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## SOME WAYS OF FUEL CONSUMPTION REDUCTION OF DIESEL RAILWAY VEHICLES

### *Abstract*

*The utilization of installed power capacity of internal combustion engines (ICE) in motive power units (especially in shunting locomotives and locomotives for industrial transport) is very low. The mean output of ICE in this operational mode is about 15 – 20 % of its installed power. The result is that most of the time the internal combustion engine works in regimes that are far from optimum mode. It means that specific fuel consumption is high. Some examples of measured operational regimes of locomotives in shunting operation and other motive power units are given in the paper.*

*Kinetic energy of a classic diesel locomotive as well as the DMUs and trains is transformed into thermal energy during braking process. Normally it is not possible to utilize this kinetic energy in a reasonable way. In order to improve fuel economy, the kinetic energy should be transformed into a suitable form and stored for subsequent use.*

*The improvement can be achieved by using of the unconventional traction drive of rail vehicles. One of possible ways is using of the hybrid traction drive. The hybrid drive includes the ICE, generator, traction motors and the energy storage device. In this case the output of ICE can be substantially lower than in the classic traction. The parameters of such traction drive must be based on analysis of real operational regimes of vehicles. Those parameters are particularly: output of ICE, output of traction motors, capacity and output of energy storage devices (accumulators).*

*There are other ways how to save fuel on railway vehicles, e.g. by better utilization of heat released from the fuel or using of solar energy.*

### INTRODUCTION

Problem with fuel and energy savings and air pollution in the rail transport should be solved at the present time [14]. A significant number of diesel locomotives with various installed power and age are in operation in the industrial transport and in shunting service on railways. Some ways how to solve those problems, including using of unconventional fuels, is mentioned for example in [1, 12].

It is known that the use of installed power capacity of ICE in motive power units (especially in shunting locomotives and locomotives for industrial transport) is very low. Average utilisation of engine power is usually less than 20 % of the installed power capacity and nominal engine performance is utilised only during minimal period of the total time of engine operation (at the level of approx. 1%). The result of this is that most of the operational time the internal combustion engine works in regimes that are far from optimum mode. It means that specific fuel consumption is high. At this type of locomotives operation the frequent and fast changes of engine regimes occur, which results in increased fuel consumption and imperfect fuel combustion with increased quantity of harmful emissions.

Kinetic energy of a classic diesel locomotive as well as the DMUs and trains is transformed into thermal energy during braking process. Normally it is not possible to utilize this kinetic energy in a reasonable way. The kinetic energy should be transformed into a suitable form and stored for following use.

If a vehicle or a train is at standstill very often the engine continues working (idling). The reasons are various, but mostly it is the continuous operation of auxiliary equipment (braking compressor, lighting, preheating etc.) or keeping ICE in optimal temperature.

Besides mechanical energy (approx. 40% of the energy released from the fuel in optimum regime of the engine operation), the internal combustion engine produces considerable amount of thermal energy, utilization of which is poor. Possibility of utilization of this waste thermal energy is limited also because of its varying quantity during engine operation. Interesting way of utilization of thermal energy of exhaust gases was demonstrated by company Voith Turbo GmbH & Co.KG with its SteamTrac System [15].

Presently the motive power units operating under normal regime almost do not use alternative fuels, with exception of natural gas or biogas, but it also happens in very rare cases [12]. Economically not acceptable concepts of engines operating on classic fuels prevail and alternative solutions are considerably neglected. Thus increased production of harmful emissions continues.

The improvement of the present state can be achieved by unconventional traction drive of rail vehicles. Such unconventional traction drive can be a hybrid drive.

We have been studying these problems for a long time and some results were published for example in [2, 3, 4, 5] etc.

## **1. OPERATIONAL UTILIZATION OF THE INTERNAL COMBUSTION ENGINE POWER OF MOTIVE POWER UNITS**

The character of utilization of installed engine power is essential for following consideration about possibilities of fuel economy. It is important to have a good knowledge of real operational utilization of ICE, based on measurements in real operation of motive power units.

