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Issues in the conservation and restoration of powertrains as engineering art monuments

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The article discusses issues related to the behavior of powertrains understood as monuments of engineering art. The theoretical part analyzed the most important issues related to the maintenance and renovation of vehicles, their share in Poland in the age category, as well as the regulations regarding the classification of historic vehicles. The next part of the article presents the renovation process of two powertrains – the K-750 motorcycle and the Volkswagen Type 117 passenger car, along with a short production history. Then, recommended procedures for unique objects were discussed in the context of their state of preservation and occurrence based on the authors' experience.

Key words: *combustion engine, conservation, monuments of engineering art, powertrains, renovation*

1. Introduction

The renovation of monuments of engineering art, which includes all types of vehicles, is a constantly developing field of science. Within its area, coherent activities must be carried out in the field of history, conservation, construction, technology, chemistry, and other fields related to a given object. However, maintenance work often requires a compromise between the above-mentioned areas. Moreover, in many areas of technology, it is difficult to determine whether a given solution is already a monument of engineering art and has some value. Therefore, scientists are developing tools that are intended to unify activities in the undertaken area and support the decision-making process. This is achieved through classification and evaluation related to multi-criteria assessment of objects [1, 2, 6, 9]. In the renovation of transport facilities, the most important decision is whether a given facility is to be kept in operation while maintaining partial or full functionality.

The heritage of engineering art allows us to learn about the level of technical culture, construction, and technology of their creation, as well as the reasons for their production in terms of social and individual needs [6, 9, 17]. Learning about old solutions combined with modern technologies can be an impulse for technical development work [13, 16]. When maintaining and renovating historic vehicles, many issues should be considered, including: originality of parts and their condition, safety during operation, and the original operation of individual units. Aesthetic values are also important, but they raise a lot of controversy because facility owners often decide to completely renovate paint coatings, often using technologies other than the original ones. However, this is debatable because the historical value is also determined by the preserved elements of the painting and varnish from the production times. In addition, for historic vehicles, the issue of preserving modifications made to the facility should also be considered. They are often a component of the historical identity of the object and resulted, for example, from a direct utilitarian need [15].

In Poland, in 2022, according to the central vehicle register, 29 727 303 passenger cars, motorcycles, and mopeds were registered [13]. Of this, a significant 20.71% were historical objects aged at least 31 years (Table 1). It should be noted that most of these vehicles no longer exist and have not been removed from the register. Some of them are still used without recognizing their historical context. However, historic objects constitute a small share of this population. At the end of 2022, there were 56,290 historic vehicles registered in the country (this group also includes heavy and agricultural vehicles). The largest share in this group are post-war objects. During World War II, the automotive industry in Poland was almost completely destroyed [8].

Table 1. Share of vehicles over 31 years of age and older [14]

	Passenger cars	Motorcycles	Mopeds	Whole
Total [pcs]	26 457 659	9 490 427	1 830 963	29 727 303
≥ 31 years [pcs]	4 999 558	2 958 423	816 922	6 155 839

2. Regulations regarding the classification of historic vehicles

In the European Union, there are no clear provisions regarding the protection of monuments of engineering art, apart from general provisions relating to monuments in general. Detailed data are defined by member states, mainly by ministries related to culture and transport.

Historic vehicles are becoming more and more popular, not only in Poland but also throughout the European Union. Very often, such objects are not formally registered as monuments despite their condition and age. This is due to users' prejudices and very often their ignorance. However, due to the policy of sustainable development and care for the natural environment, additional fees and restrictions are imposed on older vehicles. Therefore, owners are increasingly seeking entry into the register of monuments with the Provincial Conservators of Monuments. The most important normative acts in Poland in this regard are:

- Act of 20 June 1997, road traffic law (Journal of Laws of 2023, item 1047, as amended) [13]
- Act of 14 June 1960 – Code of Administrative Procedure (Journal of Laws of 2023, item 775)
- Regulation of the Minister of Infrastructure on detailed activities of authorities in matters related to the admission of vehicles to traffic and templates of documents in these matters of August 31, 2022 (Journal of Laws of 2022, item 1849, as amended)
- Regulation of the Minister of Transport, Construction and Maritime Economy on tests for compliance with the technical conditions of historic vehicles of February 27, 2013 (Journal of Laws of 2013, item 337)
- Act of April 14, 2023 on approval systems for vehicles and their equipment (Journal of Laws of 2023).

The above legislative provisions show that a historic vehicle is a vehicle that has been entered into the register of monuments or is in the provincial register of monuments on the basis of separate regulations, as well as a vehicle entered in the inventory of museum objects, in accordance with separate regulations [13]. To obtain entry in the register of monuments (depending on the region), the facility includes, among others: it must be at least 30 years old, its type has been out of production for 15 years, it has not undergone any significant design changes, and the degree of originality of the parts must be at least 75%. Moreover, such a vehicle should no longer serve its original purpose on a daily basis. To confirm these requirements, it is necessary to provide an expert's opinion. Vehicles that are at least 25 years old are unique, and have significant historical significance in the context of technology, related events, or people may also be considered a historic vehicles.

