Article citation info:
Frankowski M, Cichoński Z, Stępniewski Ł, Andrzejewski M. Use of Stage V compliant engine in modernized SM42 diesel locomotive. Rail Vehicles/Pojazdy Szynowe. 2023;1-2:27-31. https://doi.org/10.53502/RAIL-173173

Rail Vehicles/Pojazdy Szynowe

www.railvehicles.eu

Use of Stage V compliant engine in modernized SM42 diesel locomotive

Maciej **Frankowski** [a, *], Zbigniew **Cichoński** [a], Łukasz **Stępniewski** [a], Maciej **Andrzejewski** [a]

[a] *H. Cegielski – Fabryka Pojazdów Szynowych sp. z o.o., Poznan, Poland*

ARTICLE INFO

Received: 14 July 2023
Revised: 31 August 2023
Accepted: 3 October 2023
Available online: 7 October 2023

KEYWORDS

modernization
locomotive
diesel
railway

The article presents the result of modernization of the SM42 locomotive carried out by H. Cegielski Fabryka Pojazdów Szynowych from Poznań (Poland). The scope of modernization was discussed and the parameters of the locomotive before and after the introduced changes were presented. The new engine used in the locomotive was described and its parameters confirming the fulfillment of the requirements of the STAGE V standard were presented. Moreover, further development opportunities for the SM42 6D-FPS locomotive were discussed.

1. Introduction

The modernization of the rolling stock consists in introducing structural changes that improve the operational and technical properties of rail vehicles, without changing their intended use. The main goals of the modernization are to adapt the vehicle parameters to the requirements of railway regulations and to improve the efficiency of their operation. As part of the modernization of rail vehicles, i.a. replacement of engines with units that meet the applicable pollutant emission standards, brake systems and control systems.

The main advantage of modernization is that the cost of purchasing a new rail vehicle is three times higher than the cost of modernization.

According to the data of the Office of Rail Transport [4], Polish freight carriers plan to modernize 93 locomotives (60 electric and 33 diesel) in the years 2022–2025. Moreover in the years 2026–2030, it is expected that 169 locomotives operated in Poland will be modernized (100 electric and 69 diesel).

In 2021, H. Cegielski – Fabryka Pojazdów Szynowych from Poznań (Poland) modernized the SM42 diesel locomotive.

The purpose of this article is to present the effects and compare the parameters of the locomotive before and after modernization.

2. Literature review

Literature described a lot of the projects of modernization and polonization of diesel locomotives carried out even before 2005. The authors presented modernization projects of such locomotives as SM42-2000, SP32, SM48. In addition, the articles describes the changes that should be introduced to the locomotives in order to polonize them, e.g. the use of an active dead man's switch (CA), an automatic braking device (SHP), a radio stop (RS).

The model of making decisions about modernization or purchase of new rail vehicles was presented by Tułecki in 2005 [16]. The models described by the author are based on many criteria, e.g. legal and institutional requirements, operating costs and conditions, maintenance costs, availability of spare parts. These criteria should be the basis for making decisions about vehicle modernization or purchase of new rolling stock.

In 2010, Marciniak [6] presented projects of polonization, remotorization and modernization of 28 types of diesel locomotives, which were carried out by

* Corresponding author: m.frankowski@fpspoznan.pl (M. Frankowski)

Polish manufacturers of rolling stock, e.g. Pesa Bydgoszcz or ZNTK Poznań. The author emphasizes that thanks to the projects carried out, the negative impact of locomotives on the natural environment has been minimized and the costs of operation and maintenance of these vehicles have been reduced.

In 2010, Szewczyk [14] described the modernization of the SM42 locomotive carried out by Newag S.A. The modernization consisted primarily in replacing the power generator, thanks to which fuel consumption was reduced and pollutant emissions were reduced. In addition, the underframe, driver's cabin and machinery compartments have been changed, which contributed to improving the safety of shunting (increasing visibility) and ergonomics of service.

