FACULTY OF TRANSPORT ENGINEERING
25 YEARS

VII. International Scientific Conference of the Faculty of Transport Engineering
6th – 7th September 2018, Pardubice

RAIL VEHICLES FOR THE SUSTAINABLE MOBILITY

Jiří POHL[1], Roman PRELL[2]

Abstract

- sustainable mobility as part of sustainable development,
- objectives of sustainable mobility,
- interdependence of objectives in the areas of reducing energy consumption, stopping climate change and protecting the environment,
- extramodal and intramodal energy savings,
- technical innovation as a tool for the development of sustainable mobility in the field of urban rail transport vehicles,
- technical innovation as a tool for developing sustainable mobility in the field of regional rail transport vehicles,
- technical innovation as a tool for developing sustainable mobility in the field of conventional and high-speed rail transport vehicles,
- technical innovation as a tool for developing sustainable mobility in rail freight transport.

Keywords

Sustainable mobility, rail transport, energy savings, fossil fuels

1 INTRODUCTION

The discovery, mining and using of fossil fuels (initially coal, consequently oil and natural gas) has given and still gives humanity a large amount of energy which has shifted our civilization forward. Thanks to fossil fuel power, industry, transport and housing have grown significantly. Thereafter, the level of education, medical care and social security has increased.

Already many years ago, the negative phenomena of intensive burning of fossil fuels were also identified and analyzed:

- global carbon dioxide emissions that cause undesirable and irreversible climate change,
- the formation of local exhalations, especially polyaromatic hydrocarbons, nitrogen oxides and fine dust particles, which seriously harm human health

However, for almost whole twentieth century, these facts have not been solved. Only when their consequences have grown into gigantic proportions, humanity has been committed to a program-driven shift away from the use of fossil fuels.

[1] **Ing. Jiří POHL**, Senior Engineer, Siemens s.r.o., Mobility Division, Siemensova 1, 155 00, Prague 5, Czech Republic. Phone: +420 724 014 931, E-mail: jiri.pohl@siemens.com

[2] **Ing. Roman PRELL**, Engineering Head, Siemens s.r.o., Mobility Division, Siemensova 1, 155 00 Prague 5, Czech Republic. Phone: +420 733 622 936, E-mail: roman.prell@siemens.com

Replacement of fossil fuels with renewable energy sources is real, both physically, technically and economically:

- the energy equivalent of all global consumption of coal, oil and natural gas is 40 minutes of sunlight impacting the Earth's surface
- electricity from renewable sources is thanks to technical innovation becoming cheaper than electricity from fossil and nuclear power plants
- the principles of Industry 4.0 (Internet of Things) allow the coordination of power supplies and power consumption of appliances
- new forms of efficient energy accumulation are being developed
- a significant source of energy is its savings

2 DECARBONISATION OF MOBILITY

Similar to other industries, also transport faces a major challenge in reducing energy consumption and getting rid of fossil fuel dependency. This is not an easy task because in the Czech Republic, for example, 97% of the energy for transportation is supplied by oil products (diesel, automotive gas) and their substitutes (biofuels and natural gas) and only 3% electricity. But in fact, only unrestricted orientation on electric powered transport is a solution to sustainable mobility. That means mobility characterized by low energy consumption, zero local emissions and (in connection to the change in the structure of power generation) also zero global emissions. The decarbonisation of mobility is therefore solved by combination of two sub-tasks:

- replacement of fossil fuels powered vehicles by electric powered vehicles
- replacement of fossil fuels, till now used to produce electricity, by renewable natural resources

In a society with a developed division of labor, the first task is in the field of transport and the second role in the competence of the energy sector.

