

HYBRID PROPULSION OF RAILWAY VEHICLES

ХИБРИДНА ТЯГА В РЕЛСОВИТЕ ТРАНСПОРТНИ СРЕДСТВА

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Abstract: Hybrid propulsion of railway vehicles represents a modern solution of propulsion with the basic object of reducing fuel consumption and harmful emissions. The realized designs of such propulsion show the success of achieving the set goal. This paper explains in more detail the possible designs of the hybrid propulsion of railway vehicles, the advantages and drawbacks of such a design and the encountered difficulties. Two typical examples of hybrid propulsion of motor rail cars with different technical designs are presented. The paper gives a more detailed description of the design and operation principle, i.e. the specifics of the regime of individual aggregates in adequate running regimes.

KEYWORDS: HYBRID PROPULSION, EMISSIONS, RAILWAY VEHICLES, AGGREGATE

1. Introduction

The implementation of hybrid propulsion on railway traction vehicles represents an additional contribution in fuel saving and reduction of harmful emissions. This refers to an advanced form of propulsion which has already had for a certain time commercial application on passenger motor vehicles, and more recently has started to be implemented also on the bigger means of transport such as railway vehicles.

Hybrid propulsion basically represents combined propulsion most often of two sources of energy. The focus is on the application of electricity as propulsion, which is supplied from a certain source. This may be batteries, electrical energy generator, contact cable, fuel cells and similar. The other source of energy is usually a Diesel engine which is of lower power in relation to self-propulsion.

The energy storage device plays an emphasized role in the implementation of the hybrid propulsion. This primarily refers to devices for storing electricity. Therefore, recently, the focus has been on the development of various forms of electricity storage tanks.

The known lead and nickel-cadmium (Ni-Cd) batteries were available in the 1990s, but they were not satisfactory for the serial application in hybrid propulsion on vehicles, especially for larger vehicles. Today there are nickel-metal hydride (Ni-MH)-based batteries and lithium-ion (Li-ion) batteries available, which may be used both for motor vehicles and for railway vehicles.

2. Hybrid Railway Vehicles

In hybrid traction vehicles, the methods of connecting the generator in relation to batteries and traction electric motors, i.e. driving

wheels are different. The different configurations may be: series, series-parallel and parallel systems. Parallel and parallel-series systems represent a more complex design compared to series system with approximately the same effects which is why series configuration is more often implemented in practice.

In series hybrid propulsion system the mechanical energy of the Diesel engine is converted into electricity which propels the vehicle.

In parallel system the vehicle is primarily propelled by the Diesel engine. The electric motors are used in working regimes with lower Diesel engine performance. Here the batteries are kept at constant charging level. The energy for battery charging is obtained from the Diesel engine, from the kinetic energy of vehicles, i.e. train during deceleration and braking.

Basically, there is a number of hybrid propulsion design variants depending on the needs, which have to take into consideration the specific characteristics in relation to the required power, and type and size of vehicles. Here, the size and type of batteries that can fulfil the set requirements have to be taken into consideration.

For the moment the hybrid propulsion starts to be fitted on smaller railway traction vehicles, such as motor railcars and shunting locomotives.

Conventional propulsion of motor wagons consists basically of the Diesel engine with power transmission mainly of hydraulic type (Figure 1). Such propulsion requires constant Diesel engine propulsion during traction. In deceleration, braking or coasting the energy is usually converted by braking into heat and released into the environment as not used for traction.

