PASSENGER CARS IN THE 21ST CENTURY. SOME ENGINEERING DESIGN PROBLEMS

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Summary

The paper deals with some engineering design problems related to the motor cars that are to be manufactured in the early decades of the 21st century. The general construction concept of these "cars of the future" will not significantly differ from that followed at present. Instead, the vehicle development will be focused on the introduction of improvements and new engineering solutions to basic vehicle motion systems, such as power transmission, braking, steering, and suspension systems with running gear, and to the auxiliary vehicle equipment that is to ensure the highest possible standard of active and passive safety of vehicle operation, e.g. automatic systems to control the vehicle motion or additional systems intended to improve the ride comfort and, directly, safety of vehicle occupants. Attention has been separately paid to vehicle engines that may be used in the future and to the construction of vehicle bodies. The possibilities that might be offered thanks to the availability of new technologies have also been taken into account at the discussion of the engineering design solutions of the future..

Keywords: motorcar, engines, power transmission systems, braking systems, suspension systems, vehicle steering

1. Introduction

We are living at the turn of civilisation epochs. The new informational civilisation is reaching newer and newer regionsof our globe. In the new epoch of informational civilisation and globalisation coming up, which expands to different areas and fields of our activity, the pace of life is rapidly growing and, simultaneously, immediate communication between individuals as well as larger groups and communities becomes possible. However, the possibility of almost instantaneous communication does not eliminate the necessity of frequent and direct contacts between people and this requires fast and safe transport facilities to be developed. Among the transport facilities, an important role is, and will be, played by the passenger car.

What will the passenger car of the future years of informational civilisation look like? An attempt to answer this question, at least in a part, will be made in this paper.

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The theses and deliberations presented here are based on an analysis of the current state of engineering design of motor vehicles, vehicle user's needs, requirements formulated by ecologists, and some perspective in viewing the possibilities of acquisition of new energy sources.

The analysis of the current state of design of motor vehicles shows that the car of the future years of informational civilisation will be identical, in terms of mobility, to the one being in use at present. This thesis was presented and proven in [1].

Among the requirements set for motor vehicles by their users, the following should be mentioned first: economy of operation, reliability, comfort, and safety of ride.

The passenger cars of the future must also meet specific ecological requirements, which chiefly consist in a reduction of atmospheric emissions of various toxic compounds that are generated both at the vehicle manufacturing stage and during the everyday vehicle operation.

An impact on the vehicle design solutions will be exerted by new engines, where the energy supplied from outside will be obtained from energy sources that have never been used until now or even that are still only theoretically considered.

The insufficiently explored energy sources and the new engines are worth being thought about already now in consideration of the very fast development of sciences and the immediate use of new scientific achievements for the development of new technologies. However, the completely new ideas of engine design solutions will not be dealt with in this paper because such solutions are still in the sphere of scientific fiction. Some deliberations regarding the engines of the future may be found in [5].

All the engineering development of the car of the future will consist in development of design of the basic vehicle motion systems, i.e. power transmission, braking, steering, and suspension systems, inclusive of running gear, as well as development of vehicle body structure and application of new engines or improvement of existing engine designs.

The novelties in the construction of motor cars will also be visible in the use of a number of new vehicle components and systems to control the vehicle motion and thus to facilitate vehicle driving and to improve the safety of people present both inside and outside of the car. Such vehicle components and control systems should by no means be considered as mere auxiliary vehicle equipment. They are now, and will be in the future, the parts showing the level of vehicle modernity and the degree how close the vehicle is to one having the features of technical intelligence.

2. Engine of the motor car of the future

Not all the engine types known at present are used in motor vehicles. The typology of motorcar engines has been presented in Fig. 1.

