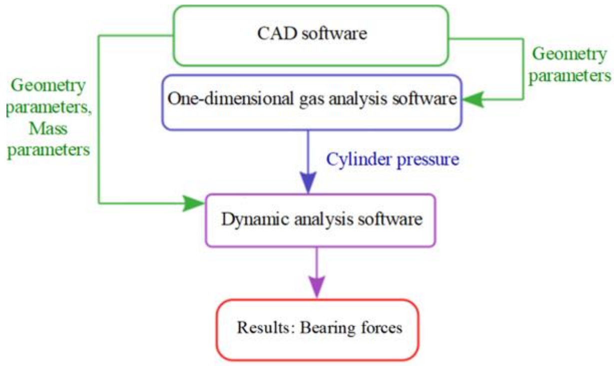

Figure 1. Flow chart of the calculus procedure.

During the dynamic simulation of a mechanism, ADAMS calculates various kinematic and dynamic quantities. In this particular case, the forces acting on the main bearings of the crankshaft are of interest, so they were extracted from the simulation results. The intensity of forces is best seen if they are shown in the Cartesian coordinate system. On the other side, if the load distribution around the bearing circumference is needed, then the polar coordinate system is the right choice. Some of the results obtained are shown in figures 2 and 3.

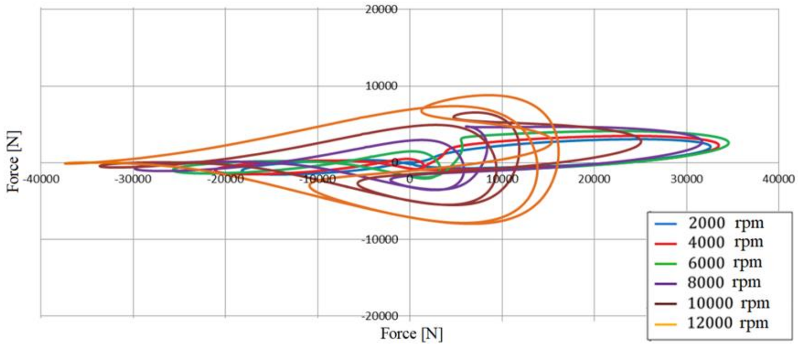

Figure 2. Polar diagram of the bearing 1 force at various engine speeds – boxer engine.

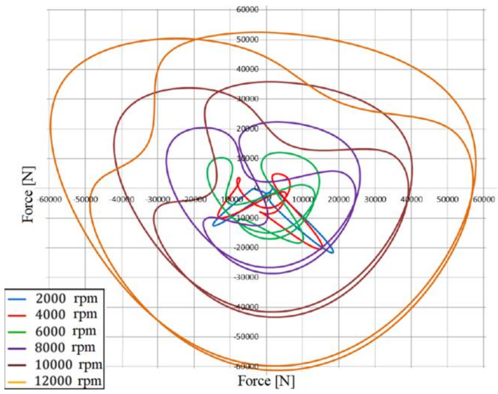

Figure 3. Polar diagram of the bearing 1 force at various engine speeds – “V” engine.

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NUMERICAL ANALYSIS OF INTAKE PORT MODIFICATION ONTO FLUID FLOW PATTERN AND FLAME PROPAGATION IN PARTICULAR COMBUSTION CHAMBER

KEYWORDS: computational fluid dynamics, turbulence modelling, flame propagation

It is known for a long time that inlet port geometry has a great influence onto fluid flow pattern and flame propagation in spark ignition IC engines. In this paper only the initial results of the very complex study on the effects that proposed inlet port modification has onto the in-cylinder flow processes including the combustion stage, in particular. The study mentioned below incorporates state of the art multidimensional numerical modelling of reactive flow in the inlet port and combustion chamber geometry layout with moving boundaries of spark ignition IC engine with two valves. The main objective of this study is to investigate the possibilities for improvement the IC engine output characteristics through the inlet port modifications. Bearing in mind that flame propagation through unburnt mixture of spark ignition IC engine is primarily controlled by dint of turbulence diffusion, it is of prime importance for engine optimization to correctly identify the influence of certain types of organized flows onto the fluid flow pattern and flame propagation. The efforts for improvement have to be aimed on the type of organized flow or eventually their combination that is of prime importance for further development of the in-cylinder processes and combustion stage.

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APPLICATION OF LIQUEFIED NATURAL GAS IN MOBILE SYSTEMS

KEYWORDS: exhaust emission, liquefied natural gas, mobile systems, transportation

In the paper, it systematized the possibilities for the application of liquefied natural gas in mobile systems for transportation on longer distances. For calculation of energy consumption and greenhouse gas production, when applied different fuels it is proposed the use of the European Standard EN 16258:2012.
In countries like the Republic of Serbia in particular (with a large river port, a big international airport, many tourist centers and the transportation of goods by trucks due to the connection with international companies, *etc*.), the demand for alternative fuels which are suitable for long distance applications is expected to remain high. Natural gas is a high-quality fuel for propulsion systems. Available reserves equal the known oil reserves; negative influence upon environment is less than with fuels derived from oil, as well as the price. Due to that, natural gas as a fuel has been having a growing application in motor vehicles.
The growing number of vehicles powered by natural gas has required in parallel new regulations and rulebooks regulating this field to be adopted. The requirements related to the aspect of safety and functionality of installation of gas devices and equipment have been defined under regulations UN ECE 110R and UN ECE 115R. Laws and bylaws applicable in the Republic of Serbia are: Road traffic safety law, Rulebook on the Classification of Motor Vehicles and Trailers and Technical Conditions for Vehicles in Road Traffic and vehicle testing rulebook.
Cryogenic fuels such as LNG (liquefied natural gas) and liquid hydrogen are attractive alternatives due to their high specific energy density, but they are at a disadvantage compared to other fuels in terms of their volumetric energy density, meaning that they require greater storage volume, a critical aspect for aviation as example. Another way to increase the energy of stored natural gas on vehicles is under higher pressure of 20 MPa onboard in cylinders as CNG (compressed natural gas). In the Republic of Serbia, natural gas was used for the first time in serially produced MAZ-BIK buses for the needs of city traffic in Kragujevac.

Figure 1 shows the parts of the installation for supplying the engine with natural gas, in the case when the gas is stored under high pressure in a gaseous state CNG or in a liquid state in a cryogenic tank LNG.

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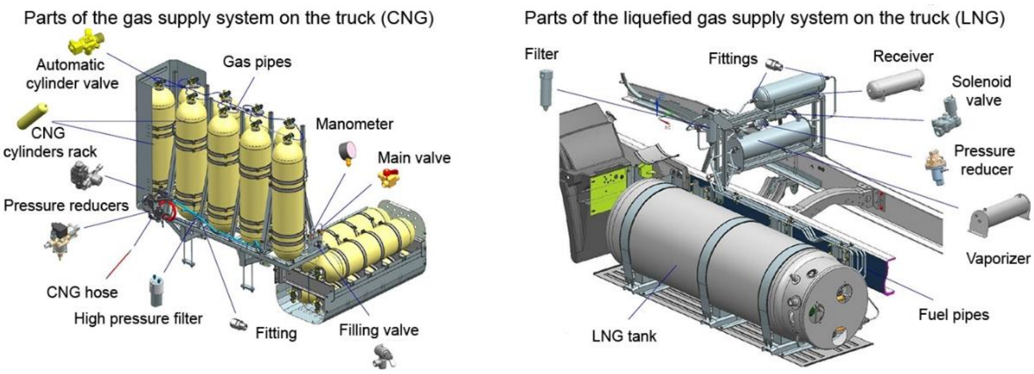

Figure 1. Gas engine power supply system - dedicated (CNG and LNG).

Liquefied natural gas is predominantly methane (92-98%), that has been liquefied by condensation at cryogenic temperatures. At atmospheric pressure, the condensation temperature of natural gas is about (–162 °C). In the process of liquefying natural gas, its volume decreases by approx. 600 times.

When using different types of fuel, it is necessary to systematize the methods for calculating fuel consumption and emissions for comparison. The EN 16258 European Standard establishes a common methodology for the calculation and declaration of energy consumption and greenhouse gas (GHG) emissions related to any transport service.

Periodical Technical Inspection of gas powered vehicles means a periodical administrative uniform procedure by which the authorized technical Inspection Centers responsible for conducting the inspection tests declare, after carrying out the required verifications, that the wheeled vehicle submitted conforms to the requirements.

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THE INFLUENCE OF NARX CONTROL PARAMETERS ON THE FUEL EFFICIENCY IMPROVEMENT OF A HYDRAULIC HYBRID POWERTRAIN SYSTEM

KEYWORDS: hydraulic hybrid powertrain, internal combustion engines, machine learning, dynamic programming

Remarkable research efforts are needed to minimize the fuel consumption and the transportation sector's environmental impact to sustain energy conservation efforts. The main objective of the study presented in this paper has been to analyze and assess the performance of a nonlinear autoregressive neural network with exogenous inputs (NARX) for controlling a parallel hydraulic hybrid powertrain system of a transit bus. A simulation model of the vehicle has been calibrated using analyzed data obtained during an experiment conducted in real-world traffic conditions. A Dynamic Programming optimization procedure has then been applied to the calibrated powertrain model and an optimal configuration that minimizes fuel consumption has been selected. The NARX has been trained using the optimal control data obtained by the Dynamic Programming optimization of the load distribution between the ICE and the hydraulic powertrain system. Several NARX configurations involving a different number of hidden layers and exogenous input and feedback delay line samples have been trained and subsequently tested in the hydraulic hybrid powertrain system simulation. It has been shown that considerable fuel savings on the order of 30% could be achieved by implementing such a system.

Rising fuel prices and increasing awareness of environmental issues place greater emphasis on the quest for solutions that improve vehicle fuel economy and reduce harmful emissions. The main objective of the study presented in this paper is to analyze and assess the performance of a NARX model for controlling a parallel hydraulic hybrid powertrain system. An experiment has been conducted on a transit bus circulating in real traffic and occupancy conditions to obtain the real driving cycle and perform the calibration of the hybrid powertrain system simulation model. Dynamic Programming (DP) has been used to derive the optimal load distribution between the hydraulic pump/motor and the internal combustion engine to minimize fuel consumption. This set of optimal data has then been used in a Machine Learning (ML) framework to derive an implementable control law for the hybrid propulsion system. For exogenous inputs of the NARX, a vector of 4 variables in total have been used – the instantaneous vehicle speed, the driveshaft torque as a representative of the actual powertrain load, the hydraulic machine normalized load and the hydro-pneumatic accumulator gas pressure. Different configurations of the network have been tested in order to find the one that will yield the closest performance to the reference control law obtained using the DP method. Various

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combinations of values for the number of Hidden Layers (HL), the number of neurons per layer (LS), Input and Feedback Delay (ID/FD) samples have been tested.

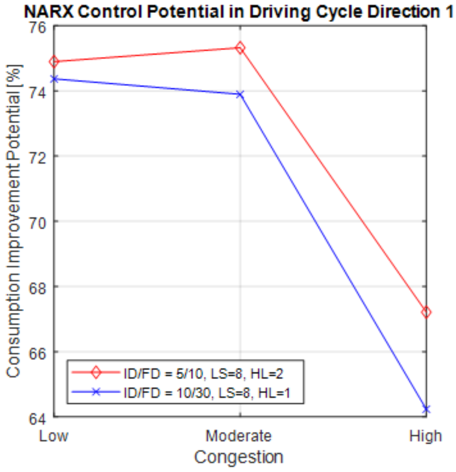

Figure 1. Relative fuel consumption comparison for the driving cycles in direction 1.

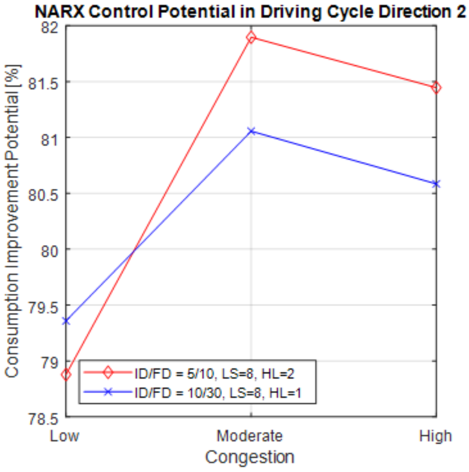

Figure 2. Relative fuel consumption comparison for the driving cycles in direction 2.

The consumption improvement potential, defined as the ratio of the realized fuel consumption decrease and the value of the optimally achievable fuel savings (using DP) is shown in figures 1 and 2 for both driving cycle directions and all congestion states. The proposed implementable control algorithm yields good performance. At least 67% of the potential fuel savings can be achieved by using the NARX control in the most congested driving conditions in direction 1. In the most favorable case, 82% of the maximally achievable fuel consumption reduction can be accomplished by using the suboptimal, implementable control algorithm. The newly trained NARX achieves better fuel economy than the previously tested one (with one hidden layer and increased ID and FD values) in all cases except for the low congestion state in direction 2. In direction 1, the difference between the two ANNs range from 0.5% in low to 3% in high congestion state. In driving cycle direction 2, the difference in the consumption improvement potential is -0.5% in low congestion state and reaches 0.8% in moderate and high congestion.
An implementable, artificial neural network-based control algorithm has been devised to control the load distribution in a parallel, hydraulic hybrid powertrain system for a transit bus. By using a NARX ANN, over 80% of the ultimate fuel consumption improvement potential obtained using a non-implementable optimization algorithm can be achieved.

ACKNOWLEDGMENTS: The research presented in this paper is conducted in the framework of the research subproject *Drive Systems and Fuels for Vehicles with Improved Energetic and Ecological Characteristics*, which is part of the project *Integrated Research in the Fields of Macro, Micro and Nano Mechanical Engineering*, funded by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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NOVEL MODULAR POWERTRAIN PROPOSAL FOR E-BICYCLE

KEYWORDS: pedal assist system, E-bicycle, Alternative powertrain

Cities around the world are being more and more exposed to problems of urban traffic (jams and congestions, lack of parking etc.) and related environmental issues. Without doubt, one of noteworthy possibilities to mitigate such difficulties is more massive use of bicycles in urban transport. Recent growth of usage of bicycles with electric pedal assist systems (further: e-bikes), can probably provide significant contribution to realization of such concept. Aiming to contribute to further increase of usefulness and flexibility of e-bikes usage, this paper proposes novel modular drivetrain concept based on a friction driving wheel, which can be easily attached to or removed from the bike. In general, friction drive uses friction wheel or roller that is attached directly to, or integrated with, the output shaft of electric motor. From this wheel, torque is transmitted to bicycle tyre by means of frictional tangential reaction force between the two. Appropriate means of tension i.e. exerting normal force to realize enough friction between friction wheel and bicycle tyre necessary for friction based torque transmission has to be applied.

In this paper, authors propose especially compact design where the whole device can be placed between the seat tube and seat stays, Figure 1. Such compact design does not interfere with rear bicycle rack as opposed to many of the present design solutions, leaving more options available for bicycle use. Simple design (Figure 2) consists virtually only of electric motor carrier, comprising parts for attachment on the bicycle, and motor with friction wheel itself. Carrier is made from two parts, one of them rigidly attached to the bicycle frame, and the other one, pivoted with respect to first one, which holds the motor with the wheel. Pivoting enables degree of freedom necessary to press friction wheel toward bicycle tyre realizing normal i.e. tensioning force. The latter can be applied by mounting torsional spring directly to the pivot of electric motor carrier, or by using coil spring between the carrier and appropriate mount located on the bicycle frame or seat post.

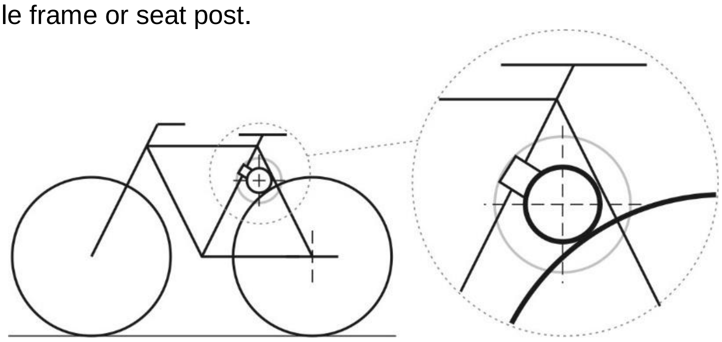

Figure 1. System placement on the bicycle

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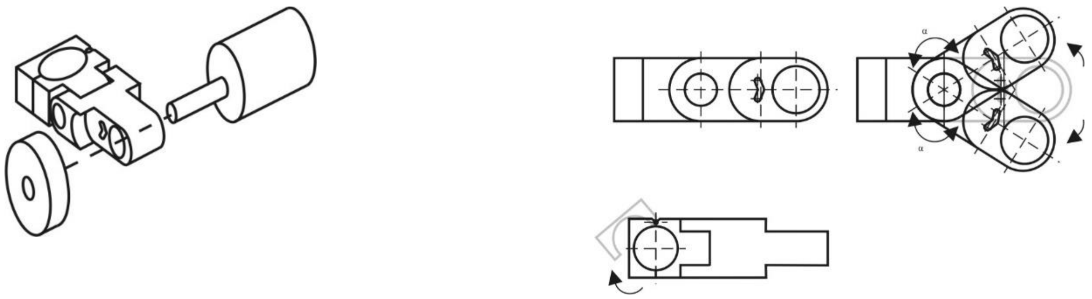

Figure 2. Device design and appearance.

SECTION B

Vehicle Design and Manufacturing

- Body Structures
- Advanced Materials
- Recycling
- Manufacturing Systems
- Quality Systems in Automotive Industry

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IMPACT DAMAGE ANALYSIS OF COMPOSITE AUTOMOTIVE COMPONENT

KEYWORDS: impact testing, PA6.6, composites, low-velocity, automotive

Impact resistance of composite components is usually investigated through series of experimental analyses in which the component is hit by impactor, and the impact resistance is described by forces that cause creation of fractures and perforation in the investigated structure. However, these forces depend on characteristics of impactor and the impact, and therefore, do not inherently represent characteristics of the investigated structure. Presented paper is giving analysis of results obtained by experimental studies of impact tests of air-intake manifold made from PA6.6 with 35% of glass fibers. The analysis consists of calculation of various kinematic and dynamic quantities during the experimental impact, with the aim to investigate alternative possibilities for description of impact resistance of composite structures. Composite materials consist of two or more materials combined in such a way that the individual materials are easily distinguishable. Most composites have two constituent materials: matrix and reinforcement. The reinforcement is usually much stronger and stiffer than the matrix and gives the composite its good properties. The matrix holds the reinforcements in an orderly pattern, and because the reinforcements are usually discontinuous, the matrix also helps to transfer load among the reinforcements. Composite materials are widely used in aerospace and automotive sectors both for their material properties (low density, high stiffness and strength, resistance to chemical and environmental agents), structural design potentials (ability to design material with desired anisotropic mechanical properties) and manufacturing advantages (energy saving due to low production temperatures and pressures, complicated shaped components can be moulded in one process rather than being assembled from components), successfully replacing not only steel, but also light alloys in mechanical structures.
The application of composite materials in mechanical engineering is limited by poor transverse and shear properties of unidirectional composites, which raise concern about their impact behaviour. Being that safety is a major priority in the automotive sector, crash performance of vehicles is one the most important aspects of structural behavior both for manufacturers and consumers, making research of high-velocity impacts of composites relevant for automotive industry. Besides, low velocity impact behaviour of composites is also of interest for automotive industry because of variety of accidental hits to which car parts and components are exposed in exploitation conditions. Lowvelocity impact behaviour has special importance because it was shown that low-velocity impacts may cause internal damage within composite structures which, may seriously reduce loading capacity of the material. The theory of impact behaviour of composites is still in development; there is still no constitutive model capable of describing the transition from an un-damaged to a damaged material and further progression of the damage. Furthermore, despite numerous efforts and decades-long experimental work, many aspects of impact behaviour of composites are still to be investigated and understood by researchers. Such state-of-the art is caused by complex structure and versatility of composites which require studies of the problem from microscopic, mesoscopic, and macroscopic point of view.
The experiment consisted of series of drop-weight impact tests performed on CAB air-intake manifolds manufactured by Italian manufacturer "Magneti Marelli", which are used in engines of German manufacturer "Audi".