The specific issue of decarbonisation of mobility is that, compared to other technical devices, that transport vehicles are mobile energy consumers. Field of ground transport is based on two ways of powering vehicles:

- use of line electric power supply to vehicles (dependent electric vehicles)
- use of mobile electric energy storage on vehicles (semi-electric vehicles)

Both of these methods are not in a competitive position. They can mutually complement and use (or co-create) a common energy infrastructure:

- high-power and high-efficiency line power supply of the vehicles is suitable for heavy and regular transport streams, where it is worthwhile to set up and operate investment-intensive linear fixed traction systems (traction lines and traction power stations)
- mobile power storage, which are characterized by lower performance and lower efficiency, are suitable for power supply for weak and irregular transport streams, where it is not worthwhile to set up and operate line rigid traction devices.

3 SUSTAINABLE, NON-EMISSIVE MULTIMODAL MOBILITY

Transport of persons and things are traditionally ensured by more methods of transport. They are in a competitive position, and they also seek to obtain transport tasks which are inappropriate for them, where they are not effective. For example use of public transport capacities for weak transport or, on the contrary, the use of individual cars to travel in the direction of strong transport flows.

In contrast to this, non-emission multimodal sustainable mobility is based on cooperation and complementarity of individual modes of transport. It operates on a hierarchical principle, structured according to the intensity of the transport stream. From the weakest transport streams provided by individual means of transport on a not-so-perfect transport route to the most powerful transport streams, provided by means of mass transport on a high-quality and highly sophisticated transport route.

4 INTRA-MODAL AND EXTRA-MODAL ENERGY SAVINGS IN TRANSPORT

Residents of the Czech Republic belong with production of about 12 tonnes of carbon dioxide per inhabitant and a year of very significant initiators of climate change, exceeding not only the average of the world but also the EU average. This is directly related to the high energy demand of the Czech economy. This fact is excused by the claim, that the Czech Republic is an industrialized country. However, this is not exactly the right defense, as transport with its 27% in the Czech Republic contributes to final energy consumption almost the same as industry (it has a 30% share). The current dynamics of energy consumption in the Czech Republic is so, that despite increasing production volumes, the final energy consumption in industry has remained roughly unchanged in recent years. However, final energy consumption in transport has increased by 12% in the last three years, 4% per year. Both the global emissions of carbon dioxide (with a negative impact on irreversible climatic changes) and the local emissions of toxic fumes (with a negative impact on human health) have increased proportionally. Such a trend is unacceptable, fundamental changes are a must. Citizens' demands for the regulation of the street transport are fully justified. Structural changes are necessary and should be supported by targeted technical innovations.

There are quite significant differences between energy demands of different category of transport:

- The rail transport systems have a lower resistance of the rolling of the steel wheel on the steel rail. Due to the low aerodynamic resistance of the long slim vehicles forming the train, roughly 3 times lower traction resistance. With that is lower energy consumption than the individual moving road vehicles
- Electric traction drives have approximately 2,5 times higher efficiency and therefore a proportionally lower power consumption than internal combustion engine drives

In the product of these two factors (3 x 2.5 = 7.5), electric powered rail vehicles are roughly 7.5 times less energy consuming than road traffic provided by cars with internal combustion engines.

From this reality there are two basic options for energy savings in transport:

- intramodal energy savings resulting from increased energy efficiency in a particular type of transportation
- extramodal energy savings resulting from the transformation of a transport from energy-intensive type of transportation to less energy-intensive type of transportation.

An effective tool for achieving both intramodal and extramodal energy savings in transport is the technical innovation:

- new technologies reduce the energy demands of each type of transport
- new technology increases the attractiveness (speed, comfort, ...) of less energy demanding types of transportation. This motivates the population to switch from more energy-intensive modes. Increasing the speed and comfort of public transport are therefore a significant way to save energy.

The fact, that the both way of the transport (transport of persons and the transport of goods) has dominated the energy-intensive road car transport in the Czech Republic, creates a great potential for the benefits of extramodal savings.