The legislative guidelines are defined differently in Germany. In addition to the minimum age requirement, modifications using non-original parts are not allowed, and the vehicle itself must meet the criteria to obtain a positive assessment following §23 of the German Road Traffic Act [12]. As part of this assessment, the expert classifies the condition of the vehicle, giving it a rating from 1 "Perfect condition" (German: makelloser Zustand) to 5 "Condition requiring renovation" (restaurierungs-bedürftiger Zustand). Additionally, the vehicle is classified as "Original" (the entire vehicle maintained in its original condition), "Authentisch" (a vehicle or its elements restored following the original) or "Nicht Authentisch" (a vehicle significantly modified, not corresponding to its original condition).

3. Renovation of powertrains of historic vehicles

3.1. General thoughts

Renovation and workshop work must be carried out with particular caution and, at the same time, analyze wear and causes of damage. This allows you to diagnose weak structure nodes and features characteristic of a given solution. Within the scope of work carried out, basic conditions should be met, taking into account, e.g., theoretical preparation. This is about theoretical knowledge of the structure in question – its purpose/function and the method of assembly and disassembly of individual and subassemblies. Such information should be included in repair manuals, but it sometimes happens that there is no documentation for a given object. Therefore, it is necessary to collect literature regarding the solutions of this manufacturer or twin units from a given era. Military literature is particularly useful, as it is always richly illustrated and has detailed operating guidelines, e.g. [5]. It is also very important to prepare the workshop, including the development and use of tools and workshop aids (often dedicated to a given facility). Using a torque wrench to disassemble drive system components can provide a lot of information that is useful for assembly or defining the causes of a given fault. When undertaking conservation work, the object should be thoroughly cleaned, but the original coatings and seals should be retained as much as possible in order to collect information regarding their restoration or replacement.

3.2. K-750 motorcycle engine and gearbox

The subject of the renovation was a two-cylinder boxer combustion engine, Soviet production, with a displacement of 750 cm^3 (Table 2). It was used to power motorcycles M-72, MW-750, K-750, and all their varieties from factories in Moscow, Irbit, and the Urals (Fig. 1). The engine design was taken from the German BMW R-71 military motorcycle in 1939. Due to its use, the engine had to be characterized by high durability and power because it powered a machine equipped with a sidecar, where the total weight of the vehicle, including equipment and weapons, exceeded 450 kg (Fig. 2). After the war, the production of motorcycle harnesses was not discontinued; their design was slightly changed to make them more suitable for urban driving, for example, the gear ratios in the gearbox were changed.

Table 2. Technical data of the combustion engine mounted in the K-750 motorcycle [4]

Type	4-stroke, bottom-valve, spark ignition
Number of cylinders	2
Cylinder diameter [mm]	78
Piston stroke [mm]	78
Displacement [cm^3]	746
Compression ratio	6:1
Maximum power [kW] at [rpm]	19.1 at 4600
Maximum torque [Nm]	39.2
Power system	carburetor K-37A

In accordance with conservation and engineering guidelines, the drive system was dismantled, and parts were verified. Previous users have not modified the engine and gearbox and have never thoroughly overhauled them, as evidenced by the condition of individual parts. It was also interesting to discover traces of foundry sand inside the engine block (in the upper parts) in hard-to-reach places, which remained after the production process. This made it possible to conduct a thorough analysis of component wear and obtain information about the weakest nodes in the engine. Examples include cracked pistons and uneven wear marks caused by the rings in the liners. This data contributed to improving the axial positioning of the elements in the cylinders and ensuring proper lubrication. However, severe wear of the camshaft slide bearing prompted a deeper analysis of this system and the implementation of material

changes in the node. Scratches on the pistons indicated that the filter in the power supply system and the mechanical oil filter should be checked frequently.

Fig. 1. Object undergoing renovation: K-750 motorcycle produced in Kiev in 1962

No significant design changes were introduced throughout the production period. Only retail changes were introduced, most often driven by economic reasons. During the main overhaul, several solutions were proposed to improve the operation and increase the failure-free operation of the engine. They are concerned with the power supply system, changing the type of crankshaft bearing, modernizing the engine cover seal, and using a different material (phosphobronze CuSn10P) in the camshaft slide bearing. Moreover, these changes bring the repaired structure closer to its prototype, i.e., the BMW engine. When Soviet designers were transforming the engine structure, simplifications were introduced that had a negative impact on the quality and durability of the historic vehicle.

