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A FRAMEWORK FOR RISK MANAGEMENT IN THE PUBLIC SECTOR FOR KEEPING VEHICLES IN GOOD OPERATING CONDITION

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Abstract: *Beyond brand preferences, performance or using price as a reference, the decision to purchase a new vehicle must be based on two key concepts: reliability and maintainability. It is often found that total life cycle costs are reduced for a vehicle with a proven reliability and for which proper maintenance services are provided, particularly since the owner of the vehicle is not an individual but an institution, therefore allocating funds for keeping it in an operable condition involves following regulations which are often changing. In this context, the risks associated with maintaining and repairing the vehicle must be managed with the utmost professional diligence and taking into account all factors influencing the supply of spare parts required for maintenance.*

Key-Words: *reliability, maintenance, supply of spare parts, risk management, quality assurance*

1. INTRODUCTION

The automotive industry has always been a controversial topic of discussion, on the one hand because it embodies significant sources of air pollution and is directly responsible for the large number of road traffic deaths and injuries, and on the other hand because vehicles are essential for our daily activities, providing transport solutions for individuals, companies or public institutions.
In order to keep up with customer expectations, automotive manufacturers keep implementing new technologies designed to improve performance, comfort and care for the environment.
One factor remains relatively constant, i.e. vehicle *availability*, expressed in terms of *reliability* and *maintainability*. Reliability describes the ability of a vehicle to run defect-free under stated conditions and for a specified period of time [14].
The analysis can be subjective because there is no certainty that a vehicle can operate in optimal conditions (depends on the driver's skills, the road conditions, the periodical technical inspections according to the manufacturer's specifications, the exclusive use of original parts, etc.), in such case reliability provides the probability that the event (failure) will not occur.
Moreover, the cost of maintenance and periodic inspection depends on the user's budget, therefore it is very likely that the price of consumables and of periodical maintenance to weigh heavily on the decision of acquiring a vehicle with a proven reliability (but at a high price and with high maintenance costs) or to focus on a vehicle with similar performance parameters but a lower reliability at a significantly lower price. Buyers must be aware that the failure rate of a cheap car is much higher, which is compensated by the availability of a large range of spare parts at competitive prices and lower labor costs.
There is a difference in approaching the issue of reliability and maintainability of vehicles in the public sector compared to the private sector, especially in the allocation of funds.
First, car maintenance costs are limited and funded by the state, while in the private sector the funds are allocated preferentially, in line with the management strategy adopted.

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The availability parameter is directly dependent on the public procurement system.
This statement can be proven by analysing the entire lifecycle of the product, starting from needs identification – setting the technical parameters, the request for proposal, contract implementation, obtaining the approvals and mandatory car insurance policies, periodical inspections, current or highly complex repairs until vehicle disposal.
Public authorities conclude contracts to ensure the supply of all those services [5].

2. SOME ASPECTS RELATED TO THE RENEWAL OF THE CAR FLEETS OF ROMANIAN PUBLIC INSTITUTIONS AND KEEPING VEHICLES IN GOOD OPERATING CONDITION

2.1. Considerations on the purchase of vehicles by public institutions

In the public sector, aside from automobiles there are a series of vehicles, e.g. fire-fighting vehicles, emergency vehicles, trucks, school buses or public transportation buses, most belonging to the Ministry of Internal Affairs, the Local Police, the Ministry of National Defense, the General Inspectorate for Emergency Situations, schools, hospitals, town halls and local councils.
Those vehicles are supplied as follows: by procurement, by redistribution from other administrative units, by accepting donations, by taking over seized vehicles and by other means laid down by the governing law. Vehicles are acquired directly by the beneficiary institutions with funds from their budgets or by European non-refundable funding programs or in a centralised manner – by the appointed structures, through public procurement procedures, most often call for tenders or request for proposal [13].
The new legal provisions oblige contracting authorities to use e-procurements (or electronic procurement) so that the process is completely transparent.
Practically, the beneficiary publishes an announcement with the performance parameters that must be fulfilled by a product, using a System Requirements Document or a technical specification as well as requiring terms and conditions (related to transport, warranty terms and conditions, the supply of spare parts, the methods of payment), all subject to the use of *competitive pricing.*
The contracting authorities cannot impose restrictive conditions which are advantageous for a particular provider, therefore the documentation cannot contain indications regarding the trademark or a performance parameter that can be fulfilled only by a certain product, in this case it is difficult to approach the issue of management of the costs for the entire lifecycle, all the more so as the beneficiary does not have a reliable starting point in estimating the vehicle reliability.

2.2. Maintenance of vehicles owned by public institutions

The maintenance system used in the public sector is complex and comprises *preventive maintenance* (periodical inspections, checks or diagnosis scheduled at certain intervals) and *corrective maintenance* (aimed at repairing the defective and/or deteriorated equipments due to normal wear or involvement in any kind of accidents or damages) [6][8][11].
Newly acquired vehicles have a warranty period of 2-3 years, in which the supplier covers the costs incurred by potential hidden defects for causes not attributed to the beneficiary.
In this period, it is mandatory for vehicles to undergo periodical inspections, the relevant costs thereof being borne by the beneficiary.
Although the beneficiary is the owner of vehicles, he is not entitled to make unauthorised interventions thereon, otherwise the supplier can invoke the termination of the warranty and the costs incurred for repairing the vehicles shall be borne by the beneficiary.
At the expiry of the warranty term (including the post-warranty term, if provided by the contract), any repair shall be conducted for a fee, and the beneficiary is free to choose the most advantageous offer.
Maintenance can be provided by the supplier of the vehicles (through the specialized service network) or by the logistical structures of the ministry to which the vehicle belongs.
Although at first sight the freedom of decision seems a categorical advantage, the decisional process depends on a series of economic and legislative constraints that entail long periods of immobilisation or faulty operation of the vehicle, additional costs or distrust in the quality of the services provided.

2.2.1 Maintenance through the national service network or in specialized units of the Ministry

According to law, maintenance and service work must be conducted only by operators authorised by the Romanian Auto Registry.

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The procurement of maintenance services shall be conducted only by designated public entities, through procurement procedures published in the electronic system SICAP – Collaborative Information System for an effective Public Procurement environment (the former SEAP).
In case of preventive maintenance, the requirements set out in the technical specifications are easy to formulate, since most of the times they are included in the user documentation issued by the manufacturer, where revisions and periodical maintenance are detailed at the level of operation, by also indicating the required spare parts and materials, as well as the estimated costs.
An important clause that can be included by the contracting authority in the procurement of maintenance services is: "spare parts and materials used by the provider must be new, original, labelled/stamped by the manufacturer and homologated/certified by Romanian Automotive Register or by other authorised institutions".
If defects appear during the warranty term, the provider shall intervene as soon as possible to remedy the deficiencies invoked, and the defective parts will be replaced at its expense, if it is found that they were not caused by the beneficiary, and the warranty term shall be extended accordingly.
Another solution is self-financed maintenance, where service works are performed in specialized maintenance centres, founded and administered by each Ministry. In such case, we discuss about the concept of *logistical management,* which includes human and financial resources, the maintenance and repair documentation, spare parts, special tools and test equipment, operational and storage areas etc.
The maintenance activity implies a mutual effort of the technical departments (vehicle operating, maintenance and repair), the procurement department but also the financial department and the quality assurance department (that can also include the environmental protection duty), as well as the ITP (Periodical Technical Inspection) inspector certified by RAR (Romanian Automotive Register).

2.2.2 *Diagram of failure of the vehicles within the public sector fleets*
Keeping the vehicles operational depends on the management of the risks related to the failure of their subsystems. This begins by analysing the main causes of such failures, their consequences and plausibility and then, according to the risk level, by establishing the measures that will be adopted at the level of the technical department.
For this study, the car fleet of a public institution will be taken as reference, consisting of older vehicles (DAEWOO: Nubira, Leganza, Cielo) - year of manufacture 2001 - 2004, but also new vehicles (DACIA Duster, Logan, Lodgy) - year of manufacture 2014 - 2016, by identifying the parts and components replaced during the last 2 years and the most frequent defects identified.
The analysis considered a lot of 15 DAEWOO vehicles,and 20 DACIA vehicles (Figure 1).

Not with standing the parts and consumables required for mandatory maintenance and revisions, we have noticed that by resolving the problems identified at the level of the suspension and steering elements, of the electrical installations and sensors, as well as the software errors, more than 80% of the total defects identified were remedied.
Moreover, the corrosion of certain body elements is a very frequent occurrence especially in new vehicles, where the price-quality ratio is directly mirrored by the quality of the materials used.
The statistical data related to the defects of the car fleet was taken over from data archives of the car repair shops and of the operating department.
Each system can be examined in depth across all sub-systems and by examining each part.
A quantitative analysis of the risks of failure of vehicles uses a value estimate for the consequences and probabilities of occurrence, which provide values for the risk level.
The most commonly used technique for risk analysis is *Fault Tree Analysis*, which is using fault tree diagrams to identify the probability of occurrence of the defect and the main sources of occurrence of the risks.
Based on successive calculations, the risk management officer (the technical department) can establish the main causes of the event (breakdown of the system), by providing a clear image on the main sources of risk and the probability of occurrence (Figure 2).
This calculation is based on the following two rules:

(1) the probabilities for each branch and sub-branch are multiplied;
(2) the sum of the probabilities associated to a node is equal to 100%[2].

For instance, the probability of a failure of the DAEWOO shock absorber is: P(3.1) = 21 x 30% = 6.1 %.

