E3S Web of Conferences **431**, 08003 (2023) https://doi.org/10.1051/e3sconf/202343108003
ITSE-2023

Sampling of a driving cycle for e-trucks with a mechatronic transmission

N.V. Buzunov[1], *M.A.* Emelyanov[1], *R.L.* Gazizullin[1], *A.B.* Kartashov[1*], and *M.V.* Murashov[1]

[1]Bauman Moscow State Technical University, Baumanskaya 2th st. 5, Moscow, 105005, Russian Federation

Abstract. Traction battery vehicles (TBV) are currently gaining more and more popularity and are gradually replacing vehicles with ICE and traditional transmissions. The usage of an electric traction drive as part of TBV solves a number of problems that manufacturers of this type of equipment face today: reducing harmful emissions into the atmosphere, reducing noise, used lubricants recycling, and the increase of the energy efficiency. From the point of view of the scientific research, this type of wheeled vehicles is also of high interest due to the large number of problems and tasks that have formed at the moment. It is a common knowledge, that one of the main problematic issues for the TBV is a rather limited range. In cargo electric vehicles and buses, in order to reduce the size and increase the usable volume of the passenger compartment or cargo space, as well as to unify the products of the power unit and drive, there are used the transmissions, which are the combination of mechanical and electrical components with appropriate control systems. The mechanical component includes a gearbox with one or more gear ratios, an inter-wheel differential, axle shafts, bearings and other components. The electrical component is a traction motor located directly in the drive axle (integrated) or on the outside of the crankcase, as well as a voltage converter with a control system and the necessary switching elements. Similar implementations of the driving axles of vehicles with traction batteries are called mechatronic transmissions.

1 Introduction

In the period from 1999 to the present moment, a large number of R&D works concerned with mechatronic transmissions of trucks and buses of various types as well as in the field of electric transport [1-5] have been published. This situation is reflected in Figure 1. This dependence indicates that the issues of choosing a kinematic scheme, design layout, operating modes, and optimizing the control of mechatronic transmissions have been researched sufficiently. The analysis of the work gives one the opportunity to formulate correctly the requirements for the newly developed mechatronic transmissions and recommendations for options for improving the design in terms of achieving the required characteristics.

[*] Corresponding author: kartashov@bmstu.ru

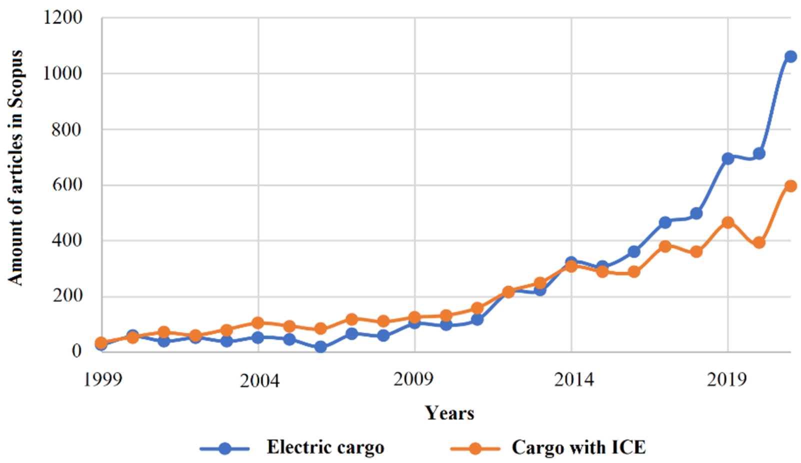

Fig. 1. Number of articles in Scopus on cargo vehicles

In most of the works concerned with the improving the energy efficiency of mechatronic transmissions. The main attention is paid to the problems of optimizing the selection of transmission ratios and the choice of gear shifting algorithm. On the other hand, researches on the new gearshift control mechanisms and schemes are published rarely.

The interest in the creation of mechatronic transmissions for cargo vehicles and buses has got the start since the 2010s with the advent of lithium-ion batteries. The number of prototypes of this technique from the indicated period to the present day has increased in four times, and serial ones - by 65%.