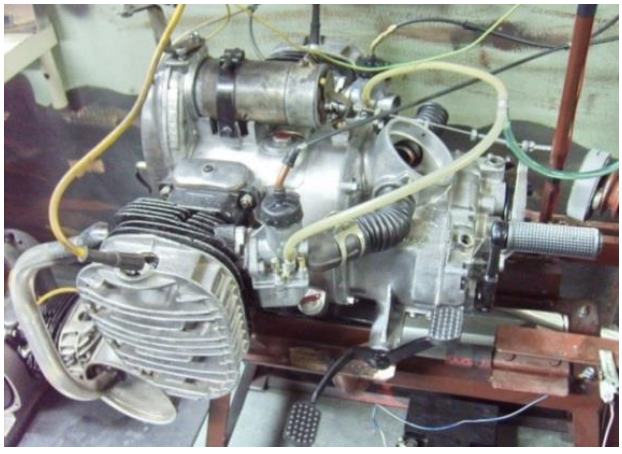

Fig. 2. The engine and gearbox of the K-750 motorcycle on the engine stand

After repairing the parts (regeneration of the crankshaft, camshaft, and camshafts), the engine and gearbox were assembled. All original and serviceable parts were used in the process. The assembly process was carried out in several stages – given nodes were assembled and disassembled several times to obtain the best fits and tolerances. After initial lapping activities, the heads were installed, and the electrical system was checked. Break-in was carried out using an electric motor connected to the gearbox output shaft. During the start-up phase, engine brake-in was an important issue. Achieving proper tightness in this process ensures that the intended power is obtained and the period until the next major repair is extended [10].

3.3. Volkswagen Type 117 vehicle: engine and gearbox

Another object undergoing renovation was a four-cylinder boxer combustion engine, made in Germany, with a displacement of 1,192 cm^3 (Table 3, Fig. 3). Its history began in 1934, when Ferdinand Porsche began design work on a vehicle intended to motorize post-war Germany. Unfortunately, the ambitious plans were interrupted by the outbreak of World War II, during which most of the units produced were used for military vehicles, such as the 4-seater Kübelwagen light off-road vehicle or the Schimmwagen floating all-wheel drive vehicle, as well as for power generators. After World War II, the engine was used in vehicles such as the Volkswagen Type 1 "Beetle", Type 2 "Transporter" and Type 14 "Karmann-Ghia" [7]. The latter, based on the "Beetle" chassis, had a special, sports body manufactured at the plant in Osnabrück. In the following years, this unit underwent several modifications aimed at improving efficiency. The most important changes included: the addition of a Bosch L-Jetronic injection system with electronic control in 1974 and the introduction of a liquid cooling system in 1982, used in the third-generation Transporter model [3].

Table 3. Technical data of the combustion engine mounted Volkswagen Type 117 [7]

Type	4-stroke, OHV, spark ignition
Number of cylinders	4
Cylinder diameter [mm]	77
Piston stroke [mm]	64
Displacement [cm^3]	1192
Compression ratio	6:1
Maximum power [kW] at [rpm]	22 at 3400
Power system	carburetor Solex 28 PCI

The renovation process of the presented engine began with disassembly, carried out in accordance with conservation and engineering guidelines, based on the service manual from the vehicle's production period. The visual assessment revealed advanced corrosion of metal covers designed to increase engine cooling efficiency. Apart from typical signs of use of the piston-cylinder assembly, such as moderate abrasion, no signs of excessive wear were found, so after cleaning, these components were reassembled. The upper cylinder covers required the use of an appropriate reconstruction technique. Knowledge from the literature and information from brand enthusiasts revealed that from January to July 1954, these covers were assembled from three separate pieces, formed by cold forming and then joined by a spot welding process. Due to the advanced corrosion of the original covers, three copies were purchased from the secondary market, based on which a set was prepared for use. All covers were covered with thermosetting black polymer-based paint with a gloss similar to the varnish originally used (based on metal oxides).

Fig. 3. Object undergoing renovation: Volkswagen Type 117 car produced in Wolfsburg in 1954

In parallel to the engine renovation, renovation works on the gearbox were carried out. The vehicle's transmission was equipped with synchronizers and helical gears for 2nd, 3rd, and 4th gear for easier operation and lower noise emission. During conservation work, it was found that the synchronizers had visible damage on the surface, which may indicate that the material was too plastic or that the impact load was too high. The element that could not be replaced due to lack of availability was the shaft transmitting torque from the engine to the transmission. Pitting occurred around the sealant, so it was decided to apply several layers of technical chrome to the damaged surface and then reduce the diameter to the nominal diameter in the process of abrasive machining. The last stage was the final assembly with the addition of lubricating liquid (Fig. 4).