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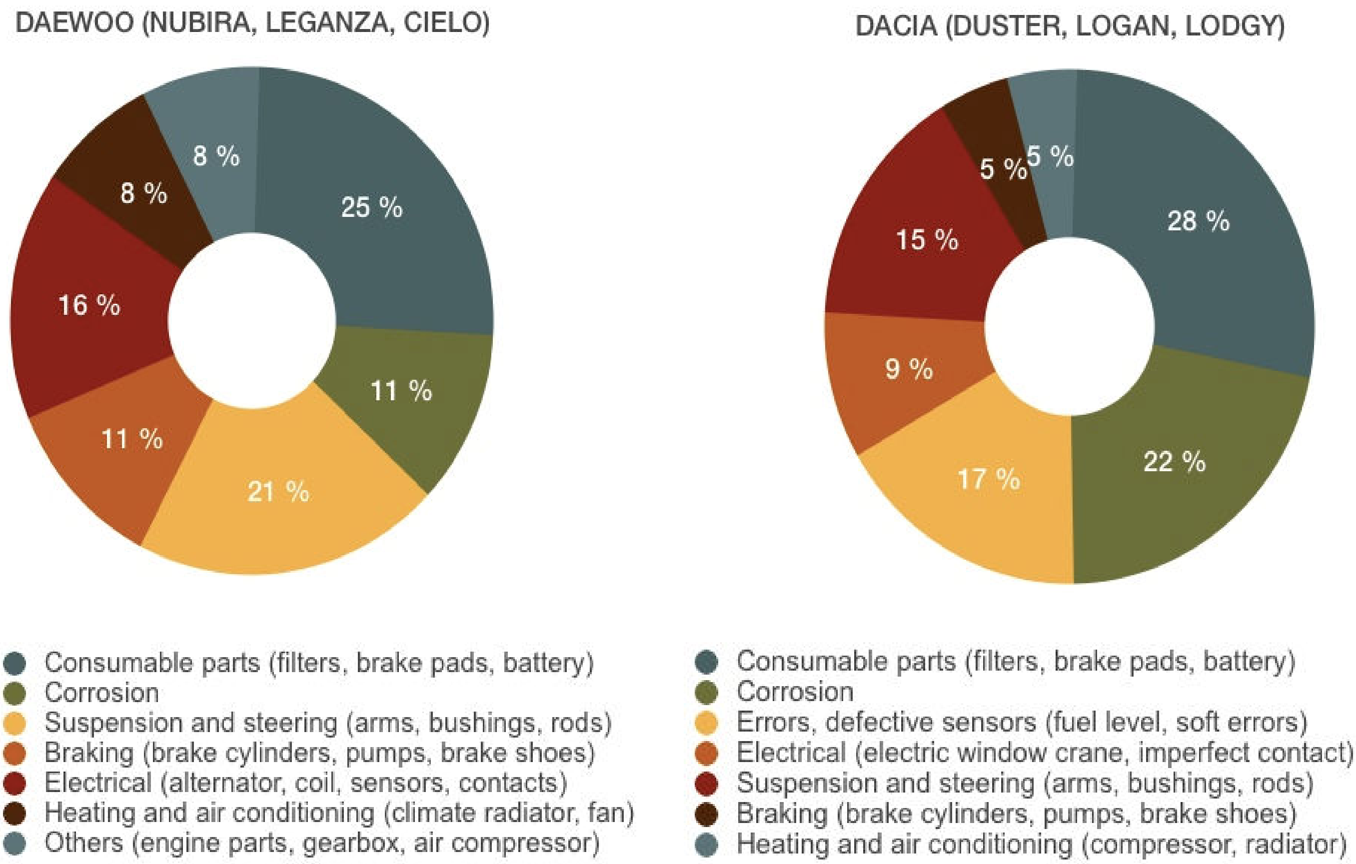

Figure 1 Diagram of failure of the vehicles within the public sector fleets

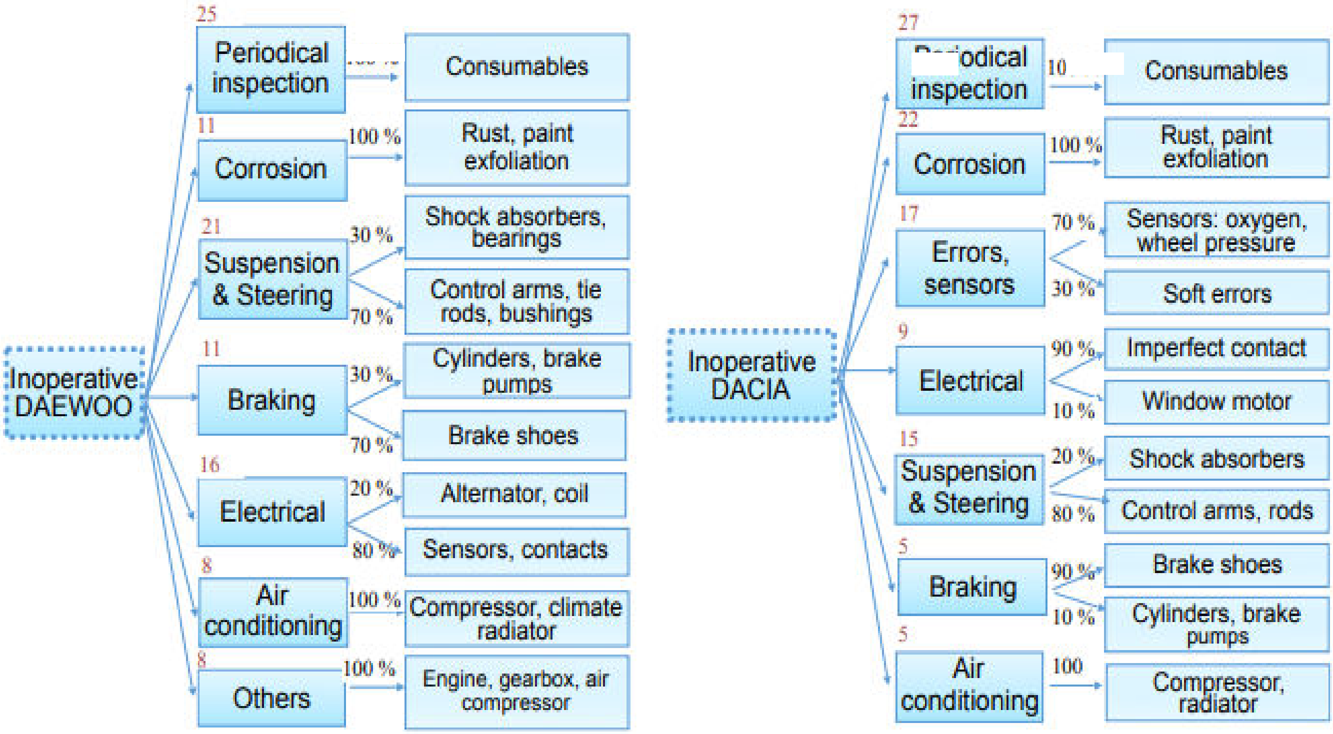

Figure 2 Fault Tree Analysis for DAEWOO and DACIA vehicles

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The spare parts and consumables used in preventive maintenance are not taken into consideration, as they are considered mandatory actions during the vehicle lifetime.
Using this iteration for all sub-systems helps identify the most frequent failures of these two types of vehicles (Table 1).
The fault tree diagram provides a clear visual representation of the most common vehicle failures, such as suspension or steering elements (control arms, tie rods, bushings, connecting rods, bearings, dampers) in both old and new vehicles.
A similar situation was observed for vehicle body and chassis, where corrosion is very frequent due to repeated exposure to extreme conditions and the use of low-quality materials, often encountered in DACIA vehicles.

Table 1.
Common faults identified in DAEWOO and DACIA vehicles

DAEWOO			DACIA		
Rust, paint exfoliation	Control arms, tie rod end, ball joint, bushings	Deffective sensors, contacts	Rust, paint exfoliation	Control arms, tie rod end, ball joint, bushings	Sensors: oxygen, wheel pressure, fuel level
11 %	14,7 %	12,8 %	22 %	12 %	11,9 %

Abnormal operation, sensor malfunctions, imperfect contacts or software errors are often reported. Figure 3 contains an Ishikawa diagram (also known as the 6 Ms) of the main causes of failure of a vehicle, or that hinder the use of a vehicle [10][12].
The factors causing the inoperability of a vehicle are complex and most often act simultaneously, so that they must be carefully monitored during vehicle lifetime, also by using instruments such as: preventive maintenance diagrams, periodic training courses or exclusive use of original spare parts.
The main struggle in the maintenance of old vehicles is the absence of spare parts, the fact that the manufacturer has ceased its activity and institutions are forced to purchase spare parts only from suppliers that fulfil a series of legal requirements (they must be registered with SICAP, they use the national treasury to make the payments and they accept the payment after delivery).
Under these circumstances, the market is monopolised by suppliers that have adjusted their strategy to the customer’s requirements and they either supply compliant parts at acceptance that during operation prove to be less reliable, or they import quality products but the price exceeds the market value.
As regards new vehicles, the operating conditions are the cause of most failures, corroborated with the drivers’ skills and the preventive maintenance actions, but also the fact that procurement based on the “best price” principle is reflected in the low quality of the manufacturing materials (bodywork), but also in the low reliability of the components.
However, by summing up the maintenance costs of old vehicles, the comfort level or the consumption costs and comparing them with the price of a new vehicle, the situation is balanced out and the renewal of the car fleet becomes a strategic decision that could be taken into consideration

3. RISK MANAGEMENT IN PROCUREMENT OF SPARE PARTS FOR PUBLIC FLEET MAINTENANCE

Self-financed maintenance implies, first and foremost, an effective management of the financial resources for procurement of spare parts.
According to the objectives set and the future activities, the purchaser must consider an effective strategy of identification, analysis and control of the risks associated to the objectives, to ensure that these are lowered to an acceptable level that does not affect the quality of the products delivered.
Effective risk management in the procurement of spare parts implies the identification and systematic analysis thereof, the development of a risk management action plan and assigning responsibility for specific risk management activities for all parties involved as well as understanding the importance of the acquisition and ensuring that the risk strategy is in line with it.