To reduce energy consumption during the driving process, as well as to optimize shift times, to optimize the gear ratio, to reduce shock loads on the transmission, it is necessary to create a mathematical model of the movement of the car according to a suitable or recommended driving cycle for this type of vehicle. Incorrect selection of the driving cycle could lead to an increase in the error in the simulation results. In some cases, the issue of developing an individual driving cycle for certain types of work or territories may be considered. Increasing the accuracy of modeling the work processes of vehicles with mechatronic transmissions would ultimately increase the range.

2 Overview and analysis of driving cycles

To simulate the movement of urban electric or hybrid transport, several driving cycles are used. Each type of cycle has certain features and disadvantages.

The first cycle is the New European Driving Cycle (NEDC). Its graph is shown in Figure 2 [6-8].

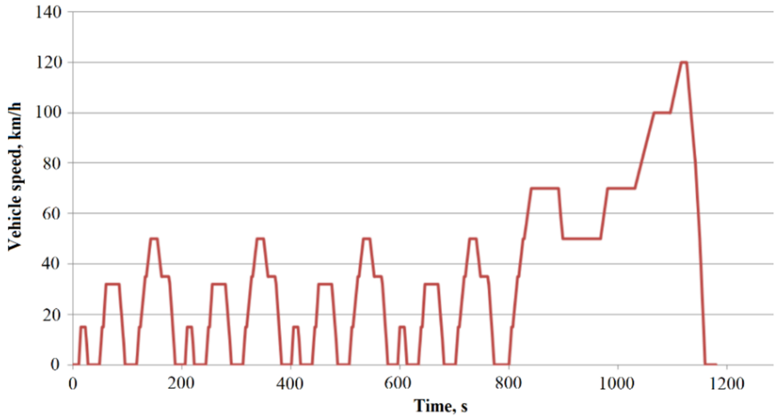

Fig. 2. NEDC driving cycle graph

The given cycle is considered applicable for urban transport; however, the last section implies movement at a speed of 100 km/h and 120 km/h, which is rarely achievable in urban conditions, even for cars. Also, the NEDC cycle is now considered obsolete.

The graph of 10-15 cycle is shown in Figure 3. This cycle is characterized by a lower average speed compared to NEDC. On the last section, the maximum speed does not exceed 70 km/h.

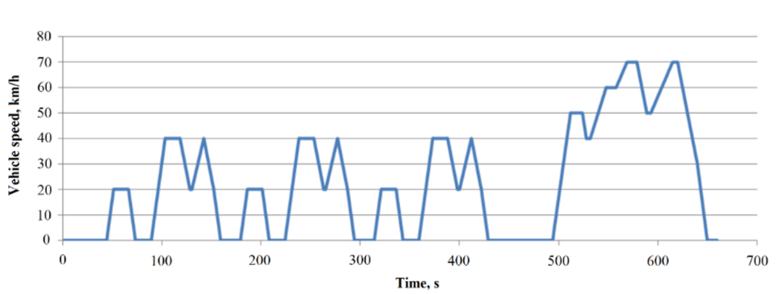

Fig. 3. 10-15 driving cycle graph

The third cycle is UDDS or FTP-72 (Federal test Procedure). The cycle graph is shown in Figure 4. This cycle has two phases delimited by a red vertical line. In the first phase, the average speed is higher than in the second one. This indicates that the vehicle has entered the high-speed highway in the cycle. In the second phase, the speed values are more consistent with urban conditions. It should be noted that there are no repeating sections in this cycle, which cannot be said about NEDC and 10-15.

A more advanced version of this cycle is designated as FTP 75. The difference from UDDS is that after the second phase, the first one is repeated. It is shown in Figure 5.

