Martin MIKOLAJČÍK, Daniel KALINČÁK

POSSIBILITIES FOR DECREASING FUEL CONSUMPTION OF RAIL VEHICLE OF INDEPENDENT TRACTION

Abstract

Article deals with issue of fuel consumption reduction of rail vehicle of independent traction. It's necessary to make analysis of operating conditions of rail vehicles for proper solution of this problems and therefrom of result choose the best solution contributing to fuel consumption reduction. It's necessary take into account economical aspect too. Some trends, which are using for design of rail vehicles in present and have effect to fuel consumption reduction and better fuel utilization (dual engine, using of waste heat of ICE, hybrid and etc.) will be also mentioned in this article.

INTRODUCTION

Railway systems always have been described as competitive, sustainable and environmentally friendly modes of transportation. However, diesel engines appear more and more like the weak point in this good picture. Fortunately, fast-growing technologies offer everyday new opportunities for improving such a technical domain as railway [1].

Most diesel locomotives used on railways using outdated types of ICE that do not meet today's emission limits for this type of vehicle and using of their installed power is low. As suitable and cheaper solution to this problem, instead of buying a new rail vehicle seems to use a hybrid system or another sytems (twin ICE, waste heat recovery of ICE) in upgraded diesel locomotives and it brings the desired reduction in fuel consumption and reduce emissions.

For suitable design of a hybrid propulsion of specific rail vehicle, it is necessary to know the operating parameters and make the analysis of operating parameters to determine the most appropriate design of the hybrid system and accumulators of energy. Improper design of a hybrid system would be extended return of investment in rebuilding and hybrid system could not be fully utilized. It is best use hybrid systems in rail vehicles, which often stop and then starting up again. In the following paper we will present the possibility of using a hybrid system in shunting and mainline locomotives and and also another ways leading to fuel consumption reduction such as instalation of two ICE instead of one with comparable output, technology of cylinder on demand and waste heat recovery of ICE .

1. ANALYZATION OF SHUNTING LOCOMOTIV´S OPERATION PARAMETERS

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 utilization of engine power is usually less than 20% of the installed power capacity and nominal engine performance is utilized 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 [2].

1.1. Shunting service of locomotive Class 742

The measurements were carried out on the locomotive class 742 (ČKD) in shunting service at railway station Trencianska Tepla [3]. 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 of ICE [2].

As we can see at the **Fig. 1**, the maximum power of locomotive

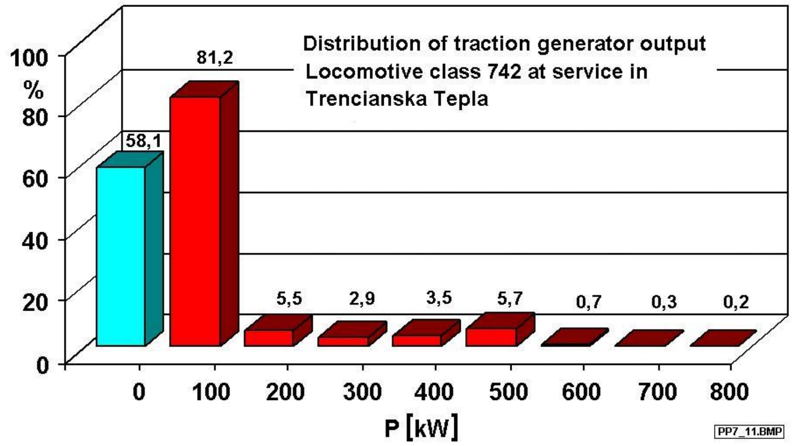

Fig. 1. The distribution of traction generator output of locomotive class 742 in the shunting service at Trencianska Tepla [2]

is using only short time period and main engine operation is idling and work with power output up to 100 kW. More efficient would be using of hybrid locomotives for these types of rail operations. In this case can be used ICE with power about 200 kW and it will cover 86.7% of power needs. The rest 13.3% have to be covered by energy from accumulator which will be charged during idling operation of ICE and recuperation braking. The accumulator should be able give short-time power about 680 kW, what is ambitious requirement. This high power of accumulators is needed for keeping up maximum traction effort of locomotive. The high power of accumulators is necessary for charging during regeneration of braking power as well.