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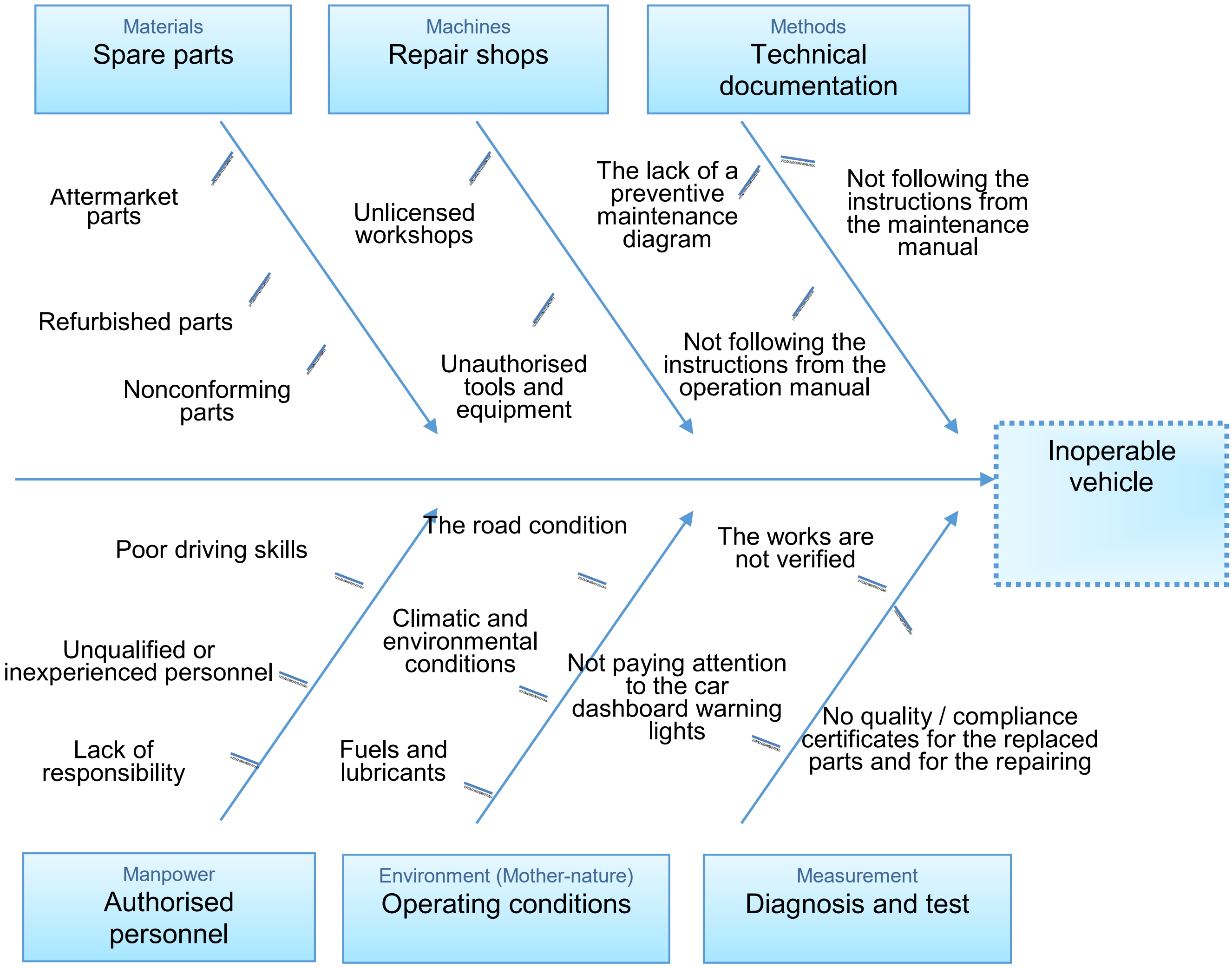

Figure 3 Diagram of the main causes of failure of a vehicle

3.1 A risk-based approach to the acquisition of spare parts

The amount of similar goods that can be purchased without submitting a proposal is regulated by Law no. 98 of 2016 on Public Procurement and can be done by using an online ordering system provided by SICAP or by publishing an announcement in the dedicated section, accompanied by a description of the products that will be acquired (according to [13]).

The purchase orders contain terms and conditions of sale and delivery, acceptance testing and the accepted forms of payment.

This study highlights several important points for consideration related to risk management in procurement of spare parts, such as:

- ***a systematic identification of risks, based on historical records***

The procurement department has a *Procurement Risk Register* that contains the risks that have the highest likelihood and potential to have significant impact to procurement efficiency and the delivery of goods in compliance with the terms and conditions.

It is also necessary to define the overall risk management goals and objectives and to develop a risk response strategy.

In the absence of a Procurement Risk Register, the purchaser can use the information collected in the form of *learned lessons* to identify the potential hazards in his workplace.

- use manufacturer part number (if any)

In duly motivated cases online orders can be performed based on requirements that in certain conditions could be considered restrictive (eg. interoperable components, genuine spare parts).

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- complete and accurate requirements, by specifying the performance and with reference to standards

The specifications must be defined by reference to available standards.
The manufacturer can choose any technical solution to develop the product that fulfil the requirements, following ISO Manufacturing Standards or equivalent.

-a certified quality management system[15]

Implementing a quality management system will give confidence to the customer and other interested parties that the supplier will provide spare parts which will consistently fulfil requirements.

- Approved Supplier List

All suppliers that have proven their ability to deliver products satisfying the conditions specified are on the Approved Supplier List. The list is periodically updated.

- Declaration of Conformity

Spare parts must be supplied to end users with a Warranty Certificate and a Declaration of Conformity.

- receiving and inspecting purchased goods

On receipt of a purchased part the inspection team (the team shall include automotive engineers) performs all the necessary tests to assess whether the delivered product is in complete compliance with the requirements.
If there are quantity discrepancies or the goods do not comply with the requirements, the inspection team refuses the delivery and draws up a report, specifying the reasons for refusal.

3.2 Best practices for risk assessment when managing contracts for the supply of spare parts

If the spare parts demand that will be acquired during the financial year exceeds the threshold of direct purchase, they shall be acquired by procurement procedure.
Defining requirements to establish specifications is the first step in the procurement of spare parts, followed by drafting the tender documents.
Since it is a high value procurement, the contracting authority's risk exposure increases significantly.
A SWOT analysis (Table 2) is a very useful tool used to evaluate the relationship between the object of the contract and the procurement management plan, to determine:

- ***the strengths*** and ***the weaknesses*** of the contracting authority in the procurement procedure and the estimated procurement timetable;
- ***the opportunities*** that the contracting authority can use to streamline the process and to ensure the quality of the products delivered;
- ***the risks*** to which the contracting authority is exposed during the procurement.

Table 2.
SWOT analysis in public procurement

Strengths	- qualified/experienced employees; - logistical support; - information technologies; - well defined procedural framework;	*Opportunities*	- employee training programs; - market analysis and well-defined specifications; - close relations with suppliers;
Weaknesses	- tasks performed simultaneously; - reserves from suppliers for participation in procedures; - late approval of funds; - frequent legal amendments;	*Risks*	- procurement of non-compliant or low-quality spare parts; - procurement of overpriced products; - delayed delivery of products; - delayed payment.

An efficient procurement planning gives the contracting authority an overall image of the entire process of procurement, of the resources involved and of the actions that must be taken in every decisional node to obtain the expected results, being a solid instrument of the decisional process, also facilitating the improvement of the process of contracting and reducing the probability of breach of the law and the appearance of errors during the procedure and after signing the contract.

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The main procurement process steps are [16]:

- procurement planning: identifying the needs, cost estimation, identifying potential suppliers, drawing up the Product Requirements Document and the tender documentation, as well as the *contracting strategy;*
- call for tenders: publishing the tender documentation, analysing the offers, awarding the contract;
- post-awarding process: contract implementation and contract monitoring, amendments, post-warranty activities.

The main risks in procurement of spare parts for vehicles as well as measures that can be taken by contracting authority to reduce the potential of exposure to the hazard are included in Table 3.
Aside from the requirements of the technical specifications, the contract between the contracting authority and the supplier includes clauses regarding the supplier's obligations to ensure the quality of the spare parts delivered,in which it must also indicate how the possible non-compliances found by the acceptance board will be remedied, as well as the sanctions applied to the contractor in case of breach thereof, and the insurance of the beneficiary for obtaining the maximum benefit from using the products.

Table 3.
Risk management in spare parts procurement procedure

RISK	POTENTIAL CONSEQUENCES	RISK MITIGATION STRATEGIES
Procurement planning		
Use of incomplete or restrictive specifications	- tender dispute; - non-compliant offers or no bids; - no approvings from ANAP;	- define the specifications by reference to available standards and regulations;
Inefficient market testing	- favouring or discriminating against any (prospective) bidder;	- identify a range of potential suppliers and obtain cost estimation;
Developing an inefficient acquisition strategy	- unacceptable / non-compliant offers; - no "value for money";	- develop the acquisition strategy in relation to the objectives;
Use of unfair or restrictive terms and conditions	- hidden costs of cost-plus pricing; - tender dispute; - no bids;	- use standard procurement document and adapt contractual terms;
Call for tenders		
Selecting non-performing suppliers, due to a superficial tender evaluation	- breach of contract; - delivery of poor quality or non-compliant products; - no "value for money";	- self-awareness of evaluation team regarding tender evaluation and the rejection of the non-compliant ones;
Implementation of the contract without obtaining the approvals	- appeals submitted to the court for administrative disputes; - cancellation of the procedure;	- ensuring that all legal provisions in the field of procurement have been respected
Post-awarding process		
Failure to comply with the contractual terms	- delays in delivery / penalties; - rejecting products at reception; - failure to meet objectives;	- contract management; - effective communication between the parties;
Receiving goods with hidden defects	- warranty claims; - non-compliant products;	- warranty terms and conditions; - preventive maintenance programs.

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The contract must also contain requirements on the main obligations of the parts, especially those related to the acceptance of the products, the manner of ascertainment/remedy of inconsistencies, the accepted payments or obligations related to the calculation of damages and default interests.
There is no pattern applicable to all types of procurements of spare parts, however there are certain recommendations that must be considered in the decisional points of the procedure, taking into account the best practices already adopted for similar procurements and that have had adequate results.

4. CONCLUSIONS

At a time when technological progress is apparent and when the automotive sector is constantly evolving, the capacity of public institutions to keep vehicles in good operating condition involves taking strategic decisions, either towards modernising the car fleet and acquiring new and efficient technical equipment, or improving the process of maintenance to extend the lifetime of the existing ones.
In any of these variants, the project managers must be aware that the budget is limited and any procurement shall be made in strict observance of relevant regulations.
In this context, the decisions on the lifetime of vehicles are taken from the time of startup of the procurement procedures, by inserting requirements related to lifetime maintenance (providing catalogues of spare parts, repair documentation etc.) so that the restoration of the vehicles to a serviceable condition is made under conditions of maximum efficiency.
A complete revitalisation of all the vehicle fleets from public institutions is difficult to put into practice and is made for a long term, so that the only solution is the maintenance of the existing vehicles, either in private repair shops, or in specialized maintenance centres, founded and administered by each Ministry.
In both situations, the procurement of spare parts is a hard to follow process and implies a series of risks that must be efficiently managed by the purchaser.
Experience shows, however, that there is no single solution that fits all suppliers or categories of spare parts, but there are certain valid practices or measures that can be taken to minimise the risk of procurement of noncompliant spare parts or that prove to be less reliable in time thus reducing the parameters of availability of the vehicles, while the final decision regarding the management of such risks and the choice of the best strategy is under the responsibility of each purchaser.