According to the simulation results, an average reduction in energy consumption over three cycles by 4% relative to energy consumption when simulating movement on the transmission parameters before optimization was established.

 https://doi.org/10.1051/e3sconf/202343108003

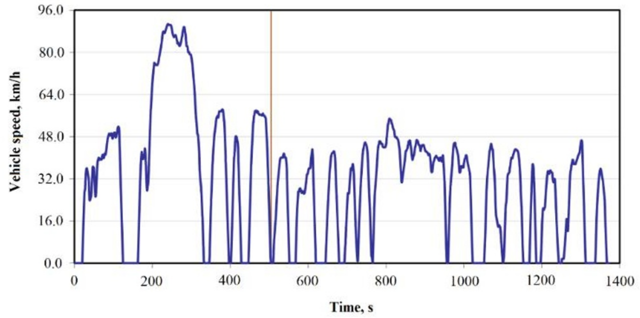

Fig. 4. UDDS driving cycle graph (FTP-72)

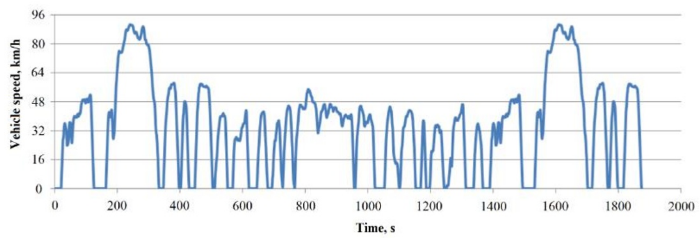

Fig. 5. FTP-75 driving cycle graph

Also, in another work, the gear ratios of a two-speed gearbox are optimized when simulating the movement of an electric vehicle with NEDC and UDDS driving cycles [9]. It is noted that the simulation result on two driving cycles diverges by no more than 0.02%.

In the article [10], a comparative simulation of the movement of an electric vehicle with a multi-stage gearbox and a variator is carried out in two driving cycles. One of them is FTP 75, which characterizes the movement in the city. The other is HWFET (High Way Fuel Economy Test). A graph of the latter is shown in Figure 6. This driving cycle is designed to evaluate the economy parameters when driving on a country road, as evidenced by the speed at the beginning and end of the journey - only at these points it does reach zero.

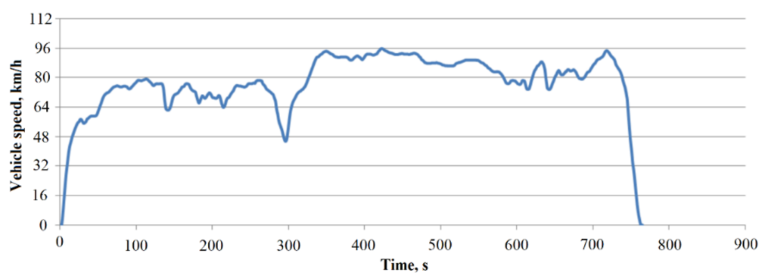

Fig. 6. HWFET driving cycle graph

The article [11] describes the simulation of the movement of an electric vehicle with two electric motors operating simultaneously in different modes, according to a combined driving cycle, consisting of two consecutive UDDS (FTP 72) and HWFET, which is shown in Figure 7.

https://doi.org/10.1051/e3sconf/202343108003

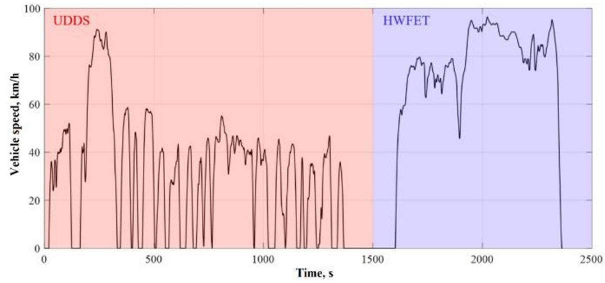

Fig. 7. Combined driving cycle graph

The UDDS driving cycle was introduced to simulate traffic in an urban environment, and HWFET, as before, on a suburban highway. As a result of gear ratio optimization, the authors managed to achieve a reduction in acceleration time by 9.3%, and a reduction in energy consumption by 11.2% relative to the value of these parameters when simulating movement before optimization.

In the research paper [12], the simulation of the movement is carried out according to the described above NEDC driving cycle and WLTP (or WLTC) (Worldwide Light vehicles Test Cycles) The latter is more modern and applicable to passenger cars and hybrid or electric vehicles, and also replaces the NEDC cycle.

