# Implementation of renewable technologies in the repair of automotive units

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**Abstract.** This article considers the introduction of restorative technologies in the repair of automotive units as a response to the shortage of spare parts, the rise in logistics costs, and the need to conserve resources. The approach is based on the idea of transitioning from "repair as a patch" to a controlled technological process that returns the part to a state close to new, with predictable characteristics and quality control. The article pays special attention to the situation in Ukraine. Here, the aging of the car fleet and the growth of the share of imported used cars are shaping the demand for the restoration of expensive components and reducing equipment downtime. The technical part considers three main approaches: laser deposition (DED) to restore the desired shape and restore working surfaces, HVOF spraying as a replacement for traditional chrome plating, and polymer composites for the repair of body parts without heating. The properties of the resulting coatings and layers are described - their structure, adhesion strength to the base, porosity, hardness and wear resistance - and attention is drawn to possible problems, in particular, a decrease in fatigue strength due to thermal effects, and how this can be compensated for by final hardening. The economic part is then presented as a convenient model for car repair shops and motor transport companies: the price of new parts is compared with the costs of restoration, it is estimated when the equipment will pay for itself, and what benefits come from reducing equipment downtime. The environmental benefit of the LCA approach was shown: restoration of parts usually requires less material and energy, therefore it produces lower emissions. It is also described how to organize the work of the repair site: which units and parts should be repaired, how to prepare surfaces, how to perform non-destructive testing and how to document the results. Therefore, these developments can be taken as a basis for a technical task for improving and modernizing a car service, but on condition that trained employees and clear standardized procedures will create and guarantee quality and durability.

**Keywords**: restoration technologies; laser deposition; DED; HVOF; polymer composites; fatigue strength; cost-effectiveness; LCA.

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## Introduction

The transition of industry to the principles of the circular economy is changing the logic of repair: parts are increasingly seen not as “consumables” but as resources that can be returned to circulation with specified characteristics. For the automotive industry, this means a shift from traditional repairs (where the main goal is to restore operability “here and now”) to major refurbishment (remanufacturing) — a controlled industrial process that returns the unit to a condition close to new, with repeatable technology, parameter control, and clear warranty terms. Global demand for such solutions is growing, as confirmed by market estimates and forecasts for an increase in the volume of the refurbished auto parts segment [1], [2].

This topic is particularly relevant in Ukraine due to a number of factors. These include the aging of the vehicle fleet, widespread imports of used cars, logistics constraints, and volatile prices for new spare parts. It is obvious that under such conditions, the refurbishment of expensive components, such as shafts, gear wheels, hydraulic cylinder rods, etc., becomes not only a way to reduce costs, but also a tool for reducing equipment downtime and increasing the stability of the transport infrastructure. Rapid technological progress has made methods previously associated with the aerospace or energy industries accessible: laser cladding/DED, high-velocity oxygen fuel (HVOF) spraying, and polymer composites for cold repair.

The purpose of this article is to provide a concise and practical analysis of the possibilities and limitations of these approaches to the repair of automotive units, to describe key technical indicators, and to develop a rationale for choosing a technology, taking into account economic and environmental consequences. Particular emphasis is placed on the issues of resource and durability of refurbished parts, which often determine the feasibility of implementing high-tech processes in real service practice.

Overview of the external environment.

The external environment for remanufacturing is shaped by both market and engineering factors. At the global level, the key driver is the economics of ownership: remanufactured units are usually cheaper than new ones while maintaining acceptable performance, and for businesses this directly translates into lower cost per kilometer and less downtime. According to analytical reports, the refurbished auto parts segment is showing steady growth and remains attractive to OEMs and independent manufacturers who are building closed-loop recycling systems for core units [1], [2]. The role of electrical and electronic components is also growing: their high price and complexity increase the motivation to refurbish rather than replace them.