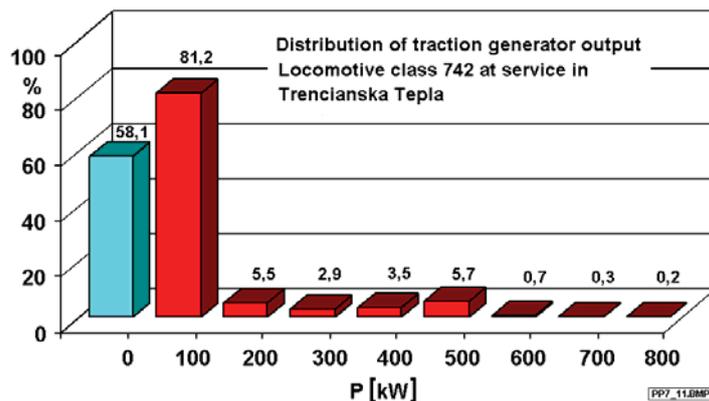
### **1.1. Industrial and shunting locomotives**

The character of utilization of installed engine power in the industrial and shunting locomotives are similar. It was shown in many measurements at different times and on different locomotives. Since the operational conditions may significantly vary in different cases, the results of measurements can vary as well. It was shown in many our papers, e.g. [2, 3, 4, 5] etc. So we will show only limited number of typical examples here.

For shunting operation, typical is poor utilization of installed power of ICE, frequent transient performance of ICE, short duration of steady power, frequent and relatively long lasting idling. On the other hand shunting locomotive must be equipped with engine of sufficient output necessary for acceleration and potential shunting of heavy trains. Operation of shunting locomotives is characterized by relatively low speed, short distance of drive and frequent braking (often only by locomotive itself).

#### **Shunting service of locomotive Class 742 in Trencianska Tepla**

The measurements were carried out on the locomotive class 742 (ČKD) in shunting service at railway station Trencianska Tepla [11]. This class of locomotives has 883 kW nominal output of engine. The distribution of traction generator output is shown in the Fig. 1. The mean output of traction generator was only about 102 kW, which represents about 11.5 % of the nominal output.

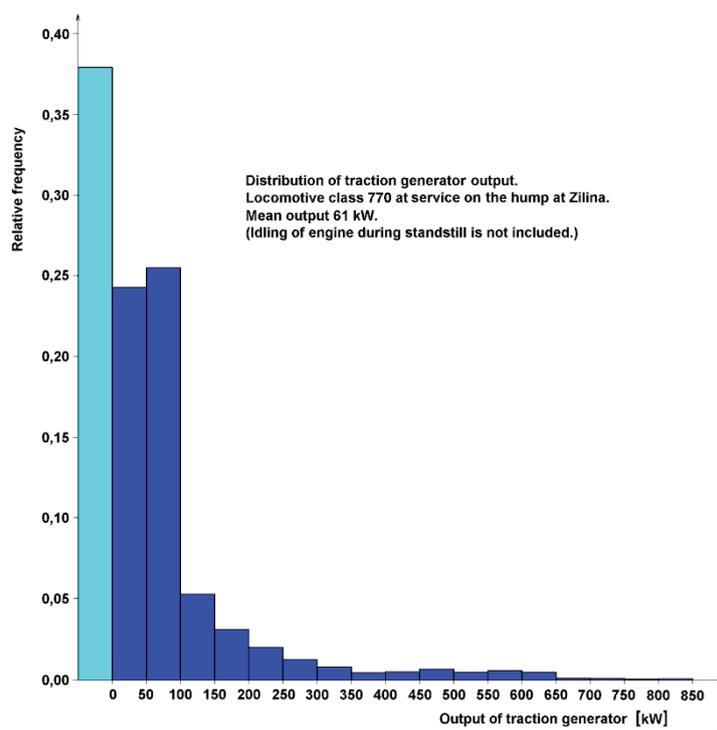


**Fig. 1.** The distribution of traction generator output of locomotive class 742 in the shunting service at Trencianska Tepla.