In 2011, Marciniak [7] presented modernized diesel and electric locomotives. The author described the modernization of such electric locomotives as ET21, EM10, ET22, EP09, 181/182, EP07, EP08. Modernizations of ST44, SU45, SM42, SM48 series diesel locomotives were also presented. In addition, the author considered the advantages of modernization in relation to the purchase of new rolling stock. Among them, one can distinguish, for example, the cost of modernization is about 50% lower than the cost of purchasing a new vehicle, the return on investment may take up to 5 years.

In 2011, Szkoda and Tułecki [15] carried out an LCC analysis and a cost-benefit analysis of the modernization of the SM42 6Dg/A series shunting locomotive. The results of the LCC analysis show that the modernization of the locomotive ensures the reduction of total costs (LCC) over the 25-year period of operation by 47% compared to the non-modernized locomotive, thanks to the reduction of diesel oil consumption, increased reliability and availability of spare parts - variables. The cost-benefit analysis confirmed that the modernization of the SM42 locomotive is fully justified economically.

In 2013 Stawecki et al. [13] presented the results of tests of toxic compounds emitted by a modernized diesel locomotive. The authors conducted stationary tests in accordance with the ISO 8178-F standard. The research object was the diesel engine of the modernized ST44 locomotive. The research shows that thanks to the replacement of the drive unit, CO_2 emissions decreased by 66%, HC by 60%, and NO_x by 18%.

Liudvinavičius and Jastremskas presented in 2017 [5] the modernization of the 2M62 and TEP-70 diesel-electric locomotives. Thanks to the use of the traction generator excitation control system developed by the authors, the locomotives' fuel consumption decreased by approx. 20%. In addition, the implementation of this system made it possible to improve the working conditions of the train driver and increased the safety of driving the locomotive.

In 2018, Andrzejewski et al. [1] described the impact of replacing drive units in diesel locomotives on the emission of toxic compounds. The authors tested locomotives of the ST45, ST44, SM48 and SM42 series. The analysis shows that thanks to the replacement of combustion engines, CO_2 emissions will be reduced by an average of 10%, HC by 13%, and NO_x by 11%.

Comparative analysis of parameters before and after modernization of 6Di and 19D locomotives was carried out by Michalak et al. in 2018 [8]. In addition, the authors described in detail the new assemblies used in locomotives after their modernization, e.g. generator set, braking control panels, compressor unit, control cabin.

In 2021, Andrzejewski et al. [2] conducted tests of fuel consumption by ST44 locomotives before and after modernization consisting, among others, in on replacing the two-stroke internal combustion engine with a new four-stroke engine unit. The authors conducted experimental research using water resistors. The research shows that when the engines were running in no-load mode at idling speed, the locomotive's hourly fuel consumption decreased by approx. 50% after modernization (engine replacement). On the other hand, when the locomotive was operating at full load, fuel consumption was reduced by approx. 4%.

In 2022, Florantsev et al. [3] presented the results of a comparative analysis of the parameters of the TGM-6 locomotive before and after the modernization, which consisted in replacing the drive unit and transmission (from electromechanical to hydromechanical). The obtained results show that the locomotive after modernization was characterized by improved traction and dynamic characteristics, higher reliability, its operating costs were reduced due to lower fuel consumption.

3. Modernization of SM42 locomotive

3.1 The subject of modernization

The subject of modernization was the SM42 diesel shunting locomotive (Fig. 1), which was designed in 1958–1962. The locomotive was designed to perform heavy shunting work and to drive light freight trains. Its producer was the Fablok Locomotive Factory from Chrzanów in Poland.

Fig. 1. SM42 locomotive [12]

The locomotive parameters are presented in Table 1.

Table 1. SM42 locomotive parameters [10]

Parameter	Value
axis system	Bo'Bo'
service weight	70 t
length	14 240 mm
width	3173 mm
height	4400 mm
wheelbase	10 100 mm
wheel diameter	1100 mm
traction	diesel
type of engines	a8C22/MTU
fuel tank capacity	2840 l
rated power	588 kW
maximum tractive force	228 kN
type of transmission	electric
design speed	90 km/h
axle load on rails	175 kN
brake system	Oerlikon

In total, 1822 locomotives of SM42 type were produced and thus it is the most popular shunting locomotive operated in Poland.