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Figure 1. a) Air intake manifold CAB (inlets marked by letters A, B, C and D); In top-right corner is visible impactor; b) CAB air intake manifold after series of impact tests

The CAB air intake manifolds are manufactured from moulding compound Ultramid, representing a composite consisting of PA66 polyamide with 35% of glass fibers. The component is manufactured by injection moulding process, and glass fibers are oriented in general direction of flow. The nominal density and tensile modulus of the material at room temperature, held during the experiment, are respectively 1410 kg/m3 and 11,5 GPa, which leads to an estimation of speed of longitudinal mechanical waves in the material around 2890 m/s. The material is characterized with comparatively very high brake strain, 3-5%, which combined with the estimated speed of longitudinal mechanical waves lead to an estimated upper limit for low-velocity impacts of 90 m/s. Impact tests were performed on eight different samples of CAB and on each of them was tested impact resistance at four points, denominated as A, B, C and D, located at the end of flat part of four different inlets of air intake manifold, as it is shown in Fig.1a. Selection of the points was made in accordance with testing procedure defined by manufacturers of the component and the engine, and the influence of geometry of the component is going to be discussed in separate paper, dedicated to the procedure itself; however, it will be noticed here that the results did not reveal any significant difference between the forces measured during impacts performed in points A, B, C and D. It appears that the influence of differences in geometry of surroundings of the points, caused by different positions of fasteners on inlets, is negligible, and that the dominant factor which influences impact resistance of the component is the thickness of the material. Therefore, for the sake of the analysis presented in this paper, points A, B, C and D will be considered equivalent. Impacts were repeated with impactor released from the same height until penetration occurred in each of the tested points of the structure. A typical sample of CAB after series of impact tests is shown in Fig.1b. The damage on the top part of inlets A and D is a consequence of further impact tests. The experimental data were processed so that time variation of kinematic properties of impactor (acceleration, speed, and displacement) and dynamic properties of the impact (contact force, kinetic energy, dissipated energy and contact force power) were calculated, and using these quantities, force-displacement diagrams of the investigated structure at various test stages were drawn and relevant equivalent stiffness in impact points was calculated (Fig.2a and Fig.2b).

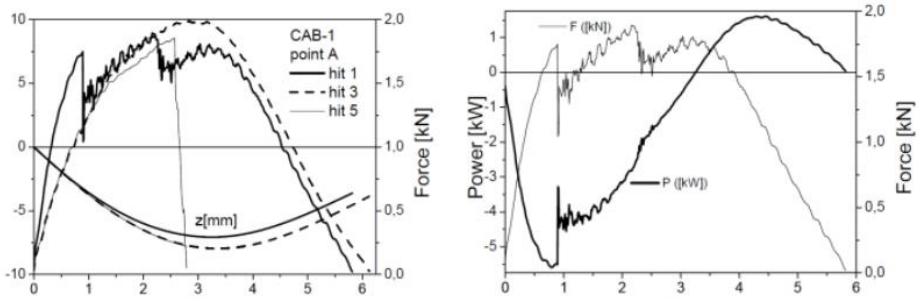

Figure 2. a) displacements of one point of CAB; b) history of impact causing initial damage of structure.

The results have shown that equivalent stiffness has the best potential of identifying the state of the structure from the point of view of experimental and theoretical approach. Besides, the results of analysis have confirmed the results of previous research that the force that causes the first failure of structure and force that causes perforation of the structure do not depend on energy of the impact or show strain rate dependence. However, the results of the study did not reveal any precursor of incoming penetration failure in behaviour of mechanical quantities except for decrease in stiffness of the structure immediately before the breakdown of the structure. Moreover, it was established that the penetration force and displacement were smaller than the forces and displacements that in previous impacts did not cause critical failure of the structure. Therefore, the research established basis for non-destructive characterization of the state of the impacted structure, distinguishing between intact and damaged structures, but it did not reveal basis for prediction of behaviour of damaged structures.

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SELECTION OF SHAFT MATERIALS USING A MULTICRITERIA APPROACH

KEYWORDS: multi-criteria decision making, shaft, material, composite

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. 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. Replacing conventional metal structures with composite structures has many advantages, due to higher specific stiffness and higher specific strength of composite materials. 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 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 analysed, 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 fs, critical speed n_{kr}.

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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. 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.
The weighting coefficients (Wi') of the criteria were determined in two variants using the Saaty procedure. In the first variant, the priority in importance was given to some criteria (sizes), while some were less significant. In the second variant considered, all criteria were equal in importance.
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 1 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.

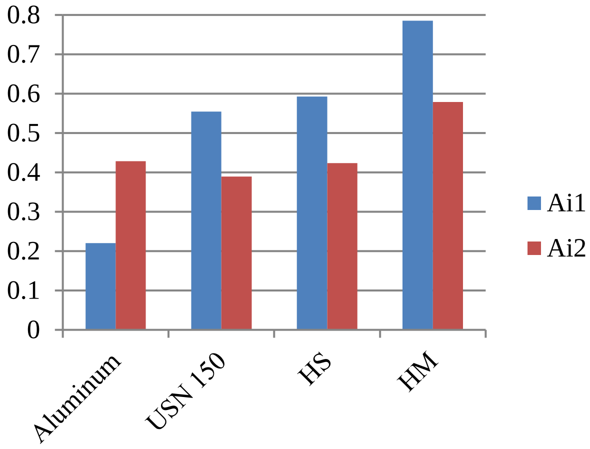

Figure 1. Aggregate characteristics in both considered variants.

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.

ACKNOWLEDGMENTS: This is result of the TR33015 project, which is investigation of the Technological Development of the Republic of Serbia. The project is titled “Research and development of a Serbian net-zero energy house”. We would like to thank to the Ministry of Education, Science and Technological Development of the Republic of Serbia for their financial support during this investigation.

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DEVELOPMENT OF MATHEMATICAL MODEL FOR DESIGN OF VEHICLE STEERING SYSTEM

KEYWORDS: vehicle steering system, mathematical model, formula student

The experiences gained in the design of the control system for the formula student vehicle in the "Road Arrow" project, led to the idea of developing a mathematical model for the calculation of the system that would be applied in some software environment and thus increase the quality and speed of the design process. It must be noted that many software packages have been developed for vehicle design purposes, such as: MATLAB, MSC ADAMS, Lotus Shark and others. All of them provide the necessary conditions for quality design process, while requiring a complete simulation model of the vehicle, experience in use and are often complicated and hard to overcome.
The development of the mathematical model is divided into two sections. The first section presents a mathematical model of the steering system, that refers to the influence of the geometry of the system itself (position of the kingpin axis, geometry of the trapezoidal steering linkage, etc.) on its characteristics. In the second section, the influence of tires on the steering system is described based on Pacejka's "magic formula"
The development of a mathematical model also implies the introduction of certain limitations, where the size of the error that may occur, must be taken into account. The reason for introducing restrictions is to simplify mathematical models that can be too complex. The restrictions that have been introduced are:

- the lateral force acts in the direction of the Y axis,
- turning is performed only to the right side of vehicle and returns to the initial position,
- the value of kingpin and castor angles must be positive,
- the change of the angle between the steering arm and the Y-axis during the vertical travel of the wheel is ignored and
- all elements that affect the transfer of forces are massless and absolutely rigid.

The last portion in the development of a mathematical model is validation. The best form of mathematical validation would be an experimental load test of the steering system. Due to the limiting circumstances, no experimental measurements were performed on the vehicle, but the obtained results of the mathematical model were compared with the results obtained in the ADAMS Car software package.

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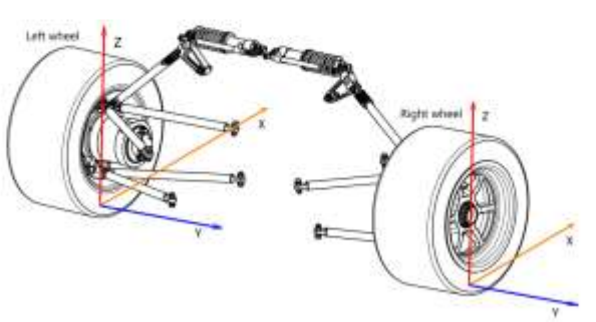

Figure 1. Adopted coordinate systems.

Figure 2. Model in the ADAMS Car software package.

A vehicle motion simulation was performed in the ADAMS Car software package, where the vehicle moves in a straight line at a speed of 50 km⁄h, when the steering wheel starts turning to the right up to 70°, after which it returns to the initial position. Part of the obtained results is shown in figures 3 to 6.

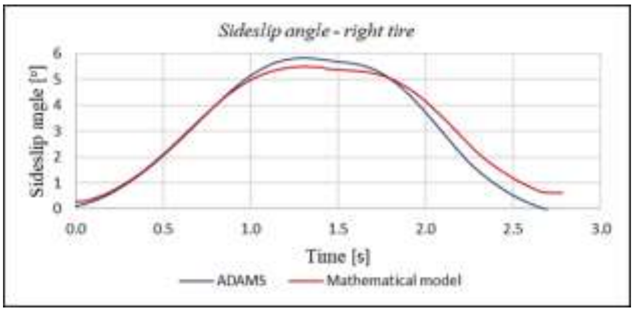

Figure 3. Right tire sideslip angle.

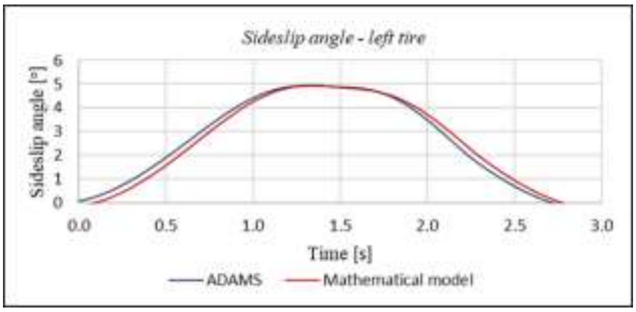

Figure 4. Left tire sideslip angle.

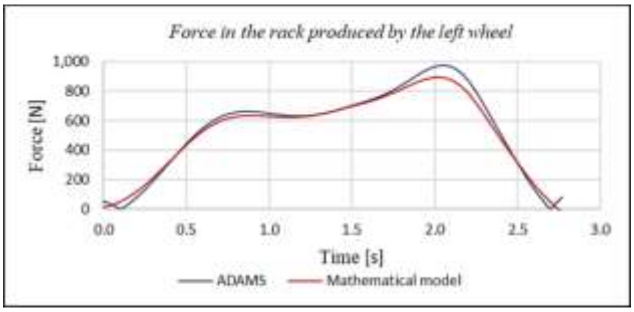

Figure 5. Change in force intensity in the rack produced by the left wheel.

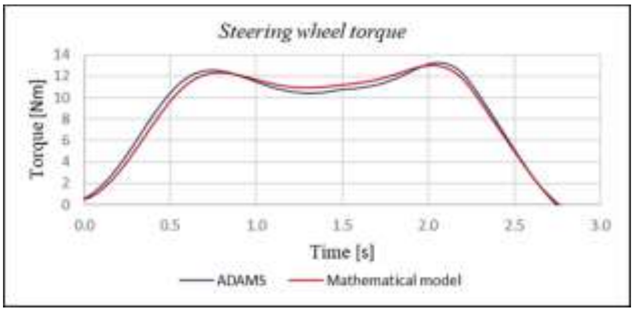

Figure 6. Change in the intensity of the torque on the steering wheel.

By comparing the obtained results, it was determined that the results obtained using the software package are within 10% relative error for torque on steering wheel. It is concluded that the developed mathematical model met the set requirements, and as such it can be used to evaluate the operation of the steering system, that is, it can be used for the calculation and design of the steering system for the formula student vehicle. The mathematical model can be expanded so that calculations can also be made in the case of turning the vehicle to the left. Also, by using the MATLAB software package, a sophisticated application can be created with the help of which calculations and optimization of the formula student vehicle steering system would be done relatively quickly and in a simple way.

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LIGHTWEIGHT MATERIALS FOR AUTOMOBILES

KEYWORDS: lightweighting, AHSS, aluminum alloys, magnesium alloys, composites

Governments worldwide are implementing official policies pressuring original equipment manufacturers (OEMs) in the automotive sector to increase fuel efficiency and sustainability, in a strive toward low-carbon vehicles (LCVs) [1,2]. As vehicle weight greatly affects fuel consumption [3] and greenhouse gas (GHG) emissions, lightweighting strategies came to the forefront of vehicle design and material selection. Lightweighting or weight offsetting is also applicable for extending the range of battery electric vehicles (BEVs). Primary vehicle body weight reduction leads to mass decompounding [4], meaning secondary weight reductions in other systems due to lesser power needs in terms of acceleration and braking. Beyond fuel economy, other benefits of vehicle weight reduction are potential higher performance levels, as well as safety [5]. To facilitate weight reduction, manufacturers are moving away from traditional materials and toward novel lighter options, such as advanced high-strength steel (AHSS), aluminum alloys, magnesium alloys, and composites within a multi-material concept [5], where optimal material is chosen based on the part requirement and other criteria.

Switching to a new material always requires a certain amount of reengineering. That being said, it is easier to substitute steel with aluminum alloys, than say, non-metallic composite materials, which is part of the reason why aluminum has seen considerable growth. The average aluminum content per vehicle for European manufacturers is estimated to reach 198.8 kg by 2025, while global premium brands have long surpassed that value, e. g. Jaguar and Land Rover with aluminum content of around 500 kg [6]. Among favorable characteristics of aluminum alloys are relatively low density, one-third that of steel, and strength-to-density ratio comparable to first-generation AHSS. Utilizing aluminum together with other materials such as steel, in accordance with the multi-material concept, brings up welding difficulties because of the difference in properties such as thermal and electrical conductivity, melting temperature, etc, the formation of brittle intermetallic compounds, and possible galvanic corrosion. Solid-state joining processes like friction stir welding and friction stir spot welding help avoid intermetallic compound formation, typical for arc and laser welding. Besides aluminum, another low-density structural metal is magnesium, although currently less favorable due to problems regarding price, ductility, joining, corrosion behavior, and primary production related sustainability issues [7].

When the goal is maximum weight reduction and the price is not an issue polymer matrix composites, such as carbon fiber reinforced polymers (CFRP), glass fiber reinforced polymers (GFRP), and natural fiber reinforcement alternatives become the best choice of material. Switching from sheet metal to composite panels introduced new material-specific problems [8], that engineers had to overcome through understanding fiber/matrix failure When the goal is maximum weight reduction and the price is not an issue polymer matrix composites, such as carbon fiber reinforced polymers (CFRP), glass fiber reinforced polymers (GFRP), and natural fiber reinforcement alternatives become the best choice of material. Switching from sheet metal to composite panels introduced new material-specific

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problems [8], that engineers had to overcome through understanding fiber/matrix failure mechanisms and establishing simulation approaches and testing methods so that new material could safely be implemented in the auto industry.

Metal matrix composites such as advanced aluminum matrix composites or AMCs [9] reinforced with ceramic particles, and titanium monoboride reinforced titanium matrix composites (Ti/TiB) [10], are also gaining importance. Ti/TiB composites solve many issues characteristic of Ti alloys. While Ti alloys are known for high strength, durability, and corrosion resistance, their high cost, difficulties in casting, forming, and machining, and lower heat and wear resistance, relative to steel (figure 1) prevent them from being widely used in the automotive sector. TiB particles suppress grain growth at high temperatures and occurrence of forging cracks, giving Ti/TiB composites good formability.

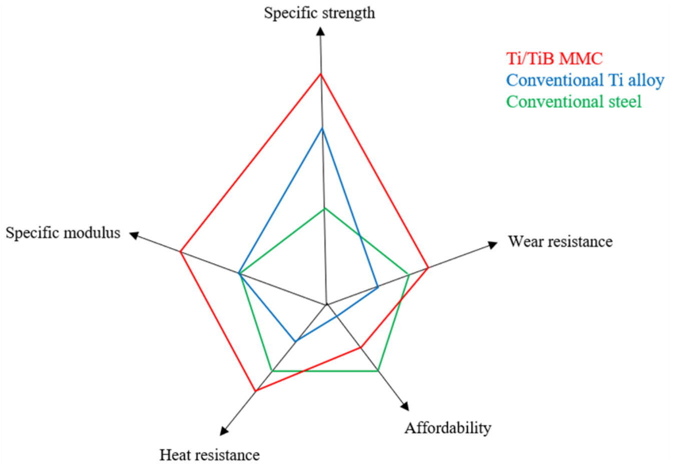

Figure 1. Comparison of relevant characteristics of TiB reinforced composites, Ti alloy, and steel.

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DEVELOPMENT OF DEVICES FOR TESTING DYNAMIC DURABILITY OF MATERIALS

KEYWORDS: body structures, fatigue strength, devices for testing material, dynamic durability, combined stress

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%.
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.
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.
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.

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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). An electric motor (2) with a power 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 compressive and tensile stresses. The specimen (3) is centered and clamped in universal chucks (4). The torque transmitting shaft rests on three 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, 12, 24, 32 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. 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 of C10 steel material with different stresses enables the creation of an S-N curve (Weller curve), Figure 2.

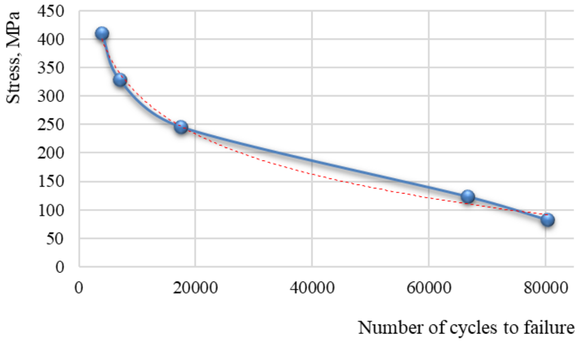

Figure 2. Weller's curve stress-number of cycles S-N.

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.

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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EXPERIMENTAL AND NUMERICAL STUDIES OF REDUCING DRAG FORCE A SEMI-TRAILER TRUCK MODEL USING THE CABIN SPOILER

KEYWORDS: drag force, semi-trailer truck, spoiler, CFD, wind tunnel

The aerodynamics of a semi-trailer truck is an important scientific discipline which includes many aspects regarding the proper behaviour of vehicles during operation. Most often unfavourable aerodynamic shapes and large dimensions make a semi-trailer truck a reasonable test object. A large number of kilometres travelled during exploitation, increases the need for improvement in the field of external aerodynamics too. By reducing the aerodynamic drag on specific parts of the semi-trailer truck, as well as by changing the air flow, the overall aerodynamic drag of the semi-trailer truck will be reduced, which directly reflects on a lower fuel consumption. This paper obtains the procedure of design and analysis of the geometric parameters of the aerodynamic spoiler on the cabin of a semi-trailer truck. The procedure was included in order to obtain the optimal geometric shape and position of the spoiler, which would reduce the drag force of a semi-trailer truck.
The testing object of the research is a semi-trailer truck. A 3D CAD model of truck and semi-trailer, scaled 1:10, was created, with some simplifications that do not have a direct issue on the aerodynamics. In the reason of aerodynamics analysis, the CAD model was transformed to CFD (Computational Fluid Dynamics) model with adding virtual testing around which imitate a real wind tunnel. The model of the wind tunnel around the CAD model is a half cylinder 6000 mm long and radius of 700 mm. The CAD model has a frontal area of 0.0979 m^2. After CFD set-up, the simulation was done for seven different velocity modes. Main outlook parameter was the value of model drag force.
The main purpose of this part of the research is to find optimal shape and position of a spoiler on the top of the truck cab. The optimization procedure includes a few steps. The initial spoiler had a shape of airfoil defined over four variable parameters and some constant parameters. Figure 1 shows the initial shape and position of the spoiler on the top of the truck cab.

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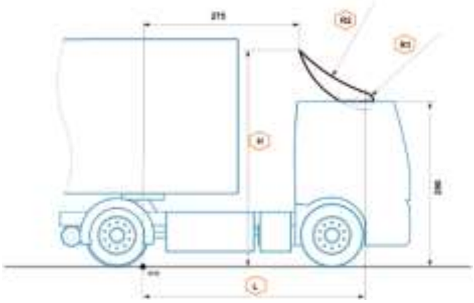

Figure 1. Initial position of the spoiler with parameters.

Full factorial design of experiments (DoE) is a first part of the optimization procedure. It has aim to find best position and shape of the spoiler over CFD virtual simulations where was changed variable parameters H, L, R1 and R2. All simulations done for the highest air flow velocity of 90 km/h. The real variable parameter values were changed on the three levels. Four parameters with three levels gave 81 combinations of a different virtual CFD experiments. Full factorial DoE gives the lowest drag force of 32.98 N. Second part of the optimization procedure is expending Full Factorial DoE by using five-level Central Composite Design (CCD). Four parameters over five level code is 625 combinations of Full Factorial DoE, but thanks to CCD that number is reduced only on the 31 experiments. With this part of the optimization procedure the drag force was reduced to value of 31.93 N. The coefficients in the response surface function of aerodynamic drag force, Equation 1, are obtained by regression analysis of the dates from response surface. The response surface coefficients are derived for uncoded parameter units.

$$F_{Wth} = 44.53 - 5.910 \cdot H - 0.561 \cdot L - 0.422 \cdot R1 - 0.968 \cdot R2 + 1.2114 \cdot H^2 + 0.1106 \cdot L^2 + 0.2688 \cdot R1^2 + \\ + 0.1599 \cdot R2^2 - 0.1291 \cdot H \cdot L - 0.4578 \cdot H \cdot R1 - 0.0523 \cdot H \cdot R2 + 0.0513 \cdot L \cdot R1 + 0.0519 \cdot L \cdot R2 + 0.0159 \cdot R1 \cdot R2 \quad (1)$$

Presented equation describes the model behaviour with an accuracy of 95.8%. The parameter values that provide the minimum of the aerodynamic drag force response function are determined by numerical quasi-Newton minimization. By applying parameter values from final step of the optimization process to the CFD model, an aerodynamic drag force of 31.75 N was obtained.