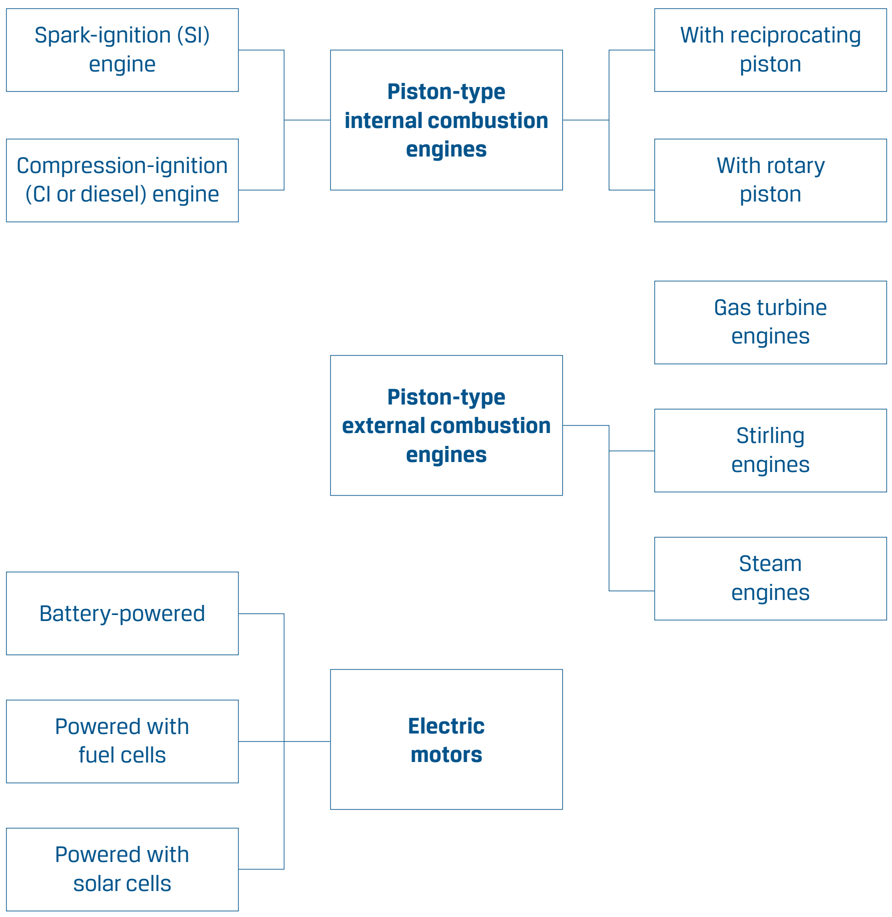

Fig. 1. The engine types that are, or may be, used to power motor vehicles

None of the engine types shown in the drawing has been definitely eliminated as a prospective vehicle engine and has been considered unworthy of interest.

The opinion about the selection and use of engines for motor vehicles in the nearest decades of the 21st century is unequivocal. Undoubtedly, spark-ignition (SI) and compression-ignition (CI) internal combustion engines will be used as standard. Such engines have feed systems that enable adaptive control of the composition of air-fuel mixture and control of the valve opening process. These two important factors of engine functioning, especially as regards the SI engines, make it possible to optimise the fuel combustion process, which leads to the combustion of air-fuel mixtures of stoichiometric composition.

The CI and SI engines still undergo intensive research work aimed at the obtaining of maximum possible performance represented by power-speed curves and optimum exhaust emission characteristics. Moreover, research works are conducted on the possibilities of using alternative fuels (different from petroleum and diesel oil) in internal combustion engines.

At the beginning of the motor car era, motor cars with electric motors were considered equal to vehicles with combustion engines. The history of rivalry between these two options in mass-production applications will not be covered herein. At present, however, a large part of attention of the motorisation world is again paid to the application of electric motors. This trend results from a specific feature of the electric motors (EM), referred to as "zero emission." In this paper, the electric motors will exclusively be meant as the solutions shown in Fig. 1. The three EM types presented there differ from each other in the sources of electric energy used to power the motors. The energy source defined as "battery" has existed from the very beginning of development of the "electric car"; the other two sources include the fuel cell and the solar cell.

The latter two energy sources are products of new technologies, although the fuel cell as such was invented a long time ago. At present, numerous studies and research works are being carried out on the possibilities to use these two energy sources for the powering of a motor vehicle.

More information on fuel cells proper and on the application of fuel cells for the powering of motor vehicles as well as on the possibility of using solar batteries with electric motors may be found in [2].

As regards the other engine types presented in Fig. 1, only a general statement can be made that they have not been definitely struck off the list of the solutions potentially applicable to motor vehicles.