In Ukraine, demand for repair and refurbishment is supported by the structure of the vehicle fleet. Open import statistics show that the vast majority of cars imported in 2024 are used, which means a higher probability of hidden defects, the need for unit refurbishment, and an increase in the share of “economical repairs” [3]. In practice, this creates two parallel niches: mass (when the customer expects the lowest price and is willing to compromise) and professional/entrepreneurial (when resources, repeatability, and warranty are critical). Since it is difficult to consistently ensure quality without a controlled process, the second category is the natural environment for remanufacturing.

An important component of the external environment is standardization and measurability of results. In industrial restoration, quality is not limited to the subjective assessment of a master craftsman—it is confirmed by measurable indicators (hardness, adhesion, porosity, roughness, residual stress, non-destructive testing results) and the traceability of technological parameters. This is particularly relevant for Ukrainian enterprises, as staff shortages and high service loads increase the risk of the “human factor.” The logic of environmental monitoring and vehicle reliability management also encourages a systematic approach: it is important to consider not only the price of a part, but also its life cycle costs and the risks of failure in operation [5]. Therefore, decisions on the implementation of refurbishment technologies should not be made intuitively, but based on data on load, typical defects, and the economic consequences of downtime.

Another practical factor is the availability of the "core" for refurbishment. Remanufacturing only works when there is a flow of worn-out units suitable for defect detection and a clear mechanism for returning them to the production cycle. In mature markets, there are deposit/return systems in place, where the customer receives a discount or a refund for returning the old unit, and the manufacturer or service provider forms a "core" warehouse and plans production. For Ukrainian services, this infrastructure is often fragmented, so companies have to independently organize collection, sorting, initial defect detection, and accounting, otherwise the cost of finding suitable parts "eats up" the economic effect. Therefore, the advantage for greater competitiveness lies not only in the machines and materials, but also in the organization of the flow itself: warehouse policy, transparent pricing, and rapid diagnostics.

Consumer perception is also considered a separate barrier. Some customers automatically equate "refurbished" with "used" and expect lower reliability, even if the technology provides better surface characteristics than the original part. This barrier can only be reduced through standardized quality control, traceability of parameters and guarantees, as well as through transparent explanations of what exactly has been refurbished, by what methods, and what indicators have been confirmed by measurements. That is why the approaches to reliability management and environmental monitoring described in specialized studies are becoming relevant even for "ordinary" car service [5].

Input data and methods.

The work uses a systematic approach to selecting restoration technology, combining engineering assessment of the defect, resource requirements, and economic feasibility. The following are considered as initial data: type of part (shaft, gear, rod, housing), base material (steel, cast iron, alloyed alloys), nature of damage (abrasive wear, corrosion, cavitation, fatigue cracks, deformation), as well as operating conditions (contact stresses, cyclicality, temperature, environment). In service practice, it is advisable to rely on typical cases of unit restoration, where data on resource and technological modes have been accumulated, in particular for diesel crankshafts and other highly loaded elements [4].

To compare alternatives, a multi-criteria "resource-risk-cost" logic is used, where resource describes the expected service life after restoration, risk reflects the probability of defects or loss of fatigue strength, and cost includes materials, energy, labor, and equipment depreciation. The technical block evaluates the parameters of the restored layer: thickness and uniformity of the coating, level of dilution with the base metal (for surfacing), porosity (for spraying), as well as the possibility of further mechanical processing to the required tolerances. The quality control section takes into account NDT methods (powder/capillary testing, ultrasound), hardness and roughness measurements, as well as documentation of process modes for repeatability and warranty support, which is consistent with approaches to operational reliability management [5].

The economic assessment is performed by comparing the cost of a new part with the full cost of restoration, supplemented by an assessment of downtime losses. For investment decisions, it is advisable to additionally consider the utilization of equipment for own needs/commercial orders, the possibility of cooperation between services, and the availability of materials. This methodology allows you to select the right technologies for the real conditions of the enterprise, where the technical advantage must be confirmed by its ability to pay for itself and manageable risk.

