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 of train 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. 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. Keywords: hybrid traction drive of rail vehicles, utilization of power of ICE, fuel utilization, accumulation of energy

1. INTRODUCTION

Problem with fuel and energy savings and air pollution in the rail transport should be solved at the present time. 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]. 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 is far from optimum mode with high specific fuel consumption. 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.

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.

2. OPERATIONAL UTILIZATION OF THE ICE POWER OF MOTIVE POWER UNITS

The character of utilization of installed ICE 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.

2.1. 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 of our papers, e.g. in [2, 3, 4, 5] etc. So we will show only limited number of typical examples here.

For shunting operation poor utilization of installed power of ICE, frequent transients, short duration of steady power (Fig. 1), frequent and relatively long lasting idling is typical. On the other hand shunting locomotives 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).

![Fig. 1. The distribution of constant duration of ICE output in shunting service](image1)

### 2.1.1. 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 and in sugar factory [11]. This locomotive has 883 kW nominal output of engine. The distribution of traction generator output is shown at the Fig. 2. The mean output of traction generator was only 102 kW, which represents about 11.5% of the nominal output of ICE. Idling of engine represents about 58.1% of total duration ICE operation. Maximum output of ICE was used only at 0.2% of duration of operation ICE without idling.

![Fig. 2. The distribution of traction generator output of locomotive class 742 in the shunting service in Trencianska Tepla](image2)
2.1.2. Locomotive class 770 in Zilina

Another example of output distribution of locomotive class 770 (ČKD) during shunting operation on hump in railway station Zilina is shown at the Fig. 3 [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.

![Distribution of traction generator output, Locomotive class 770 at service on the hump at Zilina. Mean output 61 kW. (Idling of engine during standstill is not included.)](image)

Fig. 3. The distribution of traction generator output of locomotive class 770 in the shunting service in Zilina

2.1.3. Industrial locomotive class T448 in OKR Ostrava

This is example of operational utilization of industrial locomotives. The measurements were carried out on the OKR sidings in Ostrava on the locomotive class T448 (ČKD). This locomotive is industrial version of class 742, so it has engine with maximum output of 883 kW.

The distribution of traction generator output is shown at the Fig. 4 [7]. In the graph several various regimes of locomotive work were included. The left column (55.9%) shows relative duration of idling running 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 ICE.
2.2. DIESEL MULTIPLE UNITS

The character of operational utilization 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. 5 [14]. The peak output at driving wheels was 250 kW in this case. The mean output was about 105 kW without idling at the stops.
2.3. PASSENGER MAIN LINE DE LOCOMOTIVE CLASS 757

Modernised locomotive class 757 is equipped with diesel engine with installed 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, so all shift. During this period engine was stopped 5 times in total for 2 hours and 14 minutes.

The distribution 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 is shown in the Fig. 6.

![Fig. 6. The distribution of traction generator output of locomotive class 757 at main line operation](image)

The courses of some operational parameters of locomotive class 757 during all work shift is shown at the Fig. 7. One part of shift is presented in more detailed form.
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. 8. 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.

The mean output of all auxiliaries was 33.3 kW. The auxiliaries include two fans of primary and secondary cooling circuit of engine, two fans of traction motors cooling, compressor of brake system and fan of traction and auxiliary generator, ventilator of brake resistor. Theoretically output of electrodynamic brake is sufficient for covering input of all auxiliaries. But there is problem connected with storage of energy produced by electrodynamic braking because of very high peak values of this energy. This is possible only by using of ultracapacitors.
3. HYBRID TRACTION DRIVE

As was mentioned above, one of possible ways for fuel economy is using of 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.).

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 point of view of fuel consumption and emissions,
- utilization of accumulated energy for auxiliaries systems in standstill regime of a vehicle (engine is 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 in short time.

The 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.

4. OTHER WAYS OF FUEL ECONOMY

4.1. DOUBLE GEN-SET TRACTION DRIVE

The idea of this solution lies in splitting up needed output of ICE into two smaller engines. Most of time of operation only one of engines is working, so fuel consumption during idling is less as 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].

4.2. UTILISATION OF SOLAR ENERGY

Another possibility for hybrid drive is utilization of solar energy generated by moving and/or stationary photovoltaic panels [6]. But the amount of gained electric energy is relatively small. The mean energetic contribution of solar energy for locomotive with roof area of 45 m² is only about 19 kWh/day.

4.3. HEAT RECOVERY FROM EXHAUST GASES

During the combustion of fuel only about 40% of energy released from fuel is transformed into mechanical energy. About 36% of released energy is lost by exhaust gases.

The course of exhaust gases temperature measured at tests of main line locomotive class 757 is shown at the Fig. 9. The problem of using of energy of exhaust gases lies in considerable variability of its temperature.

Voith Turbo GmbH & Co.KG offers answer to this problem by SteamTrac System – waste heat recovery system [15]. The system enables about 10% fuel savings and about 12 – 15% higher performance. The system should be used with cooperation with accumulation of retrieved energy.
Fig. 9. The course of the temperature of exhaust gases of engine at the locomotive class 757

References

**MOŻLIWOŚCI OSZCZĘDNOŚCI PALIWA – HYBRYDOWY NAPĘD TRAKCYJNY**

**Streszczenie:** Wykorzystanie mocy zainstalowanej silników spalinowych (ICE) w jednostkach trakcyjnych (szczególnie w lokomotywach manewrowych i lokomotywach do transportu przemysłowego) jest bardzo niskie. Średnia moc wyjściowa (ICE) w tym trybie pracy to około 15 - 20% swojej mocy zainstalowanej. Powoduje to, że przez większość czasu silnik spalinowy pracuje w trybie, który jest daleko od trybu optymalnego. Oznacza to, że zużycie paliwa jest wysokie. Niektóre przykłady pomiarów eksploatacyjnych lokomotyw manewrowych i innych jednostek trakcyjnych podano w artykule. Energia kinetyczna klasycznych lokomotyw Diesla, jak również DMU i pociągów jest przekształcona w energię cieplną w czasie procesu hamowania. Zwykle nie jest możliwe wykorzystanie energii kinetycznej w sposób racjonalny. W celu zmniejszenia zużycia paliwa, energia kinetyczna pociągu powinien być przekształcana do odpowiedniej formy i przechowywana do późniejszego użycia. Poprawa może zostać osiągnięta przez zastosowanie niekonwencjonalnego napędu pojazdów szynowych. Jednym z możliwych sposobów jest użycie napędu hybrydowego. Napęd hybrydowy zawiera generator, ICE, silniki trakcyjne i urządzenia do magazynowania energii. Parametry takiego napędu muszą być oparte o analizę rzeczywistych reżimów eksploatacyjnych pojazdów. Istnieją inne sposoby, jak oszczędzać paliwo w pojazdach kolejowych, np. poprzez lepsze wykorzystanie ciepła uwalnianego z paliwa lub za pomocą energii słonecznej.

**Słowa kluczowe:** hybrydowy napęd pojazdów szynowych, wykorzystanie mocy ICE, wykorzystanie paliwa, akumulacja energii