Source [11].

### Shunting service of locomotive Class 770 in Zilina

Another example of output distribution of locomotive class 770 (ČKD) during shunting operation on hump in railway station in Zilina is shown in the Fig. 2 [8]. The mean output of the locomotive with nominal rating of 993 kW was only 61 kW in this case, what represents only 6 % of nominal output.



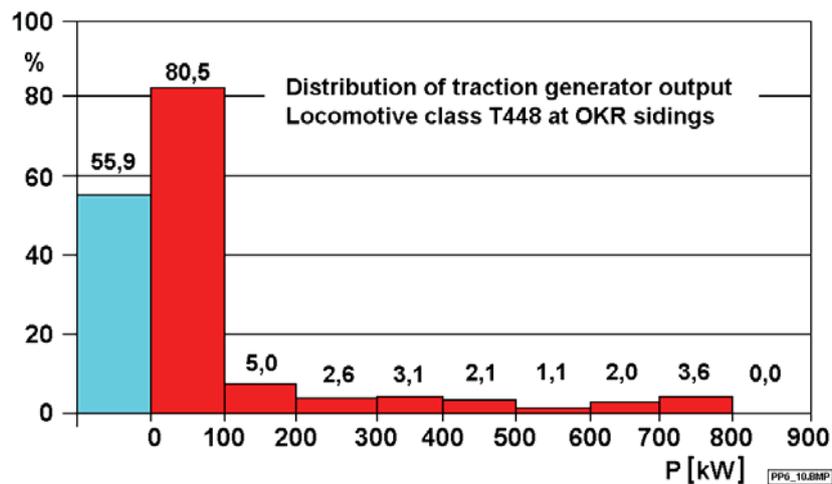
**Fig. 2.** The distribution of traction generator output of locomotive class 770 shunting at Zilina

Source [8].

## Industrial locomotive Class T448 in OKR Ostrava

Another example is from measurements at the OKR sidings in Ostrava. The measurements were carried out on the locomotive class T448 (ČKD). This locomotive has 883 kW maximum output of internal combustion engine.

The distribution of traction generator output is shown on the Fig. 3 [7]. In the graph several various regimes of locomotive work were included. The left column (55.9 %) shows relative duration of idling run related to all time of ICE work. About 7.1 % was idling run with consumption of power by auxiliaries (braking compressor and/or fans of cooler). The mean value of the traction generator output was in this case approx. 121 kW, which is about 14 % of maximum output of locomotive.

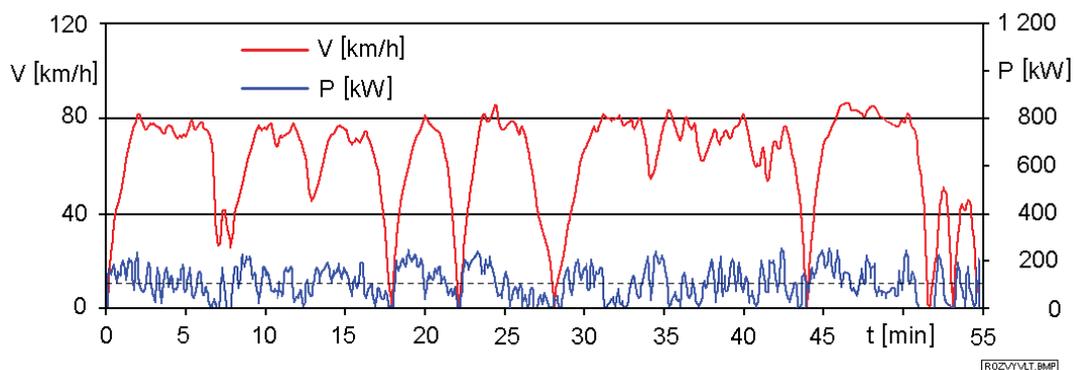


**Fig. 3.** The distribution of the traction generator output of locomotive T 448.0 at shunting operation at sidings of OKR a. s. Ostrava

Source [7].