The aim of the experimental testing is to verify the CFD simulations. The experimental testing was done in the “Miroslav Nenadović” wind tunnel within the Faculty of Mechanical Engineering in Belgrade, Serbia. That is a close type of underground wind tunnel with a circular air flow. For the aim of measuring aerodynamic drag force, which is a horizontal component of vehicle resistance, an aerodynamic drag force measuring facility was built. The measuring facility with dimensions of 1670x255x400 mm, is made of wood in a scale of 1:10 compared to the actual semi-trailer truck. The models of the truck and the semi-trailer are joined to the board via a support. The models are lifted up above the board for a vertical distance of 5 mm, same in CFD model. The board is fastened via sliders to sliding guides through which the longitudinal translational movement of the board is provided, together with models. The board rests at the force measuring cell. The measuring cell CZL623B was used with the comprehensive full scale error 0.03% and rated output 2 ± 0.02 mV/V. The signal from the measuring cell is transferred to the universal measuring amplifier HBM QuantumX MX840A. Experimental measurements were performed on the following configurations of the measuring facility:

a) drag force measurement of board only, without the semi-trailer truck model.
b) drag force measurement of the semi-trailer truck model without an aerodynamic spoiler;
c) drag force measurement of the semi-trailer truck model with aerodynamic spoiler on the cabin of the truck.

Within each measuring facility configuration, one measurement involved reading the aerodynamic drag force value at a single air flow velocity mode. Measurements were performed at seven velocity values in the range of 60 to 90 km/h, with an increment of 5 km/h. At each velocity mode, two measurements were performed for about 20 seconds. The obtained results show an acceptable agreement between the results achieved by CFD simulations and experimental tests in the wind tunnel. The adopted type of mesh and turbulent model within the CFD simulation provides good repeatability of the results for all considered airflow velocity values and all configurations of the measuring facility. The tested model during the experimental measurement showed stability and balance at the highest velocity values of air flow. The goal of the research was to develop an optimizing procedure of the geometric shape and position, used as an aerodynamic spoiler on a semi-trailer truck cabin. Four parameters (top edge height from the ground - H, horizontal position of spoiler front radius centre - L, spoiler front edge radius - R1 and spoiler leading edge radius - R2) defining the spoiler shape and position. It turned out that parameter H has a dominant influence on the aerodynamic drag force. The influence of the parameter R2 is significantly smaller, while the parameters L and R1 have the least impact on the drag force.

As a result of Central Composite design of experiments, a quadratic response surface function of drag force was generated. Spoiler parameters are optimized by minimizing the response surface function. CFD simulation results were validated by testing in the wind tunnel.

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MBSE APPROACH FOR FACILITATING THE APPLICATION OF STANDARDS IN THE VEHICLE DEVELOPMENT PROCESS

KEYWORDS: vehicle design, platform, MBSE, regulations

Today's vehicles are complex systems consisted of not only the essential mechanical components, but also an increasing amount of electrical, electronic and software components, as well as features based on latest technological advancements, aiming to be more safe, smart, convenient, reliable, and environmentally-friendly.
Vehicle developers are aiming to offer all these qualities in new vehicle models to respond to the ever-changing user needs and gain market advantage. However, in the same time they are under the increasing pressure to meet the strict regulatory requirements regarding safety and environment preservation. They are required to follow specific regulations for the design of components, their manufacturing and placement, reuse and recycling, reducing emissions, improving fuel economy and the overall efficiency. This does not only impose limitations in the design and development process, but can be difficult to follow by all team members.
Therefore, the development of vehicle systems that integrate latest trends with regulations needs to rely on a strong multi-disciplinary collaboration between experts from relevant fields.
The Model-Based Systems Engineering (MBSE) approach can provide a strategy for easier coping with the complexity of vehicle systems. This is extremely beneficial since it helps to create an information base where the information is represented in an integrated and consistent system model rather than in isolated documents.
This paper presents a concept of an information platform based on MBSE. The goal of the platform is to become an engineering tool for incorporating all relevant data (requirements, standards, regulations) in a manner that they can be directly linked to the adequate system components, simple to interpret and be used by all members of the development team. The purpose of this platform is to: (1) facilitate the development process and interdisciplinary collaboration; (2) help to follow regulations correctly and avoid mistakes; (3) keep all project data systematized.
This paper includes a simplified diagram representation of the vehicle design and development process to emphasize how this process is a daunting task which includes the use of a wide range of multi-disciplinary information and is under the continuous influence of strict regulations. Moreover, the vehicle interior is elaborated as an example to demonstrate all the multiple sources of information that need to be included for the development of all vehicle interior

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systems and components which are gathered in the form of detailed requirements to be met in order to obtain vehicle approval, as well as requirements related to occupant safety and environmental preservation.
In addition, the paper includes a system analysis of the complex system „vehicle interior“ which is composed of a set of interrelated components working together to achieve the main purpose. Conducting the system analysis and defining the system hierarchy helps to simplify the process of allocating the requirements according to the relevant system subsystems at different levels and components.
In the end, by applying MBSE methods this paper suggests the concept for an information management platform that provides a solution for linking the information from various sources with specific vehicle subsystems and components. The concept for the platform is precisely illustrated and elaborated through a class diagram and a diagram representing the architecture of the platform and its' practical use.
This platform is intended to be used at the earliest stages for analyzing and selecting all relevant data that is needed for the development of concepts for specific subsystems – data that helps to properly choose materials, position elements in the interior, choose commercial products that need to be ordered, label components, etc. The benefit of this platform is the possibility to systematize all requirements, update them on a regular basis, avoid omitting important data, and saving all used data for specific projects which can be reviewed by all team members.

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A REVIEW OF HYPEREUTECTIC ALUMINUM PISTON MATERIALS

KEYWORDS: hypereutectic, Al-Si alloys, Al-Si composites

Demands of today's automotive industry are increasing; there is a constant tendency of weight reduction and higher reliability of constructions. One of light-weight materials is aluminum and its alloys due to their properties like: good heat and electrical conductivity, light weight (only one-third the density of steel), corrosion and wear resistance, high recyclability, good castability and weldability.
Every year use of aluminium is increasing, and in 2020. was the highest in construction (25%), followed by automotive and transportation (23%), foil and packaging (17%), electrical engineering and electronics (12%), machinery and equipment (11%), consumer goods (6%) and other application (6%). In future increase in aluminum consumption is predicted.
In automotive industry aluminum and its alloys are used for: power-train, chassis and suspension and car body.
Pistons and piston liners for vehicles engines are mostly manufactured from aluminum-silicon (Al-Si) alloys and composites. Novel materials for piston production are hypereutectic (>12%Si) Al-Si alloys and composites. Composites are materials that have in their composition chemical elements that act as reinforcement and are not dissolved in the base material.
Addition of modifier like: Phosphorus, Erbium, Cobalt, Magnesium, Manganese, Calcium, Strontium, etc, and/or refiners like Al-1Ti-3B can change hypereutectic aluminum alloys properties. With addition of modifiers to the alloy the refinement of Si particles (primary and eutectic) as well as better and more homogenous distribution of particles is achieved. Most common reinforcements in composites with aluminum base are alumina, silicon carbide, basalt, glass fibre, carbon fibre and even biomaterials such as bamboo fibres.
With different manufacturing methods and/or the addition of some chemical elements, base alloy properties can be modified. Aluminum alloys and composites, in general, can be manufactured by liquid state processing, semi-solid processing and solid state processes. Different types of casting such as: gravity casting, stir casting, squeeze casting, ultrasonic assisted casting and others, fall under liquid state process. Semi-solid process includes rheocasting and tixocasting, while solid process includes powder metallurgy process, friction stir process, diffusion bonding and sintering.

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Most common methods for manufacturing of hypereutectic aluminium alloys and composites are: Gravity casting, centrifugal casting, stir casting, pressure die casting, tixocasting, rheocasting and some very new methods like selective laser melting, electron beam melting and spray-deposition.
Description of manufacturing methods for hypereutectic aluminum alloys and composites and their influence on material properties will be given in this paper. The influence of Si percentage in base alloy and how an addition of some chemical elements affects the properties of these materials will be observed as well. With higher amount of Si in alloy hardness increases, but that is not always the case if modifiers are added.
Some observations for hardness are that all manufacturing methods, when compared to gravity casting, give higher hardness and that, if applied, T6 treatment hardness increases in some cases significantly. As for microstructure maybe the best microstructures are obtained for centrifugal, stir casted and tixocasted materials. When taking into account price and complexity of production centrifugal and stir casting are most affordable ones.

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POLYMER MATRIX NANOCOMPOSITES FROM THE ECOLOGICAL ASPECT IN THE AUTOMOTIVE INDUSTRY

KEYWORDS: automobile, industry, environmental, polymer nanocomposites, recycling

Meeting the stringent requirements of the automotive industry that the material must meet in terms of price and performance is a serious challenge for engineers. The use of lightweight materials led to the use of polymer nanocomposites in the automotive industry witch have multiple advantages but has also led to new issues, such as the impact on the ecological aspect of the environment. Nanocomposites with a polymer matrix (Polymer Matrix Nanocomposites, PMNC) are materials that represent a new generation of materials with improved physical, mechanical, thermal, electrical, magnetic and optical properties. Because of their biostability and non-toxicity, they are mostly found in the military, automotive industry, space, medical or cosmetic industry. These materials have gained particular interest of the automotive industry because of their outstanding performance that enables cost reduction, weight reduction, and product improvement. Polyamides, which represent a very important class of polymers, are most often used as matrix in the production of PMNCs. In the automotive industry, these polymers are used in a wide range of applications, which include fuel tanks, reservoirs, pipelines, carburetors, injectors and many more.

PMNCs are used in various parts of automobiles, for example, in engines, drive systems, braking systems, exhaust systems, catalytic converters, body and frame parts, paint and coatings, lubrication, tires, and electrical and electronic equipment. Researchers from Toyota have found that the application of these polymer nanocomposites, at room temperature, reduces the water permeability of the nanocomposite by 40%, the tensile modulus increases by 168%, and the thermal distortion temperature by 87°C, compared to unmodified polyamide-6.

A significant reduction in vehicle weight is achieved by reducing the dimensions of the engine itself, which is most quickly achieved by eliminating the need for engine fairings. By applying biopolymer nanocomposite materials, a significant reduction in the weight of the engine can be achieved, which results in a reduction of fuel consumption by about 7%, which is a very important achievement, if the long-term results are being considered.

Environmental pollution is a global issue and has a negative impact on human development. However, with the increased use of nanomaterials, the number of researches and tests of these materials on the environmental impact increases proportionally, with the aim of preventing serious health problems that can arise, for example, from deteriorating water quality.

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Therefore, the biggest danger to the environment are not polymer nanocomposites, but their constituent parts, especially during the process of their disintegration. The constituent components of polymer nanocomposites will unavoidably end up in the environment, through waste gas or solid residues. Consequentially, aside from many ways of their exploitation, it is very important to determine the correct ways of disposing of these materials. It has already been established that incineration of waste is not ideal for disposing of polymer nanocomposites. It is predicted that for the future needs of using these materials, it will be necessary to develop new disposal procedures, in order to ensure that these materials do not end up in the environment and thus potentially cause harm.
One of the solutions to reduce the impact of future vehicles on the environment is the development of new graphene-based materials and their use in the automotive industry. According to European requirements, 95% of a vehicle must be made of materials that can be recycled and are environmentally friendly. On that basis, the growth in the use of materials such as biofibers and bio-based resins produced from soybeans, pure cellulose acetates and citrate-based plasticizers is predicted. Currently, several polymer nanocomposites meet the requirements in terms of production volume, environmentally acceptable and superior mechanical properties, better operating temperature, good surface finish and improved corrosion resistance and are considered as potential materials for structurally non-critical parts, such as front and rear fascia, bonnet inner part, ventilation grill and valve covers. The use of polymer nanocomposites in these parts could result in a weight reduction of several billion kilograms per year.
There are many car manufacturers that actively and increasingly use biopolymer nanocomposite materials in the production of components. Some of the most famous among them are BMW, Audi, Ford, Mercedes-Benz, Toyota, Nissan, Opel, Peugeot, Volkswagen which, for certain series of cars, use polymer nanocomposites based on sisal, flax, nettle, sugar cane or rice husks, for making door panels, roof panels, seat backs, floor mats, spare tire covers, interior fabrics, dashboards as well as rear storage panels.
Today's main goal of the automotive industry is to protect the environment and meet consumers' requests by using sustainable, recycled, waste by-products and bio-based polymers. It is expected that the production of plastics will increase up to 3 times compared to the production of 10 years ago. Accordingly, the consumption of petroleum oil for the production of plastics is predicted to amount 20% of the total oil-based resources by 2050.
It can be concluded that the automotive industry is investing a lot of effort in research for reduction of environmental pollution using PMNCs. Their main goal is to use an increasing number of sustainable materials, wherever possible, without compromising durability, product quality and performance.

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TOPOLOGY OPTIMIZATION OF A MACPHERSON CONTROL ARM

KEYWORDS: topology optimization, finite element analysis, control arm, passive suspension

The suspension system of a vehicle is crucial for its handling and its ride. It contributes to the safe driving of the vehicle and the comfort of the passengers by reducing the vibrations during vehicle's ride. A crucial part of a passenger car passive suspension system is the control arm or wishbone arm or A-arm and its main function is to provide a link between the body of the vehicle and the wheels.
In this paper, the possibilities of the topology optimization analysis embedded in a commercial CAD – CAE software have been explored, using a control arm that is a part of a MacPherson strut suspension as a test case.
In order define the design space for the control arm and create a baseline finite element (FE) simulation, a commercial control arm from an SUV vehicle with a MacPherson suspension has been measured and accurately designed (M1). The commercial arm is an L type control arm manufactured by two metal plates welded together. Using the outer dimensions of M1, another geometrical model (M2) is designed defining the design space of the control arm as presented in Figure 1. In the first one (M1) linear static analyses are conducted and in the second one (M2) topology optimization analyses were performed. The FE model of the M1 (FE1) consists of shell FE while the FE model of the M2 (FE2) consists of tetrahedral 3D solid FE. Both FE models are presented in Figure 1.

(a) (b)

Figure 1. Mesh of (a) M1 (FE1) and (b) M2 (FE2).

The Aluminum Alloy 7075-T6 has been considered as the manufacturing material for both FE models since it has a low density and a high value of yield strength. For both the mechanical analysis of FE1 and the topology optimization of FE2 the same boundary conditions were used. In more details, two typical load case scenarios (LC) were assumed, the first (LC1) representing the pot-hole brake case and the second one (LC2) representing typical loading of the control link during the movement of the vehicle. In Figure 2 the stress contours for FE1 in both LCs are presented.

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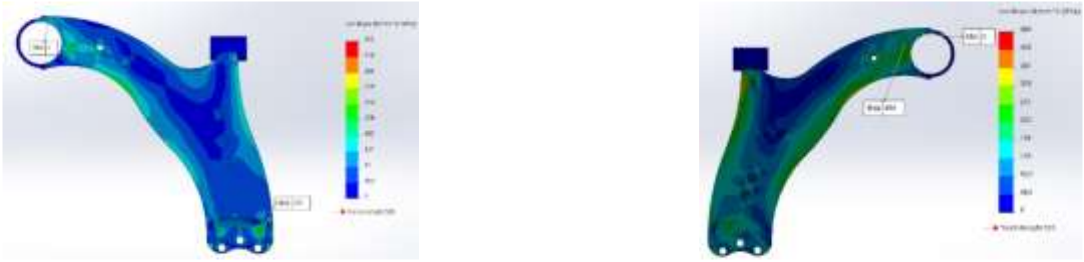

(a) (b)

Figure 2. Stress contour on FE1 for (a) LC1 and (b) LC2.

For FE2 also the goal and the restrictions of the topology optimization were defined leading to two different topology optimizations (TO1 and TO2). Both of them had the best stiffness to weight ratio as goal option and the stress constraint which demand the optimized model not to have maximum stress more than the 40% of the yield strength of the material. The difference between them is in the mass constraint, which in the TO1 is set in 50% reduction of mass and in the TO2 in 75%. In Figure 3 the results of TO1 and TO2 are presented.

(a) (b)

Figure 3. Result of (a) TO1 and (b) TO2.

These optimization procedures lead to two new geometrical models with different mass (M3 and M4) and two new FE models (FE3 and FE4, respectively) were built and to static analyses with the abovementioned boundary conditions. The results of the mechanical analyses of all FE models were compared in terms of weight and structural integrity leading to conclusions regarding the optimization procedure. In Figure 4 the stress contours for LC2 of FE3 and FE4 are presented.

(a) (b)

Figure 4. Stress contour for LC2 of (a) FE3 and (b) FE4.

In Table 1 the weight of each model, along with the maximum value of Von Mises stress and this of total displacement for LC2 is presented. It is obvious that FE4 has the lowest weight.

Table 1. Results of the mechanical analysis of FE1, FE3 and FE4 in LC2.

Models	FE1	FE3	FE4
Stress [MPa]	484	159	382
Displacement [mm]	5.44	0.47	2.13
Mass [kg]	3.3	4.4	1.5

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FUNCTIONALLY GRADED MATERIALS IN TRANSPORT VEHICLES - OVERVIEW, FABRICATION, APPLICATION, MODELLING

KEYWORDS: functionally graded material, finite element modelling, bending analysis, high order shear deformation theory, shape function

This paper deals with functionally graded materials (FGM) as modern materials in transport vehicles. Basic methods of FGM production and areas of their application are presented, as well as an example of modelling an FGM plate. Bending of freely supported square FGM plates under the influence of sinusoidal transverse load was analyzed. The plates are made of metal (aluminium) and ceramic (alumina) in which material characteristics change as a function along the thickness of the plate. The static analysis was done by applying finite elements methods in the FEMAP software package for different mesh sizes. The results were compared with those obtained in the MATLAB software package using the classical plate theory, quasi 3D theory as well as high order shear deformation theories.

FG plates whose dimensions are adopted according to the relatio a / h = 10 were analysed in case of 5, 10 and 20 layers.
The material characteristics of FG plates $(a/h=10)$ change according to the equation (1), where the properties of the metal are $P_b = P_m$ (on lower side of the plate), the properties of the ceramic are $P_t = P_c$ (on the upper side of the plate) and $P_{tb} = P_t - P_b$. The exponent p defines the proportion of constituents.

$$P(z) = P_b + P_{tb}\left(\frac{1}{2} + \frac{z}{h}\right)^p \qquad (1)$$

Due to comparison with other results, the calculation was done for $p = 1, 2, 4, 8, 20$ and eight-node 3D finite elements were used for the modelling.

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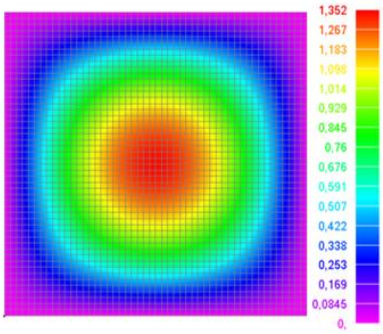

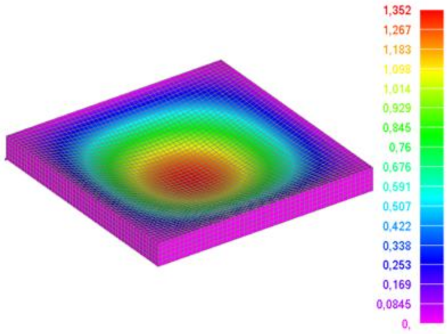

Figure 1. Normalized values of vertical displacement field $\bar{w}$ of the FG plate in case of 5 layers and value of the exponent p = 20.

Figure 1 shows normalized values of vertical displacement field $\bar{w}$ of the FG plate in case of 5 layers and value of the exponent *p* = 20. The table 1 shows the normalized displacements values of plate centre $w_s = w\left(\frac{a}{2}, \frac{b}{2}\right)$, where normalization was performed according to:

$$\bar{w} = \frac{10E_c h^3}{q_0 a^4} w\left(\frac{a}{2}, \frac{b}{2}\right). \tag{2}$$

Table 1. Normalized displacement values $\bar{w}$ for different mesh size and values of the exponent *p*.

p	5 layers, 50×50	10 layers, 100×100	20 layers, 200×200
1	0.5776	0.5852	0.5890
2	0.7638	0.7600	0.7600
4	0.9120	0.8892	0.8854
8	1.0488	0.9956	0.9804
20	1.3528	1.2008	1.1514

As was to be expected, results based on finer mesh of finite elements are closer to the values obtained by applying shear deformation theories in the mentioned references. A significant deviation is obtained in relation to CPT. It is a consequence of the fact that the mentioned theory gives worse results in the analysis of thick and moderately-thick plates. When increasing the values of the exponent *p* from 2 to 20, the error also increased, regardless of the mesh density. When comparing the obtained values with e.g. SF 13, it can be observed that the largest relative error obtained in the case of larger volume fraction of metal (aluminium) in FG plate. The best match of the results was achieved for the linear change of the modulus of elasticity in the case that the plate is divided into 20 layers.

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ANALYSIS OF THE IMPACT OF THE MACHINE ON THE FORGING PROCESS OF A CONNECTING ROD USING NUMERICAL SIMULATION

KEYWORDS: numerical simulation, finite volume method, forging

The application of numerical simulations of production technologies, using the finite element method or the finite volume method, is a widely used approach in advanced engineering design and research. Unlike industrial experiments, this approach allows the analysis of the influence of different process parameters on the output performance of a workpiece. The paper analyzes the influence of the choice of the machine on the forging process of the connecting rod, which is made, among other things, for the needs of the auto industry. For this purpose, numerical experiments were carried out, using the finite volume method and the Simufact.forming software package, with variations of three types of forging machines: drop forging hammer, crank press and hydraulic press. Finally, the results of the numerical experiments and conducted analyses are presented, with concluding considerations and recommendations.

