VEHICLES FOR HIGH-SPEED TRANSPORT SYSTEMS

Josef Kolář *)

Introduction

Style and culture traveling, its level and quality become some of criterion of the civilization advancement. In 21st century people want to travel faster, more comfortable, safely, reliably, and with acceptable costs. These demands force producers to innovate and develop vehicles, transport systems, and their components. Modern style of traveling mainly by car caused on one hand a very fast development of cars and road transport but on the other hand also showed disadvantages of this manner of transport: overcrowded roads, high number of injured or killed people, and big harm to the environment. This manner of transport is also less efficient with respect to quite a high-energy consumption. From this point of view it can be expected that modern high-speed railway can offer manner of transport that is - compared to road and air transport - more comfortable, energy saving, and less harmful to the environment. Another advantage of rail transport compared to air transport is that trains can run in city centers while airports are located far away from the city centers.

The important moments in development of high-speed rail transport systems

The construction of the high-speed railway with an operational speed 210 ÷ 260 km/h began in 1960’s in Japan, after experiments in France. The first high-speed track was built between Osaka and Tokyo and the twelve-car electric units Shinkansen started to operate with passengers in 1964. The trains of the first generation were running due to their high noise level at a maximum speed of 210 km/h. In these days the newest trains are running at a speed of 285 km/h (JR 700).

In Europe the first construction of the high-speed track began in 1976 in France and at the same time the development of the TGV high-speed units began. In next years after the successful setting into operation of the 426 km long track TGV PSE (Paris – Lyon) in 1981 the new tracks TGV Atlantique (Paris – Bordeaux) and TGV Nord (Paris – Brussel) were built. The maximum operational speed on the track Paris – Lyon is 300 km/h; on the others it is 350 km/h. While the high-speed tracks in Japan and France were built only for passenger transport, in Germany and Italy the high-speed tracks designed for mixed transport (for both passenger transport at a maximum speed of 250 km/h and express freight transport) started to be built in 1980’s. In 1988 the high-speed passenger transport by ETR 450 Pendolino units

*) Ing. Josef KOLÁŘ, CSc., FS ČVUT v Praze, U 12 120.1, e-mail: Josef.Kolar@fs.cvut.cz
with tilting system of car bodies was introduced on the track Roma – Milano. In further years they expanded also on the tracks Roma – Neapol and Milano – Turin.

In 1991 two new high-speed tracks in SRN Hannover – Würzburg and Mannheim – Stuttgart were set in operation. The ICE 1 and ICE 2 high-speed units have been operating on these tracks. The track connecting Koeln and Frankfurt am Main was set into operation in 2002 and it is designed only for passenger transport. On this track only the ICE 3 high-speed units are operating with the maximum speed of 300 km/h.

The high-speed railway with track gauge 1435 mm has been gradually expanding in Spain. Since 1992 the 574 km long track Madrid – Sevilla (trains AVE – TGV) has been operated. For the new built track Madrid – Barcelona the vehicles Velaro E and Talgo 350 I were chosen. The high-speed transport systems have also expanded in Great Britain where the Eurostar high-speed units are operated between Paris and London. In the intrastate network the nine-car units Electra 91 (maximum speed 200 km/h) and the Pendolino Britannico units with the tilting system (maximum speed 225 km/h) are operated by British Railways.

The high-speed railway with an operating speed 210 km/h has expended also in the less densely populated countries in northern Europe – Sweden and Finland. In Sweden it is represented by X 2000 units that consist of a motor car, three intermediate trailers, and a driving car which is located at the other end of the train. The intermediate trailers and the driving car have got the active tilting system of car bodies. In Finland there are the six-car units Pendolino S 220 in operation.

It results from the expected development of the high-speed railway network in Europe by the year 2020 that, due to lower transport density a rather, more extensive modernizing of current main tracks will gradually start in the middle, northern and eastern Europe with the maximum speed up to 250 km/h instead of building of completely new high-speed tracks with minimum curve radii of 4000 m and with gradients 30–40 ‰ that allow to run the vehicles at a maximum speed of 350 km/h.