## 1.2. Diesel multiple units

The character of operational utilisation of diesel multiple units is different from shunting and industrial locomotives. Example of time behaviour of velocity and power output of light diesel unit at the regional railways VLTJ in Denmark is in the Fig. 4 [16]. The peak output at driving wheelsets was 250 kW in this case. The mean output was about 105 kW without idling at the stops.



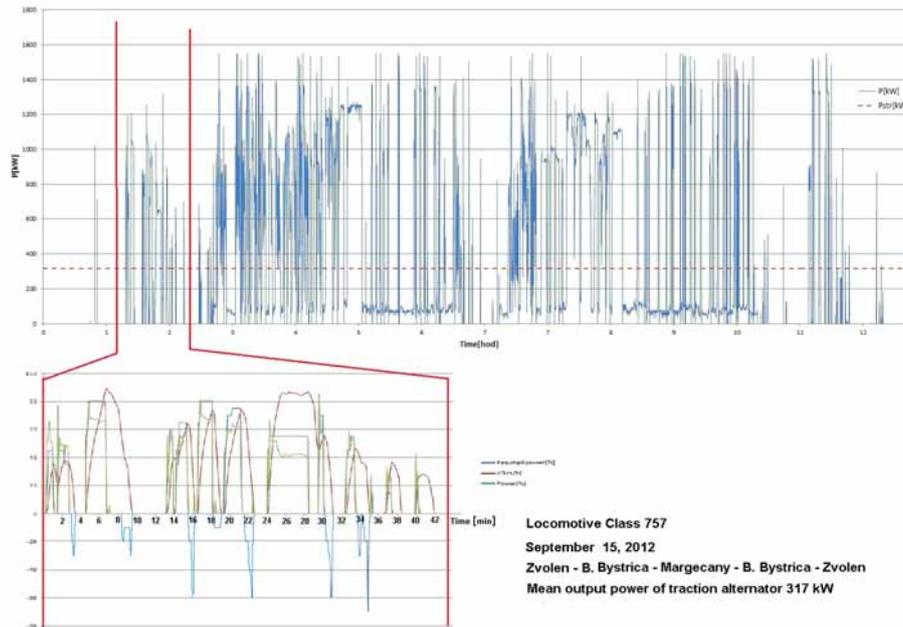
**Fig. 4.** The course of power on wheelsets and velocity of DMU at the railways VLTJ

Source [16].

### 1.3. Passenger main line DE locomotive Class 757

Locomotive Class 757 is equipped with diesel engine with installed output power of 1 550 kW and electrodynamic brake. All auxiliaries are driven by electric motors. The measurements were carried out at railway line Zvolen – Banska Bystrica – Margecany – Banska Bystrica – Zvolen. Measurements took from 7:40 to 20:36. During this period engine was stopped 5 times in total for 2 hours and 14 minutes.

The courses of some operational parameters during all work shift of loco Class 757 is at the Fig. 5. One part of shift is presented in more detailed form.