The aim of the research presented in this paper is to determine the impact of machine selection on the process of hot forging of connecting rod, that is an important component for parts in the auto industry. In order to verify the obtained results, an analysis of the industrial process was carried out, so that CAD models of the connecting rod and corresponding engravings of the forging dies for two operations were obtained from the partner company Zastava Kovacnica. In order to analyze the impact of the choice of forging machine on the forging process and the performance of connecting rod forging, three numerical experiments were performed on different machines (forging hammer, crank press, screw press). Numerical simulations of all analyzed forging processes were realized using *Simufact.forming* software and finite volume method (FVM). For all numerical simulations, the same parameters of the process were followed (filling of the engraving, material flow into the flash, homogeneity of the temperature field which affects the microstructure of the forging, required forming load, i.e. forging energy, as well as strain and stress fields in the forging). The process of hot forging of the connecting rod consists of two operations, preliminary and final forging, and the design of the technology is based on the calculation of reduced forging for the preliminary forging operation, in order to perform an optimal redistribution of the mass of the workpiece and for the correct filling of the final engraving. The billet dimensions for forging the connecting rod is ϕ65x111mm, made of 42CrMo4 material, which is heated to a temperature of 1225°C. The dies were heated to 150°C, and the ambient temperature for process simulations was set to 50°C. The properties of the considered presses (forging hammer, crank and screw press) are given in table 1. According to the data listed in table 1, in the Simufact.forming software i.e. in its press definition module "virtual presses" with given properties are defined. Forging die engravings for both forging operations are shown in figure 1.

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Table 1. Press properties

Drop forging hammer	Crank press	Screw press
Max. impact energy: 9500 kGm Weight of falling part:3570kg Number of blows: 3	Crank radius: 300 mm Rod length: 1200 mm Revolution: 30 Rpm	Gross energy: 40000 [J] Maximum ram speed: 340 mm/s Efficiency during stroke [0-1]: 0,9

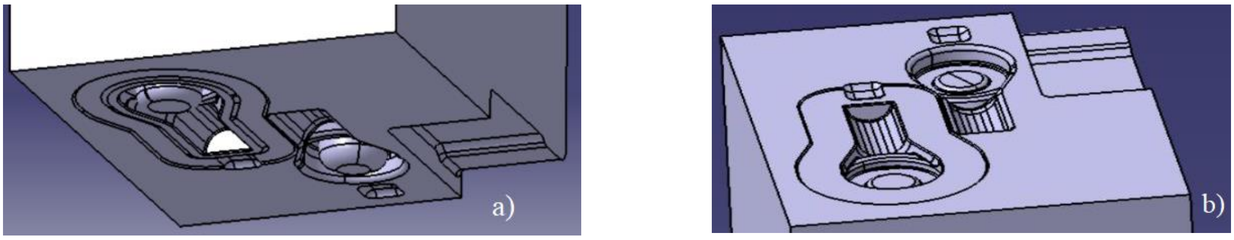

Figure 1. Tool engravings for preliminary and final connecting rod forging operations, a) upper die b) lower die.

The results of numerical simulations of the connecting rod forging process in the final forging operation were considered, namely the fields of effective plastic strain, effective stress and temperature in the forging, then forming load diagrams, and the material flow into the flash and filling of the engravings via the *Die contact option* (two-color display) were monitored.

The impact of the choice of the forging machine on the forging properties and on the forging process itself can be analyzed using numerical methods and process simulations, as shown in this paper. Due to the exploitation properties of the forging, its microstructure, it is important that the strain field in the forging be as homogeneous as possible, and that the amounts of maximum strains be within acceptable limits for a certain material.

The results of numerical simulations showed that the highest effective stress is in the inner part of the forging, and it has significantly higher values in hammer forging than in crank and screw press forging. Such values of effective stress in the forging are expected, because the forming velocity is the highest on the hammer, then on the screw press, and the least on the crank press. The stress in the forging material depends on the forming velocity, i.e. the achieved strain rate, because the viscoplastic behavior of the material is present at elevated forging temperatures. By comparative analysis of the field of effective plastic strain, maximum values were observed in the flash zone, which is not crucial from the aspect of forging quality, considering that it is removed after forging. However, for the quality of the forging, it is important to have as homogeneous a strain field as possible, which gives smaller variations in microstricture and resistance characteristics during exploitation. Highest strains in the forging occurred during hammer forging (figure 2), due to high forming velocities and impact loads. A more homogeneous strain field was obtained during forging on a crank press, and the most unfavorable distribution was obtained during forging on a hammer, due to impact loads and a high forming velocity. On the other hand, filling of the die and uniform protrusion of the material into the flash is evident in hammer forging, while in forging on the crank press, the protrusion into the flash is more prominent in the cylindrical part of the connecting rod shank, with the possibility of not filling the hub.

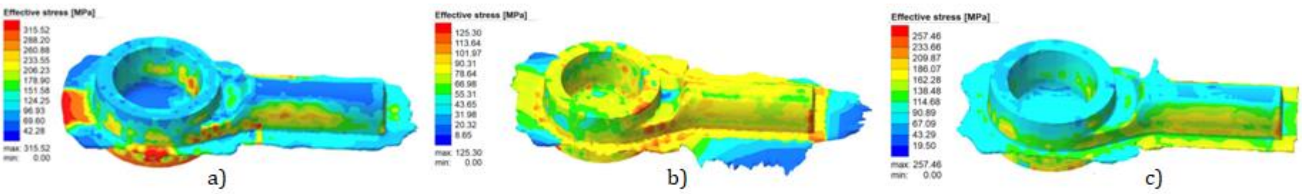

Figure 2. Effective stress a) forging hammer b) crank press and c) screw press.

The temperature distributions in the forging are in similar proportions for these three forging machines, the highest temperatures are during forging on the hammer, and the lowest during forging on the crank press, again due to the different forming velocities of these forging machines, the duration of the forging process, and especially the time of contact with the die and environment and cooling of the workpiece. Numerical process simulations provide the opportunity to review and analyze all aspects of the machine's impact on the complete forging process and forging quality, outside of the production environment, and to make correct decisions on the process parameters or on the selection of the most favorable machine based on the results.

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FE MESH DENSITY INFLUENCE ON BLAST LOADING ANALYSIS

KEYWORDS: anti-landmine protection, armored vehicles, FEM, blast loading, TNT

The bottom of the vehicle has become crucial in preventing explosion damage as a result of the threat posed by ALMs and IEDs on modern battlefields. The bottom of the vehicle has a key role in resisting the effect of the blast and thus protecting the troops aboard the armored vehicle. Within 4 ms after the explosion, the structure (armored vehicle) is exposed to large elastoplastic deformation as a result of landmine detonation.

In this paper, the FE models with different mesh densities was numerically tested to analyse the influence of mesh density on the obtained results. For the purposes of the modeling, different types of finite elements were used for the FE models. The floor of the vehicle was modeled with 3D hexahedral eight-noded finite elements, and the protective plates were modeled with four-noded plate finite elements. The maximal value of plastic strain and the maximal value of the displacement of the central node on the protective plate was chosen as the parameters to compare the obtained results.

In order to determine FE mesh density influence and to achieve convergence the floor and V-shaped hull of the armored vehicle is modeled with five different mesh densities. The number of 3D hexahedral eight-noded finite elements and four-noded plate elements which are used to model all five FE models and the number of the nodes are shown in table 1.

Table 1. Values of pedestrian throw distance for different vehicle speeds

Finite element size	Number of 3D finite elements	Number of plate elements	Number of nodes
FE model 1 – 10mm x 10mm	60000	79800	199411
FE model 2 – 20mm x 20mm	15000	17100	47867
FE model 3 – 30mm x 30mm	6800	7600	21715
FE model 4 – 40mm x 40mm	3800	4636	12543
FE model 5 – 50mm x 50mm	2400	2760	7869

All FE models were examined in order to monitor vertical displacements of the central node on the protective plate in dependence of time. Central node is located on the longitudinal plane of symmetry in the direction perpendicular

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to the protective plate. Vertical displacement of the central node on the protective plate in dependence of time for all five FE models are shown in figure 1 – left. In figure 1 – right magnified results for vertical displacement of the central node on the protective plate in dependence of time for all five FE models are shown.

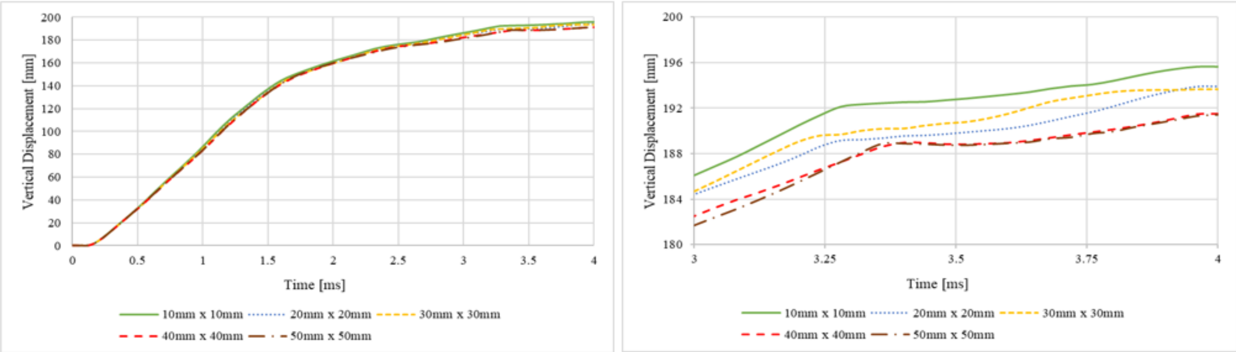

Figure 1. Vertical displacement of the central node on the protective plate in dependence of time - left, vertical displacement of the central node on the protective plate in dependence of time – magnified – right.

An example of vertical displacement of the central node on the protective plate for FE model 3 is shown in figure 2.

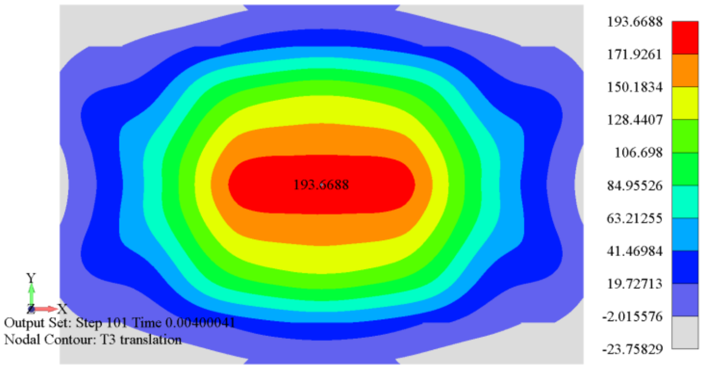

Figure 2. Vertical displacement distribution.

Plastic strain distribution of FE model 3 is shown on figure 3.

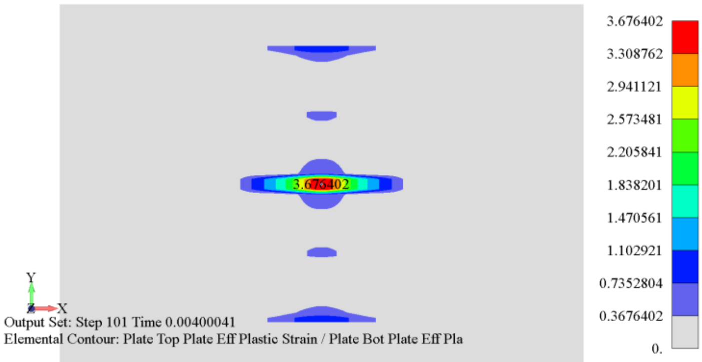

Figure 3. Plastic strain distribution.

With the increase in the size of the finite elements, the difference in the analysis values for vertical displacements and plastic deformation due to the impact of the blast wave as a result of the anti-landmine explosion, decreases. Five different FE models were tested, i.e. five FE models with different sizes of finite elements. The differences in the values of vertical displacements in the FE models 4 and 5 are minimal, so it can be confirmed that convergence has occurred. Considering the accuracy of the results in FE models 4 and 5, there is no need to further increase the mesh density. In this way, engineering and computational time is saved.

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HOW THE CORE TECHNOLOGIES OF INDUSTRY 4.0 ARE CHANGING THE AUTOMOTIVE INDUSTRY IN THE WORLD, WITH A FOCUS ON CHINA

KEYWORDS: industry 4.0, automation, robot, vehicle, production process

In the past ten years, new technologies have been rapidly changing various branches of industry, including the automotive industry. It is well-known that the automotive industry was the first to implement the latest technologies due to global competition on the market. The automation system in the automotive industry is changing the way vehicles are produced. By introducing automation into production processes in the automotive industry, tedious and time-consuming processes are performed in less time with increased quality. This is achieved by the introduction of industrial robots into production processes, which improve the very aspects of the production process, such as design technology, aerodynamic efficiency, fuel economy, determination of chassis strength, etc. It is known that the term Industry 4.0 is already widely used, and it is related to various production concepts. From a technological perspective, Industry 4.0 should be understood as the increasing digitization and automation of production processes, that is, the production environment and the design of the digital value chain from the product to the customer. Some authors call Industry 4.0 a new disruptive technology. Industry 4.0 is inevitable because the world today is in the dynamic era, and it changes the very aspect of production processes that are currently implemented in most companies. The concept of Industry 4.0 is defined by many technologies, some of which are: robotics and automation, Internet of Things (IoT), Big Data, Cloud Computing, 3D printing, smart sensors, Radio Frequency Identification (RFID), virtual and augmented reality (AR), Artificial Intelligence (AI), advanced security systems, Cyber-Physical Systems (CPS), etc. The implementation of the above technologies allows car manufacturers to simulate dangerous scenarios in order to test and develop new security measures. IoT technology enables access to information about safety operations and driving time, among others. Automotive telematics insurance and surveillance vehicles are deployed to accurately assess risk by observing mileage, driver behavior and vehicle type.
The inclusion of IoT in the automotive industry makes it easier to prevent accidents on the highway. Tracking devices and software are new technologies that will allow automotive companies to make the most of their available assets, while its optimization reduces costs, increases profits, and facilitates the growth of the company and the automotive industry as a whole.

The implementation of Industry 4.0 in the automotive industry is reflected in the implementation of the following elements [11]:

- Collaborative robots and machines, which are based on machine-machine (M2M) and human-machine (H2M) communication, which releases workers from risky jobs;

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- Augmented reality, i.e., using virtual simulations to design workplaces, production and adjustment processes, as well as repair machines;
- Greater flexibility in all segments, which gives a faster production response to global market fluctuations; digital production facilitates the production of complicated products;
- 360-degree networking;
- Virtual assembly allows employees to master and evaluate how best to perform a task using the control module;
- Increased efficiency, rational use of resources and energy consumption;
- Increased speed, flexible production processes, simplified adaptation of existing production processes and installation of new equipment enable easier and more efficient production processes;
- The goal is a smart factory where, by incorporating the real world into the digital world, it is possible to create a so-called digital twin that enables a real-time display of the process itself, the system and the entire production.

The very decision to implement Industry 4.0 in the company lies in its ability to act as a change in the economic game, which would open countless opportunities for companies to remodel or create completely new offers and business models

Two leading industries in the application of industrial robots in the world are the automotive industry and the electrical/electronic industry, which in 2020 used 50 % of industrial robots. The first place in terms of application is held by China with about 168.400 robot units. In the recent years, China has always been the first in the world to implement robots, and the reasons are:

- The cost of labor in China has been increasing in the recent years, and many companies are opting for automation;
- The Chinese government is implementing a strategy called ''Made in China 2025'' which aims to make China the most technologically developed country in the world by 2025;
- China holds the first place in the world in terms of car production, where most industrial robots are used.

Robotic technology is the basic technology of Industry 4.0, which is indicated by the research that shows that the automotive industry production processes will become ''smart'' production processes in the years to come.

Industry 4.0 has a significant impact on the automation of production processes, by causing numerous changes in three segments: companies, technology and workers. Developed countries worldwide have their own strategies on Industry 4.0, which offer guidelines on its implementation in production processes, with the aim of their complete flexible automation. The core technologies on which Industry 4.0 rests have led to a complete transformation in production processes, especially in the automotive industry. The basic technology of Industry 4.0 is robot technology, i.e., the implementation of industrial and service robots in production processes. The paper provides an analysis of the implementation of industrial robots and service robots in the automation of production processes in the automotive industry with a focus on China. The analysis of the automation of production processes of the automobile industry in China was carried out for two reasons. The first is that China has a growing middle-class population, so demographic trends are encouraging the growing demand for certain products, such as cars. Another reason is that in China (as in Japan, Russia and Western Europe) the average age of factory workers is increasing (the labor force is older), thus the performance of certain tasks becomes more difficult so greater efficiency is not achieved. The paper analyzes vehicle production in China, as well as the readiness of production processes in the automotive industry for the implementation of Industry 4.0.

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ANTI-WHEEL SLIP DEVICES

KEYWORDS:

When moving tracked and wheeled vehicles off-road, due to the low grip of the wheel with the surface, slippage increases, which makes the use of the machine ineffective or completely impossible due to the fact that the traction force exceeds the forces of adhesion of the wheel or track to the surface of the road or soil. Slippage can begin after an increase in torque or a decrease in traction associated with a change in the properties of the road surface (layer of water, dirt, ice) and wheel load (usually due to maneuvering). Slipping is the cause of failure of the transmission elements, since when the engine of the car is stalled, it works at high speeds, leading to overheating of the flywheel of the engine (clutch) and gearbox (gearboxes), gearboxes, friction pads, failure of the cardan shafts.
One of the directions for improving the adhesion characteristics of wheeled vehicles 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 work. 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.
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]. The adhesion coefficient is also affected by the tread pattern of the tire [8]. Various techniques to reduce wheel slip, given in the article, were taken from the personal experience of drivers, and the illustrations were 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. To increase traction, various devices installed on wheel tires are also widely used, increasing the depth of the tread (spikes), chains, linings).
The use of traction control devices to reduce wheel slipping belongs to the category of their modernization. Device to reduce their slippage. They are removable and stationary – for example, a wheel with retractable roof hooks [9].
The device proposed by us (see figure) refers to the undercarriage equipment for pneumatic wheels and is designed to reduce their slippage.
In the proposed device, the wheel hub is fixed with a pneumatic cylinder, to the piston of which a fixed guide is attached in the piston cavity freely moving through the hole, and on the guide there is a bushing 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 base of the hydraulic cylinder a and the piston there is 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

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different depths, which leads to uneven ground shear forces under the lugs. Extension of lugs is possible due to an additional pneumatic actuator device when air is discharged from the wheel.
The calculations carried out showed that in order to ensure the movement of the wheel on loose soil without slipping, the proposed device is placed in the amount of 2 ... 6 pcs. in diametrically opposite ends of the wheel, protruding beyond the surface of the tire.

SECTION C

Driver/Vehicle Interface, Information and Assistance Systems

- Communication & Informatics
- Noise & Vibration
- Human Comfort & Thermal Management
- Vehicle Security & Occupant Protection
- Driver Assistance & Information Systems

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MEASUREMENT NOISE LEVEL OF E-BUS HIGER KLQ6125GEV3 ON THE POLYGON

KEYWORDS: noise level, E-bus, environment

Buses for public city transport in cities represent a significant source of noise, especially in the central city zones, on the traffic corridors with the highest hourly frequencies of public transport vehicles. The introduction of electric buses is one of the possible ways to reduce noise. The paper will present the results of the experimental measurement of noise levels of e-bus Higer KLQ6125GEV3 on the polygon, using the Lutron SL-4001 measuring instrument, following UN ECE 51.02 regulations and a comparison with the results of noise levels measurement with buses on diesel and CNG driveline.
Conventional public transport buses are a significant source of noise, especially in central urban areas. The term noise means an unwanted sound, ie a sound phenomenon (noise, noise, etc.) that interferes with human activity. Noise in vehicles occurs as a result of work: drive unit, transmission, exhaust system, tires, brakes, aerodynamics, auxiliary systems on the vehicle. Noise emissions from buses can be viewed in terms of environmental impact (external noise) or driver impact and passenger comfort (internal noise).
Measurement of emission noise emitted by E-bus Higer KLQ6125GEV3 performed in accordance with UN ECE 51P Regulations, at the prepared polygon within the tram depot "Sava" JKP GSP "Belgrade", using a digital measuring device Lutron (Lutron SL-4001 Digital sound level meter).
The measured value of the emitted noise when the vehicle is stationary is 63.1 dB. The measuring device was placed at a distance of 0.5 m from the middle of the vehicle, observed from the left side of the vehicle.The values of emitted noise from the moving E-bus at speeds of 30 $km\cdot h^{-1}$ and 40 $km\cdot h^{-1}$ were measured. The values of the measured noise levels that had the greatest mutual homogeneity are shown in Table 1 [15].