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STUDY ON THE INFLUENCE OF THE RADIUS OF CONNECTION OF THE SPECIMEN OBTAINED BY FDM ON THE AREA OF PROPAGATION OF THE RUPTURE

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Abstract: *In order to determine the mechanical characteristics of the parts obtained by the additive manufacturing technology, FDM procedure, are used tensile specimens made according to the European standard D638 - 14, printed with different parameters, so that the results obtained are as conclusive as possible. Because in many situations it was found that the breaking of the specimens occurs outside the calibrated area, the results not showing a high degree of confidence, in this study we investigated the influence of some parameters, (the radius of the specimen connection and the printing direction) on the position of the breaking area. In the study, following a plan of experiments, 12 samples of Z-Ultrat material were made using a Zortrax M200 printer.*

Key-Words: *FDM, Z-ULTRAT, mechanical characteristics, connection radius, printing direction*

1. INTRODUCTION

In the process of product development, especially in the parts design and prototype stages, the additive manufacturing, AM (additive manufacturing) allows the production of parts in a short time and at low costs compared to the classical technologies, injection molds, or mechanical processing.
Also, when making small series products, it is much more cost effective to use this technology.
One of the 3D printing processes is FDM (fused deposition modeling), being the most used in additive manufacturing due to the simplicity and accessibility of the technology.
Through this process, the parts are obtained by adding material, layer by layer. The base material may be a plastic material, or a composite matte, which is found in the form of a filament is heated in a controlled manner and extruded by an extruder [6].
As the layer solidifies, the movement of the extruder is coordinated according to the geometry of the part to obtain that layer, after which a new layer begins to deposit which solidifies in contact with the previous layer and adheres to it. The material deposition continues until the piece is fully realized.
Some papers focus on only one processing parameter such as building direction [7] and investigates it thoroughly, while other papers focus on 3 or 4 parameters at the same time and study their coupled effects such as in [8][9] and [10] where the effect of layer height, building direction, raster angle and more parameters are investigated at the same time. In the second approach, usually 2 or 3 levels are investigated for each parameter.
The current techniques allow the use of several materials for the production of parts with improved mechanical performance, or in the case of complex geometric models, support material is used.
The material used in this study is Z-ULTRAT.

2. EXPERIMENTAL PART

The mechanical properties and the particularities of the behavior of the plastics requested mechanically have a great importance in performing engineering calculations especially in the field of Mechanical Engineering. These characteristics are determined by the tensile test, which is carried out on special machines. The tensile test is performed on tests made according to the specifications of the European standard D638 – 14. In figure 1 are presented the dimensions of the specimens used for the experiments and the two printing directions.

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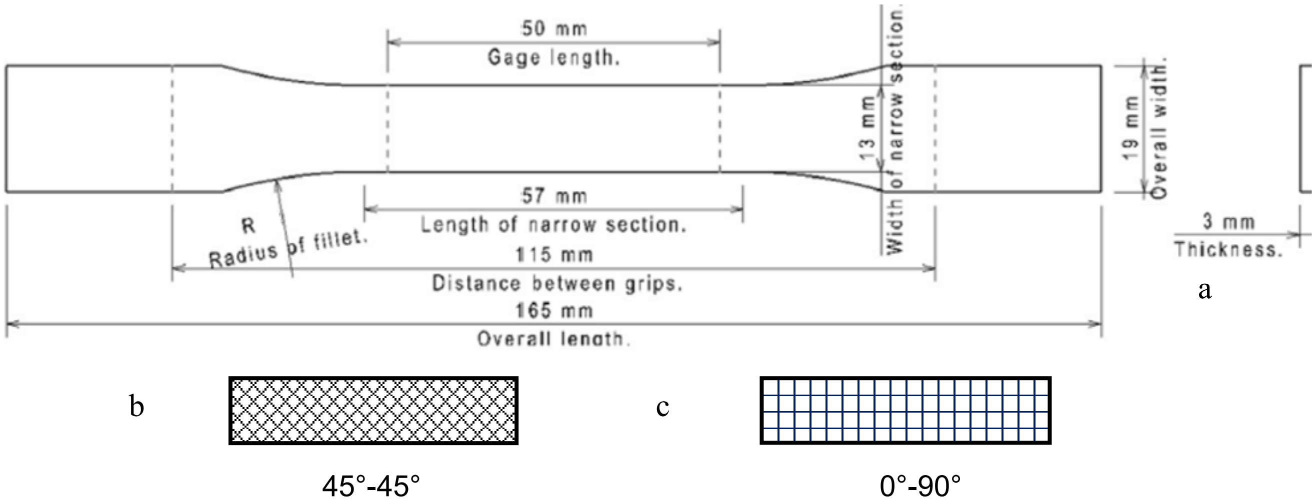

Figure 1. Fused deposition modelling samples
a) sample dimensions - ASTM D638 (Type I); b) printing direction

The recommendation of the standard is that the value of the connection radius between the calibrated area and the catching area in tanks should be 76 mm, the length of the calibrated area 57 mm, the total length 165 mm, and the catchment area in the tanks of the equipment 20 mm.
Following the results obtained in previous researches in the project, researches regarding the optimization of CAD methods for the development of additive manufacturing in the automotive industry, using samples made by FDM technology, from the same material, Z-ULTRAT, following the recommendations of the standard, it was found that the breaking zone following the tensile test is in most cases outside the calibrated area. Therefore we set out to study what parameters may cause the positioning of the break in the calibrated area.
One of the parameters of the specimen that can influence the position of the breaking zone is the radius of connection. In order to investigate the influence of the radius of connection of the specimen on the area of propagation of the rupture, 12 specimens were made, varying the radius of connection, starting from 25 mm and going up to the maximum value, 130 mm, while maintaining the recommendations. of the standard regarding the length of the calibrated area, the total length of the specimen and the fastening between the bins. Also, a second parameter, the printing direction (45 ° - 45 °, 0 ° - 90 °) [1] was taken into account. The specimens were made on a Zortrax 200 printer, the filling degree being 100%, and the layer thickness was 0.29 mm. The experiment plan used to determine the influence of the connection radius on the propagation area of the rupture is presented in table 1. To determine the mechanical properties of the material under static conditions, a tensile machine of type WD50E was used, the speed of movement of the tanks was 2 mm / min.

Table 1.
The experiment plan used for the tensile test

Specimen no.	1	2	3	4	5	6	7	8	9	10	11	12
Specimen coding	R 25		R 50		R 75		R 90		R105		R 130	
Connecting radius [mm]	25		50		75		90		105		130	
Printing direction [°]	45-45	0-90	45-45	0-90	45-45	0-90	45-45	0-90	45-45	0-90	45-45	0-90

The dimensions of the 12 specimens (thickness - t, and width - w,) measured with a digital calliper are presented in table 2.

Table 2.
The measured geometrical elements of the specimens

Specimen code	1	2	3	4	5	6	7	8	9	10	11	12
w [mm]	13.3	13.2	13.3	13.2	13.3	13.2	13.2	13.3	13.3	13.2	13.3	13.2
t [mm]	3	3	3	3	3	3	3	3.2	3	3.1	3	3

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3. RESULTS AND DISCUSSIONS

The tensile test determined the maximum strength and maximum strength for each test, and the values are presented in table 3.
Tensile test diagrams are shown in figure 2.
Also the position of the breaking zone, marked in table 3, was observed, figure 3.