5 TECHNICAL INNOVATION AS A TOOL FOR DEVELOPING SUSTAINABLE MOBILITY IN THE FIELD OF URBAN RAIL TRANSPORT

In the sense of the mentioned principles, it is necessary to assess the relationship of individual transport (mainly ensured by cars powered by internal combustion engines) and mass transport (mainly provided by rail systems with electric power) in cities. For example, the City of Prague demonstrates the energy and environmental impacts of both:

- individual car transport provides about 50% of the transport capacity of the urban transport in Prague and consumes 88% of the energy spent on Prague passenger transport
- urban public transport also provides about 50% of Prague's public transport services, but uses only 12% of the energy for Prague's passenger transport.

By the assessment of the exhalation of harmful substances (NOx, PAH, especially benzo(a)pyrene, PM 2.5 and PM1 fine particulate elements) the disproportion between individual and mass transport is even sharper.

The basic aim are therefore extra-modal savings, so such solutions of the public transport systems, that motivate people to move away from the use of cars. Automobile transport is available for the population (material poverty has passed) and creates basic criteria for urban transport:

- traveling by public transport must not be slower than traveling by car
- people are sitting in a car, it does not make sense to offer them stand places, even worst in crowded vehicle
- modern cars are normally equipped with air conditioning, and there will be no success to offer them vehicles without air conditioning.

Of course, importance in urban transport also has intramodal energy savings. Territorial operation of public transport, based on the principle of stopping, that is, based on the constant periodic creation and abatement of the vehicle's kinetic energy. There are two basic requirements for urban public transport vehicles:

- weight minimization (as a parameter weight/seat)
- wide application of electrodynamic regenerative braking

Both in light vehicle construction and in the field of electric traction drive management, ways to reduce of the energy consumption of the driving cycle are still sought and found. However, given the matured state of the technic, there are no longer potential of significant saving.

Attention is paid to the savings of the secondary energy consumption, especially the energy needed to create thermal comfort inside the vehicle. With respect to the relatively low travel speed (and therefore long time needed to travel a certain distance) and the frequency of the opening of the doors at stops, urban public transport vehicles have a secondary energy consumption comparable to traction consumption. Therefore, measures to reduce non-traction consumption are important. A very positive contribution can, for example, be achieved by controlling of the amount of fresh ventilation air based on the carbon dioxide concentration inside the vehicle.

Another very important and very perspective trend is the extension of the electric car to sections without line power supply. That means the application of electric energy storage on vehicles. Depending on the time available for charging and the required range, either the fast-reacting two-layer capacitors or the slower lithium electrochemical accumulators are used. Or combination of both above mentioned solution.

6 TECHNICAL INNOVATION AS A TOOL FOR DEVELOPING SUSTAINABLE MOBILITY IN THE FIELD OF REGIONAL RAIL VEHICLES

Regional passenger rail transport has two fundamentally different forms:

- suburban regional transport, which takes place on main lines radial heading to large cities. The tracks are electrified, two-track, with a relatively high speed (typically 160 to 200 km / h). Regional passenger trains are operated on tracks with passenger and freight trains. They are the slowest segment of train traffic, limiting the track performance
- rural regional transport, which takes place on regional lines, usually departing from the main lines. The relevant tracks are not electrified; they are only single rail, with low speed (typically 60 km / h). Regional passenger trains are almost the only kind of the train traffic.

These two different forms of regional passenger rail transport determine a pair of different vehicle requirements:

- for regional suburban trains running on main lines, high-capacity vehicles are required as the interval between regional trains can no longer be reduced. The lines must remain also free for other types of the transport, especially long-distance passenger coaches and freight transport. The solution could be semi-double-deck vehicles. Complete electric units combine double-deck non-traction wagons, fully used for passenger transport, and single-deck traction wagons with electric equipment on the roof. Vehicles of this type achieve the highest ratio between the number of seats and the required platform lengths, which is the decisive parameter in providing traffic on the heavily loaded main lines. The second basic requirement for these vehicles is the highest operation speed. It assists in addition to the fast changing of passengers at stops (double-leaf doors placed along the whole length of the vehicle), especially the proper driving dynamics. That cause rather big technical speed of the vehicle. Its achievement is conditioned by a high proportion of driven and dynamically braked wheelsets and high traction power, as well as even higher braking power. Dynamic operation, typical by periodic alternation of the acceleration and braking, that means the creation and dissipation of kinetic energy, leads to the demand on low vehicle weight (more precisely: the low weight of a vehicle per seat) and using only electrodynamic regenerative braking. This is on the rail, in the case of AC power supply, able to transmit recovered brake energy to other (just starting) vehicles but also back through the traction power stations to the general three-phase distribution network
- in order to enable regional railways to motivate the population to use them, they must be integrated into the regional transport system. The way how to achieve that, are no-stop trains without that switch from main electrified lines to secondary non-electrified lines. It is not in many cases useful to electrify these tracks. Therefore, a two systems (pantograph / accumulator) are needed to provide direct trains using the network of both electrified and non-electrified railways. In case of the tractionless operation, the traction accumulator uses the traction battery not only with the basic energy source for driving but also with the use of regenerated kinetic energy during stopping and braking.

A very important technological innovation that has significantly shifted forward traction technology are bogie frames with an internal bearing. Their use was conditioned by the construction of traction drives and brakes into a more limited space. However, the result in the form of savings of about one third of the weight achieved on the bogie, that is very big benefit for a component which determines the total weight of the rolling stock. It has very positive consequences for rail transport:

- there is a significant saving in the overall weight of a vehicle with a positive impact on driving dynamics and energy consumption

- the reserve obtained in the weight balance of the vehicle can be used to extend wagon length and thereby increase its transport capacity. There will be further reduction of the vehicle's specific weight per seat
- Due to the extension of the carbodies, the same length and capacity can be realized with units with fewer vehicles, that mean with fewer bogies, which further increases the weight reduction effect and corresponding energy savings
- the reserve obtained in the weight balance of the vehicle can be used for the application of light Jakobs bogies with inner frame also in the vehicle, where the use of the Jakobs bogies with traditional heavy frames with the outer frame did not seem appropriate. Particularly in combination with the extension of the vehicle bodies, it is possible to make concept of very light and simple (with a small number of wagons and bogies) units with low energy consumption
- obtained reserve in the vehicle's weight balance can be used to place energy storage lithium accumulators needed for the creation of two-source (trolley/accumulator) vehicles with a range of approximately 80-100 km, suitable for the operation of 40 to 50 km of non-electrified lines. Charging their accumulators is carried out from the traction line while running or when standing on electrified lines, or in electrified stations. These vehicles can be provided with clean, non-emissive operation even on lines without line electrics
- obtained reserve in the vehicle's weight balance can also be used alternatively to place hydrogen cells

7 TECHNICAL INNOVATION AS A TOOL FOR THE DEVELOPMENT OF SUSTAINABLE MOBILITY IN THE FIELD OF LONG-DISTANCE AND HIGH-SPEED RAIL

The ability of rolling stock to complete a train, a long group of cars moving in mutual overlap, has a major impact on their aerodynamic resistance and also on the energy consumption. Importance of this ability increases with the second power of driving speed. The practical usability of individually moving vehicles (cars) ends around speeds just over 100 km / h, which leads to very long transport times even when they are operating at medium distances. This limits for example business trips to a distance of about 200 km, with longer distances more than half of eight hours of work time is lost. This limit undesirably growth of social and economic activities only in the near of the capital (typically in the Czech Republic: Prague and the Central Bohemian Region) and separates them from the wider area. Even the airplane is not a suitable solution for one-day business trips, which are the basis of functional territorial integration. The minimum travel time is (in addition to the trip to the airport) even at a short distance of 2 to 3 hours. On the rail, thanks to long slim aerodynamically shaped vehicles with low air resistance, the speeds of 300 to 350 km / h can be used, and thus short transport times, without being accompanied by high energy consumption, in addition with non-emission electricity.