Table 1. The noise emission level of the E-bus Higer KLQ6125GEV3

Side of the E-bus	Measurements	Speed, 30 km·h-1 dB	Speed, 40 km·h-1 dB
left	1.	67,4	70,4
	2.	67,5	70,5
	3.	67,4	70,3
right	1.	67,2	69,8
	2.	67,1	69,8
	3.	67,2	69,6

The table concludes that the level of emitted noise of the E-bus in the direction K'-K (left side of the E-bus) has a slightly higher value. In the E-bus, electric motors (two electric motors) a summation transmission, Cardan shaft, and

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the main gearbox with a differential are centrally located in the rear part of the wheelbase before the drive axle. Noise from these components is emitted evenly on both sides. The position of the auxiliary electric motors for the compressor and hydraulic drive is on the left side of the vehicle in boxes located in front of the driveshaft, so their work affected the noise level in the K-K direction (left side of the E-bus) to be slightly higher. The average noise level emitted at a speed of 40 $km \cdot h^{-1}$ is higher by 2.7 dB compared to a speed of 30 $km \cdot h^{-1}$.

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THE ERGONOMIC ASPECTS OF A PASSENGER CAR CLIMATE CONTROL PANEL

KEYWORDS: thermal comfort, HVAC, control panel, motor vehicle, driver-vehicle-interface

To achieve and maintain comfortable thermal environment inside the passenger compartment, the motor vehicles must have an efficient heating, ventilation and air-conditioning system (HVAC). This problem is especially notable in electric (EV) and hybrid vehicles (HV) because of the influence on the driving range. Ambient conditions as well as individual thermal preferences could be very different, making necessary wide range of possible HVAC settings in terms of thermal conditions control inside the vehicle cabin. A driver must be able to control the HVAC system while driving, depending on the current thermal conditions, sensation and preference. The HVAC system adjustment is done via the climate control panel (CCP) as a part of driver-vehicle-interface (DVI). The CCP configuration is characterized by the control type, layout and location. The HVAC control panel could be very complex, in close relation with the complexity of the vehicle thermal management system. The parameters that can be adjusted are air flow temperature, fan speed, air flow direction, ventilation intake air mode (outside or recirculated), air-conditioning on and off, windshield demisting, rear window heating as well as other options, depending on the system configuration.

In this paper, the CCP's of several typical compact/middle class family cars are analysed and discussed in terms of the ergonomic characteristics using the heuristic approach: findability (visibility, grouping), reachability, identification (logical grouping, labelling, graphics, tactility, discrimination), interpretability, operability and understandability. Although there is an evident tendency to replace secondary controls and displays with touch screens, regarding the design and content of the touch screen, a vehicle is not (and must not be) a smart phone on four wheels. Moreover, the touch screens could be considered as less suitable for complex tasks like HVAC adjustment while driving than use of physical controls. From that reason, the focus of this study is on the CCPs realized mostly as a cluster of individual physical controls. The results of the analysis and recommendations from the available literature are compiled in form of general recommendation for user-centred design of the CCP by considering the ergonomically suitable solutions. The passenger cars whose CCPs are used in the study are Fiat Tipo, MY 2015 (manual and automatic climate control: ACC), Ford C-Max HV MY 2013 (ACC), Mercedes Benz A-class, MY 2020 (2-zone and 3-zone ACC), Opel Astra MY 2016, (manual and ACC), Renault Captur, MY 2020 (manual and ACC), Volkswagen Golf, MY 2016 (manual and ACC), Toyota Corolla hybrid, HV, MY 2020 (ACC), BMW i3, EV, MY 2018 (manual and ACC), Kia E-Niro, EV, MY 2020 (ACC) and Nissan Leaf, EV, MY 2020 (ACC).

Visibility and grouping: A typical location of the CCP on the lower part of the central console (center stack) is outside of the driver's centre field of view. Although the CCP is visible from the driver's seat, the controls must be often used with looking at it. In addition, on CCP's with digital control an infinitely rotary knob or button is used to control temperature or fan speed. In those cases, the temperature or fan set value must be read on display which could be positioned away from driver's direct field of view. The better option is a design where an each change of settings is shown in the main info-display located closer to the driver's view line.

Identification: Use of symbols instead of text for describing control's function is more preferable way. However, increasing of a symbol complexity within the available control space may present a problem in the control identification, without previous familiarization. Beside of the labelling according to the standard, a shape coding is also used, although a "typical" shape for some control actually does not exist. The better results for the continuous adjustment (temperature, fan speed) are supposed to be achieved with rotary knobs, compared to the push buttons. However, there are CCPs that have only push buttons. The ergonomic recommendation is that controls that are to

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be used quickly should be placed closer to the driver and to be distinctive in shape or appearance. Those are controls for activation of demisting or air recirculation. On the most of the CPPs this is not a case and they are blended with the rest of controls, probably due to the aesthetic reasons. Some text labels or pictograms could look similar, demanding longer glances and drawing more attention to decide which to activate. This problem is more evident when the controls are cluttered and/or placed next to each other.

Interpretability and operability: A direction of motion of a control should be logical and suggestive according to its function and the operation. Actuation of the climate controls for temperature and fan speed is according to the direction of motion stereotypes: clockwise/up/right for "increase" (the standard ISO 12214: Road vehicles - Direction-of-motion stereotypes for automotive hand controls). However, in order to set the air flow distribution mode using either rotary or push control, a driver must look on the control and/or on the visual indication, because of the size and similarity of the pictograms. This is especially evident if single push button is used for sequential mode selection. Important issue regarding the operability is a climate control for the rear seat row. Typical solution in small-, compact- and middle-class cars is that driver has full control over the climate in the whole passenger compartment. Therefore, the climate setting relies on the feedback from the passengers from the rear seat row as well. The HVAC system has one evaporator and one blower while the air distribution is a way to achieve desired thermal conditions on different points in the cabin space. Four zones HVAC is a feature of high-class vehicles, which in turns have more complex HVAC system (several heat exchangers and evaporators, more than one blower).

Understandability: The adjustment time will differ depending on that is the driver familiar with the vehicle controls or not. Previous knowledge about the basic controls is expected (temperature, fan speed), usually originated from the use of home air-conditioning devices. Without the automation, a driver must be able to adjust car's HVAC using at least three or four controls (temperature, fan speed, air distribution mode, and air direction from the individual vents) and to change settings while driving. Sometimes he or she must operate additional controls such are temperatures in passenger zones, electric heater(s), seat ventilation etc. Although the use of standardized labels, pictograms and shapes facilitate the initial understandability of individual functions, the proper setting and the use of a HVAC system is described and explained in the car's owner handbook. The designation of the controls is not suggestive in a way of a proper setting according the current conditions and desired thermal sensation. The user could not be familiar with suitable settings of all parameters which should result in thermal comfort inside the cabin.

As main ergonomic downsides of the analyzed CCPs are lack of standardized layout, too many cluttered controls and the controls which demand a visual guidance for the operation, to mention a few. The CCP should be designed in such a way that it is to be used by end user (common driver), not by HVAC engineer. Past and current CCPs offer a control of every part of the HVAC system, making the CCP very complex. Of course, automatic mode makes unnecessary use of the most of the controls, except of the temperature control. Some of the recommendations would require changes in the HVAC system or cabin interior design. The CCP solutions proposed in the paper must be tested using the subjects in a driving simulator to analyse time required to adjust the system, to collect subjective responses and to determine the influence on the driver's performance and workload compared to the conventional CCPs.

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INVESTIGATION OF THE PERMITTED LEVEL OF DAMAGE OF VEHICLE SAFETY GLASS

KEYWORDS: safety glass, level of damage, technical inspection

Glass plays an important role as active and passive elements of a vehicle safety. That is why the automotive industry uses the so-called safety glass. It is called safety glass because when damaged, it does not create sharp edges that can cause injuries to drivers and passengers, but scatters into many small pieces that are not dangerous (tempered glass) or pieces remain attached to the central foil (laminated glass). Rulebook of the European Commission R43 - *Uniform provisions concerning the approval of safety glazing materials and their installation on vehicles*, provides definitions of materials used in the manufacture of glazing for vehicles, definitions of glazed surfaces and their geometric characteristics, characteristics that must be met through prescribed tests, marking methods. According to the Rulebook R43, safety glasses are made as tempered (mainly side car windows) and as laminated (mandatory windshield).
Damage of the windshield is a common occurrence in a traffic. A cracked windshield can break at any time, which can seriously jeopardize driving safety. According to the fact that smaller damages can be located at such location on the windshield so they do not interfere with the clear visibility of the driver's field of vision, there is a dilemma - what level of damage of the windshield is acceptable without jeopardizing the safety of the vehicle. Using available literature data, regulations and standards applied in other countries, the goal of our research was to set the limits of permissible damage to windshields that do not endanger the safety of the vehicle and do not affect the evaluation of the vehicle's roadworthiness during its technical inspection.
Methodology:Studying the international standards related to safety glasses, using the available literature and analysing the experience of others countries, especially EU countries that have high standards in traffic safety, the testing methodology and the permissible level of damage of windshields were defined by the technical inspection professionals. This methodology was adopted by the state institutions (Ministry of Transport and Communications of Bosnia and Herzegovina) and published in Rulebook No. 83/20, (Official Gazette of BiH).
Results and discussion: According to the defined methodology for testing the windshield, the permissible limits of damage are determined depending on the category of the vehicle and the position of the damage on the windshield. In order to uniformly define the position of damage, the windshield is divided into three zones - A, B and C:

- Zone "A" is the area of the windshield that represents the driver's direct field of vision. The boundaries of this zone are determined as the area of the windshield which could be swept by the wipers. This is 290 mm wide area for vehicles of categories M1 and N1, or 350 mm wide area for vehicles of categories M2, M3, N2 and N3, measured so that the central axis of the steering wheel also represents the central axis of this area.
- Zone "B" is the rest of the windshield surface swept by the wipers.

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- Zone "C" is the rest of the windshield surface, which is out of zones "A" and "B".

Template for determining the level of windshield damage: In order to assess the size of the windshield damage, a single tool - a template - has been defined. The template is in the form of a ruler with a length of 290 mm, for vehicles of categories M1 and N1, or 350 mm for vehicles of categories M2, M3, N2 and N3.
Checking of windshield damage is done so that the inspector, sitting in the driver's seat, places the template on the windshield so that the center line of the template coincides with the center axis of the steering wheel. Then, with the wipers sweeping across windshield, the zones on the windshield are determined depending on the vehicle category (zone A, B or C). Using the template having drawn circles (damage limits), it is checked whether the damage on the windshield exceeds the permissible limits prescribed for defined zones and specific vehicle categories.
Failure due to windshield damage is only justified if the damage significantly affects the driver’s view of the road. Especially critical area is the area of the driver's direct field of vision, so maximum damage below 10 mm in diameter is allowed in that zone. In other zones, greater damage is allowed depending on the type of vehicle. Also, if the damage is in the form of a crack, it is necessary to check its tendency to spread. However, even though the damage is not large, it is very important that the driver or the owner of the vehicle carry out the repair as soon as possible after the appearance of the damage, because getting dirt into the cracks reduces the quality of repair.

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SIMULATION OF PEDESTRIAN THROW DISTANCE IN THE SOFTWARE PACKAGE PC-CRASH - COMPARISON WITH EXPERIMENT AND THEORY

KEYWORDS: accidents, distance of pedestrian rejection, PC Crash software package, vehicle speed

Pedestrians are the most vulnerable group of road users, especially because of their bodily insecurity. The increased number of traffic accidents involving pedestrians is the result of the increase in vehicle speed. Pedestrians account for about 24% of all seriously injured people in traffic, and when it comes to minor injuries, pedestrians account for about 11%.

The collision of vehicles and pedestrians leaves traces on both the vehicle and the pedestrians in the form of structural damage and in the form of injuries to the body. In order to determine the circumstances under which the accident occurred, it is necessary to analyse the both participants (the vehicle and the pedestrian). Due to the difference in mass between vehicles and pedestrians, as a result of an accident, pedestrian injuries are always more significant. In order to analyse the distance of pedestrian throw using the PC Crash, pedestrian modelling with body dimensions was performed, in the Multibody module. It is possible to get accurate information about the characteristics of the vehicle and the speed of the vehicle within the software database. Seven different vehicle speeds were taken into account: 38.46 km/h, 39.27 km/h, 43.61 km/h, 34.12 km/h, 55.04 km/h, 61.15 km/h and 64.86 km/h, while the weight of the pedestrian was 67 kg and the height was 1.78 m. The total weight of the vehicle was 1872 kg. Experimental data were taken from literature for the purpose of comparison with simulation data.

In this paper, the frontal collision of vehicle (Ford Crown Victoria 2005) and pedestrian was analysed. Based on various tests, the most commonly used theoretical dependence between the vehicle collision speed and the pedestrian throw distance can be presented in the following form:

$$S_{od} = \frac{v_s^2}{144}\left(\pm 10\%\right) \quad (1)$$

where:

S_{od}, m - distance from the place of collision to the final position of the pedestrian (pedestrian throw distance) and

v_s, $\frac{\mathrm{m}}{\mathrm{s}}$ - impact speed.

Value 144 in equation (1) has the dimension of acceleration. Research has shown that equation (1) can be used for real accidents, but the results deviate by ± 10%.

In this paper, empiric Dekra formula (2) is used for the analytical calculation of the pedestrian throw distance and various comparisons:

$$s = 2.5 + 0.38448 \cdot v + 0.05858 \cdot \frac{v^2}{a_{car}} \quad (2)$$

where:

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$v, \frac{\mathrm{m}}{\mathrm{s}}$ – impact speed,

s, m – pedestrian throw distance and

$a_{car}, \frac{m}{s^2}$ – average car deceleration.

The obtained PC Crash software results for the pedestrian throw distance depending on the impact speed of the vehicle are shown in table 1, together with the data obtained experimentally and analytically.

Table 1. Values of pedestrian throw distance for different vehicle speeds

Test number	Vehicle impact speed, km/h	Pedestrian throw distance, m		
		Experimental	Analytic	PC Crash
1	38.46	10.61	10.49	10.54
2	39.27	11.34	10.84	10.94
3	43.61	14.78	12.74	13.25
4	34.12	9.05	8.76	8.65
5	55.04	17.53	18.48	16.98
6	61.15	24.75	21.95	22.90
7	64.86	26.03	24.20	25.23

Based on table 1, it can be concluded that, as the impact speed of the vehicle increases, so does the throw distance of pedestrians. This increase was observed in all three types of analysis: experimental, analytical, and in the PC Crash program, figure 1.

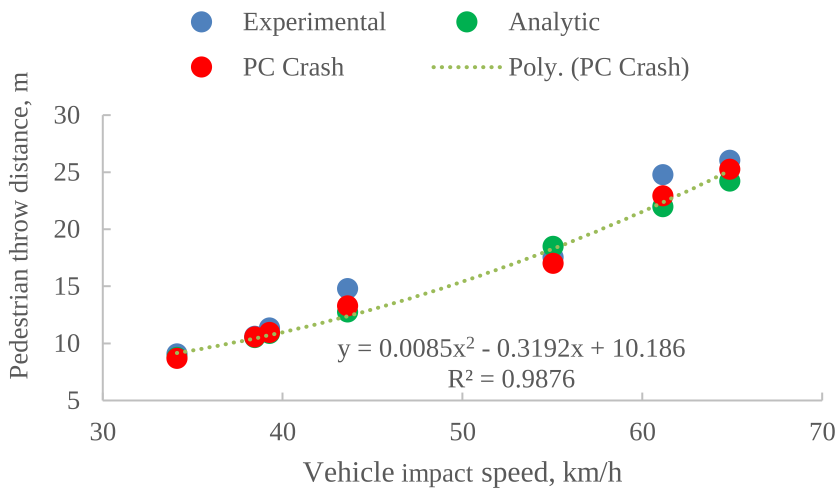

Figure 1. Pedestrian throw distance depending on impact speed.

Figure 1 shows a strong (parabolic) correlation between the pedestrian throw distance and the vehicle impact speed in PC Crash simulation results (R^2=0.9876). The smallest value of the pedestrian throw distance of 8.65 m was obtained numerically, using the PC Crash program, for impact speed of 34.12 km/h. The highest value of the pedestrian throw distance of 26.03 m was obtained by experimental determination, for impact speed of 64.86 km/h. The application of computer programs for the analysis of traffic accidents enables a more precise analysis of the elements of the traffic accident, taking into account the place of the collision, the collision speed as well as the circumstances under which the traffic accident occurred. Based on various comparisons, it was found that the pedestrian model in PC Crash gives good estimates for determining the pedestrian throw distance, better than analytical model. Different vehicle shapes and pedestrian kinematics can be taken into account in the analysis. The pedestrian model in PC Crash proved to be easier to analyse, compared to the analytical way of analysis, because all the parameters that influenced the occurrence of the accident could be taken into account.

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IN-VEHICLE COMFORT ASSESSMENT DURING FORE-AND-AFT RANDOM VIBRATIONS BASED ON ARTIFICIAL NEURAL NETWORKS (ANN)

KEYWORDS: comfort, vehicle, r.m.s. accelerations, ANN model

During driving, certain forces are transmitted from the road to the vehicle in the form of vibrations. The appearance of these vibrations is felt by the driver and passengers and can lead to a feeling of discomfort. In this work, the ISO 2631 standard was used, on the basis of which the comfort criteria were defined.
The role of vibration measurement is to record the movement of the body as a reaction to some kind of stimulus. Whole body vibration is particularly significant in the frequency range from 1 Hz to 80 Hz. In this frequency range are also the main resonance points of certain organs and parts of the human body (e.g., head, eyes, stomach and spine). In this paper, based on the obtained experimental results, an ANN model was created in order to evaluate the oscillatory comfort of the human body.
In the first part of the work, experimental research was carried out. Causing excitation of different amplitudes and frequencies was achieved using an electro-hydraulic pulsator HP-2007. A portable vibration analyzer NetdB1 was used to measure the transmission of vibrations from the seat through the human body. Twenty male healthy subjects, with mean age 30.7±6.15 years, height 183.25±4.43 cm, weight 89.4±11.72 kg, BMI (BMI Body Mass Index) 26.57±2.96, seating height 88.35±4.79 cm, were exposed to random vibrations of the whole body for three excitation values 0.45, 0.8 and 1.1 m/s^2 r.m.s., in the frequency range 0.1-20 Hz. The angle of inclination of the backrest was 90°. The duration of each experiment was 60 s, and the number of repetitions was 2.

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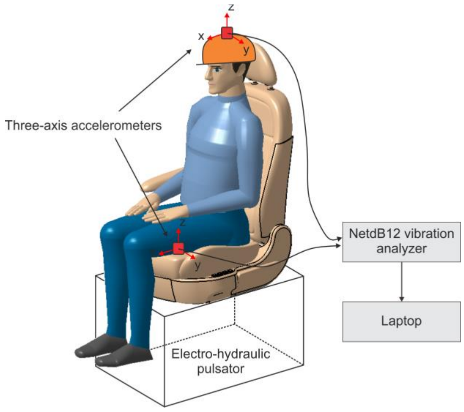

Figure 1. A scheme of the laboratory setup of the experiment.

The second part of the work was dedicated to artificial neural networks. Neural networks are formed in which the outputs of the neuronal elements of the following layers have synaptic connections with the neurons of the previous layers. This leads to the possibility of taking into account the results of information transformation by the neural network in the previous stage for processing the input vector in the next stage of the network operation. The data for training the neural network were data obtained from experimental measurements of 20 subjects exposed to random fore-and-aft vibration for three excitation amplitudes. Each subject was characterized by BMI, height, weight, sitting height and age (Fig. 2). The mean absolute error was used as the loss function in a training phase, while the effective Adam optimization algorithm was used to search for the minimum of the loss function.

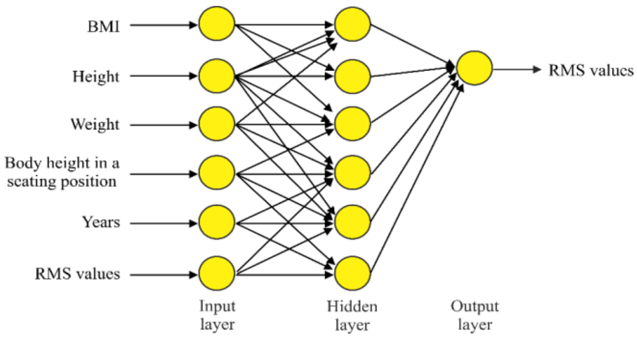

Figure 2. A scheme of a LSTM recurrent neural network.

The ANN model was trained with 100 training epochs, while the data series size was 20. The coefficient in training, validation and testing was over 98% for all types of stimuli. The root means square error of the predicted r.m.s. value was 0.024. R.m.s. the values of the original and the values after the process of training the network, for the fore-and-aft excitation, of the male subject under ID number 20, are shown in table 1.

Table 1. Prediction results of r.m.s. values of the male subject under serial number 20 for excitation in the fore-and-aft direction.

	0.45 m/s^2 r.m.s.		0.8 m/s^2 r.m.s.		1.1 m/s^2 r.m.s.	
	Original	Predicted	Original	Predicted	Original	Predicted
R.m.s.	0.362	0.347	0.705	0.682	0.967	0.974
Comfort rating (ISO 2631)	A little uncomfortable	A little uncomfortable	Fairly uncomfortable	Fairly uncomfortable	Uncomfortable	Uncomfortable

The developed model of artificial neural network shows that it has adequate precision of biodynamic modeling. The main feature of the ANN model is to consider height, weight, sitting height, BMI and age during whole body vibration exposure.