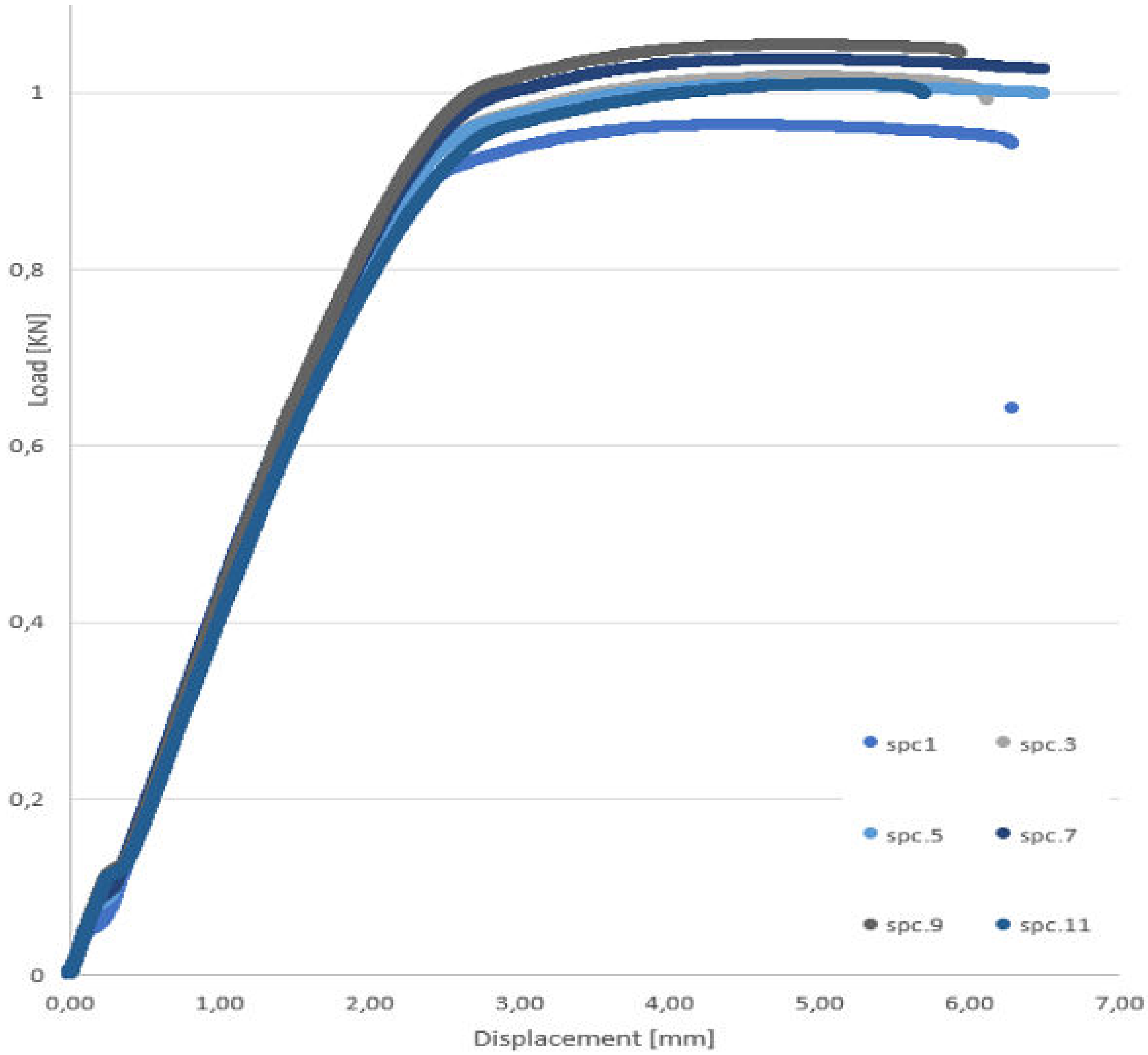

Figure 2. Tensile test diagrams - specimens 1,3,5,7,9,11

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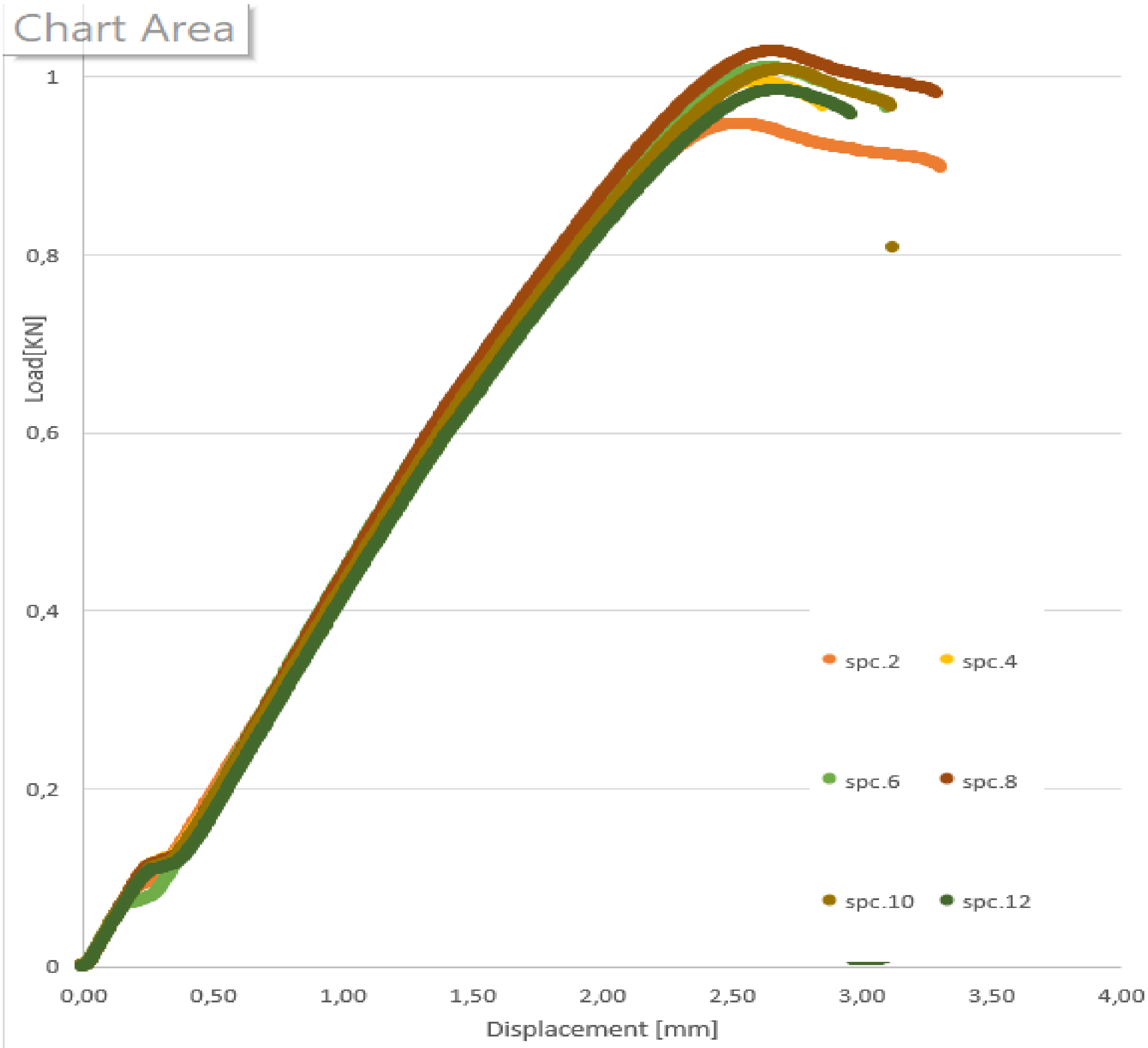

Figure 2. Tensile test diagrams - specimens 2,4,6,8,10,12

Table 3.
Maximum force values and displacement

Specimen no.	Specimen coding	F_m [KN]	σ_m [MPa]	Position the breaking area
1	R 25-45°-45°	0.962	24	In the calibrated area
2	R 25-0°-90°	0.947	24	Outside the calibrated area
3	R 50-45°-45°	1.017	25	In the calibrated area
4	R 50-0°-90°	0.994	25	Outside the calibrated area
5	R 75-45°-45°	1.008	25	In the calibrated area
6	R 75-0°-90°	1.01	26	Outside the calibrated area
7	R 90-45°-45°	1.036	26	In the calibrated area
8	R 90-0°-90°	1.028	24	Outside the calibrated area
9	R 105-45°-45°	1.053	26	In the calibrated area
10	R 105-0°-90°	1.008	25	Outside the calibrated area
11	R 130-45°-45°	1.008	25	In the calibrated area
12	R 130-0°-90°	0.984	25	Outside the calibrated area

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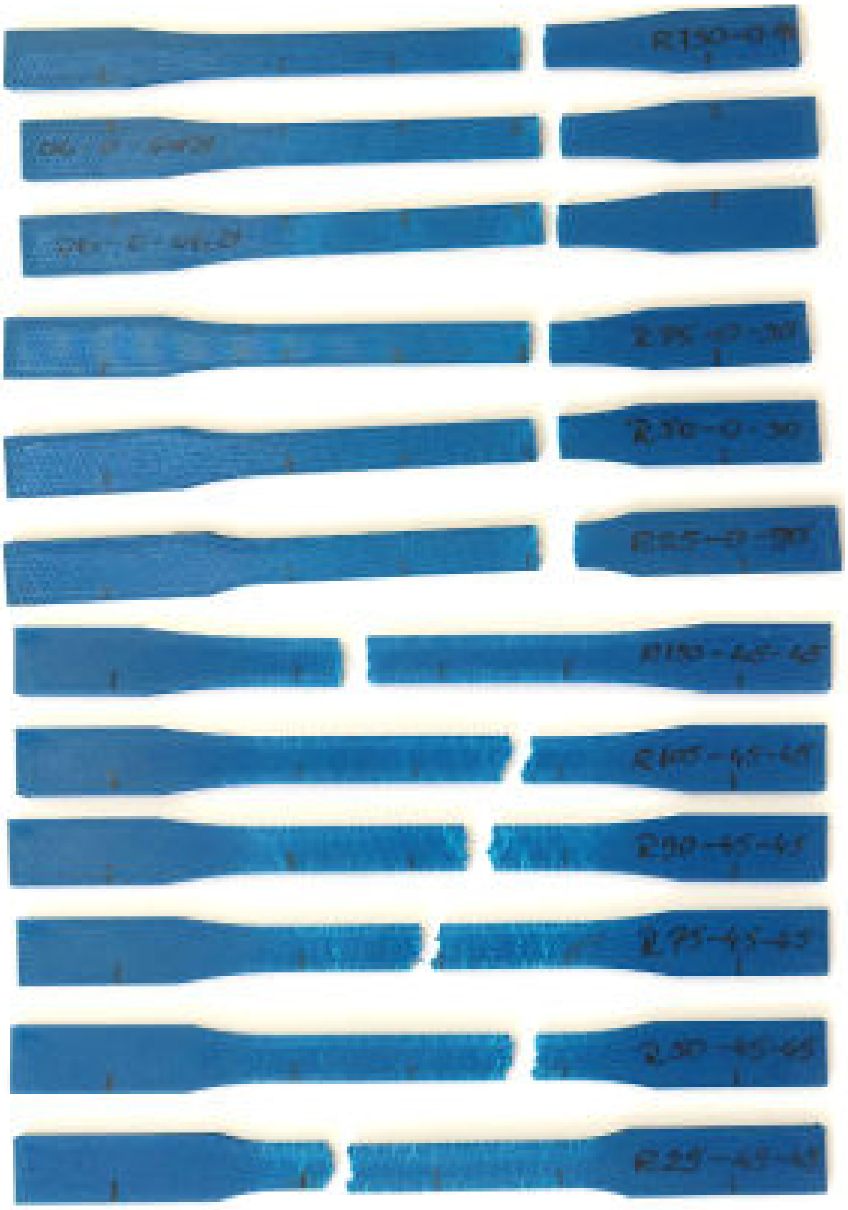

Figure 3. Breaking area

The macro aspect of the tensile test specimens is shown in the figure 3.
The microscopic aspect of the breaking zone, depending on the printing direction, is shown in figure 4 in which the positioning of the layers 0 ° - 90 ° and 45 ° - 45 ° is observed.

4. CONCLUSIONS

From the analysis of the results it is observed that the position of the breaking zone is significantly influenced by the printing direction, all the specimens printed at 0 ° - 45 ° breaking inside the calibrated area, and those printed at 0 ° - 90 ° breaking outside the calibrated area.
It was also found that the value of the radius of the connection of the calibrated area with the clamping area has no influence on the position of the breaking zone.
The tensile test determined the maximum resistance to breaking on specimens made of the Z-Ultrated material by FDM, which has an average value of 23% lower than the standard value of the material. When designing the pieces made by FDM, when there are requirements regarding the mechanical properties of the elevator, we must take into account this fact and choose a material with superior mechanical properties, or properly dimension the sections of the piece.