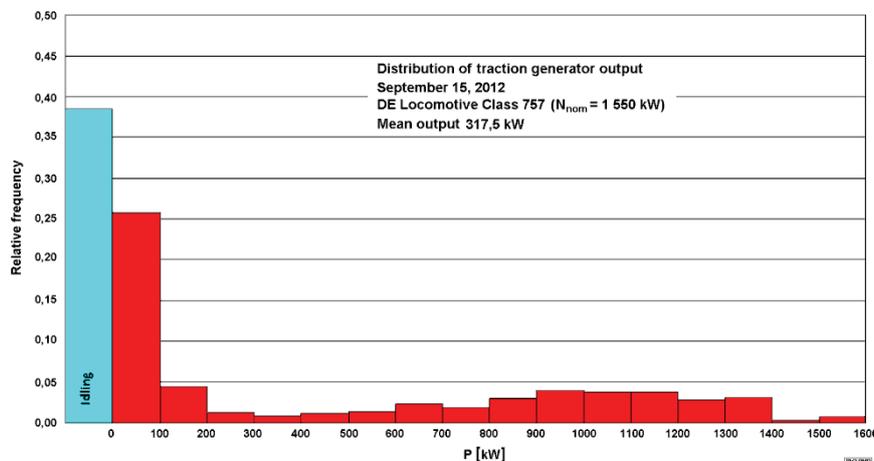


**Fig. 5.** The courses of some operational parameters of main line locomotive class 757

Source [Authors].

The mean value of the traction generator output was in this case approx. 317 kW, which is about 20.5 % of maximum output of engine. The using of output power of engine is better than at previous locomotives in different operational conditions.

The distribution of traction generator output power is shown in the Fig. 6.

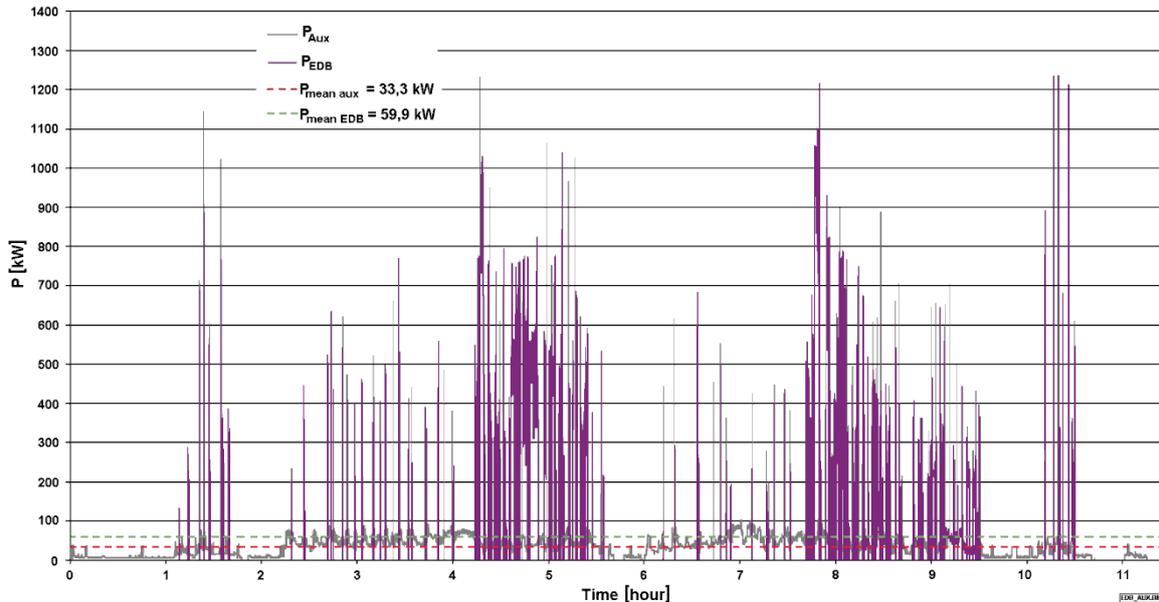


**Fig. 6.** The distribution of the traction generator output of locomotive class 757 at main line operation

Source [Authors].

Percentage of idling (approx. 38%) is alike as in case of shunting and industrial locomotives. The distribution of traction generator output is more proportional than in the previous cases. Relatively more important part of output is in the region of approximately 2/3 of maximum engine output.