By this way, we can achieve that ICE will be working at optimal conditions and it will cause lower fuel consumption and emission. The next step in designing hybrid locomotive is to choose correct accumulator of energy, which can be fast charging and discharging with high power and will not damage storage of energy during years of using. For shunting services is suitable use flywheel, ultracapacitors and superconducting magnetic energy storage system and Ni-MH or LiFePo4 batteries as storage of energy, because they can be charged and discharged by high power in short period.

1.2. Shunting service of locomotive Class 770

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** [4]. 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 of ICE [2].

The **Fig. 2** shows that ICE shunting locomotives working for not negligible duration in the idling mode (approx. 37%) in the area of high specific fuel consumption. This is from reason to power peripheral devices such as compressor. In the case of a hybrid propulsion would be auxiliaries driven by an electric motor and, if it is necessary, could be powered by energy from accumulator with turn off ICE. This would achieve the operation of the ICE in area of low specific fuel consumptions.

1.3. Passenger main line locomotive class 757

Modernized locomotive class 757 (**Fig.3**), intended for passenger transport, is equipped with diesel ICE with installed power of 1550 kW and EDB (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 were realized from 7:40 to 20:36. During this period engine was stopped 5 times with total duration of stopped ICE for 2 hours a 14 minutes.

Fig. 3. Passenger main line locomotive class 757 after modernization [5]

The average distribution of the traction generator output was in this case approx. 317 kW, which represents about 20.5% of maximum output of ICE [6]. Distribution of traction generator output of locomotive class 757 is shown in **Fig.4**. From the figure follows, that the ICE is running most of the time with outputs up to 100 kW and also considerable part of the engine work is an idling ICE.

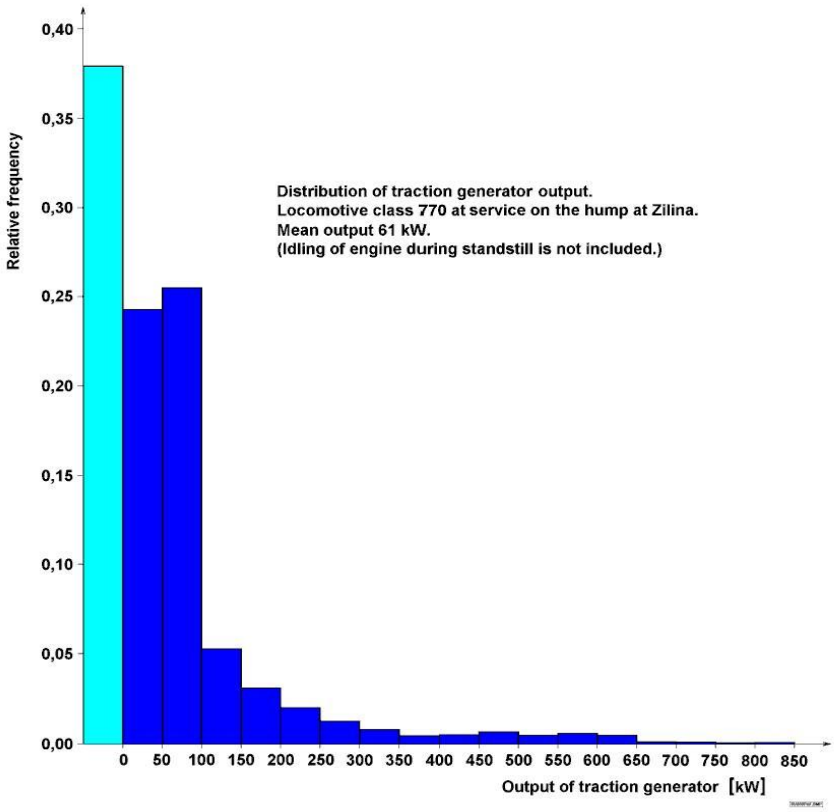

Fig. 2. The distribution of traction generator output of locomotive class 770 shunting at Zilina[4]