3.2. The aim and scope of modernization

On 2018-12-05, PKP INTERCITY S.A. announced a tender procedure for the modernization of 13 diesel locomotives of the SM42 series under the name "Performance of periodic repairs at the 5th maintenance level along with the modernization of 13 diesel locomotives of the SM42 series". The procedure was announced as a public open tender in accordance with the Public Procurement Law.

In accordance with the provisions of the Specification of the Contract Conditions, the Contracting Authority required the replacement of the a8C22 diesel engine with two new diesel engines and specified the basic parameters of the locomotive after modernization:

– the locomotive is to have two identical internal combustion engines with a total rated power of at least 1000 kW at 400 above sea level
– the engine must meet the requirements for emission of pollutants according to Stage IIIB (Regulation of the Minister of Economy of 30 April 2014 on detailed requirements for internal combustion engines in the field of reducing the emission of gaseous and particulate pollutants by these engines, Journal of Laws of 2014, item 588)
– specific engine fuel consumption at rated power cannot be higher than 225 g/kWh
– engine oil consumption at rated power – cannot be greater than 0.2% of fuel consumption
– it is required to adapt the auxiliary systems of the internal combustion engine, to combine existing systems with new systems
– it is required to control the engine starting sequence in such a way as to obtain the minimum fuel consumption and to ensure that the engines are operated in an even manner.

3.3. Modernized SM42 locomotive

In December 2022, H. Cegielski FPS completed the contract for the repair of P5 with the modernization of 13 SM42 diesel locomotives to the SU4220 series (Fig. 2).

Fig. 2. SM42 locomotive after modernization (SU4220)

The SU4220 locomotives were created as a result of a deep modernization of the classic SM42 series diesel locomotives. The vehicles are equipped with two modern TCD 16.0 V8 diesel engines from Deutz. These engines meet the Stage V emission standard. Engine characteristics are shown in Table 2.

Table 2. Characteristic of TCD 16.0 V8 engines

Parameter	Value
type	TCD 16.0 V8
producer	Deutz
engine power	2 × 480 kW
number and arrangement of cylinders	8V
cylinder diameter	132 mm
piston stroke	145 mm
total engine capacity	15,874 dm^3
exhaust emission standard	Stage V

In the Stage V standard, the European Commission tightens the permissible amount and size of particulate matter contained in the exhaust gases of machines and non-road vehicles (this applies to all engines with a power of 19 to 560 kW). Since the entry into force of the document, such engines can emit a maximum of 15 milligrams of particulate matter per kilowatt hour. For comparison, in Euro IV it was 25 mg/kWh. The novelty introduced by Euro Stage V is not only a reduction in weight, but also in the number of particulate matter in the exhaust gases, which can now be reduced to a maximum of 1×10^{12} 1/kWh.

The main features of the locomotive after modernization to the 6D-FPS type:

– maneuvering – linear purpose
– modular construction (Fig. 3)
– a new, air-conditioned driver's cabin with modern desktops (Fig. 4)
– possibility of multiple control
– meeting the latest Stage V emission standard by using a modern internal combustion engine
– dual-band radiotelephone – for shunting and train communication/GPS system
– driving trains with the possibility of supplying the wagons with electricity (heating coupler 3 kV)
– modern vehicle extinguishing system.