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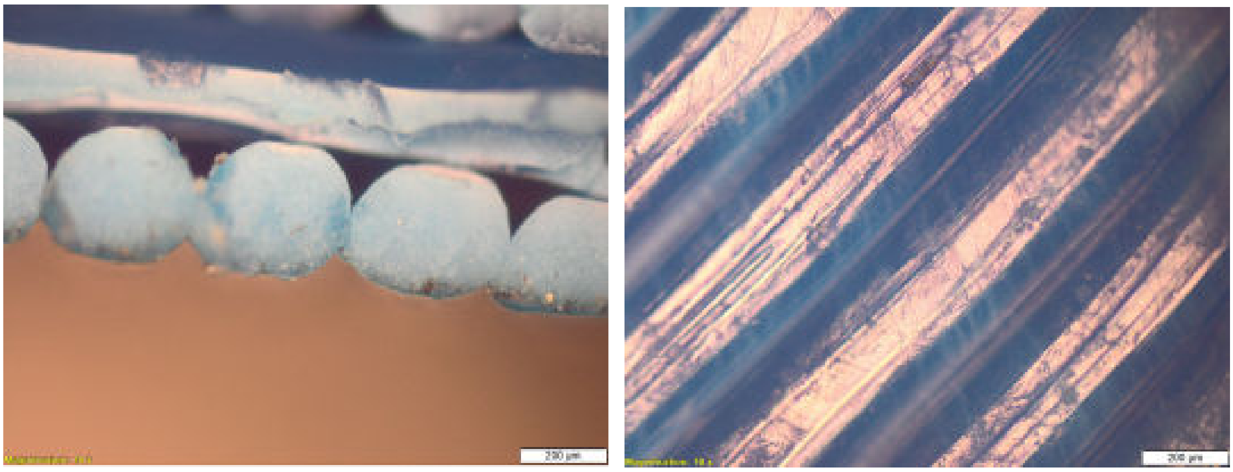

a) printing direction 0°-90° b) printing direction 0°-45°

Figure 4. Microscopic aspect(magnification 10x)

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THE USE OF A VORTEX TUBE TO CONTROL RECIRCULATION AND ELECTRICAL CLEANING OF SOLID FRACTIONS AND TOXIC GASES FROM EXHAUST GASES OF INTERNAL COMBUSTION ENGINES

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Abstract. *This article presents a technical solution to the problem of cleaning the exhaust gases of a car. The composition of the main toxic gases in the exhaust gases of a diesel engine of an average car is given and the disadvantages of known methods for reducing the toxicity of exhaust gases of modern cars are indicated. The operation of a device for purifying automobile exhaust gases from particulate matter and toxic gases using a vortex tube (Ranque-Hilsch tube), in the energy chamber of which an electric filter is installed, is described. The article presents the calculation results: vortex tube design; exhaust gas flow rates in a vortex tube; the rate of drift of solid particles from a hot stream to a cold stream in a vortex tube energy separation chamber. A calculation was also made of the amount of heat for heating the air used to burn soot in a permeable particulate filter. The expected efficiency of the exhaust gas cleaning of the proposed device is based on the calculation and partially on the results of studies of other authors.*

Keywords: *diesel engine exhaust gas components, exhaust gas density, Ranque-Hilsch vortex tube, purification of exhaust gases from toxic gases in a vortex tube, electrostatic cleaning of exhaust gases from solid particles, exhaust gas recirculation, burning soot in the particulate filter.*

1. INTRODUCTION

Auto-tractor ICE pollute the atmosphere with harmful substances emitted with exhaust gases, fuel fumes and crankcase gases. At the same time, 95% of the toxic components emitted by diesel engines account for exhaust gases, which are a multicomponent mixture of gases, vapours, drops of liquids and dispersed solid particles (Table 1) [3].

With the use of new types of fuel and/or improvement of the processes of fuel combustion, it is constantly necessary to again solve the problem of reliable and maximally complete removal of solid particles with a different structure and/or composition from exhaust gases (EG) generated during the operation of ICE. New diesels emit a larger amount of small particles (<15 nm) than diesels manufactured using old technology [2].

The National Institute for Occupational Safety and Health (NIOSH, USA) has recognized diesel emissions as a carcinogen (that is, a substance that causes cancer). In this regard, the standards on the maximum permissible emissions of harmful substances generated during the operation of ICE are constantly being improved. From the exhaust gas stream, it is required to remove the toxic gases contained in it, liquid and solid fractions, or to turn them into harmless substances.

In the European Community, legislation has toughened the maximum permissible emission standards for particulate matter (soot) [3] into the environment, primarily diesel engines. In many Germany cities, diesel entry into the central part of municipalities was restricted.

The exception was fuel-powered cars that meet Euro-6 standards.

To comply with Euro-6 standards for engines, SCR and EGR systems are used. Up to 30% of the exhaust gases passing through the cooler are returned to the cylinders to lower the temperature and reduce the formation of nitrogen oxides.

And what they could not cope with is processed in the silencer, where the oxidation catalyst is located, after burns everything that has not burned, then the particulate filter.

After that, the gases exit into the mixing chamber, where the reagent is fed through a nozzle, which evaporates, and all this, in essence, enters the SCR catalyst, in which the reaction between the urea residues and NOx takes place.

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And at the exit there is a catalyst that breaks down the ammonia remaining in the reaction [4].
The main advantage of this SCR system is its high NOx reduction rate (90% or higher).
The disadvantages involve the space required for the catalyst, high capital- and operating costs, formation of other emissions (NH3 slip) and formation of undesirable species which may lead to catalyst poisoning and deactivation. In addition, a truck with SCR becomes more expensive by 5..6 thousand euros. The weight of the equipment of the SCR system is 150–300 kg, and the payload of the car is reduced by the same amount.

Table 1.
Diesel engines account for exhaust gases

Name of exhaust gas components	Density (ρ) kg/m³	Component content in diesel exhaust	Toxicity	Above average gas density
Nitrogen,(N2)	1.25	74 -78 %	Nontoxic	
Oxygen, (O2)	1.43	2-15 %	Nontoxic	
Watervapor,(H2O)	0.0048	3- 5.5 %	Nontoxic	
Carbon dioxide, (CO2)	1.97	1.0 - 12.0 %	Non toxic	+
Carbon monoxide,(CO)	1.15	about 0.4 %	Very toxic	
Hydrocarbon,(CHx)	1 - 1,2	0.009 - 0.3%	Toxic	
Nitric monoxide, (NO)	2.05	0.004 - 0.5%	Very toxic	+
Nitric oxide, (NO2)	2.05	0.0013-0.013%	Very toxic	+
Benzapyrene, (C20H12)	1240	0.05 - 0.4%	Differs in special carcinogenic activity	+
Aldehydes, aldehyde (C7H6O)	1041.5	0.005%	Toxic	+
Sulfur dioxide, (SO2)	2.63	about 0.02%	Toxic	+
Formaldehyde, (HC2O)	815	0.001-0.0019	Very toxic	+

Recently, research has been carried out on the introduction of electrostatic precipitators for diesel exhaust gas cleaning.
Electrophysical purification of exhaust gases is one of the promising areas of theoretical and experimental research on the development of toxicity reduction systems. The essence of electrophysical cleaning is the use of electric discharge energy to influence the flow of exhaust gases in order to change their qualitative and quantitative characteristics.
The use of an electrostatic precipitator using the external corona discharge region is an effective method to reduce the smoke and toxicity of exhaust gases of diesel engines [5].
Electrostatic precipitators have relatively high collection efficiencies (99-100%) over a wide range of particle sizes (~0.05–5 μm) [6].
The Ranque-Hilsch vortex tube (RHVT) has interesting properties of energy separation, which is used as: fission RHVT, cooling RHVT, self-evacuating RHVT, double-circuit RHVT, vortex vacuum pump-ejector [7]. RHVT surpasses other types of energy converters in terms of reliability, resource, ease of maintenance, and overall dimensions.
These properties may be useful in an exhaust gas purification device.
Based on the foregoing, the aim of this work is to consider an exhaust gas recirculation system including a vortex tube with an electric filter to maximize the cleaning of exhaust gases from particulate matter and toxic gases to meet the requirements of the Euro 6 standard, devoid of the disadvantages of the SCR system.

2. DESCRIPTION AND PRINCIPLE OF OPERATION OF THE VORTEX DEVICE PROPOSED FOR ELECTRIC CLEANING OF EXHAUST GASES

To reduce the severity of technical problems associated with the reduction of environmental pollution proposed device [8]:
- for efficient capture of particulate matter from exhaust gas;
- o reduce exhaust toxicity

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- for cooling the exhaust gas sent to the exhaust gas recirculation system;
- to control the flow in the exhaust gas recirculation system;
- for regeneration of a permeable (particulate) filter with a heated reverse air flow (Venturi flow) from the intake manifold of the internal combustion engine.

In the proposed technical solution (Figure 1), the exhaust gas stream from the exhaust manifold of the internal combustion engine is fed into the vortex chamber RHVT through one or more nozzles tangentially connected to the cylindrical wall of the chamber.

In a vortex chamber, toxic gases (marked + in table 1) with a density higher than the average density of the exhaust gas and solid fractions (soot) are removed and cooled from the vortex flow of exhaust gases moving along the wall into the axial flow and are discharged along the pin of the precipitating electrode into a permeable filter element through the diaphragm to the recirculation system.

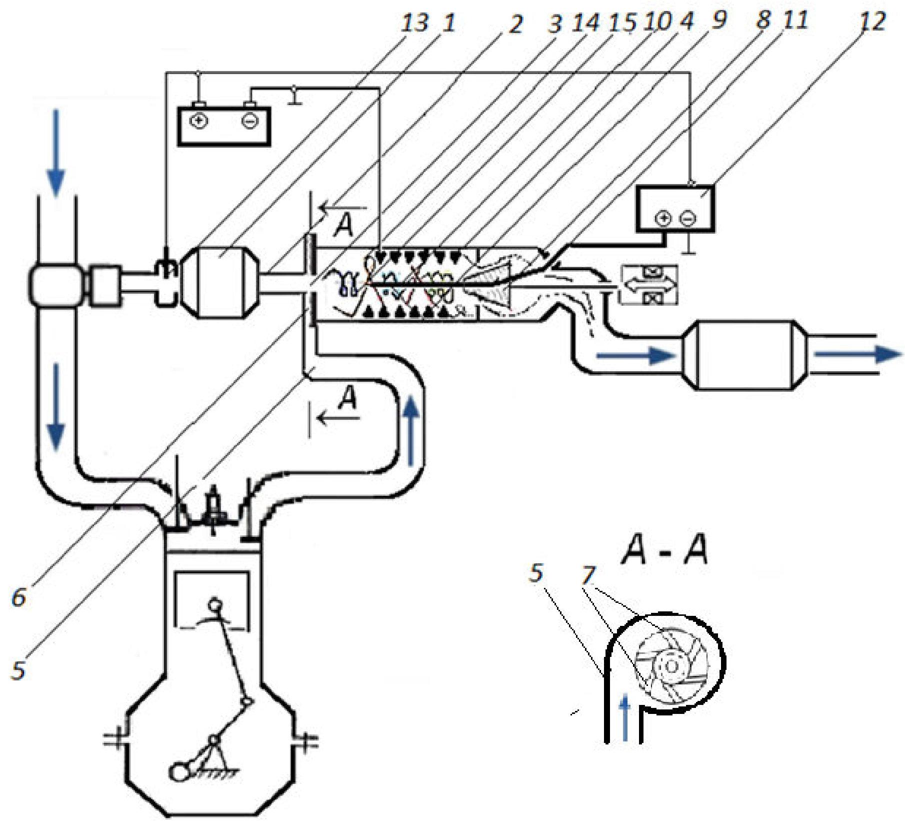

Figure 1.Vortex device for electrical cleaning of exhaust gases from solid fractions and recirculation

1- permeable filter element; 2- inlet nozzle of a permeable filter element; 3- diaphragm; 4- energy separation chamber (cylindrical tube); 5- inlet pipe of the RHVT vortex chamber; 6-cylindrical vortex chamber of the RHVT; 7- nozzle for supplying exhaust gas (tangential input); 8- controlled throttle valve; 9- cathodic electrode (metal spiral); 10- precipitating electrode; 11- high-voltage wire in insulation; 12- source of high-voltage pulse current; 13- electric heating elements (glow plugs);
14,15- tangential and axial flows of hot and cold exhaust gas.