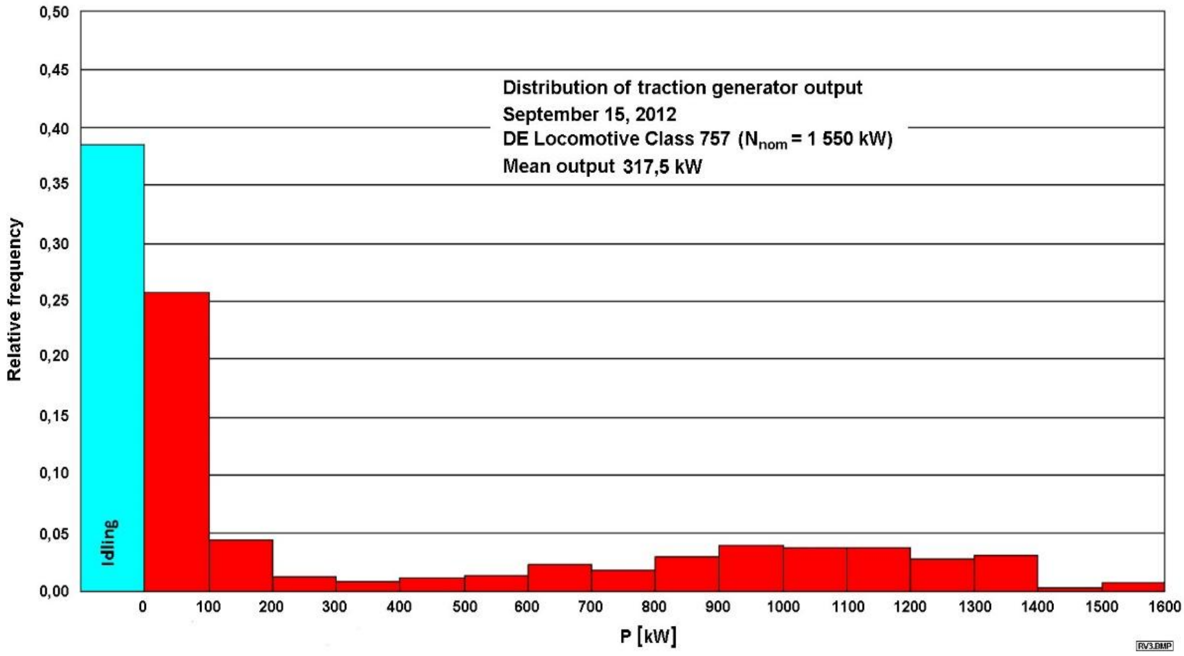

***Fig. 4.** The distribution of traction generator output of locomotive class 757 at main line operation [6]*

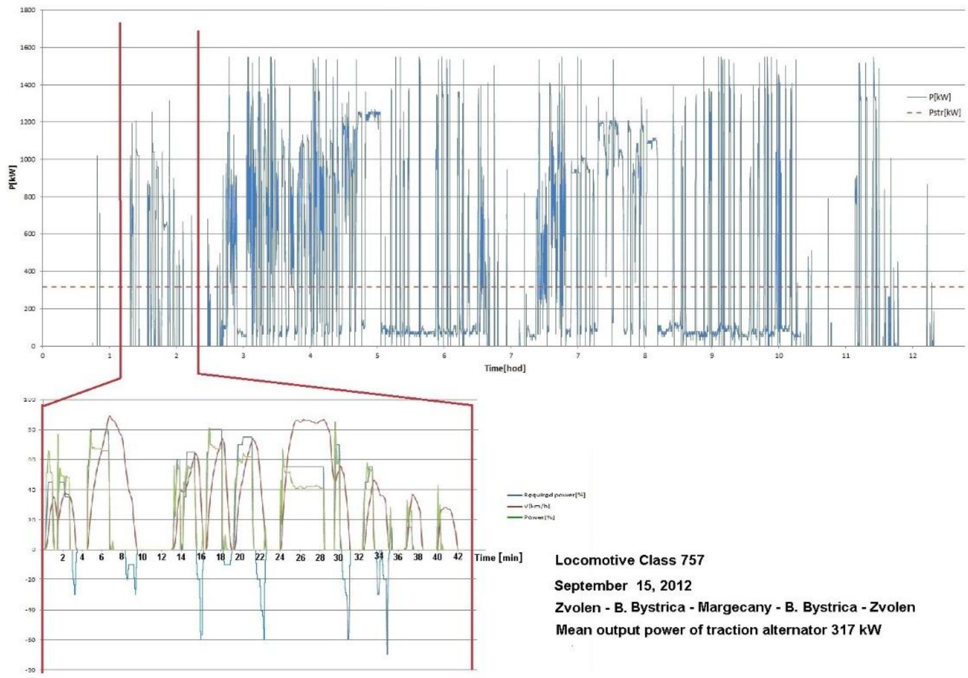

***Fig. 5.** The courses of some operational parameters of main line locomotive class 757 [6]*

The courses of some operational parameters of locomotive class 757 during all work shift is shown at the **Fig. 5**. and one part of shift is presented in more detailed form. Percentage of engine idling (approx. 38 %) is similar as in case of shunting and industrial locomotives. Distribution of electrodynamic brake (EDB) power and input of auxiliaries is shown in **Fig.6**.

It is apparent that EDB was used quite frequently and its mean output was 59,9 kW which represents approximately 19 % of mean traction output (317 kW). 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 and also ventilator of EDB brake resistors [6].

Theoretically it would be possible to cover the energy consumption of auxiliaries with the energy produced during electrodynamic braking, but there is a problem with the storage, because EDB produces large amounts of energy for a short period of time. Therefore, they cannot be used for energy storage batteries, because they can´t be charged with high power, which produces EDB, but must be used ultracapacitors, which are capable to accumulate large amount of energy over a relatively short period of time.