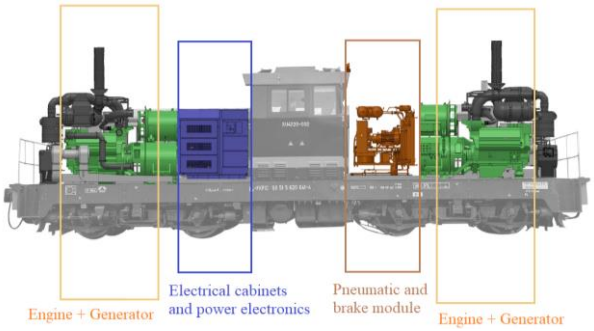

Fig. 3. Modular construction of modernized SM42 locomotive

Fig. 4. Driver's cab of modernized SM42 locomotive

A new solution that the locomotives have been equipped with is a microprocessor control system that improves the traction properties of the vehicles and also allows to reduce fuel consumption. The modernization increased not only the safety of the locomotive, but also its reliability.

According to the client's order – PKP INTERCITY S.A., H. Cegielski – Fabryka Pojazdów Szynowych sp. z o. o. performed the modernization of the SM42 series locomotives into two-aggregate vehicles with the function of supplying the wagons with electricity. The vehicles have been equipped with modern internal combustion engines that meet the latest emission standards. As a result of the modernization, the traction properties of the vehicle improved, fuel consumption was reduced, the safety and reliability of the locomotive operation increased.

During the design, great emphasis was placed on the driver's comfort. The design assumptions were verified during a series of tests [11]. Vibration measurements carried out during test runs at the driver's workstation in the locomotive cabin indicated that the daily vibration exposure for each vibration direction was not exceeds the criteria set out in Regulation [5]. Block diagram of the system for measuring and analyzing the vibration acceleration value driver's workstation in the cabin of a diesel locomotive type 6D-FPS is shown in the Fig. 5.

The comparison of SM42 locomotive parameters before and after modernization is shown in Table 3.

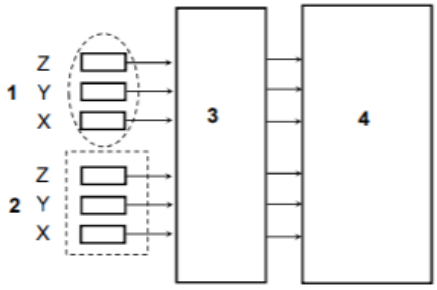

Fig. 5. Block diagram of the vibration measuring system [11]: 1 – measuring disk with acceleration transducer, 2 – board with transducer, 3 – meas uring power supply, 4 – computer set for data recording and processing

Table 3. Parameters of SM42 locomotive before and after modernization

Parameter	Value before modernization	Value after modernization
axle system	Bo'Bo'	Bo'Bo'
service weight	70 t	72 t
length	14 240 mm	14 240 mm
wheel diameter	1100 mm	1100 mm
traction	diesel	diesel
engine type	a8C22/MTU	TCD 16.0 V8
rated power	588 kW	960 kW
type of transmission	electric	electric
design speed	90 km/h	90 km/h
axle load on rails	175 kN	185 kN

The first two modernized diesel locomotives were delivered to the carrier on January 19, 2022. One of them made its debut with the PKP Intercity train at the

end of January, when it set off from Wrocław Główny to the Kudowa Zdrój station, driving the IC Śnieżka train. In September 2021, the vehicle with the number 002 was exhibited at the Trako International Railway Fair in Gdańsk (Fig. 2).

In total, 13 locomotives underwent modernization, which can now not only perform shunting work, but also operate with light passenger trains on secondary, non-electrified lines, at speeds below 90 km/h.

4. Summary

In this article the effects of modernization of the SM42 diesel locomotive carried out by H. Cegielski – Fabryka Pojazdów Szynowych from Poznań were presented.

Thanks to the modernization of the SM42 locomotive, the traction properties of the vehicle have been improved, fuel consumption has been reduced and the safety and reliability of the locomotive operation have increased. In addition, the vehicles' engines meet the Stage V emission standard.

The construction of the 6D-FPS locomotive has the potential for further development towards ensuring zero-emission operation through the use of an electric-battery drive.