3. Development of power transmission systems

The tasks to be fulfilled by the power transmission system of a motor vehicle are perfectly known. The general engineering basis for the preparation of preliminary designs of such systems has also been well defined. The only question that still remains an open issue is how to design the system to obtain optimum efficiency of energy flows with simultaneously maintaining adequate "flexibility" of the system (meant here as the system capability to adapt quickly or even automatically the transmission ratios to variable loads occurring during drive). This may be illustrated by a comparison between the following examples of two opposing solutions: torque converters, with low efficiency and high flexibility thanks to automatic adaptation to variable loads on the output shaft, and transmissions with gear wheels, with high efficiency but the necessity of external intervention to change the transmission ratio in the case of a change in the load on vehicle wheels. These two features have also an impact on the general evaluation of vehicle economy.

In the motor cars of the future, new power transmission system designs, different from those known at present, may be expected to appear. The hybrid systems considered now a state-of-the-art solution will no longer be thought of as recommendable for being commonly used in the cars of the future. The fascination with hybrid systems has vanished already now and the fact that they are applied to some production modelsrather arises from manufacturers' will to regain at least a part of the money laid out for the work on the development of such systems.

The construction of a power transmission system to a new energy transmission concept is an open issue. One of the initial conditions that would determine the formulation of such a concept will be the engine, in which not everything can be predicted already now.

We may expect the appearance of power transmission system designs where the medium to be used for energy transmission is even not known yet. Moreover, it cannot be excluded that a driving motor will be invented, for which a power transmission system with a transmission ratio of 1:1 would be sufficient.

4. Braking system and brake mechanisms

The functioning of vehicle brakes chiefly consists in a reduction of the kinetic energy of the vehicle when moving with a speed of v. It is worth recalling here the energy conservation law, according to which energy may only be converted from one form into another but it can never be annihilated. This principle governs the functioning of brakes. This means that the kinetic energy of a vehicle during the braking process is reduced by a certain value but it does not disappear. In most of the present motor vehicles, the kinetic energy of the vehicle with brakes applied is converted into work done by friction forces and subsequently changing into thermal energy, with the resulting heat being carried away to the atmosphere. An analysis of this process of conversion of the kinetic energy into heat, which is irretrievably lost, provokes to thinking how to solve this problem in order to recover this dissipated energy. This idea to regain the vehicle braking energy, which is now lost in friction brakes, is nothing new and it is partly implemented in vehicles with hybrid systems, where special energy accumulators rechargeable with the vehicle braking energy are provided. In the engineering solutions of hybrid systems known at present, both mechanical and electric energy may be stored in the energy accumulators [2]. Regardless of the known solutions aimed at the recuperation of vehicle braking energy, this issue is still open. We may expect that brakes of the cars of the future will be developed, *inter alia*, to ensure recuperation of vehicle braking energy with the required vehicle braking performance being maintained.

The controlling of the braking forces that are generated in the area of contact between the wheel and the road surface makes another important problem related to the course of the vehicle braking process. This problem is solved to some extent by a system to control the friction brake mechanisms, which is known as ABS. If other brake mechanism types are employed, the brake control system will also have to be changed. This constitutes another direction of development of braking systems and brake mechanisms of the motor cars of the future.

5. Steering system

The steering system of the motor car of the future will have a form that is now difficult to be predicted. However, even if the vehicle is steered with the use of a lever, as it is in the Luna Roving Vehicle (LRV), or another element, such as a joystick, rather than a steering wheel, the steering system design concept based on the Ackerman system may be maintained.

The steering system in its present form, with power-assisted steering wheel control, which makes it possible to simulate appropriate moments of resistance of the steering wheel depending on vehicle speed, seems to be an optimum solution even for the car of the future years.

Not every motor car will have to be provided with a lever instead of a steering wheel. The freedom of choice and user's wish will certainly decide in the future.

The suspension system as an object of creative activities of designers of the motor cars of the future seems now to leave a relatively little room for improvements, at an assumption made that the basic design pattern of this system in the future will not significantly differ from that prevailing at present.

It is already now that spring and damping elements of non-linear characteristics, which have a significant impact on the ride comfort, are employed in motor car suspension systems. The engineering design solutions adopted in suspension systems have also an influence on general improvement of the conditions of vehicle use.

As an example, we might mention the systems that make it possible to level the vehicle floor or to adapt the vibration damping characteristics to the nature of the external inputs applied to the vehicle.

All the problems related to the design of the vehicle mass suspension system are now well known from the theoretical point of view. Only the problems related to the physical implementation remain to be solved. In general, this may be formulated as follows: the objective is to build such a vehicle suspension system that would ensure optimum functioning in the case of various external disturbances as well. Nevertheless, the modern technologies related to the development of electronics make it possible to solve this problem.