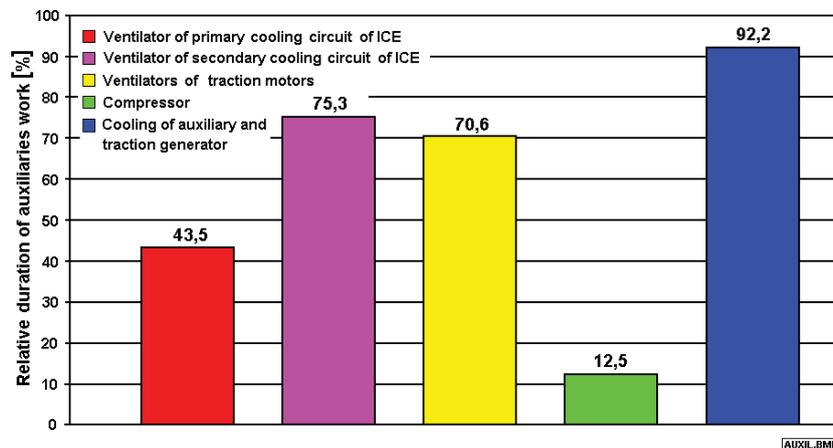
Distribution of electrodynamic brake power and input of auxiliaries is shown at the Fig.7. It is apparent that electrodynamic brake was used quite frequently and its mean output of 59.9 kW represents approximately 19 % of mean traction output.



**Fig. 7.** The distribution of the electrodynamic brake and input of auxiliaries of locomotive class 757 at main line operation

Source [Authors].

The mean input of all auxiliaries was 33.3 kW. The auxiliaries include two fans of primary and secondary cooling circuit of ICE, two fans of traction motors, compressor of brake system and fan of auxiliary and traction generators, ventilator of brake resistor. The relative duration of individual auxiliary run is shown at the Fig. 8. It is apparent that majority of auxiliaries run relatively long time (substantial part of engine run). The exception is duration of brake compressor work.



**Fig. 8.** The relative duration of individual auxiliary run of locomotive class 757 at main line operation

Source [Authors].

## 2. HYBRID TRACTION DRIVE

As it was mentioned above, one of possible ways for fuel economy is using of a hybrid traction drive [9, 11, 13]. This system comprises an ICE and electric generator or fuel cells, electric traction motors and an energy storage device (flywheel type storage device, electrochemical batteries, double layer capacitors, flow batteries etc.). Basic block diagram of a hybrid traction drive is at the Fig. 9.

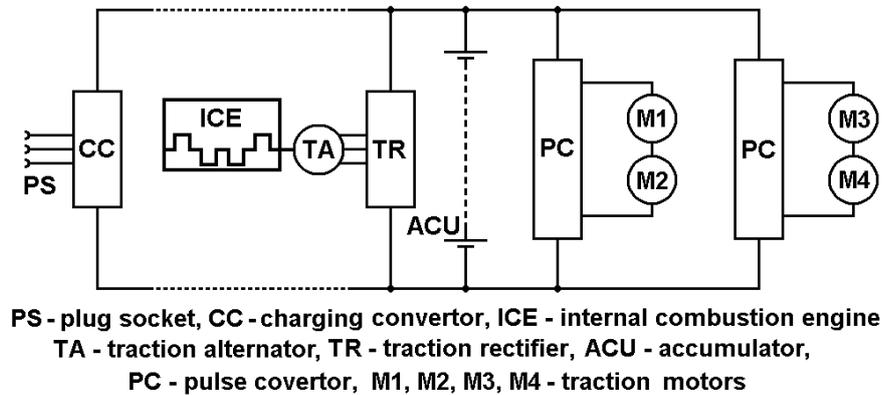


Fig. 9. Basic block diagram of hybrid traction drive

Source [Authors].