Nomenclature

CA	active dead man's switch	RS	radio stop
LCC	life cycle cost	SHP	automatic braking device

Bibliography

[1] Andrzejewski M, Daszkiewicz P, Rymaniak Ł, Merkisz J, Kamińska M. Impact of modernization of locomotives operated in Poland on the emission of toxic compounds in exhaust gases. Autobusy – Technika, Eksploatacja, Systemy Transportowe. 2018; 19(12):54-57. https://doi.org/10.24136/atest.2018.353

[2] Andrzejewski M, Daszkiewicz P, Urbański P, Rymaniak Ł, Woch A. Impact of a locomotive engine modernizatio on fuel consuption. Matec Web Conf. 2021;338:01001. https://doi.org/10.1051/matecconf/202133801001

[3] Florentsev S, Polyukhovych V, Evpakov V. Modernization of industrial shunting diesel locomotives for technological railway transport. 2022 International Ural Conference on Electrical Power Engineering (UralCon), Magnitogorsk. 2022:64-68. https://doi.org/10.1109/UralCon54942.2022.9906764

[4] Investment plans of freight carriers 2022-2030 (in Polish) https://utk.gov.pl/pl/aktualnosci/17788,Plany-inwestycyjne-przewoznikow-towarowych-2022-2030.html (accessed on 2023.09.26)

[5] Liudvinavičius L, Jastremskas V, Modernization of diesel-electric locomotive 2M62 and TEP-70 locomotives with respect to electrical subsystem. Procedia Engineering. 2017; 187:272-280. https://doi.org/10.1016/j.proeng.2017.04.375

[6] Marciniak Z, Polonizacja, remotoryzacja i modernizacja lokomotyw spalinowych eksploatowanych w kraju. Pojazdy Szynowe. 2010;1:17-31. https://doi.org/10.53502/RAIL-139712

[7] Marciniak Z. Electric and diesel locomotives modernised in Poland. Technika Transportu Szynowego. 2011;4(18):14-35.

[8] Michalak P, Jakuszko W, Far M. Modern systems and assemblies in modernized 6Di and 19D locomotives. Rail Vehicles/Pojazdy Szynowe. 2018;(2):38-51. https://doi.org/10.53502/RAIL-138483

[9] Rozporządzenie Ministra Rodziny, Pracy i Polityki Społecznej w sprawie najwyższych dopuszczalnych stężeń i natężeń czynników szkodliwych dla zdrowia w środowisku pracy. Dz. U. 2018 poz. 1286. https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180001286

[10] Shunting diesel locomotive https://pl.wikipedia.org/wiki/Fablok_6D (accessed on 2023. 09.26)

[11] Sieć Badawcza Łukasiewicz IPS „Tabor", Raport z Badań, Badania drgań o ogólnym działaniu na organizm człowieka w kabinie zmodernizowanej lokomotywy spalinowej typu 6D-FPS serii SU-4220.

[12] SM42-916 diesel locomotive https://en.wikipedia.org/wiki/PKP_class_SM42#/media/File:Sm42-916.jpg (accessed on 2023.09.26)

[13] Stawecki W, Marciniak Z, Pielecha I, Pielecha J. Ekologiczne aspekty modernizacji lokomotyw spalinowych w Polsce. Prace Naukowe Politechniki Warszawskiej. 2013;98:615-624.

[14] Szewczyk W. Modernizacja lokomotywy SM42 wersja 6Dg produkcji Newag Nowy Sącz – nowoczesność, ekologia i ekonomia (in Polish). Technika Transportu Szynowego. 2010;4:22-24. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BGPK-2826-0904/c/Szewczyk.pdf

[15] Szkoda M, Tułecki A. Analiza efektywności modernizacji lokomotywy manewrowej serii SM42 (in Polish). Technika Transportu Szynowego. 2011;1-2:77-81. https://yadda.icm.edu.pl/baztech/element/bwmeta1.element.baztech-article-BPK3-0005-0010/c/Szkoda.pdf

[16] Tułecki A. Modele decyzyjne w odnowie parku spalinowych pojazdów trakcyjnych. Technika Transportu Szynowego. 2005;9:69-73. https://bibliotekanauki.pl/articles/251586.pdf