The high-speed railway should be gradually built also in Asia (Korea, Taiwan, etc.) by 2011. In 1991 – 1994 Texas High Speed Rail Corporation unsuccessfully tried to build the TGV system in U.S.A. The studies of the high-speed railway in Canada are being elaborated.

Design concepts of high-speed rail vehicles

High-speed rail vehicles are produced and operated in two main design concepts:

a) **With concentrated power and electric equipment** in the cars situated at the ends of the train. The train consists of two head motor cars situated at the ends of the train and intermediate trailers (TGV, Eurostar, AVE – S 100, ICE 1, ICE 2, ETR 500, Talgo 350 I, HSR 350 X, Electra 91, X 2000).

b) **With distributed power and electric equipment** spread along the whole length of train. The train consists of several motor cars and possibly of trailers situated between them (Pendolino – ETR 450, ETR 460, … , Shinkansen – JR 100, JR 300, JR 500, … , ICE 3, Velaro E).

Vehicles of the category a) create modern high-speed units with motor cars with very unevenly distributed mass along the train (maximum axle load of motor car – 17 t TGV; 19.5 t ICE) which are operated on new high-speed tracks with large curve radii at a speed of 250 – 350 km/h. The advantage of this solution is the placing of the electric equipment in an engine-room in the motor cars. In a case of drop-out of one of the motor cars one half of the power is lost but mostly it is possible to get through a journey. The vehicles do not use tilting
The exception is Talgo 350 unit (AVE S-102) with the wheel arrangement
\[B_0B_0 + 1'1'1'1'1'1'1'1'1'1'1'1'1'1'1'1'1'B_0B_0,\]
it's intermediate trailers have got passive tilting system of car bodies. The significant and the most numerous type of the a) category are the TGV high-speed units which are either one-floor (TGV PSE, TGV Atlantique, Eurostar, AVE-S100) or double-deck (TGV Duplex), produced by Alsthom. It is characteristic for the TGV units that car bodies of the intermediate trailers are articulated together and are laying on two air springs of secondary suspension of Jacob’s bogies. The shorter units have got four drive bogies placed under the vehicles at the ends of the unit; this leads to the wheel arrangement
\[B_0B_0 + 2'2'2'2'2'2'2'2'2'B_0B_0.\]
The longer train units have got six traction bogies with the wheel arrangement
\[B_0B_0 + B_0'2'2'2'2'2'2'2'B_0B_0 + B_0B_0.\]
The Italian ETR 500 units and German ICE 1 units have got two head motor cars and 10 or 12 intermediate four-axle trailers (ETR 500) or 12 (eventually 14) intermediate four-axle trailers (ICE 1), that leads to the wheel arrangement
\[B_0B_0' + 2'2' + 2'2' + ... + 2'2' + 2'2' + B_0B_0.\]
The arrangement of the ICE 2 units is: motor car, 6 intermediate trailers, and driving car. If needed, two train units can be connected together.

Design of bogies gear and drive of the motor cars of this category has got these characteristics:
- individual drive of wheel set with asynchronous motor with power 1.1 – 1.2 MW
- driven wheel sets with small radius of the wheels (920 mm)
- Traction motors and other parts of the drive are fixed to the car body (TGV) or attached (through rods vertical shackles that allow it to move) to the bogie frame and car body (ETR 500). This arrangement can be completed with an active element which allows the motor to move in lateral direction relatively to the bogie frame (ICE 1, 2).
- transmission of traction torque from traction motor to a wheel set is realized by:
  - two gearboxes which are connected to each other by Tripod shaft; the first three-wheel gearbox is fixed to the cover of the motor, the other one is attached to the axle of the driven wheel set and it is suspended by using of vertical shackles that is attached to the car body transom (TGV drive)
  - tube-type propeller shaft with two “more rod” couplings that are transmitting the traction torque from the output tube-type shaft of the three-wheel gearbox to the disc of the driven wheel set; the three-wheel gearbox creates together with the motor integrated drive unit; (ICE 1, 2, and ETR 500).

The main advantage of this design of the drive which is realized at the motor cars is the reduction of the total mass of the bogies and its unsuspended part. Thus the dynamic effects resulting from mechanical parts of the drive, the mass influencing the lateral dynamic behavior of the vehicle (run stability on straight track), and forces acting on the railway are reduced.