Until the construction of high-speed railways is finished, long-distance passenger rail transport is provided on conventional lines by speed of 160 to 200 km / h. In this service, the locomotives operated (pushed or pulled) non-traction units are very well proved:

- delivering intramodal energy savings because they achieve a low aerodynamic resistance, which determines the energy performance of fast-moving vehicles
- delivering extramodal energy savings. The high level of travel comfort of a branded transport product with a guaranteed level of travelling motivates citizens, traditionally using energy-intensive automotive transport, to switch to rail.

In the high-speed rail segment, a continuous technological development is taking place on both the railways (CCS subsystem: switching to ETCS level 3, ENE subsystem: continuous single phase 25 kV 50 Hz (or 2 x 25 kV 50 Hz) using IGBT multilevel traction power stations 3 AC / DC / 1 AC) as well as on the vehicle side.

As in the area of regional transport, bogie frame technology with an internal bearing also comes into the field of high-speed vehicles. In addition to the already mentioned extension of the unit length, which the bogies with the inner frame allow (usually 200m long unit could consists of 7 wagons 28m long instead of 8 wagons 25m long), there is also lower aerodynamic resistance on narrower and more covered bogies with an internal frame at high speeds. The result is a reduction in the train's aerodynamic resistance and, therefore, 30% energy consumption compared to the former vehicles solution of the previous generation. This is a very significant step forward, bringing the energy demands of high-speed trains with aerodynamic trains to the energy demands of conventional railways run at half-speeds by traditional train. The doubling of speed does not mean higher energy consumption.

8 TECHNICAL INNOVATION AS A TOOL FOR DEVELOPING SUSTAINABLE MOBILITY IN RAIL FREIGHT VEHICLES

Also in the rail freight sector are innovative vehicle trends, represented in particular by the development of interoperable high-performance electric locomotives which replacing older, less efficient locomotives, motivated by extramodal and intramodal energy savings. In the field of freight transport, energy savings have strong economic accent. Transported goods do not require as much care as the transport of persons. Freight wagons are therefore both investment and operating significantly cheaper than passenger transport vehicles. As a result, the cost of energy in the total cost calculation of rail freight is a relatively more significant item than the cost of energy for the rail transport of persons. This motivates rail freight operators to take energy-saving innovative solutions.

In the area of extra-modal savings, that mean savings achieved by replacing energy-intensive and environmentally high-cost road freight transport by rail transport, the basic motivational factor is travel or transport speed, which determines the attractiveness and productivity of freight rail transport. Traditional freight trains with a specific output of around 1 kW / t (using 2 MW locomotives to transport 2 000 tons trains) are moving slowly, so they have difficulty to reserve the route on the heavily loaded lines. Freight trains transported by high-performance 6-MW electric locomotives have a specific output of around 3 kW/t and are therefore able to be operated with fast trains and thus have a higher travel speed.

In the area of intramodal energy savings, the used frequency-controlled asynchronous traction motors technology positively demonstrates not only lossless start and recuperative braking, but also lower losses in fixed traction systems of the 25 kV 50 Hz as they only take active power (sinusoidal current in phase with voltage). Modern electric locomotives do not burden (unlike older locomotives with diode rectifiers) the traction network by taking reactive or deformation power. Also, they do not need filtering compensating devices for their operation in traction power stations, which work with high energy losses.

9 CONCLUSION

In the nineteenth century, the development and construction of railways was essentially connected with the mining, transport and use of fossil fuels, mainly coal. Nearly two hundred years have passed, during which the whole society (including the railways) has shifted due to the fossil fuel energy forward. The related development of technology and education gave human society the knowledge and the economic power to reduce its energy consumption, to stop using fossil fuels and replace it with electricity from renewable sources. The goal is to stop irreversible climate change and harming of the human health through toxic exhalations. However, this is not a reason to limit traffic. This can be further developed on the basis of sustainable and non-emission multimodal mobility.