Fig. 4. The engine of a Volkswagen Type 117 car at the assembly station

4. Conservation and renovation of unique powertrains

The examples of powertrains presented in the previous chapter concern historical objects. However, they are not unique because, due to the volume of production, there are still hundreds of such copies. The changes introduced in the publication do not affect their functionality. They are primarily used to improve the durability of drives and extend their service life. This offers the prospect of maintaining greater originality in the long term. Moreover, the implemented changes are inconsistent with the technologies originally used, but they constitute a small contribution to the originality of the objects.

Based on the authors' experience and in consultation with conservators, certain guidelines for the protection of unique objects have been formulated (Fig. 5). During conservation work carried out by both enthusiasts and conservators, it is very important to create documentation of the progress of the work. This not only has a positive impact on expanding operational knowledge but also allows for the preservation of the history of a specific object. Any documentation assigned to a vehicle should accompany it when transferred/sold to subsequent owners.

When referring to monuments of engineering art, unique in their existence or related to historical figures, the conservation process and possible renovation should be considered individually. For objects in a poor state of preservation, renovation means replacing most of the parts with new ones. In such a case, a better solution is to preserve the remnant and create a vehicle modeled on what remains of its original structure. Operation (even for demonstration purposes) is also not recommended for unique objects because each start-up of, e.g., a heat engine, involves its destruction. Examples of such objects that require special conservation care include a two-stroke stationary engine manufactured by "Motor Polski" from Żnin (1930, Fig. 5a), the prototype Ursus C-342 (1965, Fig. 5b), or the concept Polish car FSM Beskid. All objects have been preserved in fewer than 10 pieces, which makes them unique in the world. They are all in museums.

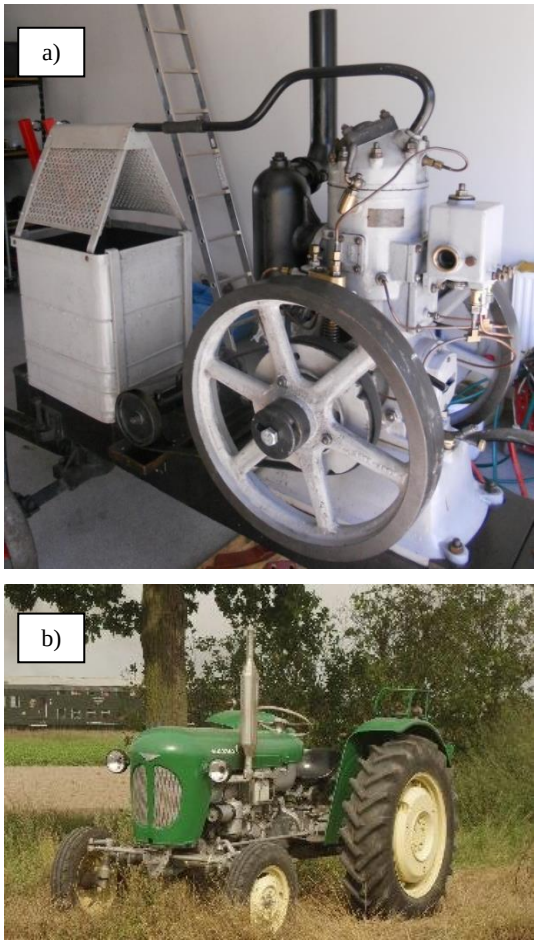

Fig. 5. Unique monuments of engineering art in the collections of the National Museum of Agriculture and Food Industry in Szreniawa: a) Motor Polski produced in Żnin in 1930, b) Ursus C-342 produced in Warsaw in 1965

Currently, it is very important to build awareness among people, especially those related to technical activities in the field of saving monuments of engineering art. Referring to

the topic of the article, each historic object related to powertrains and their operation or service should be protected against weather conditions. Consultations with historians or conservators should then be carried out, and on this basis, a decision should be made on further activities related to it. At the same time, conservators without technical education or experience should consult with engineers related to the field. Creating international organizations and societies will allow us to identify these types of facilities with greater precision and select the best security measures.

5. Summary

The article discusses the current issue of the protection and renovation of historic vehicles. Current national regulations apply to the entire facility, with no specific attention given to powertrains. German regulations are more restrictive. However, there are no guidelines for the entire European Union, which could unify activities and facilitate the exchange of information between member states, especially in the field of unique objects. It is necessary to disseminate knowledge about monuments of engineering art, unique objects. However, history enthusiasts and conservators have the greatest opportunities to save historic vehicles. It is also important to define guidelines and, later, regulations for the maintenance and renovation of powertrains. In the presented work, the authors of the article proposed certain procedures that are fundamental in the field of the problem being discussed.

An example of activities related to protecting unique objects on a larger scale was establishing the Tarpan Museum at the National Museum of Agriculture and Food Industry in Szreniawa. Many objects and documentation were collected there, and the memories of living employees and users were recorded. The collection is constantly being expanded, but significant promotional and research activities are required.

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