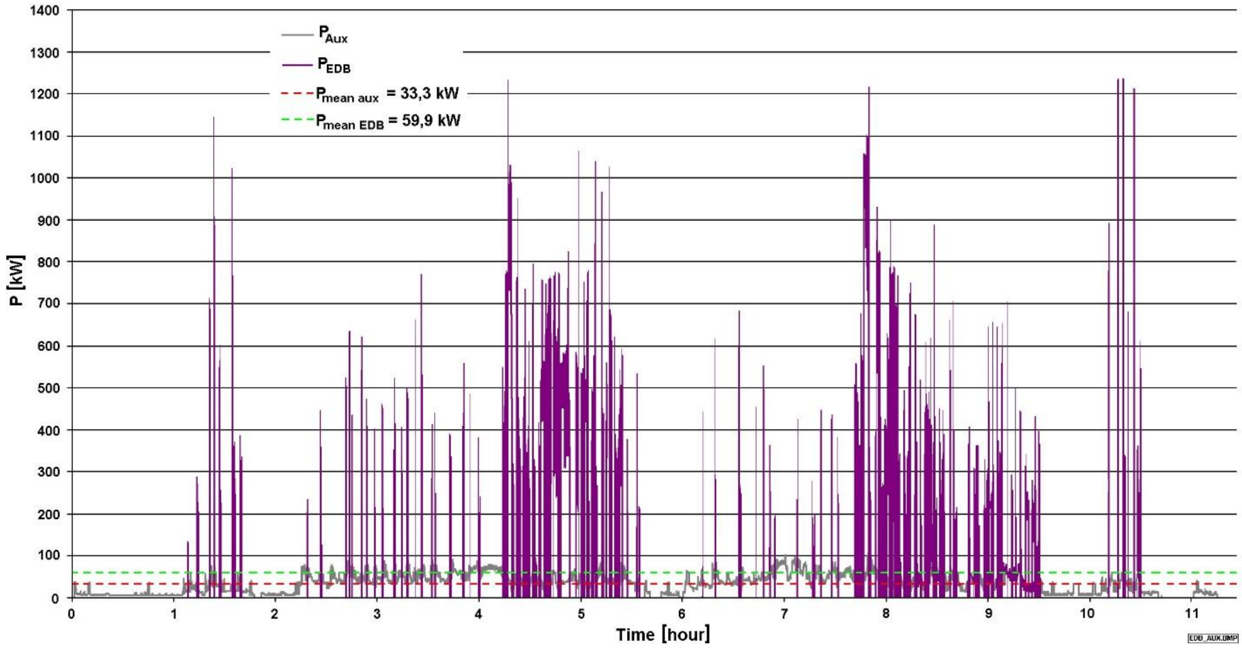

Fig. 6. *The distribution of the electrodynamic brake and input of auxiliaries of locomotive class 757 [6]*

2. COMPARISON BETWEEN SHUNTING HYBRID LOCOMOTIVE CLASS 718 AND NON-HYBRID LOCOMOTIVE CLASS 730

The hybrid locomotive Class 718 was built In the former Czechoslovakia in 1986. Measurements were carried out for comparison of this hybrid locomotive and non-hybrid locomotive Class 730. Design and operational properties of locomotive Class 718 was based on locomotive class 730. The results of measurements showed that hybrid locomotive is more effective in all type of shunting except of shunting to hump as it is shown in Tab. 1. It is possible to save up to 24% of fuel compare to non hybrid locomotive, but it´s depend on type of shunting. Increasing fuel consumption of hybrid on shunting to hump is caused by using of hybrid traction drive on maximum. Regenerative braking is rare in this operational regime. To reduction of fuel consumption significantly contributes using of regenerative braking, which save braking blocks or braking pads and achieves higher efficiency of hybrid drive. The measurements at this hybrid locomotive were executed with various loads up to 2500 t. Locomotive class 718 has ICE with power only 189 kW and replaced original ICE with power of 600 kW. It is only 31.5% power of original ICE which cause lower fuel consumption and emission compared to original ICE.

Tab. 1. *Comparison of fuel consumption in shunting service [7]*

Type of shunting	Fuel consumption dm^3/h		Ratio of fuel consumption
	Class 730	Class 718	
Shunting on hump	14,92	13,09	0,88
Pushing off and allocation of load	13,62	10,33	0,76
Shunting to hump	23,53	25,56	1,09
Pulling of load	12,87	10,86	0,84

3. POSSIBILITIES FOR DECREASING FUEL CONSUMPTION OF RAIL VEHICLE OF INDEPENDENT TRACTION