6. Running gear

The running gear of a terrestrial vehicle consists of road wheels, caterpillars, or wheels and caterpillars occurring together. An overwhelming majority of passenger cars have road wheels. Off-road passenger cars intended for special applications may be an exception, but the running gears of such vehicles will not be dealt with in this paper.

At present, road wheels of motor vehicles are provided with tyres filled with compressed air.

It might make us wonder how it has happened that no other mass-produced competitive solution has appeared for the period of existence of the pneumatic tyres. This does not mean, however, that no solution exists now that would make an alternative for wheels with pneumatic tyres.

The development of new material technologies has offered new possibilities of designing road wheels that might oust the pneumatic tyres being now in use. It should be stressed here that the new wheels made of composite materials are capable to carry multidirectional loads, are flexible, and ensure good vehicle behaviour at high speeds.

This may be confirmed by results of works on the new automotive wheel concept,carried out in the USA and Sweden.

In 1982, Goodyear patented an idea named Integrated Wheel-Tire (IWT). Other concepts of "composite wheels" were presented in Sweden in 1990. More information about the IWT solutions may be found in [3].

Today, we may hazard a guess that the running gear of motor vehicles will change in the future. The wheels with pneumatic tyres being in use at present will be ousted by wheels made of composite materials.

7. Motor car body

The body of the passenger car of the future will have to meet very stringent requirements, in particular it will have to be capable of absorbing energy generated at collisions of various types, to have low mass, and to be easily adaptable to current fashion requirements and users' wishes regarding ride safety and comfort.

It is now a very difficult task to satisfy simultaneously all these requirements. We may expect, however, that the creation of new materials based on scientific achievements related to the constitution of matter will make it possible to build vehicle bodies of materials that are now considered only theoretically. Then, the low mass and the high capability of damping the energy of vehicle collision will not exclude each other and the achieving of the best results of evaluation of these two characteristics will be possible quite naturally. The low mass of vehicle body has a significant impact on the total vehicle mass and is a decisive factor for the energy absorption capability of the motor car. Reductions in vehicle mass are a permanent objective of vehicle designers' efforts.

These basic requirements set for all vehicle bodies, especially the bodies of motor cars, are of general nature and they will be formulated in every epoch when motor vehicles would exist. Therefore, in the next years of the informational epoch as well, the bodies of passenger cars as terrestrial vehicles will have to be light, to meet safety and ride comfort requirements, and to respond to fancies of prospective car users.

8. Automatic control systems and additional vehicle equipment intended to improve the safety and comfort of ride

The engineering solutions of automatic control systems as mentioned below already exist and some of them, such as ABS, are already commonly used in the cars manufactured at present.

We may hazard a thesis that the future car of the informational epoch will be enriched with various systems mentioned here, but not necessarily with all of them at the same time.

The currently known systems of automatic control of vehicle motion systems have been specified below;the abbreviations used as names of these control systems have been derived from the English or German terms originally defining the systems and they are commonly used in the Polish technical terminology:

- ABS prevents vehicle wheels from locking-up during braking;
- ASR prevents driven vehicle wheels from excessive slip when a driving torque is applied to them;
- ESP prevents the vehicle from losing its lateral stability;
- EC4WS is an electronically controlled four-wheel steeringsystem;
- ESC causes the suspension system to be active;
- ATC automatically controls the transmission ratio.

The functioning of many of these systems overlaps. At present, many research and development workers endeavour to build one integrated control system. This issue is particularly important because the devices that can automatically control the vehicle motionsystems eliminate to a significant extent driver's errors and often take over driver's actions, especially when such actions must be done very quickly while this becomes infeasible due to natural physical and psychic limitationsof the human being.

The automation of functioning of the vehicle motion systems does not ensure that the motor vehicles of the future decades of the informational epoch would have all the features necessary for them to function as subsystems of the Intelligent Transport System. The intelligent motor vehicle as a subsystem of the Intelligent Transport System will not be dealt with in the subsequent part of this paper.

However, trying to predict the future equipment of the motor car, we have adopted an assumption that it must meet all the requirements regarding the safety of vehicle motion in order to ensure safety for both the vehicle occupants and the people and property around. Being aware of the current state of knowledge, therefore, we should understand that the passenger car should be provided with special systems to ensure this safety. The vehicle motion safety systems have been summarised in Table 1.