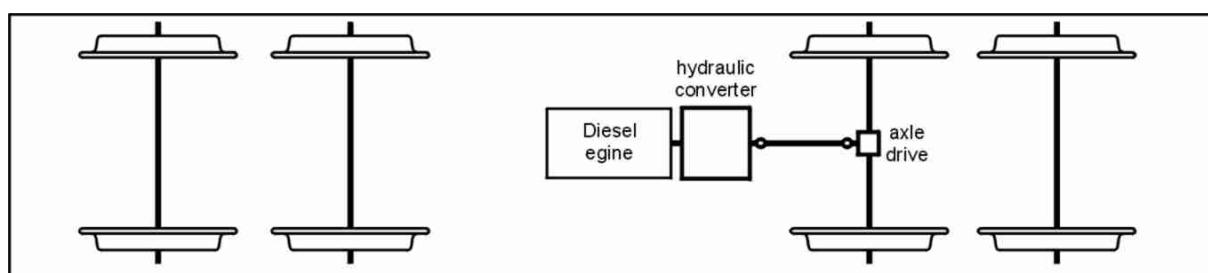


Figure 1: Classical propulsion with hydraulic power transmission

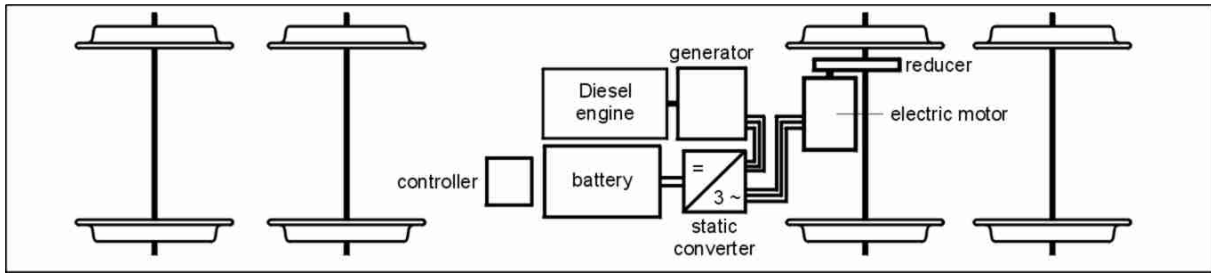


Figure 2: Series hybrid propulsion

Series hybrid propulsion means conversion of mechanical energy of the Diesel engine into electricity using the generator. The generated electric energy is used, depending on the running regime, for the traction via static converter and traction electric motor, usually the three-phase asynchronous motor and for battery charging (Figure 2).

One of the specific designs of hybrid propulsion, the “Motor-Assisted (MA) Hybrid Traction System” was developed by Hokkaido Railway Company (JR Hokkaido) as the Innovative

Technology Train (Figure 3) [1] whose propulsion scheme is presented in Figure 4.

The vehicle does not use the Diesel engine at low running speeds which reduces the noise level from the vehicle during the stay at stations and when leaving the station. The implementation of specific transmission (mechanical shift transmission) increases the traction performance and enables the conversion of mechanical energy in deceleration and braking into electric energy which can later be reused. Modular design of the entire propulsion system reduces the lifecycle costs (LCC)..



Figure 3: Innovative Technology Train of Hokkaido Railway Company (JR)

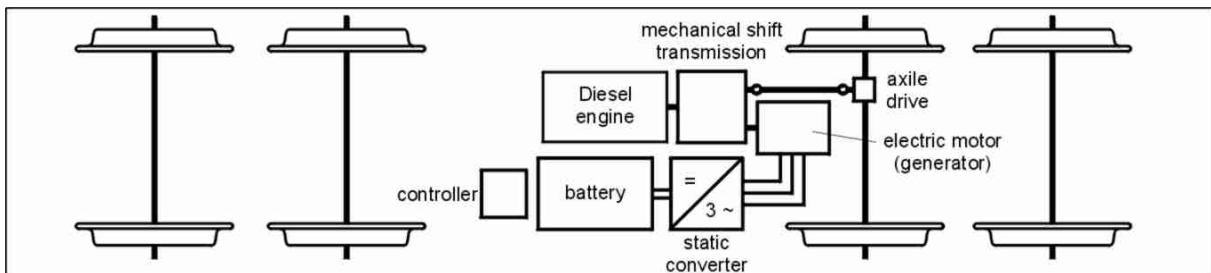


Figure 4: Motor-Assisted (MA) Hybrid Traction System

During electric motor propulsion the ride comfort is improved since the jumps of the revolution moment are absorbed by the electric motor with the change in transmission levels in the mechanical shift transmission. The vehicle is environmentally-friendly since it cuts down the fuel consumption and the emissions of CO, NO_x and particulate matter.

MA hybrid propulsion consists basically of a Diesel engine and the so-called active transmission which includes a mechanical shift transmission, traction electric motor, static converter, batteries and a controller. Propulsion can be realized by a Diesel engine only via mechanical shift transmission, by traction electric motor only via mechanical shift transmission and by a combination of a Diesel engine and a traction electric motor. When braking, the traction electric motor operates as a generator, and the generated electricity is used to charge the battery.

The mentioned hybrid propulsion has been programmed so as to operate in the following way (Figure 5):

1. Propulsion by traction electric motor in acceleration when the vehicle is leaving a station up to a running speed of 45 km/h in order to reduce noise. During longer stay the controller stops the Diesel engine also to reduce noise.
2. At a speed of 45 km/h the Diesel engine is switched on and its power is used for further vehicle acceleration. The lack of power is supplemented by the electricity from the batteries.
3. In coasting operation the Diesel engine drives the traction electric motor which changes to generator operation, and the obtained electricity is used to charge the battery.