Manufacturers of rolling stock are constantly trying to reduce fuel consumption and emissions of their products, to which various modifications and innovative solutions help them. It is not always cost-effective to use hybrid drive, because of high acquisition costs. Therefore, manufacturers have come with other various solutions , and what is important to mention, especially cheaper solutions leading to fuel savings. Today the most used designs are two internal combustion engines (ICE), cylinder on demand system, as well as systems for energy recuperation from waste heat of ICE. With simplified description of the various systems we will deal in the following chapters.

3.1. Dual engine – installation of two ICE and system for energy recuperation from waste heat of ICE

Probably the easiest option, how to favorably influence fuel consumption is the use of two engines with about half power of original engine for propulsion of shunting locomotive. As an example we mention the reconstruction of the locomotive SM42 by company CZ LOKO for polish customer, where was used two Caterpillar C15 engines with power of 2x403 kW instead of the original engine with an output of 588 kW, respectively Cat C27 with an output of 703 kW. It turns out that 62% of the total time locomotive worked with only one engine, which brings savings especially when ICE works in idling, respectively when there are lower demands on power output [8].

In the case of system for waste heat recovery of ICE is a problem, because temperature of the exhaust gases and cooling fluid is quite variable. Temperature course of exhaust gases of locomotive class 757 is shown in Fig.7. You can see significant variation of exhaust gas temperature from the figure. The mean value of the exhaust gas temperature represents 395 ° C. Voith Company has developed "Steam Trac system", which allows to gain energy from the exhaust gases, it power range is from 15 kW to 160 kW [9]. There are also solutions in which are used thermocouples and they are installed in the exhaust system and energy which they produce is then stored in batteries.