Vehicles of the category b) create modern high-speed units which have got rather more complicated distribution of power circuits along the train unit (a failure of one of its part may cause the train unit impossible to run), worse accessibility of the electric equipment placed on the roofs of the car or under the floor but on the other hand this design concept allows to reach higher number of places for passengers in the vehicle, even distribution of mass along the train, and distribution of traction power to higher number of driven wheel sets. This causes better usage of adhesion weight of the vehicle for accelerating or braking even during worse adhesion conditions. The axle load is 10 – 14.5 t. For elimination of mentioned disadvantages the system of redundancy of main components of the vehicle and maintenance-free components with higher reliability placed in replaceable blocks of modular arrangement are used.
For running at a speed of 300 – 350 km/h on new built high-speed tracks the units without tilting system are used (ICE 3 or JR 500 Shinkansen) because the influence of tilting on increasing of the operational speed is negligible in new curves of large radius. Specific power of these train units is about 20 kW/t. Due to high installed power (8 MW) and a need of using of pantograph with its light head (which are minimizing dynamic effects to trolley during the run at a high speed), DC supply is practically not possible to be used in this category of vehicles; 15 kV or 25 kV AC systems are suitable only.

In these days on current modernized main tracks with large number of curves the high-speed units with tilting system of car bodies (active systems tilt the car body up to 8 degrees) are used. These units have to be generally equipped with a special stabilizer hanger of the pantograph to the car body.

The axle arrangement of electric units with distributed power, i.e. the vehicles of the category b), depends on the number of driven wheel sets (wheel radius is approx. 860 mm) and the arrangement of individual drive of the wheel sets.

The Japanese Shinkansen units are mostly using a large number of driven wheel sets (mostly all of them), i.e. the wheel arrangement is $B_BB_B + B_B'B' + B_B'B' + ... + B_B'B' + B_B'B'$. Each wheel set is driven by a lighter asynchronous motors with a power 230 kW (JR 100) up to 305 kW (JR 700) that do not need to be mounted to the car body but they are through rubber silent blocks elastically mounted on the bogie frame. The traction torque is transmitted from crosswise oriented motor through saw tooth-type spherical coupling to an input shaft of an axle gearbox. Reaction torque is transferred by vertical shackle in bogie frame. Axle guiding at the new bogies WTD 205 is realized by swinging arms.

Eight-car German ICE 3 units are equipped with traction and running bogie SGP 500 with more powerful and heavier asynchronous motors (500 kW); the wheel arrangement is $B_BB_B + 2'2' + B_B'B' + 2'2' + 2'2' + B_B'B' + 2'2' + B_B'B'$. The motors are together with a vertical shackle of an axle gearbox mounted to an auxiliary frame. The auxiliary frame is then connected through vertical shackle to a central console, which is fixed to bogie transoms, and thus the drive is suspended in a lateral direction. The traction torque is transmitted from crosswise oriented motor through saw tooth-type spherical coupling to an input shaft of an axle gearbox. Axle guiding is realized by inclined longitudinal rods enabling the gravitational steering of the wheelsets during running through a curve.

The similar system of Lemniskat A-bracket axle guiding enabling the passive steering of the wheel sets is realized also at the traction and running bogies of the Pendolino units. But they have got different drive arrangement where for individual drive of the wheel sets the lengthwise oriented asynchronous motors (500 kW) are used, fixed to the car body. The traction torque is transmitted from the motors through propeller shaft to conical axle gearbox. The electrical units of the Pendolino type are using a combination of motor cars and trailers e.g. with this wheel arrangement $(1A)(A1) + 2'2' + (1A)(A1) + 2'2' + (1A)(A1) + 2'2' + (1A)(A1)$. 

References:

André Werske: *Die schnellen Züge der Welt*, http://www.hochgeschwindigkeitszuege.com
Isao Okamoto: *Shinkansen Bogies*, Japan Railway & Transport Review 19, March 1999
Fiat Ferroviaria S.p.A, 12038 Savigliano(CN) –Italy, *Pendolino*, str. 70,