4. When braking, the kinetic energy of the vehicle is used for generator propulsion, and the produced electricity is used to charge the battery which can later be used for vehicle propulsion via traction electric motor. Compared to conventional propulsion, the mentioned design reduces the fuel consumption by 15 to 20 %, i.e. respective reduction of CO₂ emissions. This result from the fact that Diesel engine runs in optimal regimes from the fuel consumption aspect and lower losses in the mechanical shift transmission compared to the

hydraulic or electric power transmission. Lower NO_x and particulate matter emissions are achieved by sophisticated designs of the Diesel engine, such as e.g. application of the common-rail fuel supply system. Further reduction of dimensions and weight of such hybrid propulsion would reduce also the price of the batteries, static converter even on the existing motor wagons with adequate reconstruction.

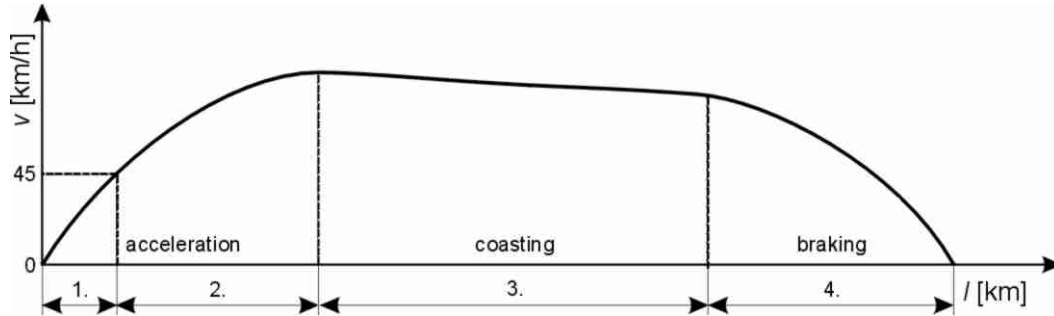


Figure 5: MA hybrid propulsion operating modes

An example of a hybrid propulsion of a motor wagon is a prototype entitled New Energy Train developed by East Japan Railway Company (JR EAST) and Hitachi Ltd. (Figure 6) [2]. The development that followed had the objective of reducing fuel consumption, harmful emissions and noise. The train has been designed with diesel-electric hybrid propulsion of series configuration (Figure 7). The Diesel engine is of maximum power of 330 kW at 2100 rev/min which powers a three-phase

asynchronous generator of 230kW. The generated electricity is converted in an AC/DC converter from a three-phase system into a direct current system, and this direct current can be used for the propulsion of the traction electric motors and/or for battery charging. The train has two three-phase traction electric motors of 95 kW each so that direct current for their supply has to be converted in a DC/AC inverter into three-phase alternative current with adjustable frequency for running speed regulation.



Figure 6: New Energy Train JR East

The battery can be charged from the generator at the same time as propelling the traction electric motors and during braking by the electricity generated from the electric motors that act as generators during braking, converting kinetic train energy into electricity. Harmonized operation of the entire system is ensured by the controller with the aim of realizing maximal energy efficiency.

The battery is lithium-ion battery of high capacity of 10k Wh and output power of 250 kW. The battery operates in the inter-area between the converter and the inverter of the static converter and may be charged from the generator or electric motor in regenerative braking and serves to supply the traction electric motors in traction of the planned regimes.

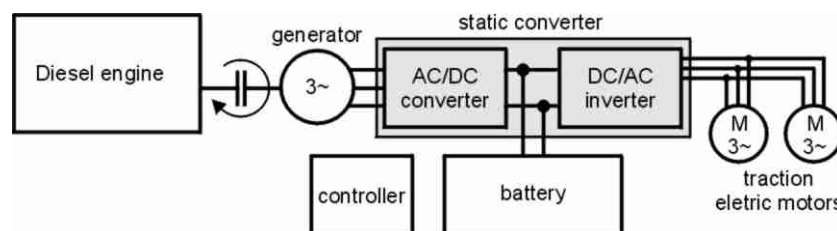


Figure 7: NE train (New Energy Train) series hybrid propulsion

The series hybrid propulsion operating regimes are presented in Figure 8. This is acceleration when only battery supplied electricity is used (1), continuation of acceleration by using

electricity supplied from the battery and from the generator propelled by the Diesel engine (2), coasting (3) and braking (4).