The complexity of the model, which takes into account different anthropometric characteristics of the subjects, as well as different vibration amplitudes, is not a problem, but highlights the ability of the model to predict oscillatory comfort via r.m.s. values, in the time domain, defined by the ISO 2631 standard. Future research will go in the direction of investigating the influence of the change in the angle of inclination of the seat back on the r.m.s. values, as well as determining the most influential factor on the response of the human body to the vibrations of the whole body.

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OPTIMIZATION OF THE AIR DISTRIBUTION SYSTEM IN MOTOR VEHICLE CABIN USING COMPUTATIONAL FLUID DYNAMICS

KEYWORDS: HVAC, pressure drop, CFD, adjoint optimization

The paper presents the application of CFD software for simulating the conditions that prevail inside the air distributor of the vehicle's ventilation system with the aim of increasing the efficiency of the distributor. The simulation results were validated based on the experimental data found in the literature. Based on the results of the simulation, the geometry of the distributor was optimized with the aim of reducing the pressure drop through the ventilation system. It was found that optimizing the distributor geometry to some extent can provide a more energy efficient ventilation system.
Within the air distribution system there is a relatively large number of elements and obstacles of complex geometry. The result is local losses that occur with each change of the velocity vector. In the characteristic places where losses occur, in general, there is a local pressure drop. The total pressure drop represents the sum of local losses that occur between the point of air inlet into the ventilation system in the engine compartment and the point of air outlet at the cabin ventilation openings. The subject of study in this paper is one of the system segments, the air distributor.
In order to approach the CFD analysis of the air flow through the distributor, the 3D model was formed on the basis of real dimensions of distributor. After the model is imported into the CFD software, boundary surfaces are defined. Inlet boundary surface is set to be velocity inlet. Defined value for the velocity inet is 6,435 m/s. By analyzing the experimental data from literature, it was concluded that the most pronounced pressure drop occurs when the side vents are open, at maximum fan speed. Same case is analyzed within the paper because in that regime the greatest improvement is expected in terms of the reduction of flow resistances that are a consequence of the geometry of the distributor. In order to be able to validate the simulation results with experimental data, the same properties of the boundary conditions are used as in the literature. After defining boundary conditions, the mesh is generated. The properties selected when defining the mesh are as follows: surface remesher, polyhedral mesher, automatic surface repair, thin mesher, prism layer mesher. In order to determine whether the formed mesh is fine enough, or too fine, the independence of the mesh was examined. The study was performed for fourteen different mesh settings from the coarsest setting forming a mesh of 73788 cells to the finest setting forming a mesh of 1222716. By observing the results, it can be noticed that the results are stable when the mesh consists of 500,000 or more cells. The mesh

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generated according to the specified parameters contains 509933 cells. Since the problem being analyzed is the flow of air through pipes, it is a three-dimensional problem, air is a gas that moves at a relatively low speed, so it can be considered incompressible and its flow is steady. The model that in this case is used is Realizable K-Epsilon model, with activated All y+ Wall treatment and Wall distance. Most important quantity to monitor is the distributor pressure. Based on the pressure difference at the inlet of the distributor and the outlet from the corresponding line, data on the pressure drop for a specific case can be obtained. When defining the boundary conditions, the static pressure that prevails in the cabin is defined at the entrance as 102375 Pa, however, the total pressure is the one that is valid when determining the pressure drop. The total average pressure at the entrance is 102521 Pa, and at the exits from the lines it is: left - 102432 Pa, right - 102433 Pa. In Figure 1, it can be observed that the lowest pressure occurs in the bifurcation zone as a result of flow separation, as well as that the pressure at the central openings is higher than at the side openings, which is a consequence of the central ventilation openings being closed. The value of the pressure drop for the left and right lines is, respectively, 88.79 Pa and 87.89 Pa.

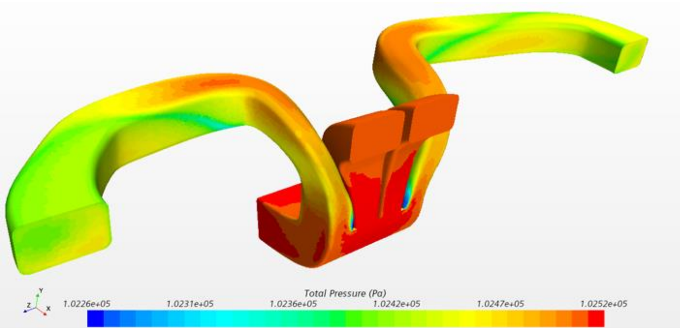

Figure 1. Pressure drop through air distributor (STAR-CCM+)

Adjoint analysis, which is conducted, is an effective way to predict the influence of structural characteristics and input physical parameters on some engineering quantity of interest for a specific problem. This method is applied to determine how much influence distributor geometry has on pressure drop. The optimized geometry (Figure 2) of the distributor is more complex compared to the original one, where it is important to emphasize that the position and shape of the ventilation openings in cabin and the inlet opening have remained unchanged. Through optimization, the pressure drop through the left pipe was reduced from 88.79 Pa to 62.89 Pa (29%), and between the inlet and outlet of the right pipe from 87.89 Pa to 73 Pa (17%).

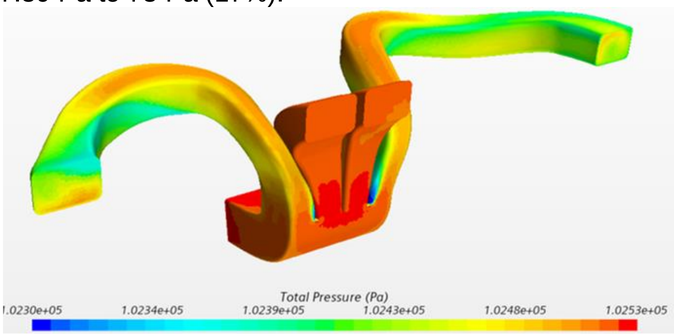

Figure 2. Pressure distribution inside the modified air manifold (STAR-CCM+)

The results showed that by applying adjoint optimization in the specific case, a reduction in pressure drop from 17% to 29% can be achieved. Although in the analyzed case the mentioned improvement of the geometry of the distributor have a relatively small effect on the efficiency of the air distribution system, if the described procedure were applied to the rest of the ventilation system, a significant improvement could be achieved. Also, considering the large number of mass-produced vehicles whose efficiency can be increased, the energy savings that can be achieved in this way are significant.

ACKNOWLEGMENTS: This research has been supported by the Ministry of Education, Science and Technological Development through project no. 451-03-9/2021-14/ 200156: “Innovative scientific and artistic research from the FTS activity domain”.

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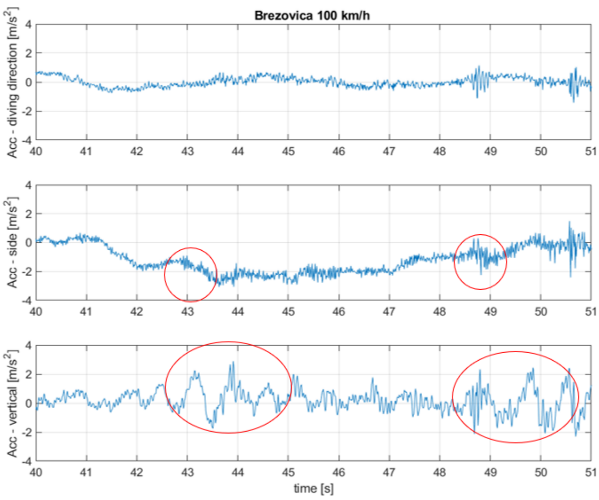
THE INFLUECE OF STEP SHAPED ROAD SURFACE ON SAFETY WHEN DRIVING IN A BEND ON THE ROAD

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

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. 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 following figure:



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, shown is 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% ($F_{fr} = m \cdot g \cdot \mu = m \cdot (g - a_{vertical}) \cdot \mu$). Further in this work the practical cases are shown and analysed. From those we will 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).

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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.

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SIMULATION OF A PEDESTRIAN COLLISION AVOIDANCE USING THE PEDESTRIAN PROTECTION SYSTEM

KEYWORDS: autonomous vehicle, critical scenario, pedestrian collision avoidance, Simcenter Prescan

Autonomous vehicles are a growing concern nowadays, therefore the knowledge and expectations regarding pedestrian safety have risen substantially. Additionally, ensuring pedestrian safety has become a crucial requirement for autonomous driving. The current research focuses on the contribution of the Pedestrian Protection System (PPS) in the prevention of pedestrian collision impact. The simulation technology that Simcenter Prescan and Simulink are providing, has been used to develop the virtual traffic scenario which highlights the performance of the main sensors: camera and RADAR (radio detection and ranging). The Simcenter Prescan simulation framework includes realistic vehicle dynamic models and virtual traffic infrastructure along with sensors that were placed in several locations on the vehicle to capture the position of the pedestrian. Three variations of speed were analysed in order to observe where the collision is avoided considering the safety conditions. The results of the considered speed were primarily observed using the visualization output of the sensors from the PPS system. To develop trustful autonomous vehicles, it is fundamental to incorporate efficient pedestrian crash avoidance systems that increase traffic safety.

Vehicles that have a high level of performance must assure and operate within the limits of safety without affecting the good well-being of the participants in the road traffic. The development of the autonomous vehicle systems relies on the conception of a large range of critical scenarios that can cover a highly possible situation that can occur in real life. Critical scenarios are an important milestone in terms of safety for the automated vehicle system in order to strengthen the design but also to the verification and validation stages. As autonomous vehicle performance has increased in a vast range of scenarios, it is crucial to find events where the systems are likely to drop to cover even the most unfeasible events.

One important system that has huge importance in people's live and it is of very interest to researchers as well as to industries is the pedestrian protection system which is used mainly for avoiding the collision between the vehicle and a pedestrian. In advance of a certain frontal collision, the pedestrian protection system is activated by the feedback of the sensors which is sending a warning to the driver and changing the behaviour of the vehicle. PPS (Pedestrian Protection System) is based on a combination of sensors, primarily camera and radar which offers a high potential for eliminating fatalities and detecting the pedestrian and its position. The PPS relies on multiple advanced technologies like brake assistance, driver caution and control collision avoidance which are in high demand in the automotive industry and in continuous need of improvement. Therefore, a safe automated vehicle is required to have a robust algorithm whose performance is capable of dealing with all types of events, especially in critical situations. This study presents an approach to increase the knowledge about the weak and strong points of the pedestrian

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protection system and investigate the response in a critical situation where a pedestrian is crossing the street in an unmarked space.
The simulations in this research have been carried out by using Simcenter Prescan and one of Matlab's modules, Simulink, to design and simulate autonomous vehicles which were exposed in critical safety scenarios and analysed from a safety point of view. Simcenter Prescan is a software that focuses on solving a large variety of automated vehicles functionality based on real-world traffic scenarios (roads, infrastructure, weather, road signs, pedestrians). Also, it has a substantial number of automated systems that contains sensors along with algorithms for data processing, decision making and control, used to design a more realistic simulation that can be later compared with results from physical experiments.
The current study presents an automated vehicle which avoids a collision with a pedestrian. Three variations of speed were analysed in order to observe where the collision is avoided considering the safety conditions. The results of the considered speed were primarily observed using the visualization output of the sensors from the PPS system. To develop trustful autonomous vehicles, it is fundamental to incorporate efficient pedestrian crash avoidance systems that increase traffic safety. The focus is on the effectiveness of the pedestrian protection system (PPS) with the main purpose of assuring the avoidance of collision with the pedestrian and contributing to a highly safe automated system traffic environment.
The scenario presents an Audi A8 which is entering a roundabout, moving forward, and avoiding a pedestrian walking across the street in an unmarked location. The vehicle has a Technology Independent Sensor or TIS, which is used to increase the performance of the radar sensor at a system level. This sensor has a great impact on the performance of the tracking and tracing algorithms by validating the standard specifications of the active scanning sensors. Together with the TIS is attached a camera on the front part of the vehicle in order to capture the object along the road. The main system which is required to react in this study to avoid the collision with the upcoming pedestrian is the PPS. The pedestrian protection system uses two essential sensors in order to reduce the severity of the collision or to completely avoid: the camera and a radar. The PPS algorithm based on the data received till the moment the object appears in the range of the camera will consider that the vehicle is moving strictly forward to determine the point where the collision will take place. The time to collision (TTC) is used in this situation as a core value to be calculated and the results are compared with the set values. TTC is defined as the time needed for two vehicles to collide if these two vehicles meet. The minimum value of TTC is an indicator for the severity of the encounter and a lower value of TTC indicates a higher risk of collision. If the time of the collision between the vehicle and the object is below 2s the contact is considered dangerous. Certainly, there is a difference between an object and a pedestrian, and therefore the pedestrian detection algorithm relays on the camera sensors in order to determine whether the object is a pedestrian.
In this paper, a critical scenario is presented where a vehicle runs at various speeds and encounters a pedestrian crossing the street. The vehicle is analysing the object and determining if the object is a pedestrian using the Pedestrian Protection System. The result of this study shows the output of the PPS at different speeds, providing a larger view of the capabilities and limitation of the system.

SECTION

D

Vehicle Dynamics and Intelligent Control Systems

- Aerodynamics
- Vehicle Ride and Handling
- Intelligent Safety Systems
- Tires
- Braking Systems
- Steering
- Suspension

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COORDINATED CONTROL OF ESC WITH ACTIVE FRONT STEERING AND ACTIVE SUSPENSION NORMAL FORCE CONTROL FOR BETTER VEHICLE'S DYNAMIC RESPONSE

KEYWORDS: Active-Control System, ESC, AFS, NFC

Advances in vehicle technologies brought changes into architectures of integration of chassis control systems. Alongside other improvements, integration can provide better vehicle handling, stability and safety. Different chassis control systems can use different control methods. Considering while in motion vehicle has movements in longitudinal, lateral and vertical direction, different control systems target different motion. If there is no coordination among active control systems, interaction and performance conflict can arise. Studies and years of experience had proven the efficiency of electronic stability control systems, acting through individual wheel brake. ESC usually consists of two modes of operation, direct yaw control which helps the driver to maintain the desired direction of the vehicle and anti-roll control, which reduces the possibility of the vehicle to roll over. In order to improve overall vehicle performance and to reduce the load on the braking system, integration or coordinated cooperative control is introduced in numerous researches and papers. This paper presents coordination of three control systems: electronic stability control (ESC), active front steering control (AFSC) and active suspension normal force control (ASNF). ESC is actually direct yaw and anti-roll control using selective wheel braking. ASNF is considered only on front axle and AFSC changes the steering angle given by the driver. All systems use fuzzy-logic as a control method. This method is chosen because it is a knowledge-based method that mimics human skills for control of systems. It has wide application due to its convenience in the control of nonlinear dynamic systems. Vehicle is presented as 14-DOF nonlinear full vehicle model, which was developed for the study of roll dynamics by Shim and has been validated using CarSim and ADAMS/Car. For the control purposes 3-DOF reference model was introduced, to obtain the desired values upon which the control determines the error. Emphasis was given on vehicle parameters characterizing dynamic behaviour in longitudinal and lateral direction, but rollover stability was also considered. First the ESC was modelled and to avoid frequent activation β-$\dot{\beta}$ phase plane method was introduced. This model was upgraded through coordination with ASNF and AFSC separately, and then with both controls. Coordination of the ESC with AFS and ASNF control was done using scaling coefficients, so every system contributes with a certain share in dynamic behaviour corrective actions. The coefficients have been obtained by try-outs, so that the control requires lower forces that should be provided by active components and at the same time it effectively stabilizes the vehicle. Test manoeuvres used in this paper are cornering event (step input) and single lane change (one period of sinusoidal input). Also, fishhook manoeuvre, which is not included was simulated and gives the same results as single lane change. Manoeuvres were performed with initial vehicle speed of 130 (km/h).

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The speed is chosen according to the limitations in traffic regulations in the majority of European countries. Benefits of coordinated action of the three systems can be seen from the results gained through simulation in Matlab/Simulink. Results showed that during sudden manoeuvres and at higher speeds, the ESC system has the highest efficiency. Coordinated control adds to the action of ESC itself. It lowers brake torques and tire slip angles per wheel. Coordinated control gives lowest rollover angle and has least effect on vehicle speed. So, it can be concluded that coordinated control results in improved stability and handling, and thus safety of the vehicle.

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THE DETERMINATION OF THE DISC BRAKE THERMAL STRESSES FOR DIFFERENT VEHICLE SPEEDS

KEYWORDS: test rig, BRAKE DYNO 2020, temperature field, thermographic representation

From the aspect of traffic safety, the brake system is one of the most important systems. For all exploitation conditions, for which vehicles are projected, and for loads in prescribed boundaries, no matter to the vehicle speed, it is important, for the brake system to be reliable and to provide a very fast stop, or speed adjustment to road conditions. During the stop or during the speed adjustment it comes to the disc brakes temperature increment. So, because of this, the experimental investigations were conducted, in order to determine final values of the temperature for multiple braking processes until stop. Respectively, one of main questions is, will a brake system provide safe vehicle stop, no matter to the temperature of the brake disc and brake pads. Also, how much will heat up the brake disc and brake pads, in respect to the vehicle speed. This paper shows, how much are the temperatures for different vehicle speeds, as well as how the speed influences on the temperature increment. Besides these answers, the paper provides and thermographic presentation of temperature distribution on the contact surface of the brake disc. In this paper, were conducted two experimental tests for the same vehicle, but for different speeds, which were 60 km/h and 80 km/h, while the other parameters (initial temperature, the mass of the simulated vehicle, number of repetitions) were the same for both tests. The temperature field of the brake disc for the 1st and 10th braking cycle is shown on the figure 1, for the case, when the speed of the simulated vehicle was 60 km/h. While by figure 2 is shown for the case when the speed of the simulated vehicle was 80 km/h. The final temperature on the entering side of the external brake pad for the case of 60 km/h was 116.95 °C, while for the case of 80 km/h was 169.98 °C. The speed increment of 20 km/h, cased the temperature increment of 45.34 %. The highest values of the temperature appeared in the case of greater vehicle speed.
During the first braking cycle, by exit of the brake disc from the contact with the brake pad, are noticeable hot bands, on the contact surface of the brake disc, and that, one hot band for the case when the speed of the simulated vehicle was 60 km/h (figure 1.a), and two hot bands for the case when the speed of the simulated vehicle was 80 km/h (figure 2.a). The consequence of hot bands is the reduced contact between the brake disc and brake pads, which can result with the appearance of one or more hot bands The temperature of the brake disc, after ten consecutive braking cycles, in the case of the vehicle speed 60 km/h, was 114 °C, while for the case of the vehicle speed 80 km/h, was

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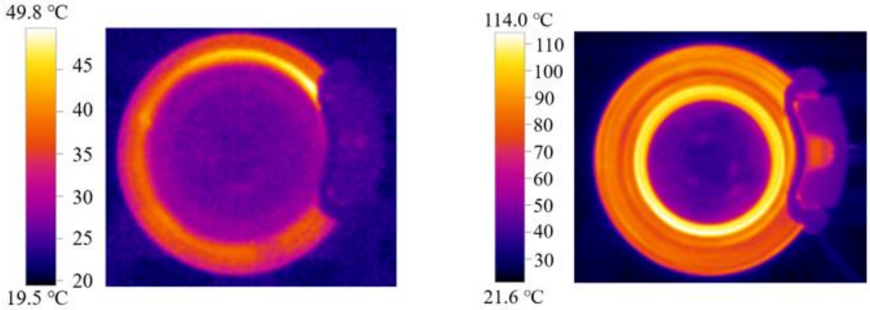
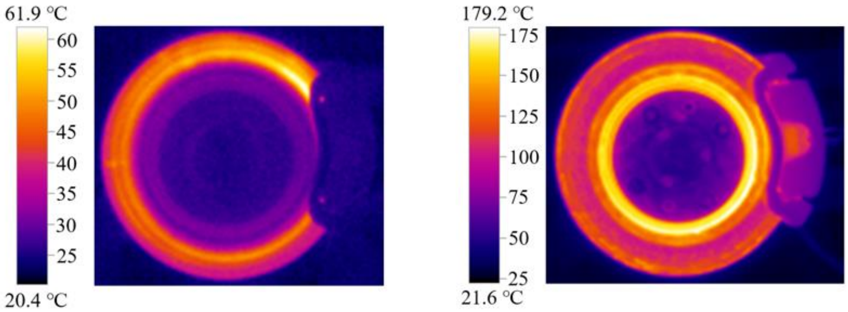
179.2 °C. The increment of the vehicle speed for 20 km/h, after ten consecutive cycles of acceleration and stop, caused temperature increment of 57.19%.



a) b)

Figure 1. The temperature field on the contact surface of the brake disc during the first and tenth braking cycle, for the case when the speed of the simulated vehicle was 60 km/h.



a) b)

Figure 2. The temperature field on the contact surface of the brake disc during the first and tenth braking cycle, for the case when the speed of the simulated vehicle was 80 km/h.