This occurs in the vortex chamber due to centripetal energy separation (Ranque-Hilsch effect) of the exhaust gas stream. A negative potential from the source of high-voltage pulse current creates a crown on the inner edge of the metal spiral and charges the solid particles of the exhaust stream.

In an electric field, charged solid particles are deposited on a pin of a precipitating electrode and are discharged into the filter element by an axial gas flow.

Thus, the quality of purification of exhaust gases from particulate matter is improved.

The cleaned and additionally heated (due to the Ranque-Hilsch effect) exhaust stream from the energy separation chamber is directed through an electrically controlled conical throttle valve to the exhaust channel of the internal combustion engine.

If necessary to burn soot in the filter element: open the fully conical electrically controlled butterfly valve at the hot end of the energy separation chamber.

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This causes a backflow of air in the diaphragm at the cold end of the cylindrical energy separation chamber. Before the filter element, the return air stream is heated with electric heating elements (glow plugs) to a temperature above 600°C and soot is burned in the filter element.
Schematic diagram of RHVT with an integrated coronal spiral and a precipitating electrode in the form of a spiral is shown in Figure 2.

3. ARGUMENTS FOR USING A VORTEX DEVICE TO CONTROL EXHAUST FLOW

In the recirculation mode, the exhaust gas is supplied to the intake manifold of the engine, and its amount is controlled using a controlled valve (Figure 3).
In the mode of stopping the supply of exhaust gas to the recirculation system using the controlled valve at the hot end of the energy separation chamber, the absolute pressure at the inlet of the cold end (PCE) opening with the pressure in the intake manifold (PIM) is cut out[9].We do not get a stream coming out of the cold end, which leads to a knee-type stream (Figure 4).

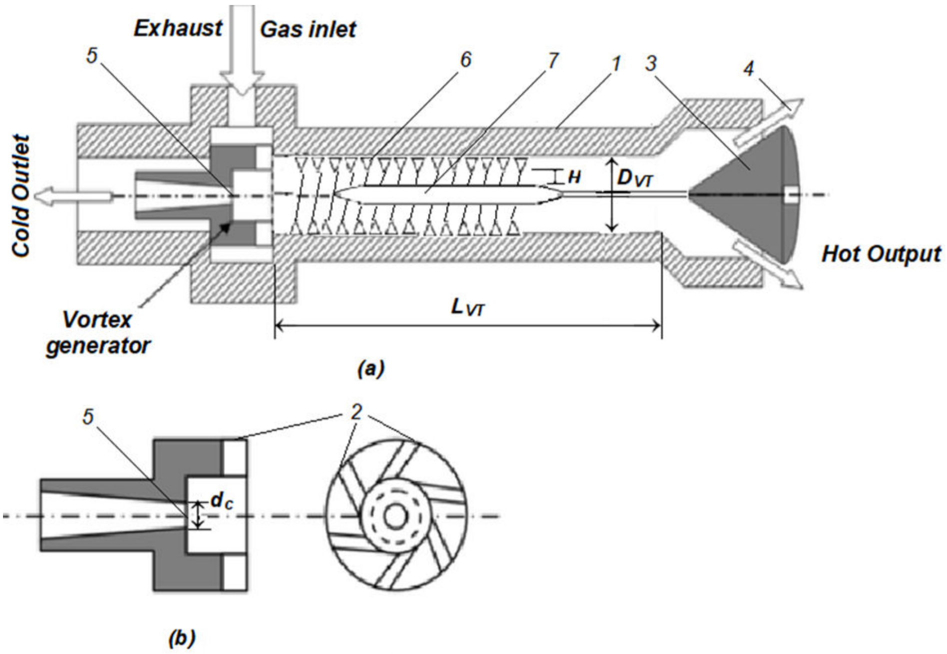

Figure 2. Schematic diagram of vortex tube of counter current type
1 - a smooth cylindrical tube; 2 - swirl tangential or snail-type feed Compressed natural gas; 3 - throttle valve (throttle valve); 4 - Output hot gas through the annular gap; 5 - diaphragm for output cold gas; 6 - corona spiral; 7 - precipitating electrode made in the form of contra wound helix.

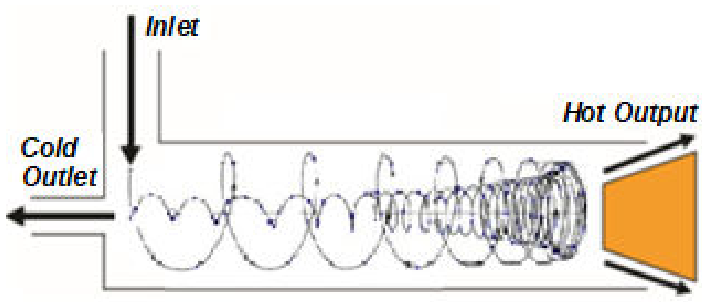

Figure 3. The mode of supply of exhaust gas to the recirculation system

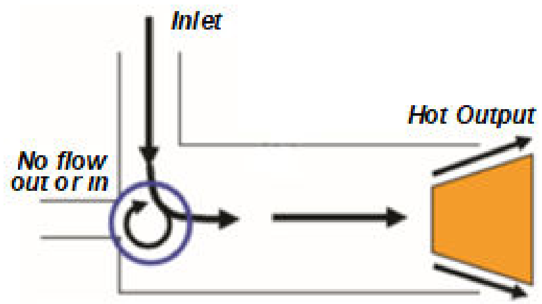

Figure 4. The mode of stopping the supply of exhaust gas to the EGR system

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To burn filtered solid particles in a permeable filter, it is necessary to fully open the adjustable valve on the hot end of the energy separation chamber, this will lead to the effect of air suction from the intake manifold at the cold end (Figure 5) [9].
At this time, the air is heated with glow plugs to burn solid particles in a permeable filter.

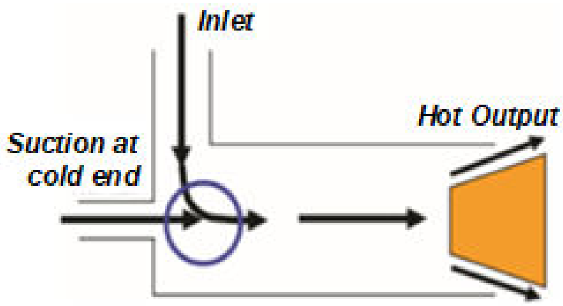

Figure 5. The mode of intake of air from the intake manifold of the engine

4. ARGUMENTS ABOUT THE EXPECTED EFFICIENCY OF THE VORTEX DEVICE FOR THE ENERGY SEPARATION OF TOXIC GASES

Samira Mohammadi and Fatola Farhadi [10] experimentally investigated gas separation in RHVT.
For a gas mixture LPG - N2, (all of hydrocarbon components are summed up in one component, named LPG) in which the nitrogen density is half the density of LPG, the gas separation in VT is experimentally studied. At a specific pressure of 236.37 kPa (2.36bar) at the entrance to the vortex tube, an efficiency of separation of about 65% C4+ from the specified gas mixture was obtained (in the form of a mixture of hydrocarbon components).
In this experiment, a convincing confirmation was obtained of the efficiency of gas separation for a mixture of gases of different densities at a gas pressure at the inlet of the RHVT tube identical to the exhaust gas pressure PEG =2.5 bar of a diesel engine, therefore, using the Ranque-effect in the proposed device will make it possible to isolate from a flow of exhaust gas heavier than nitrogen (density ρ(N2) = 1.25 kg/m³ under normal conditions) gases: carbon dioxide (density ρ(CO2) = 1.98 kg/m3) and toxic gases propane C3H8 (density ρ (C3H8) = 1.882 kg/m3), propylene (density ρ (C3H6) = 1.748 kg/m3), benzene (density ρ(C6H6) = 3.486 kg/m3) for combustion in the combustion chamber of the internal combustion engine n the recirculation mode (Figure 3).

5. ARGUMENTATION OF THE EXPECTED EFFICIENCY OF THE VORTEX DEVICE FOR CLEANING EXHAUST GASES FROM SOLID PARTICLES

To prove the effectiveness of the separation of solid particles from exhaust gases in an RHVT vortex tube, we use the results of an experiment conducted by R.Kap-Jong et al. [11].
They investigated particle separation characteristics in a countercurrent vortex tube using lime powder (density ρ (CaO) = 3.35 g/cm3) with an average particle diameter of 5 μm and 14 μm.
Their results also showed that with increasing pressure and inlet flow rate, the separation efficiency for larger powder particles decreases, but increases for small powder particles.
They found that a separation efficiency of 93% can already be obtained with an inlet velocity of Vi = 14.52 m/s. In this experiment, convincing confirmation of the efficiency of particle separation in the countercurrent vortex tube RHVT was obtained.
To confirm the applicability of the conclusions of the work to the proposed technical solution [8], we calculate the speed of the exhaust gases at the entrance to the proposed device when it is installed on a diesel ICE of medium power PEA = 138 hp (101.5 kW) [12].

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We take the diameter of the energy separation chamber of the tube RHVT- DVT=0.06m (cross-sectional area SVT= 0.00283 m2), pressure of the exhaust gas entering the tube - PEG = 2.5 bar and volume exhaust gas - QEG = 0.45 m3/s has an RHVT in a vortex tube in the presence of a precipitating pin with a diameter of the precipitating electrode DPE = 0.01 m (cross-sectional area SPE= 0.000785 m^2), the axial flow velocity Vi is equal to:

Vi = QEG / (SVT- SPE) / PEG (1)
Vi = 0.45 / (0.00283 - 0.0000785) / 2.5
Vi= 65.42 [m/s]

As indicated above, with increasing pressure and inlet flow rate, the separation efficiency for fine powder particles increases. Therefore, at an exhaust gas flow rate of Vi = 65.42 m / s, the removal efficiency of solid particles of less than 1 μm in size will be higher than in the experiment conducted by Kap-Jong et al. [11].