Hybrid traction drive enables:

- storage of energy gained by electrodynamic braking and its exploitation,
- installation of a primary power source with significantly lower output as in the case of classic traction drive,
- operation of primary source of energy in optimum regime from the point of view of fuel consumption and emissions,
- utilization of accumulated energy for auxiliary systems in standstill regime of a vehicle (engine not running),
- improvement of conditions for alternative fuels and fuel cells using.

Principle of hybrid traction drive is simple. In those regimes of operation which require smaller traction power than the primary source of power produces, the surplus energy would be accumulated in proper accumulator and on the contrary in case of higher traction power demands than the primary energy source offers, missing energy would be drawn from accumulator (in such way it is also possible to use energy acquired from electrodynamic braking). Using of kinetic energy of train which can be transformed by electrodynamic braking is very important and leads to much better energy balance. There is problem with quite great power produced by electrodynamic braking and possibility of its storage in accumulators of energy. Classic electrochemical accumulators usually do not enable to store such great power.

Possibility to use smaller engine brings reduction of fuel consumption while idling, what is important in case of industrial locomotives and locomotives for shunting operation. As was shown, idling takes about 70 - 80% of the total time of engine operation in some cases.

A partial hybrid drive is more appropriate for main line locomotives. The partial hybrid drive should be used for propulsion of auxiliaries from accumulator charged by energy gained from electrodynamic braking (and from other sources). The energy saved up on auxiliaries drive should be used for example on increasing traction capability. The comparison of mean output of electrodynamic brake and mean input of auxiliaries shown at previous chapter

enables this. Double layer capacitors (supercapacitors) are probably the most appropriate storage device in this case.

### 3. OTHER WAYS OF FUEL ECONOMY

#### 3.1. Heat recovery from exhaust gases

During the combustion of fuel only approximately 40 % of energy released from fuel is transformed into mechanical energy. About 36 % of released energy is lost by exhaust gases. Voith Turbo GmbH & Co. KG offers answer to this problem by SteamTrac System – waste heat recovery system, Fig.10 [15]. The system enables about 10% fuel savings and about 12 – 15 % higher performance.

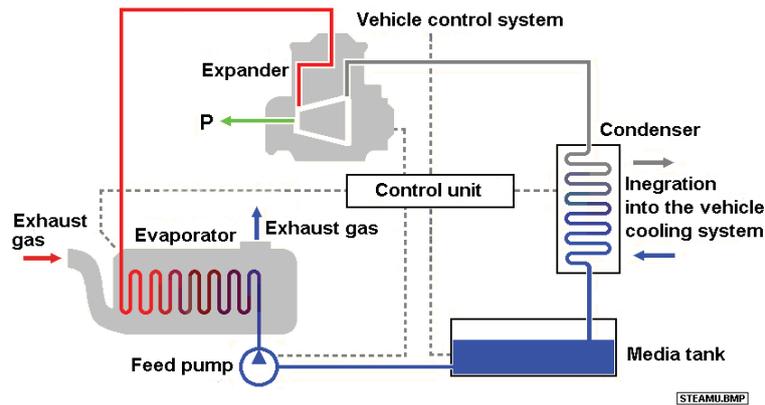


Fig. 10. Basic block diagram of Voith's waste heat recovery system StemTrac System

Source [15].

#### 3.2. Double gen-set traction drive

As it was shown, utilization of ICE is very poor and great portions of time are in idle run regime. Large engine has large fuel consumption also in idling regime. The idea of this solution lies in splitting up needed output of ICE into two smaller engines. Most of the operation duration only one of engines is working, so fuel consumption during idling is half. The measurements on modernized locomotive class SM42 at railway station Rybnik (Poland) shown that approximately 62 % of time locomotive worked with only one engine (Caterpillar C15) [10], see Fig. 11.