Besides that, on the basis of the type of the temperature field, which appears on the contact surface of the brake disc, comes the conclusion that in these regimes of the vehicle drive, appear the highest thermal stresses, which further influence on the mechanical stresses. Future researches should direct to the investigation of brake discs with different shape of ribs, as well as to brake discs and brake pads manufactured from alternative materials, under normal and extreme exploitation conditions.

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THE ECOLOGY-BASED OPTIMIZATION OF TRAFFIC SIGNAL TIMING ON SUPERSTREET

KEYWORDS: superstreet, ecology, microsimulation, optimization, traffic congestion

A Superstreet (also called Restricted Crossing U-turn Intersection or RCUT) is a relatively new research concept of non-traditional intersection with an alternative geometrical structure. This type of intersection became very popular due to reducing control delays and improving traffic safety because movements on the main road are carried out without opposing flows. In this paper, we treat the environmental impact of traffic on Superstreet and present the optimization of an ecology-based performance index. The mathematical model based on the Genetic Algorithms (GA) for controlling Superstreet in fixed-time control mode is developed. The number of stops on the Superstreet approach is weighted with a different penalty factor (K), which depends on traffic and geometric parameters for each movement. The geometry of a field-like Superstreet has been coded into the Vissim simulation model and used as the approach tool for the evaluation of GA and Webster signal plans. Webster's method, for calculation of the standard signal plans at the signalized intersections, is a common method applied many times in practice. We suppose a set of traffic demand patterns and carry out all necessary calculations. The results show improvements in evaluation parameters and reveal the applicability of the proposed methodology.
Intersections with alternative geometrical structures are designed to improve the safety performance of traffic flow operations. Conflicts are reduced, usually without crossover points of left turns and straight demands. But, the need for additional space and the confusing manoeuvres (at first glance) are the flaws of this concept. Additionally, it is also noticed that those intersections can improve the delay. Due to the overall increase in traffic congestion, alternative intersections are recognised as suburban traffic facilities with significant potential.

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Because of conflict point distribution from the main intersection, signal plans on alternative intersection designs are usually fixed time and simplified. As suburban facilities, alternative intersection designs are connections between urban and non-urban roads, where traffic should operate smoothly.
Superstreet is a well-known alternative intersection design, where left and straight movements from side streets are allocated to new U-turn intersections. In this research paper, we try to identify the traffic signal control problem at Superstreet from an ecological aspect. Due to increased mobility, congested and polluted urban streets are everyday issues for many people around the globe. In that sense, emissions and fuel consumption become needful performance measures in evaluations of traffic signal timing solutions.The problem of ecology fixed time optimization at the Superstreet intersection is considered. Furthermore, the proposed methodology is applied for undersaturated traffic demands.
To address the defined problem, one must answer the following question: What are the best values for cycle lengths and splits to minimise the Eco Performance Index on the Superstreet during the analysis period?
GA optimization parameters are set as follows: Crossover probability – 30%; Mutation probability – 1%; Convergence threshold – 0,01%; Maximum number of generations – 20; Population size – 20; Elitist method is included. GA is performed in the MATLAB Optimization ToolBox.
We use the following evaluation parameters to compare Webster and GA signal plans: EcoPI (including control delays and the number of stops) and the number of stops for heavy vehicles.
After the expiration of simulation time, the GA signal plans obtained better results than the Webster method. In the case of EcoPI, GA provides 8.83 % better signal plans than Webster. Compared to Webster, GA obtained lower delays of 18.13 %. In the case of the number of stops, GA provides 3.48 % better signal plans than Webster, while in the case of the number of stops of heavy vehicles the improvement is 9.29 % in favour of GA.
In this paper, in a microsimulation environment of the Superstreet, we evaluate the optimized signal plans from Webster and GA approaches. All of-line calculation was done in MATLAB. Our goal was to improve the ecological parameter on Superstreet by treating the number of stops of heavy vehicles.
The results presented in this paper have shown that it is possible to improve objective parameters using GA. Compared to the classical Webster approach, GA makes decreased the number of stops of heavy vehicles by 9.29%, while EcoPI improved by 8.83%.
Due to the results of this paper, the GA signal plans could be considered as a viable approach to executing ecology traffic control on the Superstreet. Future research should take into consideration different demand patterns (levels of saturation) under different phase plans to further justify the prosed methodology. Furthermore, it would be worthy to consider the real-time control on the Superstreet, by taking into consideration the ecological parameters.

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REGENERATIVE BRAKING ON ELECTRIC VEHICLES: WORKING PRINCIPLES AND BENEFITS OF APPLICATION

KEYWORDS:

The application of electric vehicles leads to a change in the principle of operation and functioning of some systems in the vehicle, which also lead to a change in the concept of the vehicle itself. One of those systems that has a new concept, which differs from vehicles powered by IC engines, is the braking system. The previous function of the braking system was to stop the vehicle, i.e. to reduce the speed of the vehicle in a safe way. In the case of electric vehicles, the friction brakes were retained, with the addition of a regenerative braking system that has the role of replenishing the vehicle's batteries. The regenerative braking system has the role of converting the vehicle's kinetic energy into electrical energy that recharges the batteries. This system is already used today on full electric and hybrid vehicles, i.e. on vehicles powered by an electric motor. The benefits of regenerative braking are reflected on the fact that the vehicle batteries are recharged during braking, vehicle maintenance costs are reduced, the service life of discs and drum brakes on the vehicle is extended, brake non-exhaust emission is reduced, and heat energy emission is reduced, too. The development of vehicles has led to the fact that today the sale of electric and hybrid vehicles, i.e. vehicles that electric drive or a combined electric and drive via the IC engine, is increasing. This is supported by the fact that the increasing sales of electric vehicles in the world have been on the rise in recent months and years. The use of electric and hybrid vehicles requires the use of electricity. The braking process itself leads to the conversion of electrical energy into thermal energy. In order not to waste energy, a system of regenerative braking, i.e. recuperation, was designed. This system aims to convert the vehicle's kinetic energy into electrical energy to charge the electric vehicle's batteries. Bearing in mind the application of this system on electric vehicles and hybrid vehicles, the aim of this paper is to review the principles of operation of this system, the advantages and benefits of applying this system on motor vehicles, but also the disadvantages of this system. The paper also shows the monitoring of the operation of this system by the driver, as well as the strategies for activating the regenerative braking system and the friction brakes on the vehicle.

The regenerative braking system, as well as the entire system on the vehicle, enables monitoring of the flow of power and energy by the driver. As the system recharges the vehicle's batteries, the driver has the ability to monitor the flow of power as well as the consumption of electricity, and the energy used to recharge the batteries. Figure 1 shows an example of power flow monitoring as well as electricity consumption, i.e. battery charging. The regenerative braking system and its effectiveness depend primarily on the vehicle as well as on the system itself, i.e. braking strategy and activation of the regenerative braking system. This system has a number of advantages, the most significant of which are an increase in the range of the vehicle, an extension of the service life of the friction pairs,

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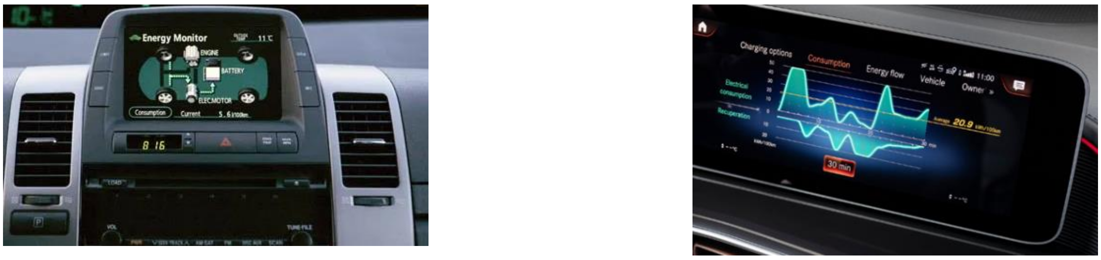
and thus a reduction in the emission of particles that occur during brake wear, and an efficient use of the vehicle's kinetic energy.



a) b)

Figure 1. Power flow monitoring, a) display of power monitoring on the driver's control monitor, b) monitoring of electricity consumption and battery charging [1, 2].

The regenerative braking system works according to the principle shown in Figure 2. Electric vehicles are powered by an electric motor, as are hybrid vehicles. Depending on the braking strategy of these vehicles that is, on the activation strategy of the regenerative braking system and the activation of the friction brakes, this system may differ. During braking, the electric motor switches to operating mode as a generator, which enables the conversion of the vehicle's kinetic energy, i.e. by turning the wheels, it starts and acts as a generator, converting kinetic energy into electrical energy, thus charging the batteries. Depending on the braking strategy, the activation of the recuperation system and the friction brakes can be simultaneous, where they complement each other, or the regenerative braking system is activated first, and then, with the increase in braking force, the friction brakes are activated.

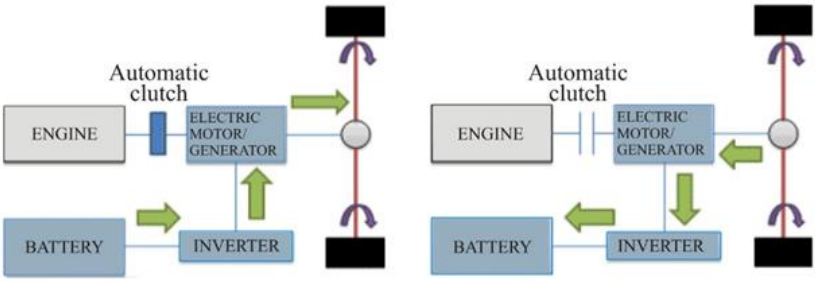


Figure 2. Schematic representation of energy flow due to vehicle acceleration and regenerative braking [3].

Modern systems on motor vehicles today, in addition to increasing safety and optimizing the operation of every system on a motor vehicle, enable the improvement of vehicle characteristics. One of those characteristics that is important for electric vehicles is the range that the vehicle can travel on a single charge. The regenerative braking system, as an integral part of electric hybrid vehicles, enables the vehicle's batteries to be charged during braking. The principle of operation of this system depends primarily on the braking strategy and the activation of the regenerative braking system and friction brakes. The advantages of this system before increasing the range of the vehicle are reflected in the extension of the life cycle of friction pairs, preservation of the environment, reduction of fuel consumption in hybrid vehicles.

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IMPROVING VEHICLE DYNAMICS EMPLOYING INDIVIDUAL AND COORDINATED SLIDING MODE CONTROL IN VEHICLE STABILITY, ACTIVE FRONT WHEEL STEERING AND ACTIVE REAR WHEEL STEERING SYSTEMS IN CO-SIMULATION ENVIRONMENT

KEYWORDS: co-simulation, sliding mode control, vehicle stability control, active front wheel steering, active rear wheel steering

The goal for the future, safer and more sustainable transportation leads to implementation of many advanced systems in vehicles. In this paper, a vehicle model with vehicle stability control (VSC) that uses the braking system is regarded as a base “active vehicle”. Two alternative vehicle models are considered where this system is combined and integrated with active front wheel steering (AFS) and active rear wheel steering (ARS) system, separately. For the purpose of this research, 3D virtual vehicle models based on a B-segment vehicle were created in ADAMS/Car.
As a research tool, a co-simulation approach between ADAMS/Car and MATLAB/Simulink was used. Several sliding mode controllers (SMC) have been proposed and implemented in MATLAB/Simulink in order to analyse the potential improvements of the vehicle dynamics due to the integration and coordination of these systems. In the same MATLAB/Simulink environment, a reference 2DOF nonlinear bicycle model was used.
For the integration of the VSC and the ARS systems in a 4 wheel steering (4WS) vehicle, this reference vehicle model wasn’t suitable to satisfy the necessary requirements for the activation of the sliding mode controller and the reaction of the 3D vehicle model wasn’t suitable and led to degradation of the performance and its stability (this was due to the fact that the reference model had slower reaction than the virtual 3D model). In order to overcome this, a 2DOF 4WS bicycle model was created.
The benefits of using the proposed sliding mode controllers are presented by conducting co-simulation between ADAMS/CAR and MATLAB/Simulink and result analysis. In the analysis, the vehicles are simulated in standardised test procedures on a wet surface with friction coefficient of ϕ=0.4 according to the standard ISO 7401, for testing lateral transient response of the vehicles. Deliberately, within the manoeuvres, a passive vehicle, without any advanced system, is forced over its limits and loses its stability.
The results and the analysis are presented for the step-steer manoeuvre and the single lane change by using comparative diagrams between the passive and the alternative vehicles. The diagrams that are presented are: steering wheel angle, lateral acceleration, yaw rate, side slip angle, longitudinal velocity, trajectory of the vehicles and the braking torque vs time.

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As input signals to the ADAMS 3D vehicle models, where VSC system is implemented, the braking hydraulic pressure of the 4 wheels are used. Beside these signals, in the vehicle with implemented VSC and AFS controllers (VSC+AFS vehicle) the corrective steering wheel angle for the AFS system is used, while as an input in the vehicle with implemented VSC and ARS controllers (VSC+ARS vehicle), the rotation of the rear pinion gear for the ARS system is used. The output signals of the ADAMS model, such as the steering wheel angle, side slip angle, and yaw rate are used in the Simulink models as inputs for the reference vehicles and for the control strategies.
By using co-simulation approach with a complex 3D vehicle model and nonlinear reference models, more accurate results were obtained that are closer to a real driving scenario. The implementation of the SMC controllers and their coordinated activation and action results in improvement in vehicle dynamics and stability. Although the VSC controller alone, has the biggest effect on the vehicle's stabilisation, it can be stated that the coordinative action of the controllers further improves the vehicle behavior. This can be substantiated with the smaller amplitudes of the vehicle yaw rate and side-slip angle, the smallest required road space to complete the manoeuvre and also by the faster response from the vehicles. Beside the co-simulation approach, the research showed the importance of using appropriate reference model. This is especially important when the reference vehicle has rear wheel steering. If a 2DOF bicycle model is used as reference model, it can lead to non-optimal controller output and unwanted vehicle behavior. By implementing 2DOF 4WS bicycle model with a certain control strategy, improved controller output signal is produced enforced to follow the reference variable from the 2DOF 4WS model and achieve better vehicle dynamics and stability.

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NUMERICAL SIMULATION OF AN ELECTROMECHANICAL BRAKE CONCERNING ASSOCIATED DIFFICULTIES

KEYWORDS: electromechanical brake, magnetorheological grease, Comsol, simulation, automotive

The biggest challenge in developing any type of brake (or any other actuator) is overcoming its inherent disadvantages. Brakes that use materials whose rheological properties change under the influence of an external magnetic field are called magnetorheological brakes. In addition to the mechanical issues, magnetorheological brakes are troubled with cooling, sealing, settling, fluids` gap size, etc. Furthermore, there are issues with brake's magnetic field density distribution and propagation. The poor distribution of the magnetic field density through the body of the magnetorheological brake is one of these inherent disadvantages. Magnetorheological's brake magnetic circuit modeling forms the basis for further development. This paper is part of ongoing research into the feasibility of using magnetorheological brakes in automotive applications. Certain points of the numerical simulation process are addressed. The research uses part of the results from previous numerical simulations, carried out using commercial finite element method software - COMSOL Multiphysics, AC/DC module, and results from the previous experiments. A magnetorheological brake - MRB is an electromechanical brake consisting of rotating and non-rotating elements, which can be made either from magnetic or non-magnetic materials. The working medium flows between the MRB stators and the rotors. Both magnetorheological fluids - MRFs and magnetorheological greases - MRGs are the best-known examples of working mediums, regularly used in the MRBs, [1, 2]. The working medium's resists to flow changes under the influence of the magnetic field. This induces a change in the stator-to-rotor rotational resistance, thus generating the braking torque. The main issues with any MRB application are the working medium's viscosity level, solid-phase settling, and the overall braking torque value. There are several ways to overcome these issues. The first is to use a high viscosity, low setting rate MR working medium. Second, if possible, to further reduce the MR gap size and increase the applied magnetic field acting on the MR working medium. The last one is to increase the total active area of the MR working medium by increasing the MRB's diameter and multiplying the number of working media layers. Compared to the previous [3], illustrated in figure 1, a) this iteration was corrected for some small design imperfections which have been subsequently noticed. This design iteration also relied on a variant of the MRB [4, 5]. The Model has twenty-four coil pairs, figure 1 b), thus forming a double-sided, multi-pole structure. The magnetic field is generated radially, on both sides of the brake, due to the excitation coils' orientation, figure 1 b). Each magnetic flux vector is directed from the center of the MRB body outwards, acting almost perpendicularly on the MRG layer, figure 1 c). Magnetically non-conductive housing, used to contain MRG, figure 1 a) - in color, reduced magnetic field dissipation and focused it (as much as possible) on the MBR's core and MRG areas.

3. Finite element method

Computers cannot handle continuous variations in the intensity of the magnetic field of a solid object. This is forcing us to divide the proposed space into many small - finite-size elements. The properties of the magnetic materials may vary with their orientation and may depend on their previous exposure to magnetic fields [6].

To reduce the size of the model, two types of symmetry were used: *Sector symmetry* and *Reflection symmetry* relative to the mid-plane, perpendicular to the axis of the Model. In order to use the Sector symmetry, *Periodic Boundary Conditions* must be used on the sides of the chosen sector, figure 1 d), of the model. The Reflection symmetry forces the normal component of the magnetic field to be zero at the mid-plane. A highly non-linear B-H curve node was used to describe the magnetic behavior of both the soft-iron core and the MRG layers in simulation.

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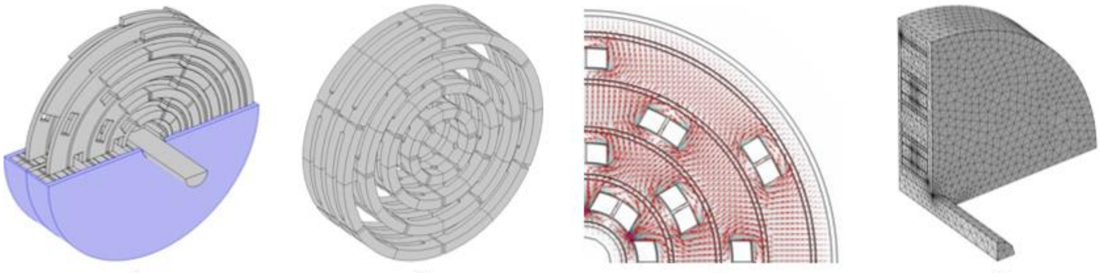

a) b) c) d)

Figure 1. Illustrations of the multi-pole, multi-layer, double-sided magnetorheological brake Model, a) segmental cross-section, b) multi-pole coils arrangement, c) magnetic field density distribution pattern, d) meshed Model.

The next step in the modeling process is mesh generation. Due to the complexity of the MRB geometry and numerous coils, a 3D space dimension option was used. However, the previous finite element method simulation [3] had approximately 4.000.000 elements, which contributed to the high computational cost. The aim is to reduce the complexity of the Model by exploiting its symmetry, removing the less important elements, and simplifying the geometry. In order to reduce the size of the Model, its symmetry was exploited, and it was reduced to a one-eighth of its size, figure 1, d). The one-eighth section of the Model now has two orthogonal planes, both passing through the center of the coils and the center of the MRB. The magnetic field was mirrored across these two planes, sequentially using *The Magnetic Insulation Boundary* condition. Non-magnetic properties for: air, stator, and shaft nodes were selected from the software's database. Rotor - construction steel and MRG were defined with previously acquired data, [6]. Large Model parts, e.g. Stator, shaft, etc., were meshed using User-controlled mesh. The MRG layers, rotor, and their small radii were all meshed in the *Free tetrahedral* with various element sizes. Special attention was placed on the curvatures and the narrow regions of the MRG segments of the brake. To calculate the current in the coils, a *Coil Geometry Analysis study* step was added. The solver was stationary but non-linear.

This paper deals with some aspects of a novel magnetorheological brake design. The materials with different magnetic properties shaped the unique distribution of magnetic flux through the magnetorheological brake's body, especially through magnetorheological grease layers. Some difficulties with the finite element method simulation process were discussed. For this purpose, the magnetorheological brake finite element Model was made To reduce the computation cost, the Model was simplified to a one-eighth the size of the original Model. To simplify the Model an assumption needed to be introduced: the coils have a constant cross-sectional area along their circular paths. This assumption is not completely accurate and needs to be addressed in future studies. A combination of different materials types contributed to the magnetic flux intensity increase in specific, small areas of the core and its better propagation through layers of the magnetorheological grease.

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EVALUATION OF THE ROLLOVER THRESHOLD OF TANK VEHICLES

KEYWORDS: tank vehicle, rollover, dynamic stability, tank cross section

The improvement of the driving safety and the eradication of accidents is a matter of high priority in research in the area of automotive engineering. Especially in heavy vehicles transporting dangerous goods, every accident means high cost due to probable loss of life, environmental pollution and infrastructure damage. The present paper focuses on the analysis of the dynamic behavior of tank vehicles used to transport flammable liquids.

In more details, a 4-axle tank truck has been considered and it has been tested in two scenarios in order to evaluate the risk of rollover using the TruckSim ® mechanical simulation software. Four different cross-sectional shapes have been considered for the tank of the heavy vehicle (a) one box shaped, (b) one circular and (c) two ellipticals. The alternative tank designs were produced considering the same maximum capacity, equal to 28187 lt. The scenarios used in the investigation are the tilt table test and a double lane change. Lateral acceleration and roll angle have been monitored in the first scenario and lateral acceleration, roll angle, yaw rate and vertical tire forces have been monitored in the second scenario.