The loop extents (WLTC) selection is based on the ratio of the rated engine power to the curb weight of the vehicle, excluding the driver, and on the value of the maximum speed. For an exact vehicle in this research, the WLTC Class 3b driving cycle is suitable. Its graph is shown in Figure 8. The same cycle is used in the research [13].

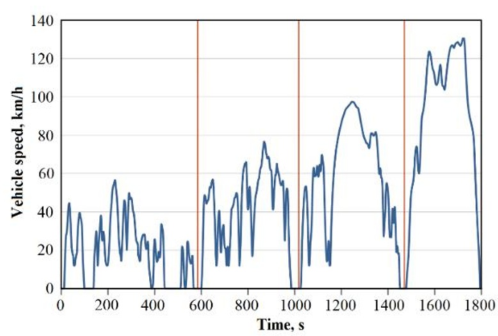

Fig. 8. WLTC Class 3b driving cycle graph

The research paper [14] simulates the movement of a hybrid vehicle on a sequential set of driving cycles FTP-75, HWFET and US06. The combined cycle graph is shown in Figure 9.

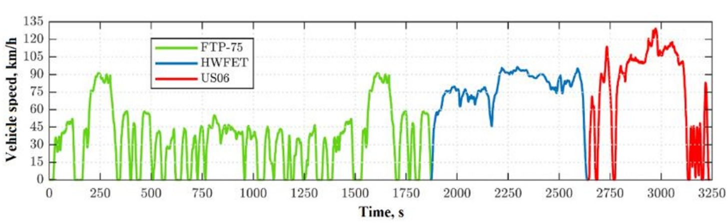

Fig. 9. FTP-75+HWFET+US06 driving cycle graph

https://doi.org/10.1051/e3sconf/202343108003

The US06 drive cycle is more aggressive than the FTP-75 and HWFET drive cycles as the top speed is higher and the number of accelerations from standstill to high speeds is increased. Thus, it could be concluded that the US06 driving cycle is not suitable for simulating traffic in an urban environment.

In the researches [15, 16], the mathematical modeling of the movement of an electric vehicle according to the UDDS driving cycle is carried out. In works [17, 18] – the similar modeling is carried out on the driving cycle of UDDS and HWFET.

The mathematical modeling of the movement of a hybrid city bus is also carried out according to the CCBC (Chinese City Bus Cycle) driving cycle [19]. The graph of this cycle is shown in Figure 10. It could be seen that the cycle consists of two repetitive phases. The value of the speed of movement does not exceed 60 km/h, and frequent accelerations and decelerations to zero speed correlate with the nature of the bus movement in the city.

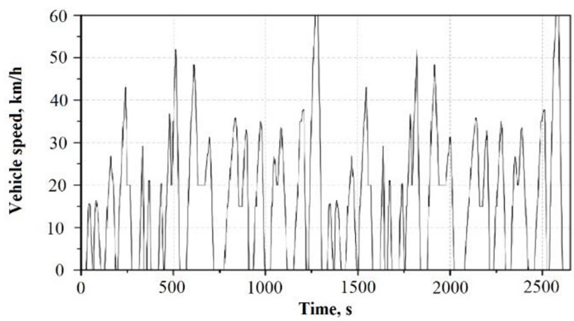

Fig. 9. CBCC driving cycle graph

In the research work [20], the authors develop their own driving cycles for vehicles of different categories in the district of Toronto city. Based on cartographic data about the district, including the width of streets, average speeds, average workload of other drivers. As a result, the driving cycles shown in Figure 11 were obtained for medium and heavy vehicles.