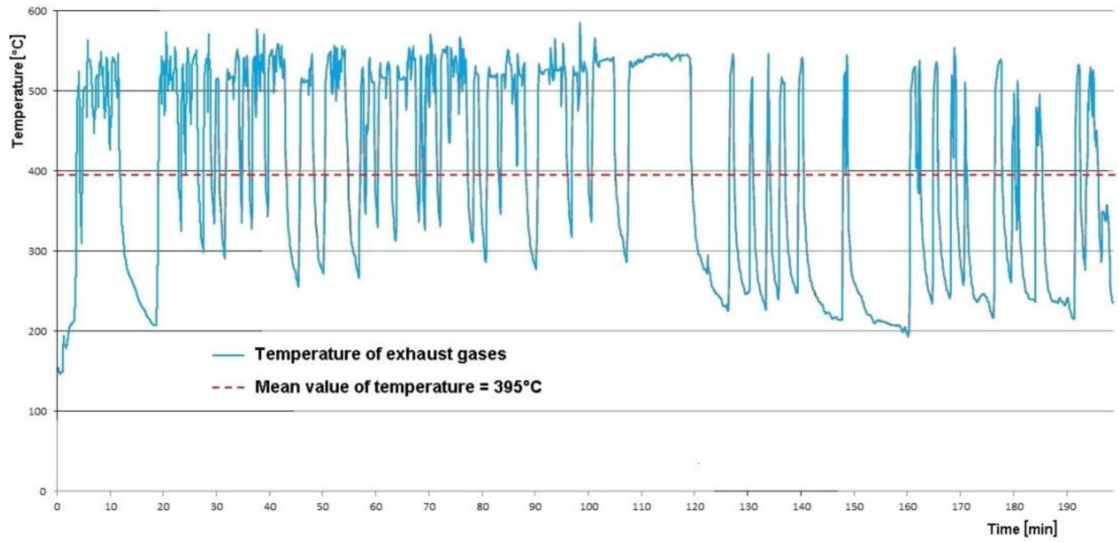

Fig. 7. *Temperature course of exhaust gases of locomotive class 757 [6]*

3.2. Technology of cylinder on demand

The basic idea for the implementation of this system to the traffic engineering is that the optimum efficiency an ICE reaches at the load of about 70 - 80% and rpm is in area of the highest torque. Also the findings of measurements show that in case of partial load, which occurs relatively often, it is enough to propel the car from 10 to 30% of maximum engine power. Based on the above facts several systems "cylinder on demand" were created. The common feature is that at low and medium loads of ICE g half of cylinders is disconnected, thereby rise of load at the remaining "working" cylinders is expected, which now work under the load of about 80%, and thus they reach the lowest specific fuel consumption and also combustion is improved, wherein exhaust emissions are the lowest.