For the tilt table test, the payload condition is the same for all tanks and equal to 100% maximum payload. The results, among others, showed that the cross section providing the highest rollover threshold was the elliptical which looks like the box shaped with rollover threshold of 0.39 g.

The same conclusion can be drawn also from double lane change scenario with the maximum payload where the cross section with the lower risk of rollover is the elliptical one followed by the box-shaped. Both do not rollover in double lane change with constant velocity of 70 km/h.

Furthermore, the maximum feasible speed for the double lane change maneuver and each shape of cross section was investigated considering 3 different speeds, 30, 50 and 70 km/h, for every shape of cross section.

The results showed that only 2 cross sections can successfully carry out the double lane change at 70 km/h without rollover. On the other hand, in the double lane change, with constant velocity of 30 km/h, the dynamic responses of all tank cross-sectional geometries are quite similar.

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Finally, the dynamic response of the tank truck with each cross section in double lane change has been investigated with four different filling ratios, 0% - 20% - 80%-100%.

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COMPUTATIONAL ASSESSMENT OF LIGHT EXPERIMENTAL HYBRID VEHICLE BRAKING EFFICIENCY

KEYWORDS: vehicle dynamics, braking performance, adhesion utilization

Braking performance of the road vehicles, in the sense of being able to deliver the maximum achievable braking rate in critical situations, depends on the road adhesion utilization of all vehicle wheels engaged with the road during braking. Sophisticated design solutions for braking system and its control were developed and upgraded in the last several decades, including systems that can use regenerative braking, to provide for optimum braking performance while maintaining vehicle handling, stability and energy efficiency. As opposed to contemporary series-production vehicles featuring complex braking systems and advanced devices, this paper deals with simple vehicle prototype developed by the group of students of Faculty of technical sciences – University of Novi Sad, Serbia, to serve as further educational and research platform. Vehicle (figure 1) is equipped with conventional hydraulic braking system without any means of affecting brake force distribution between front and rear, i.e. with linear proportioning. At the same time vehicle has in-wheel electric motors at the front axle, capable of applying regenerative braking torque. Acting on the front wheels only, this additional braking torque will affect brake force distribution and therefore capacity for road adhesion utilization during critical braking. Aim of this work is to assess the magnitude of this effect on the ground with both strong and weak adhesion with tyres. Values for adhesion coefficient for these two cases were chosen according to the UN Regulation for braking of passenger cars R13H to be 0.8 for normal and 0.2 for slippery road.

Figure 1. Light experimental vehicle.

Taking into account vehicle design parameters, braking efficiency was calculated for two cases: braking only with friction brakes and braking with both friction and regenerative brakes. Regarding braking using only friction brakes, on the high adhesion ground relatively high braking efficiency (0.95) is achieved. This was expected, because brake proportioning was designed so as to obtain good adhesion utilisation in such conditions, which is why real brake force distribution will be more close to the ideal one. On the ground with low adhesion, wheel lock will happen at

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significantly lower deceleration rate, so that the ratio between front and rear brake force will be more distant from the ideal point and efficiency will therefore be lower (0.76).
As expected, braking with simultaneous applying of both frictional and regenerative braking will feature lower efficiency. This is because when adhesion at the front wheels is fully utilized, front friction brakes share only a portion of overall braking force, so that, due to linear proportioning, brake force at the rear wheels will be less than without regenerative braking, leading to decreased deceleration rate and therefore lower efficiency (0.82). This is especially distinguishable in case of low adhesion, where even pure regenerative braking would lead to wheel lock, i.e. by full adhesion utilization at the front wheels, friction braking system does not even take a part in the process, which means that the braking force at the rear axle will also remain zero, leading to particularly low braking efficiency (0.35).

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IMPROVING RIDE COMFORT BY OPTIMISING SUSPENSION SYSTEM OF AN ELECTRIC STREET SWEEPER

KEYWORDS: multibody dynamics, electric sweeper, ride comfort, suspension system, optimisation

The opinion of the operators of the working machines in today's world is much more valued than in the past. Their comfort, safety and satisfaction during the working hours can be crucial in the decision making process of buying new working machine. Therefore, in this research paper the vertical dynamics and ride comfort of an electric street sweeper would be analysed by using a multibody dynamic model. The model is created using MSC.ADAMS, based on a real electric street sweeper. In order to test the ride comfort of the existing model, a C-level road profile is modelled, according to the standard ISO 8608. During the tests the RMS value of the vertical acceleration of the driver's seat on which the driver is exposed during his working hours are measured and analysed. The virtual tests are conducted while the vehicle is traveling with maximum velocity of 40 km/h, achieved during transit and lower velocities which are achieved during the operating hours of the machine in transit and sweeping regime.
Highest RMS values of the vertical acceleration of the driver's seat are gained while traveling with maximum velocity thus several design studies were made in order to analyse the impact of the machine's suspension on the ride comfort. The idea is to try to make minimal changes of the suspension system which would initiate minimal changes of the chassis, attachment elements, springs and dampers. This analysis were conducted in order to achieve desirable improvement of the ride comfort of the machine without drastically increasing the production cost or delay of the machine. The possibility of repositioning the attachment points between the springs and dampers with the axles is not analysed because any change in the axles would result in procurement need of new or modified axles, leading to increase of the research budget and spendings. Also, the seat replacement is not subject to the design studies because the seat is specially designed for the electric sweeper. Beside the suppling cost, the replacement of the seat would lead to additional changes in the cabin itself.
By utilizing the influence of the certain elements on the ride comfort and by trying to maintain the same vertical distance between the cabin and the road, an optimisation is made.
An optimization of the suspension system of the real electric sweeper is made, by targeting its components location and positioning, stiffness and damping characteristics. The optimisation in ADAMS was made by taking into consideration the previous conclusions of the design studies and by examining the individual elements position and the their influence on the ride comfort, and combining them in order to further improve the ride comfort. Several iterations were made in which there was significant improvement in the ride comfort, but that also contributed to lowering the front part of the vehicle, worsening the contact between the brushes and the road, but also endangering the front part of the machine colliding with the surface during intensified braking. Therefore, those iterations were

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excluded from the analysis and the optimised solution is presented where an improved ride comfort is achieved without endangering the safety of the machine and it’s sweeping performances.
In this research, the optimisation had shown that with relatively small changes in the geometry of the suspension system and its elements an improved ride comfort can be achieved in transit and sweeping regime. That would result in improved operator’s comfort and health and would make the machine more desirable for the byers. All of these changes would result in modifications of the current chassis and systems but those modifications will not drastically increase the production cost of the machines or delay their shipment. The study had also shown that even further optimisation can be achieved in order to improve the ride comfort, but in that case, larger investments and modifications must be made which would question the value and the production profit of the machines. Also, it was concluded that beside the main focus of improving the ride comfort, a detail analysis and observation must be made on the main functionality of the machine. That was presented by analysis of the vertical distance between the cabin and the ground in order to maintain a satisfactory contact between the brushes and the ground and not endangering the safety of the machine while braking. If the contact is worsen then the main function of the machine (sweeping), could be lost. Because of this beside the RMS values of the vertical acceleration of the driver’s seat, the vertical distance between the cabin and the road is used as a reference value that should not suffer larger changes. Results are presented using comparative diagrams of the original and optimised model.

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VEHICLE SUSPENSION SYSTEM WITH INTEGRATED INERTER - EXTENDED ANALYSIS

KEYWORDS: inerter, suspension system, formula SAE, ride comfort

Inerter devices are used in Formula 1 vehicles for a decade to reduce rolling displacement at corner or double change lands and provide higher tire grip on racing challenges. In this study, the paper clarifies some issues related to suspension system with inerter to reduce displacement under impact from road disturbance on Formula SAE Car. To improve dynamics, several topological designs for suspension system are already proposed and published. Based on our passive suspension system for quarter-car model, we carried out analysis for different parameters and demonstrated when integrated inerter device can increase ride comfort and decrease vertical displacement. Proposed solution system with integrated inerter mechanism can improve development of vehicle suspension systems and have effects on the vehicle dynamics and stability.
In this paper is studied application of inerter elements to Formula SAE race car (SAE – Society of Automotive Engineers) in order to provide lower vertical displacement at corner or double change lands, i.e. higher tire grip on racing challenges. Some pioneering work in this field has been done by Tran et al. The usual way to improve ride comfort of vehicles in engineering practice is by using passive, semi-active and active suspension systems. However, it is not easy to improve riding comfort and dynamics stability with passive suspension systems. To achieve it, several control methods have been proposed, but most of them relate the active suspension. In our study, we investigated passive suspension systems which can increase drive comfort by the passive suspension system containing springs, dampers and inerter elements and discusses its influence on behaviour of both the sprung and un-sprung mass when vehicle have road disturbance. Based on the conventional quarter-car model, we design two structures called quarter-car suspension parallel and series structure model (Fig.1). This model will change from normal passive suspension to new suspension with stiffness, damping and inerter in parallel or series.

First, the minimum and maximum value of each variable was calculated using the aforementioned software. Then the interval between those values was divided into 500 fields and the number of occurrences of the variable within the limits for each field was automatically determined (histogram, %). The calculated values are, for the sake of illustration, partially shown in figure 2.

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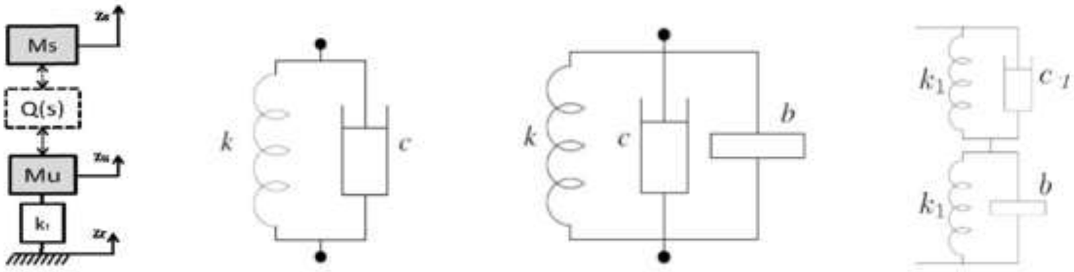

F**igure 1.** The quarter-car model with suspension function Q(s) represented in Laplace domain (a), and different arhitectures for Q block: b) basic, c) parallel, d) series

With data from for Formula SAE car, displacement and acceleration for sprung and unsprung mass are obtained for three different configurations (Fig.1). Since the parallel configuration gave the best results, it is used in the further analysis. Influence of intertance parameter on ride comfort, displacement and acceleration of sprung mass is studied.

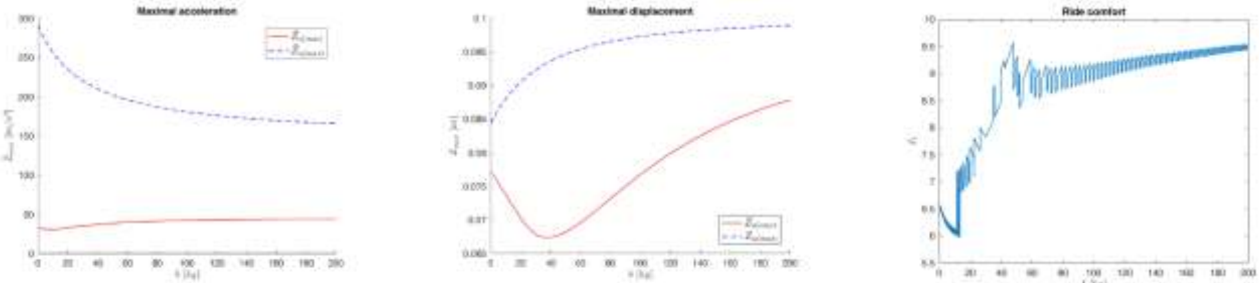

Figure 2. Parallel quarter car model: a) Maximal acceleration, b) maximal displacement, c) ride comfort as a function of inertance b.

This paper has described the background and application of inerter in the passive suspension synthesis in Formula SAE car. The parallel suspension system is more stable than series, and can be designed to improve vehicle dynamics. The results showed that suspension with inerter have better displacement of sprung mass body on quarter-car model. Additionally, it was shown that the use of inerter can reduce the oscillation, comparing to conventional spring and damper model. Influence of inertance on dynamic behavior is also presented which can serve for an optimal suspension design. For more profound investigation, this study can be extended with half-car and full car model.

SECTION

E

Transport Challenges in Emerging Economies

- Safety
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THE INVESTIGATION OF THE SINGLE VEHICLE ACCIDENTS SEVERITY BY USING A PROBABILISTIC APROACH

KEYWORDS: single vehicle accidents, logistic regression, keyword 3, probabilistic, road safety

The aim of this paper is to assess the severity of such accidents by estimating the probability of the fatalities (Pd1) and major injuries (Pd2) generated by the single vehicle accidents and to identify the factors affecting those probabilities. Single vehicle accidents (SVAs) arouse the interest not only of researchers, but also of the European Commission and other international road safety bodies, since a third part from all road fatalities from Europe are caused by the single vehicle accidents. In Romania, around 20% - 25% of the total number of fatalities is generated by SVA and the Romanian authorities consider SVA as a major problem since the injury index is higher compared with other type of collisions (1.2 – 1.3 for SVA and 1.1 – 1.2 for non SVA). According to the Romanian authorities, the drivers' mood and their actions has a great impact in SVAs causation and injury severity. Therefore, knowing the causational factors of the single vehicle accidents not only mitigate the accident and injury risk, but also will help the road safety authorities to implement appropriate counter measures.
As for this research, a complex 6 -year- accidents data base has been used and the accidents records have been aggregated on a daily basis. According to the SVA's European definition, the collisions with one vehicle have been filtered, regardless the category (personal vehicle, light or heavy commercial vehicle, moped or motorcycle). Those accident records which involved pedestrians or cyclists were removed and all the data were aggregated on a daily basis. Finally, the dataset used for this research has 2.190 rows (corresponding to those 6 years included in this analyse).
A binary multiple logistic regression has been developed for each type of severity (fatality and major injury) using 86 predictors related to the place of accidents, road category and feature and characteristic, the number and the width of the lanes, horizontal road markings, safety components of the road, road surface characteristics and adherence, weather and lighting conditions, vehicles mileage and drivers' sex. The severity of a road accident is generally shown by the severity of the victims. Therefore, using the Binary Multiple Logistic Regression (BMLR), two types of probabilities are assessed for predictive purposes by using SPSS: the probability of a SVA to be fatal or not (P_{d1}) and the probability for a SVA's victims to have or not to have major injuries (P_{d2}). The road accidents' severity assessed by using BMLR techniques is often found in the literature, as it is shown in other researches.
The logistic models have been tested on their statistical significance and their explanatory efficiency was discussed. Two kinds of statistical tests will be used in order to check the significance of the logistic models, as SPSS outputs: G^2 chi-square likelihood ratio test and Hosmer and Lemeshow's Goodness of Fit Test. G^2 test will be used in order to check whether all predictors' logit coefficients, except the intercept, have null values.
In this paper, the logit coefficients b_k of the predictors will be assessed using the odds. In order to do this assessment, an OR odds ratio will be calculated and will show to which extend the odds will be changed for a SVA to be fatal/non-fatal or with major injuries/no major injuries, when a predictor changes its value by onw unit, when the other predictors

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remain constantA descriptive analysis has been conducted for both models in order to discuss the distribution of the probability values.

Pd_2 model has a better explanatory power than P_{d1} and its overall percentage of the predictions is 96.10 %. It is also has a very good homogeneity since all its predictors have positive values. An interesting finding is that no other predictors related to weather or lighting conditions do significantly explain the probabilities of a SVA to be of fatality or to generate major injuries.

The probability of a SVA to be of fatality is increased by the number of SVA that occur outside or inside built-up areas, on those roads with paved hard shoulders, safety barriers and slides and no horizontal markings, and those vehicles with mileage between 25,000 km – 50,000 km that are involved in this collisions, as the logit coefficients of these predictors have positive values. Better roads maintenance that would consist in applying of more horizontal markings will decrease the probability of these accidents to be of fatality. As the odds of having a fatal SVA inside and outside the built-up areas are unusually higher, a better law enforcement and development of sustainable mobility plans will play a major role on decreasing the number of fatalities.

The car manufacturers, dealers and the insurance companies, as well, could contribute to the decrease of the number of fatalities as well, by development of educational programs, especially those focused on ADAS (Advanced Driving Assistance Systems) and of awareness campaigns for those who drive relatively new cars with mileages between 25,000 km – 50,000 km.

Other interesting finding of this paper regards the P_{d2} model, where all those 5 predictors included have positive values of the logit coefficients. This means that any decrease of these coefficients will lead to an important decrease of the victims' numbers that are seriously injured in these types of collisions. The simple "T" intersections are the most dangerous, as each SVA occurred in this intersections leads to an increase by 272.10 % of the odds of being seriously injured. The drivers of the those old vehicles whose mileage is between 100,000 km – 150,000 km have a greater risk of being seriously injured in the single vehicle accidents, as the odds values are very high.

Of the two P_{d1} and P_{d2} models, the second one is better significantly explained by the predictors in a proportion of 10.50 % - 37.20 % and has a prediction accuracy of 96.10 %. In addition, all the predictors of P_{d2} have positive values, a thing which gives a practical applicability to this model since any decrease of a predictor's values will lead to a decrease of the serious injuries' probability. Rehabilitation of the simple "T" intersections, reducing the speed around them and improving the lighting during nights, will decrease the number of accidents around these intersections and consequently will lead to a decrease of the numbers of the seriously injured victims.

We should remark that no other predictors related to weather or lighting conditions do significantly explain the probabilities of a SVA to be of fatality or to generate major injuries. These constraints are to be further researched since the daily level of data aggregation studied in this paper influences the "immediate effect" of random phenomena, as weather or lighting conditions.

P_{d2} model has a good applicability in the identifying, prioritizing and treating of the black spots. Knowing the predicted probabilities on the road segments where a higher accident concentration is found would help the road administrators to implement suitable countermeasures in order to mitigate the major injury risk at lower costs. The road features with a higher major injury probability can be improved in terms of safety by implementing different countermeasures or by a better maintenance.

The Romanian road authority could also use it in driver education and injury risk identification in order to mitigate the severity of the accidents, including in the process of road law improvement.

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USE OF ALTERNATIVE INTERSECTIONS IN ORDER TO IMPROVE TRAFFIC SAFETY

KEYWORDS: alternative intersections, traffic safety, DLT, DDI, RCUT, MUTs, superstreets

Traffic problems are more complex than ever. Engineers have a complex task, to meet the needs of a growing population with limited resources. At many intersections, traffic jams are increasing, which results in drivers and pedestrians are wasting a lot of time waiting at such intersections, with an increased risk of being involved in a traffic accident. It is considered that conventional intersection designs are insufficient to alleviate existing transportation problems. Consequently, many engineers are researching and implementing innovative solutions in an attempt to improve both, the mobility of road users and their safety. One of the ways to solve this complex problem is precisely alternative ways of managing intersections.

Traffic is an extremely complex, stochastic phenomenon that cannot be modelled, because it depends on a number of parameters that affect the volume of traffic, and this later entails a number of problems arising from this. Alternative intersections can reduce the number of major conflict points by redirecting traffic flow, especially left turns and turns at multi-arm intersections. Reducing the number of conflict points leads to the realization of operational and safety advantages for alternative intersections compared to conventional intersection designs under certain traffic and location conditions, often at significant cost savings compared to other more conventional alternatives, such as adding a turning lane or replacing the intersection with a loop, etc. In the world, one of the most famous and widespread alternative ways of managing intersections is the roundabout. In addition, there are Superstreet, Median U-Turn, Continuous flow intersection, Continuous green-T, Jughandle, Quadrant roadway intersection, Single point diamond interchange, Diverging diamond interchange, etc.

The intersection of two or more roads represents the possibility of a conflict between vehicles. Alternative intersection designs can improve intersection performance by changing the configuration of conflict points by redirecting traffic, reducing the number of signal phases, as well as significantly reducing time losses at intersections. Use of alternative intersections such as continuous flow intersections (CFI) (also known as shifted left turns or DLT), divergent diamond loops (DDI), superstreets (also known as J-turns, restricted crossing U-turns, or RCUTs, reduced conflict intersections, or RCIs, reduced conflict U-turns, and synchronized streets), median U-turns (MUTs) became more common, as traffic demand increases. They are usually more complex than conventional design intersections and they are used when conventional intersection designs do not allow adequate safety improvements or adequate traffic flow. Alternative intersection designs have fewer points of conflict resulting in increased safety for both, drivers and pedestrians. As shown in this paper, each alternative intersection has its advantages and disadvantages.

Depending on the location, intersection geometry, traffic flow structure and traffic conditions, the most favourable solution can be chosen. When everything is summed up, all intersections have the same goals, which are to reduce

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the number of conflict points, reduce waiting time and, most importantly, increase the safety of road users (drivers, pedestrians, motorcyclists and cyclists). In the Republic of Serbia, roundabouts are the only type of alternative intersections that is represented. This paper showed a high potential for alternative intersections in order to improve safety in Republic of Serbia by turning some of conventional safety critical intersections into alternative ones.

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