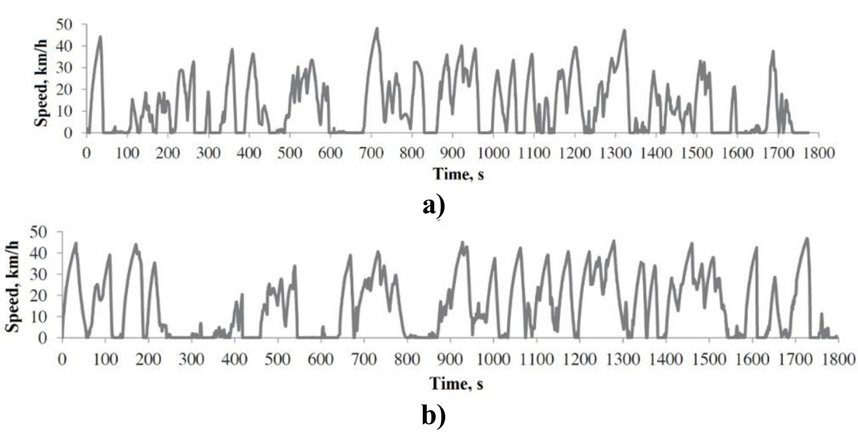

Fig. 10. Driving cycles for the district of Toronto: a) medium vehicles; b) heavy vehicles

The results of the research emphasize that the resulting driving cycles are similar to the international UDDS driving cycle, but have a number of features, which could be associated with the considered urban district.

3 Conclusion

As a result of the analysis of driving cycles in the mathematical modeling of the movement of vehicles with traction electric drive, the most frequently used ones were identified. A diagram of the distribution of driving cycles depending on their repetition in various sources is shown in Figure 12.

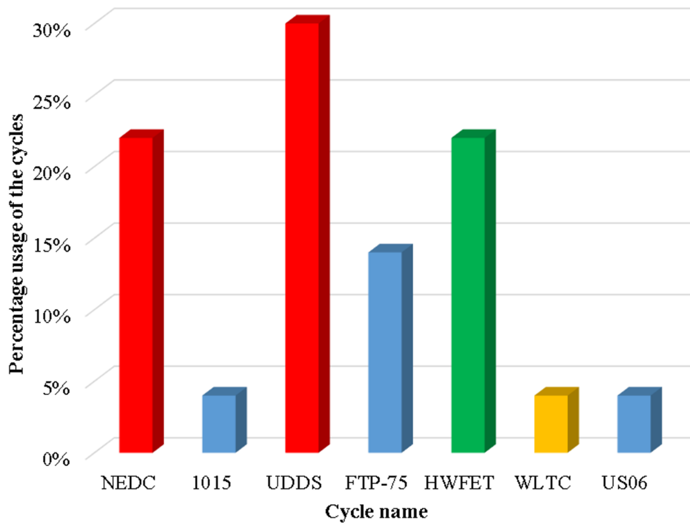

Fig. 11. Diagram of the reusage cycles distribution

Driving cycles, which are red marked, are used most commonly in an urban environment. These cycles are NEDC and UDDS. Of these, the UDDS driving cycle is in the lead. It could be seen also that the FTP-75 cycle, which is an advanced version of the UDDS cycle, is used with sufficient frequency. As it was mentioned above, these two cycles are similar.

The HWFET driving cycle is highlighted in green in the diagram and it is suitable for simulating suburban traffic. This cycle is close in repetition frequency in the studied references. This is due to its often usage in conjunction with NEDC, UDDS or FTP-75 drive cycles.

The usage of several cycles during the optimization of the same parameters is due to the following. All the above standardized cycles are not universal. With unique features, each of these cycles is more or less suitable for modeling the movement of the considered vehicle. Therefore, to achieve the most reliable calculation results, several cycles are used. After that, the convergence of the values of the selected parameters with the established range is analyzed.

The WLTC driving cycle is highlighted in orange. It is rarely seen in the reviewed researches due to its relatively recent introduction. However, it is one of all, which would allow one to create a driving cycle for both a hybrid vehicle and an electric one.

Thus, to simulate the movement of trucks and buses with electric energy storage devices equipped with a mechatronic transmission, it is necessary to use the UDDS or FTP 75 and WLTC driving cycles, and then analyze the convergence of the parameter values of interest to the designer.

4 Acknowledgements

This research work was financially supported by the Ministry of Science and Higher Education of the Russian Federation under agreement No. 075-11-2022-015 dated 07.04.2022 with PJSC "KAMAZ" under the complex project "Creation of high-tech production of mechatronic transmissions for promising KAMAZ trucks and buses with electrical energy storage devices and hydrogen fuel cells" in terms of R&D and technological works.