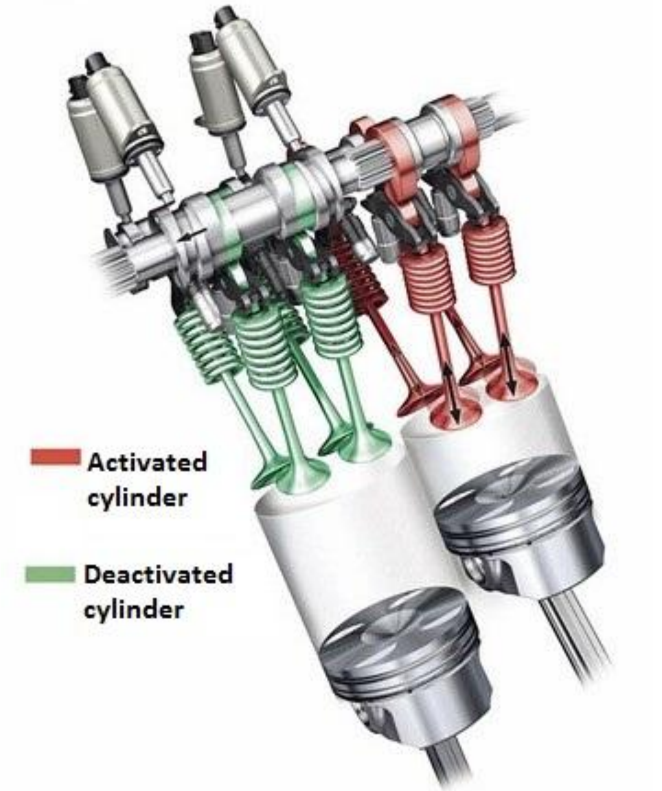

Fig. 8 *System "Cylinder on demand" [10]*

The **Fig. 8** [10] shows the "cylinders on demand" system for road vehicles, which is similar to the rolling stock and in the **Fig. 9** [11] detail view of the camshaft of the engine with system "cylinders on demand" and principle for turning cylinders on and off are shown. This system is deactivating cylinder by sliding the plug into the green portion of the helix located at the camshaft (marked by green) to make the transverse displacement of the mobile part of the camshaft and moving the valve plunger from red (working) area to the green part, which results in turning off the operation of the valves of the cylinder. Turning on of the cylinder goes in reverse. The next step is to stop the fuel injection to the cylinders and aerate cylinders with atmospheric pressure. The above described method is suitable for vehicles with intermittent load such as the industrial and shunting locomotives.

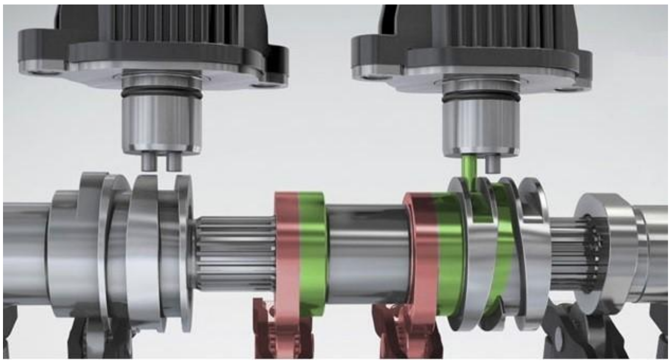

Fig. 8 *System "Cylinder on demand" [10]*

CONCLUSION

Rising prices of fossil fuels are forcing manufacturers of rolling stock to improve efficiency of ICE as well as the efficiency of power transmission and optimize the work of ICE to operate in areas with the lowest specific fuel consumption. This results in a lower fuel consumption and a lower production of harmful emissions that seriously undermine the ecosystem and pollute our planet.

In the paper we analyzed operating parameters of rolling stock equipped with ICE, which is necessary for the proper selection of a suitable propulsion of locomotives. Based on the analysis of operating parameters it can be decided if it is necessary to apply hybrid drive, which is more expensive, or if it is sufficient to use easier and cheaper solutions like installation of two internal combustion engines, "cylinders on demand" system or the waste heat recovery of

ICE. In the future, options will be probably increasing, which lead to reducing fuel consumption and emissions. We can hope that ecological systems applied in rail vehicles will not significantly increase the purchase price, and that decreasing price of batteries will have a positive impact on the introduction of hybrid locomotives in operation at the industrial sidings and in shunting.

ACKNOWLEDGEMENT

This article was supported by the Scientific Grant Agency of the Ministry of Education of the Slovak Republic and the Slovak Academy of Sciences in project no. VEGA 1/0927/15 "Research of the possibilities of using alternative fuels and hybrid propulsion in rail vehicles with the aim to reduce fuel consumption and production of air pollutants".

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Authors:
Ing. Martin MIKOLAJČÍK, Department of Transport and Handling Machines, Faculty of Mechanical Engineering, Univerzity of Žilina, Univerzitná 1, SK-010 26 ŽILINA, SLOVAKIA, martin.mikolajcik@fstroj.uniza.sk.
Prof. Ing. Daniel KALINČÁK, PhD., Department of Transport and Handling Machines, Faculty of Mechanical Engineering, Univerzity of Žilina, Univerzitná 1, SK-010 26 ŽILINA, SLOVAKIA, daniel.kalincak@fstroj.uniza.sk.