6. ARGUMENTATION BY CALCULATING THE EXPECTED EFFICIENCY OF THE SEPARATION OF SOLID PARTICLES FROM EXHAUST GASES USING AN ELECTROSTATIC FIELD IN A VORTEX DEVICE

As shown above, in the RHVT energy separation chamber with an exhaust gas velocity of 64 m/s, it is possible to expect effective removal of solid particles with a diameter of less than 1 μm from the hot stream to the cold one.
To output larger particles in the energy separation chamber of the proposed device, we create an electrostatic field for electric cleaning of exhaust gases.
The principle of electric cleaning of gases from suspended particles is to charge the particles with their subsequent release from the gas stream under the influence of an electric field.
The physical nature of the electrical cleaning of exhaust gases from solid particles is that a gas stream containing solid particles is pre-ionized.
In the corona discharge field of the corona electrode, under the influence of an electric field and due to diffusion of ions, the particles contained in the gas acquire an electric charge.
In an electrostatic precipitator, particles are charged very quickly: in less than 0.10 seconds, the particle charge approaches 94.0% of the limit value [13].
The degree of heterogeneity of the electric field between the electrodes is characterized by the coefficient of heterogeneity k, which is equal to the ratio of the maximum electric field strength Emax to the average intensity Emean between the electrodes.
The unevenness coefficient of the electric field k for an electrostatic precipitator with electrodes in the form of two coaxial cylinders is determined by the formula:

k = (r2-r1)/(r1×ln (r2/r1)) (2)

where
r1 = DPE / 2 = 0.005 [m],
r2=DVT/2-HCS = 0.025 [m],
k = (0.025-0.005) / (0.005 × ln (0.025 / 0.005))
k = 2.48

With an electric field strength Emax = 106 V/m, air (with some approximation, this can be accepted for exhaust gas) ceases to be a reliable insulator and spark discharge occurs in it, therefore, to exclude a spark discharge in a vortex tube, the average electric field strength between the settling and corona electrodes Emean should not be more than:

Emean = Emax / k (3)
Emean = 106 / 2.48
Emean = 403 000 [V/m]

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We take the ratio of the length LVTof the chamber of the energy separation of the vortex tube to the diameter DVT of the vortex tube LVT/DVT= 9.3 [13].
For the diameter DVT = 0.06 m, the length of the pipe of the energy separation chamber of the RHVT will be: LVT = 0.56 m.
The distance between the corona and precipitating electrodes H (m) with a tape height of the metal spiral of the corona negative electrode HCS = 0.005 m and the diameter of the precipitation electrode DPE = 0.01 m will be:

$$H = DVT / 2 - (HCS + DPE) \quad (4)$$
$$H = 0.06 / 2 – (0.005 + 0.01/ 2) = 0.02 \ [m]$$

To create a corona discharge in a vortex tube, the voltage of the negative DC power supply must be no more than:

$$UHVDC = Emean \times H \quad (5)$$
$$UHVDC = 403\,000 \times 0.02$$
$$UHVDC = 8\,060 \ [V]$$

Accept DC voltage UHVDC= 8 [kV]
To prove the efficiency of the separation of solid particles from the exhaust gas in the RHVT using an electric field, we calculate the drift velocity of the solid particles in the electric field and compare it with the residence time of the solid particles in the RHVT.
Let us determine the velocity VS of the swirling exhaust gas along the spiral of the corona electrode in the RHVT. If there are six nozzles in the swirl ni = 6, with a diameter di= 0.02 m (cross-sectional area Si = 0.000314 m2)

$$VS = QEG / (ni \times Si) / PEG \quad (6)$$
$$VS = 0.45 / (6 \times 0.000314) / 2.5 = 95.54 \ [m/s]$$

A metal spiral of the corona negative electrode from the beginning of the vortex chamber of energy separation having 100 turns is inserted into the vortex chamber of energy separation RHVT with a step of 0.5 cm. With the length of the vortex chamber of the energy separation L = 0.56 m, the spiral length will be slightly more than LS = 18.84 m, therefore, the exhaust gas swirled in the vortex chamber will move in the field of the corona of the negative electrode 9 with the velocity of the swirling exhaust stream VS time t :

$$t = LS / VS \quad (7)$$
$$t = 18.84 / 95.54 = 0.197 \ [s]$$

The velocity of charged particles with a diameter more than 1 μm, for example particles of aerodynamic diameter - 10 μm (PM-10) in an electric field, can be determined by the formula [13]:

$$Vp = 10^{-11} \times Emean^2 \times rP / \mu EG \quad (8)$$

Where μEG - is the dynamic viscosity at 1000°C (Exhaust), $\mu EG = 7.5\times10^{-7}$ Pa×s[14],
rP - the radius of a particle with a diameter of 10 μm (PM-10) is equal to
0.000005 m.
$$Vp = 10^{-11} \times 403\,000^2 \times 0.000005 / 7.5\times10^{-7}$$
$$Vp = 10.83 \ [m/s]$$
The speed of charged particles with a diameter of less than 1 micron [13] :

$$Vp = 0{,}17 \times 10^{-11} \times Emean / \mu EG \quad (9)$$
$$Vp = 0{,}17 \times 10^{-11} \times 403\,000 / 7.5\times10^{-7}$$
$$Vp = 0.913 \ [m/s]$$

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When moving in a swirling hot stream of exhaust gases for t = 0.197 s, solid particles under the influence of an electrostatic field acquire up to 94% charge in 0.1 s [13] and in the remaining time they pass in a vortex tube from a hot stream to a cold stream a distance of 0.02 m (distance between electrodes H = 0.02 m).
In the electric field of the proposed device, particles with sizes less than 1 μm are potentially capable of covering a path of more than 0.089 m, and particles with sizes of, for example, 10 μm(PM-10), a path of not more than 0.525 m, i.e. with a large margin.
Therefore, in the proposed device, conditions are created for 100% removal of particles from the hot exhaust gas stream into the cold stream of the vortex tube energy separation chamber both by the electric field and by the Ranke Hills effect.
From the vortex chamber, solid particles will be carried away by a cold stream into the particle filter, where particles with sizes greater than 1 μm will be retained by the filter, and particles with sizes less than 1 μm will pass through the recirculation system and enter the combustion chamber of the engine.

7. CALCULATION OF THE AMOUNT OF ENERGY FOR HEATING AIR TO BURN SOLID PARTICLES (SOOT) IN A PERMEABLE FILTER

Let us calculate the amount of energy for heating air with typical automobile glow plugs, to the ignition temperature of soot, for burning it.
Technical data of CY 55 glow plug [15]: Voltage: U = 11 [V]; Resistance: R = 0.5 [Ohm].
Four glow plugs n = 4 consume power:

$$P = I2 \times R \times n \tag{10}$$

where, I - the current flowing in the glow plug:
I = U / R = 11 [V] / 0.5 [Ohm] = 22 [A]
P = 222× 0.5 × 4
P = 968 [W]
Soot ignites at a temperature of T = 550°C. Let us take the temperature of heating the air for burning soot with a margin of T2= 600°C, and the temperature of the air in the collectorT1 = 20°C.
When heat is transferred to air by the heated surface of glow plugs, heating of flowing air will occur as in an electric air heater, therefore, to heat one cubic meter of flowing air L1= 1.0 m³/h, taking into account energy losses during heat transfer, we use, as a first approximation, the formula [16]:

$$Q = L1 \times \rho \times s \times (T2-T1) \tag{11}$$

Where ρ- is the air density, the standard value at sea level in accordance with the International Standard Atmosphere is the value ρ = 1.225 kg / m³, which corresponds to the density of dry air at 15°C and a pressure of 101.33 kPa; s - is the specific heat of the substance in J/(kg×K).
The mass specific heat of dry air is 1 kJ/(kg×K) = 0.24 kcal / (kg×°C).
Q= 1 [m³/h]×1.225 [kg/m³]× 0.24 [kcal/(kg×°C)]× (600°C - 20°C)
Q = 170.5 [kcal/hour]
Since 1 kcal = 1.163 W, the required electrical power will be P1 = 198.3 W/hour.
To heat 1 liter of air in 1 second, you need power Ql = 713.9 W.
With a total power of theglow plug P = 968 W for 1 sec, they can be heated from T1 = 20 ° C to T2 = 600°C

$$L = P / Ql \tag{12}$$

L = 968 / 713.9 = 1.35 [l / s]

At idle speed of 600 rpm, a 4-stroke diesel engine with a cylinder capacity of 2.0 litters per minute draws in 150 litres of air. When 20% of the air drawn in by a diesel engine is taken into the regeneration system, this will be 0.5 l/s; therefore, reliable burning of solid particles (soot) in the filtering element 1 can also be achieved with fewer candles.

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8. CONCLUSIONS

Based on experimental studies known from open press, a device for efficient purification of exhaust gases of a diesel engine based on a vortex tube is proposed, which allows, in particular, to perform:

- purification of the exhaust gas flow from toxic gases: benzapyrene, aldehydes, sulfur dioxide, nitric oxide and from solid fractions (soot) with sizes less than 50 nm and burning them and toxic gases in the engine combustion chamber;
- regulate the flow of exhaust gases in the exhaust gas recirculation system, using a valve with a vortex tube instead of an EGR valve;
- clean the exhaust stream from relatively large 1 - 100 microns solid fractions (soot) using a permeable filter connected to the recirculation system;
- partially cool the exhaust gases entering the exhaust gas recirculation system;
- increasing the temperature of the exhaust gas supplied to the exhaust tract, in particular to the catalyst, to increase the efficiency of oxidation of carbon monoxide in the exhaust gas.

The calculation showed that in a device based on a vortex tube, due to the Rank-Hills effect, the reverse flow of exhaust gases arising in the energy separation chamber when an electric field is applied will increase the efficiency of solid removal. particles. with sizes less than 1 micron from the hot stream in the cold state in addition to particle removal caused by the separation of the energy of the gas vortices in the vortex tube of the device.

Based on experimental studies known from open press, the expected effectiveness of the proposed device based on a vortex tube for separating the energy of toxic gases and solid particles from the exhaust stream, as well as the ability to control the gas stream in the recirculation system, is justified.

For the practical application of the proposed device based on a vortex tube on automotive diesel engines, it is necessary to conduct experimental studies with the goal of: optimizing the size of the vortex tube of the proposed device, evaluating the effectiveness of cleaning exhaust gases from solid particles (soot) and toxic gases, as well as developing a control algorithm exhaust gas recirculation and particulate filter (soot).

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