Everything that has been written in this paper has a general nature and applies to any passenger car that would be manufactured in 2020s or even 2030s. It would be a mistake, however, to think that every car in the future would be provided with all the control systems as described here and with all the equipment as specified in Table 1. This would be unrealistic, *inter alia* because of significant differences in the road infrastructure and population density in various regions of our planet.

Table 1. Description of vehicle motion safety systems

System group	System
Monitoring of hazards to the drive safety: • Monitoring of driving conditions • Warning about a possibility of danger	To inform about driver's tiredness
	To warn about insufficient tyre pressure
	To warn about an obstacle during night drive
	To warn against a risk of collision with a vehicle approaching from behind
	To create virtual images that display current values of vehicle motion parameters
	To provide navigation aids
Accident avoidance	To keep adequate distance to the vehicle ahead
	To prevent a sudden change of traffic lane
	To control the vehicle speed according to the behaviour of the vehicle ahead
	To avoid the collisions and impacts during automatic braking
	To warn about the appearance of a STOP road sign
Reduction of possible accident effects	To absorb the impact energy in case of a front-end or side impact collision (air bags)
	To minimise the effects of a collision with a pedestrian
Facilitation of post-accident activities	To detect and extinguish fire under vehicle bonnet
	To release door lock mechanisms after an accident
	To notify of the necessity of help after a collision
	To record vehicle motion parameters (a "black box")

Natural tendencies induce people to live in groups. In consequence, population centres were gradually formed and this is one of the reasons for the existence and development of large urban agglomerations. Already now, significant parts of population in developed countries live in urban areas, according to various research works. Some data illustrating this issue have been shown in Table 2 (according to [4]).

Table 2. Percentage of population living in urban areas (according to [4])

Country	Population percentage [%]	Country	Population percentage [%]
United Kingdom	91.5	Sweden	83.4
Denmark	88.8	Germany	81.0
Qatar	88.0	Lebanon	80.1
Australia	85.3	Japan	76.5
Argentina	84.6	USA	73.9

In 2025, the population of 93 metropolises in the world is to exceed 5 million, according to UNO forecasts. In 1984, there were only 34 such cities.

The urban traffic organisational system prevailing in a specific town and the number of parking places available determine some limits that cannot be exceeded by the numbers of motor vehicles that may move within the town.

The above leads to one important conclusion: the passenger car of the future years should be designed and equipped in accordance with the conditions in which it will be used and with the unequivocally defined tasks that it will have to fulfil. This thesis has already been reflected in the forecasts regarding the concept of building passenger cars in the USA [4]. In Europe and Japan, where the conditions of people's existence considerably differ from those prevailing in the USA, passenger cars intended for specific tasks are also built. As an example, urban cars, commuter cars, or family cars may be mentioned as the passenger cars designed for special applications.

To discuss detailed design basis for such cars or their equipment, a separate paper would be needed. Here, only a statement may be made in conclusion that all the passenger cars intended for specific applications will be designed in accordance with a design concept that already exists and that is generally known. The component assemblies and systems of such cars will include the most modern engineering solutions corresponding to achievements of new technologies and, therefore, they will meet all the requirements set for them as mentioned at the beginning of this paper.

References

[1] SZCZEPANIAK C.: *Pewne problemy dotyczące samochodu przyszłości* (*Some design questions of the future motor cars*). The Archives of Automotive Engineering – Archiwum Motoryzacji, 3/2010.

[2] SZCZEPANIAK C.: *Motoryzacja na przełomie epok* (*Motorisation at the turn of epochs*). Wydawnictwo Naukowe PWN S.A., Warszawa, 2000.

[3] SANDBERG U., EJSMONT J. A.: *Tyre/Road Noise*. Reference Book, InfornexHarg, SE – 59040 Kisa, Sweden.

[4] Q. RILEY R.: *Alternative Cars in 21st Century*. Published by SAE Inc., 400 Commonwealth Drive Warrendan P.A. 15096 – 001, USA.

[5] SZCZEPANIAK C., DYCHTO R.: *Pojazdy w kosmosie* (*Vehicles in the Universe*). Wydawnictwo Politechniki Łódzkiej (Publishing House of the Lodz University of Technology), 2003.