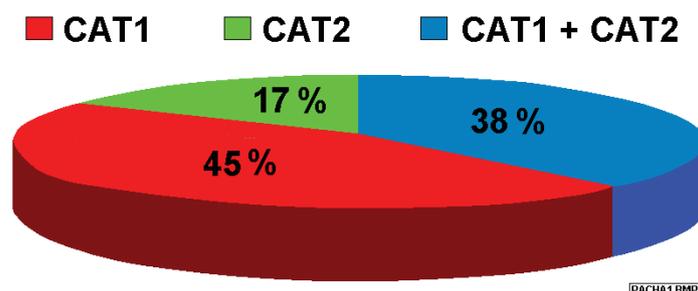


Fig. 11. The distribution of action of engines at two engine locomotive class SM42

Source [10].

#### 3.3. Utilization of solar energy

Another possibility for hybrid drive is utilization of solar energy generated by moving and/or stationary photovoltaic panels [6]. The amount of gained electric energy is relatively

small. The mean energetic contribution of solar energy for locomotive with roof area of 45 m<sup>2</sup> is only about 19 kWh/day.

## CONCLUSION

At many types of motive power units the utilization of the output of internal combustion engines is very poor. As was demonstrated, the mean output in many cases is below 15 % of installed output. This leads to uneconomical operation. One of the possible ways how to solve the problem is using of the hybrid traction drive. Knowledge of operational regimes of locomotives is necessary for right choice of appropriate parameters of hybrid traction drive.

It is possible to gain about 15 – 20 % savings in fuel consumption of shunting locomotive by introducing a hybrid traction drive. It was proven by measurements at the first hybrid locomotive class TA 436 in the former Czechoslovakia [N]. This locomotive has engine output 189 kW instead of 600 kW of compared locomotive.

It is possible to improve fuel economy also in case of main line locomotives by utilization of energy gained by electrodynamic braking for auxiliaries drive.

There are other possibilities of reduction of fuel consumption, for example using two smaller engines instead of one big or using of solar energy.

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## NIEKTORÉ SPÔSOBY ZNÍŽENIA SPOTREBY PALIVA MOTOROVÝCH KOĽAJOVÝCH VOZIDIEL

### *Abstrakt*

*Využitie inštalovaného výkonu spaľovacieho motora na hnacích koľajových vozidlách (najmä posunovacích rušňov a rušňov pre priemyslovú dopravu) je veľmi nízke. Priemerný výkon spaľovacieho motora v takýchto prevádzkových podmienkach je okolo 15 – 20 % jeho menovitého výkonu. Výsledkom je, že motor pracuje počas dlhšej doby v režimoch, ktoré sú vzdialené od optimálneho režimu. To znamená, že merná spotreba je veľká. Niekoľko príkladov nameraných prevádzkových režimov rušňov v posunovacej službe a iných hnacích vozidiel sú uvedené v príspevku.*

*Kinetická energia klasického motorového rušňa ako aj motorovej jednotky a vlaku je transformovaná do podoby tepelnej energie v procese brzdenia. Bežne nie je možné využiť túto kinetickú energiu rozumným spôsobom. Aby sa dosiahla úspora paliva, kinetická energia by mala byť transformovaná do vhodnej formy a uložená pre ďalšie využitie.*

*Zlepšenie môže byť dosiahnuté použitím nekonvenčného trakčného pohonu koľajového vozidla. Jedna z možných ciest je použitie hybridného pohonu. Hybridný pohon pozostáva zo spaľovacieho motora, generátora, trakčných motorov a zariadenia na akumuláciu energie. V takomto prípade môže byť výkon SM podstatne menší ako pri klasickom pohone. Výber parametrov takéhoto trakčného pohonu musí byť podložený analýzou reálnych prevádzkových podmienok vozidla. Takéto parametre sú najmä: výkon SM, výkon trakčných motorov, kapacita a výkon zariadenia na akumuláciu energie (akumulátorov).*

*Existujú aj iné spôsoby úspory paliva na koľajových vozidlách, napríklad lepším využitím tepla uvoľneného z paliva, alebo využitie slnečnej energie.*

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