References

1. A. Kartashov, B. Kositsyn, G. Kotiev, S. Nazarenko, D. Dubinkin, *Ensuring Energy Efficiency and Safety of the Cyclic Operation of the Mining Dump Truck* Vth International Innovative Mining Symposium (2020). DOI: 10.1051/e3sconf/202017403009
2. A.S. Muravyev, V.A. Shishkina, N.V. Buzunov, A.B. Kartashov, D.M. Dubinkin, Sh. Nozirzoda, *Research of control algorithm of traction drive of a mining dump truck using simulation models of motion* Journal of Physics: Conference Series (2021). DOI: 10.1088/1742-6596/2052/1/012028
3. N.V. Buzunov, R.D. Pirozhkov, A.B. Kartashov, D.M. Dubinkin, A.B. Efremenkov, *Simulation of operation of a sequential hybrid drive of a haul truck with a traction battery and a bilateral DC-to-DC converter* IOP Conference Series: Materials Science and Engineering (2020). DOI: 10.1088/1757-899X/939/1/012017
4. A.B. Kartashov, G.I. Skotnikov, *Simulation based feasibility confirmation of using hybrid powertrain system in unmanned dump trucks* IOP Conf. Series: Materials Science and Engineering (2020). DOI: 10.1088/1757-899X/819/1/012010
5. D. Butarovich, A. Smirnov, G. Skotnikov, *Test bench for experimental research of hybrid powertrain algorithms based on rapid control prototyping unit* IOP Conference Series: Materials Science and Engineering (2020). DOI: 10.1088/1757-899X/819/1/012023
6. L. Guo, et.al., *Shift schedule optimization of 2-speed electric vehicle using model predictive control*, Proceedings of the 33-rd Chinese Control Conference. IEEE, 2014. pp.156–161 (2014). DOI: 10.1109/ChiCC.2014.6896614
7. Y. Li, et.al., Advances in mechanical engineering **12(1),** 1-16 (2020). DOI: 10.1177/1687814020901652.
8. Z.Q. Tang, D.P. Ma, X.W. Gong, Applied Mechanics and materials **722**, 271–275 (2015). DOI: 10.4028/www.scientific.net/AMM.722.271
9. M.R. Ahssan, M. Ektesabi, S. Gorji, Energies **13(19),** 5073, 24 (2020). DOI: 10.3390/en13195073
10. J. Ruan, P. Walker, N. Zhang, International Journal of Automotive Engineering **9(4),** 268-275 (2018). DOI: 10.20485/jsaeijae.9.4_268
11. K. Kwon, M. Seo, S. Min, Appl. Energy **259**, 114190, 12 (2020). DOI: 10.1016/j.apenergy.2019.114190
12. W. Huang, J. Huang, C. Yin, Applied sciences **10(18),** 6612 (2020). DOI: 10.3390/app10186612
13. K. Kwon, J. Jo, S. Min, Energy **236**, 121419, 20 (2021). DOI: 10.1016/j.energy.2021.121419

14. J. Eckert, T. Barbosa, et al., Energy Conversion and Management **252**, 115094 (2022). DOI: 10.1016/j.enconman.2021.115094
15. V. Saini, et al., SAE Int J Alternative Powertrains **5(2),** 348–356 (2016). DOI: 10.4271/2016-01-9141
16. L. Guo, B. Gao, H. Chen, IEEE ASME Trans Mechatron **21(6),** 2858–2869 (2016). DOI: 10.1109/TMECH.2016.2586503
17. K. Han, et al., *Hierarchical optimization of speed and gearshift control for battery electric vehicles using preview information,* American Control Conference (ACC), IEEE, 2020, p.4913–4919 (2020). DOI: 10.23919/ACC45564.2020.9147841
18. P.D. Walker, et.al., Adv. Mech. Eng. **5**, 340435, 13 (2013). DOI: 10.1155/2013/340435
19. H. Yu, et al., IEEE Trans. Veh. Technol. **69(11),** 12705–12715 (2020). DOI: 10.1109/TVT.2020.3018445
20. G. Amirjamshidi, M.J. Roorda, Transportation Research Part D: Transport and Environment **34,** 255-266 (2015) DOI: 10.1016/j.trd.2014.11.010