In practice, the decision-making algorithm can be presented as a sequence of actions: defect detection → failure risk assessment → technology selection → process roadmap development → control and acceptance. For defect detection, it is important to distinguish between “wear that can be restored by coating” and defects that require replacement of the part (deep cracks, critical deformations, overheating with loss of structure). For parts with a high level of responsibility, such as crankshafts, it is advisable to have a local database of typical defects and proven modes, which simplifies the selection and reduces the risk of repeated failures [4].

The process roadmap includes surface preparation (cleaning, oxide removal, roughening), selection of masking for non-treated areas, and determination of allowances for machining. For surfacing, this also includes controlling the heat input to minimize HAZ and dilution, and for spraying, controlling the powder feed rate and distance to avoid increased porosity. After applying the layer, it is advisable to formalize the acceptance criteria: hardness/microhardness range, permissible porosity (for sprayed coatings), roughness after finishing, non-destructive testing results, and, if necessary, resource or bench tests. Even in small-scale production, it is useful to implement elements of statistical process control (SPC): recording parameters, analyzing repeatability, and adjusting modes based on measurement results, which corresponds to the general logic of operational reliability management [5].

**Research results**

The generalizations obtained show that modern restoration technologies should be considered as a set of tools, each of which “covers” its own class of defects and operating conditions of a part. Laser cladding and DED are the most versatile for restoring the working surfaces of shafts, cams, seating areas, and locally worn areas. Studies of the microstructure of the deposited layers show that, with the right settings, it is possible to obtain a dense coating with high hardness and a minimal heat-affected zone, which reduces deformation and simplifies further machining [6]. In practice, this means that the technology is suitable not only for “strengthening” the surface, but also for restoring the geometry within tolerances, especially when the part has a high initial cost or long delivery times.

At the same time, thermal methods have a critical limit of application: fatigue strength. For parts operating under alternating stresses (e.g., crankshafts), it is often the fatigue life that determines whether restoration can be considered a full-fledged alternative to replacement. Experimental research data show that without additional measures, laser restoration can reduce the endurance limit due to residual tensile stresses and structural inhomogeneities in the fusion zone [7]. Therefore, it is advisable to consider the technological route as a “set”: surfacing + final surface hardening. In particular, laser impact hardening or related post-processing methods can form a layer of compressive stresses and significantly increase the fatigue life of the deposited zones [8]. For service, this boils down to a simple rule: if a part operates under high loads, surfacing should not be limited to turning or grinding. An additional step is needed to remove or stabilize residual stresses.

HVOF spraying occupies a separate niche, which is suitable for parts that require high wear resistance and corrosion resistance with minimal thermal impact on the base. Comparative reviews of coatings show that WC-Co(-Cr) carbide compositions applied by HVOF can provide high layer density, low porosity, and hardness sufficient to replace traditional hard chrome plating, which has environmental and technological limitations [9]. In repair practice, these are primarily hydraulic cylinder rods, plungers, and shafts that operate in a corrosive and abrasive environment. Importantly, HVOF allows for coatings that are suitable for final grinding, meaning that the process can be easily integrated into the standard “restoration + finishing” route.

For body parts where heating is undesirable (risk of warping, difficulty of dismantling, local corrosion or cavitation), “cold” restoration with polymer composites is effective. Practical cases of cylinder block restoration and cavitation zone repair demonstrate that a properly prepared surface and composite selection allow for stable geometry restoration and protection against further erosion, without welding deformations and with minimal downtime [10]. This approach is particularly appropriate in the field or for equipment where removal of the unit is expensive and time-consuming.