Starting of the vehicle and acceleration up to 25 km/h is realized by traction electric motors powered by the batteries. When this speed is reached, the Diesel engine is started and operates in idling up to the vehicle running speed of 30 km/h. After that, the Diesel engine accelerates the rotational speed and power and starts powering the generator. By the end of acceleration the electric motors are supplied from the generator and battery. In case the Diesel engine generates via generator more power than required to supply the traction electric motors, the power surplus is used to charge the batteries.

In coasting, the Diesel engine continues to supply energy to the generator for some time, and the generated electricity is used to charge the battery. After that the Diesel engine turns to idle and turns off the generator.

In braking the Diesel engine continues to operate in the idle mode up to the speed near stopping when the engine is switched off. Braking is regenerative, i.e. kinetic energy of the train when braking is used to propel the electric motors that operate as generators, and the generated electricity is used to charge the battery.

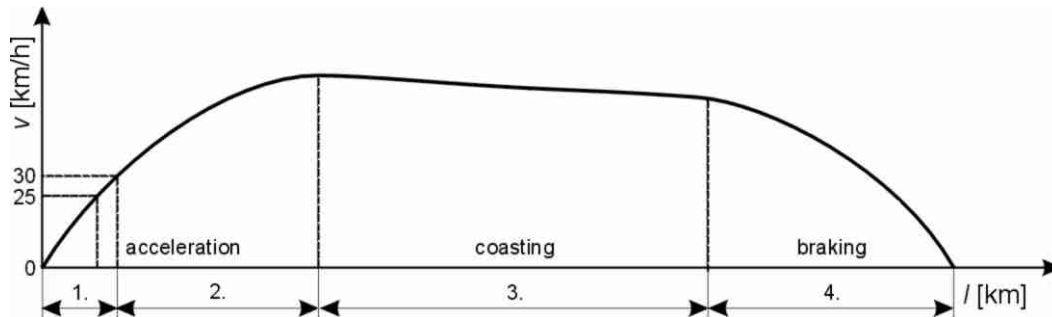


Figure 8: Operating regimes of NE train series hybrid propulsion

The tendency in using the Diesel engine is to ensure its operating regime with minimal specific fuel consumption, thus reducing the total fuel consumption. In order to reduce noise and harmful emissions, the Diesel engine is switched off in the stations, and switched on only when the speed of 25 km/h is reached.

The presented hybrid propulsion allows savings in fuel consumption of up to 20 % compared to conventional Diesel propulsion, and harmful emissions of exhaust gases (NO_x , HC, CO and particulate matter) are reduced up to 50 % [2].

3. Conclusion

The hybrid propulsion of railway vehicles is still in the development phase. Various technical solutions are being designed in an attempt to achieve optimal results regarding fuel consumption and harmful emissions from Diesel engine exhaust gases. Apart from the hybrid propulsion which basically consists of the Diesel engine and batteries for energy supply and the electric motor for the traction, the hybrid propulsion can also include fuel cells as source of electricity instead of the Diesel engine-generator aggregate.

of the railways and the distinguished companies capable of such solutions. Prototype testing has shown satisfactory results regarding fuel consumption and harmful emissions. Depending on the technical solutions and the manufacturer, with hybrid propulsion the fuel consumption is reduced up to 20 % and harmful emissions are reduced up to 50 %.

The presented examples of hybrid propulsion refer to motor wagons the propulsion of which has been developed in Japan in cooperation

Further improvements of hybrid propulsion refer to enhancement of energy storing devices and electronic devices for the management and regulation of the system regarding both hardware and software.

References:

- [1] ... "The world's first environmentally-friendly "Motor-Assisted Hybrid Traction System" successfully developed!", Hokkaido Railway Company, Japan, Oct. 23, 2007. www.japanrail.com/pdf/news/ITT_technical_details.pdf
- [2] P. Cooper, "Hybrid Traction System", Hitachi Rail, www2.theiet.org/oncomms/pn/railway/06innovation_cooper.pdf
- [3] H. Schuh, "Moderne Antriebsbatteriesysteme für Schienenverkehrs-Hybridfahrzeuge", EI-Eisenbahningenieur Juli 2008. 27-31.
- [4] M. Nick, "Hybridantrieb mit Nutzung der Bremsenergie bei Dieseltriebwagen", EI-Eisenbahningenieur (53) 9/2002. 76-87.