A summary of the economic and environmental effects shows that refurbishing units often yields a total benefit greater than the simple difference between the price of a new part and the cost of repair. First, in many scenarios, refurbishment reduces direct costs by 30–50% by returning the expensive base of the part and using material only in the wear zone. Second, downtime losses are reduced, which is often more critical for commercial transport than the price of spare parts. Third, the results of LCA assessments in the literature indicate a significant reduction in energy consumption and $CO_2$ emissions during remanufacturing compared to the production of a new unit, which supports the logic of "green" modernization of service infrastructure [11]. Thus, refurbishment technologies can simultaneously work on cost, repair availability, and environmental goals.

From the point of view of implementation at the enterprise, the key limitation is the capital intensity of high-tech equipment, primarily laser complexes. However, reviews of the cost of laser cladding systems demonstrate a wide range of solutions and the possibility of selecting a configuration for a specific nomenclature, which lowers the barrier to entry for the service, provided that the load is planned correctly [12]. The practical conclusion is that the restoration technology itself does not guarantee economic benefits. Profitability comes when the right parts are selected for repair, stable quality control is ensured, and the flow of orders is competently organized.

The practical choice between surfacing and spraying is often determined not by the "superiority" of the technology, but by the configuration of the part and the permissible thermal impact. If you need to restore a significant amount of material or correct local geometry loss (e.g., worn cam, tooth edge, seat with high ovality), DED/surfacing offers more options because it forms a metallurgical bond and allows you to build up a layer with subsequent finishing to size. If the part is sensitive to heat or requires a thin wear-resistant coating with minimal deformation, HVOF appears to be a more rational choice. For the service, this means that investing in one technology rarely "covers" the entire range of needs: either cooperation (sharing of technologies between enterprises) or a phased build-up of competencies — from "cold" repairs and finishing mechanics to spraying/surfacing — is effective.

According to materials science research, nickel-based coatings with hard carbide particles can provide a working surface hardness sufficient for operation under conditions of intense abrasive wear, while minimal HARDENING reduces the risk of warping of thin-walled areas [6]. In the case of HVOF, carbide compositions form dense layers with high microhardness that perform well in sliding and abrasive contact areas and are also resistant to corrosion [9]. Polymer composites, on the other hand, do not compete with metal coatings in terms of hardness, but they excel where sealing, cavity filling, and cavitation protection without thermal impact are important [10]. Thus, in the "matrix of solutions," polymers are often the best option for housing parts, while metal coatings are best for shafts and friction surfaces.

The economics of implementation depend significantly on the workload and the selected nomenclature. Capital expenditures for laser cladding can be significant, but the market offers both industrial robotic complexes and compact solutions; cost reviews emphasize that the "entry ticket" is formed not only by the price of the laser source, but also by the powder feeding system, CNC/robotics, and safety measures [12]. Therefore, it is important for car service centers to start with parts that have high margins and high demand, as well as to factor in the costs of quality control and staff training. An additional argument in favor of remanufacturing is the environmental effect: life cycle assessments for engines show that refurbishment can significantly reduce material and energy costs, and thus reduce the carbon footprint of repairs [11]. As a result, the technology becomes profitable not only in terms of money, but also in terms of compliance with modern sustainability requirements, which are gradually being incorporated into procurement practices and corporate reporting.

## Conclusions

This brief summary confirms that remanufacturing in the repair of automotive units is a practical way to increase the resource independence of the service and reduce the life cycle costs of equipment. Laser cladding/DED is suitable for precision and expensive parts, but requires thermal management and mandatory post-processing for fatigue-sensitive parts. HVOF spraying is an effective solution for wear- and corrosion-resistant coatings with low thermal impact and can serve as a technological replacement for chrome plating. Polymer composites provide rapid “cold” restoration of body elements without the risk of deformation and with minimal downtime.

Three things are critical for the implementation of these technologies in Ukraine:

1) selection of a range of products where restoration provides maximum effect (expensive parts, long delivery times, high losses from downtime);

2) a quality control and process documentation system for repeatability and assurance;

3) staff training and standardization of procedures.

It is these factors that transform a “one-time successful repair” into a stable production process that can be scaled and integrated into a modern service model.

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