IMPROVEMENT OF AXIALLY SYMMETRICAL PLASMA REACTOR STRUCTURE WITHIN A FRAMEWORK OF PARTICLES POLLUTION DECREASE IN ENGINE'S EXHAUST

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Abstract

Within a framework of researches on cleaning of Diesel engine's fumes of particulates the sequence of construction variants of axially symmetrical device was examined. The device was fitted with the plasma reactor, in which the particles gained the same electric charge as a result of passing through the corona discharge zone. Then they were tilted aside in electrostatic field and finally collected in filter module. The principal functional problem met during research works was that the soot gathering on insulators of electrodes caused the drop of voltage and fade-out the corona discharge. It was solved by introducing the air stream blowing away the soot layer as well as the back flow induced by pressure difference within stream of exhaust gas. The latest version of device was put the 8 - phase test of particles and gaseous pollutants on test bed equipped with two-way exhaust pipe. The applied arrangement made possible the testing of engine in cases:

- *without purifier,*
- *when exhaust gas swam through inactive purifying device (without voltage),*
- *when exhaust gas swam through active plasma reactor (purifier supplied with voltage of 15 kV).*

Using the final version of device, the 66 % cleaning efficiency of exhaust gas from particles and 10% decreasing of gaseous pollutants volume was achieved. The developed device may be a good basis for working up of prototype version and subsequent operational research works, especially on turbocharged engines.

Keywords: *exhaust gas, particulate matter, plasma reactor, experimental investigation*

1. Introduction

The preliminary recognition research works on an application of corona discharge to cleaning of exhaust fume were initiated at Institute of Aviation within a framework of research project already in 2002. Starting with the reactor in flat arrangement there was finally achieved almost 40% effectiveness of particulates separation. One of the most important and also the most difficult problems to resolve, relevant to functionality of purifying device, was the phenomenon of the soot deposition on insulators of the electrodes. The current conductivity between electrodes and their shields across the soot contained in exhaust gas restricted the maximum value of working voltage to 12 kV. Initially the operation of device supplied with above mentioned voltage with fully developed corona discharges has corresponded to assumptions. However, in short time the turbulent diffusion of soot into insulators of electrodes caused the fall of working voltage and drop-off in corona discharges. Results of these research works were published in [1]. During these investigations there was acquired a file of valuable practical information, inaccessible in literature, which created the obtainment possibility of considerable progress in developing of effective device appropriate for cleaning of Diesel engine exhaust gas. The aim established for scope of research

works in presented project was the elimination of functional imperfectness of above mentioned flat arranged reactor by development of its axially-symmetrical variant. Carrying on with idea of protection of insulators electrodes against their pollution with soot throughout location them possibly deep inside the covering sleeves, the basic variant of device in axially-symmetrical arrangement has been worked out, in which insulators of three electrodes being simultaneously cantilevers for blades and deflecting electrode were hidden deep inside covering sleeves as well. Description of some construction details and the test results of axially-symmetrical arrangement systems were presented in preceding editions of "Journal of KONES" [2-4].

2. The initial variant of device

The worked out initial variant of device in axially symmetrical arrangement is shown on Fig. 1. The device located behind the engine's exhaust manifold has operated in high temperature zone of fumes. The central shield (1) of the electrode (2) as well as three insulators of electrodes (5), the cantilevers for blades (6) and deflecting electrode (7) simultaneously, were deep hidden inside the covering sleeves (4), far beyond the exhaust gas flow zone, in order to protect them against soot pollution. The installed conical element (8) having series of holes enabled relocating of particulates deflected in electrostatic field to the pocket (9) arranged between channel (11) and slideable liner (10).

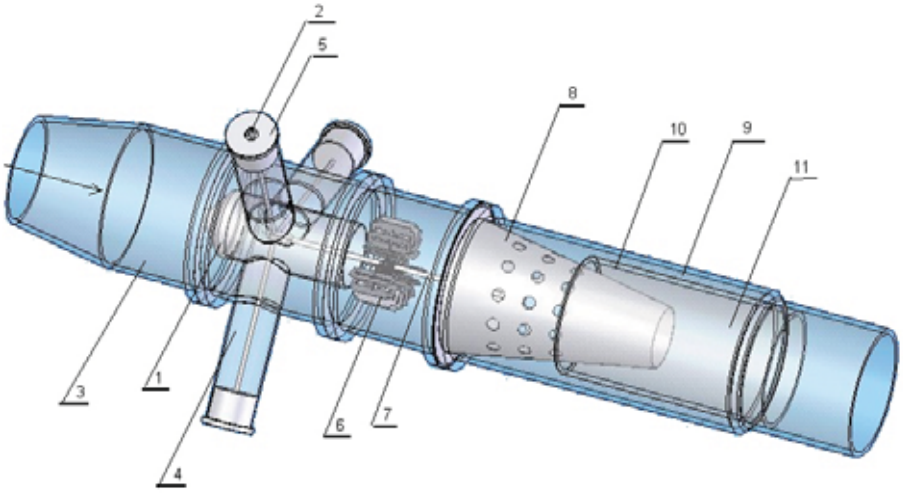

Fig. 1. Initial axially-symmetrical model device of exhaust purifier of particulates

Sliding of liner (10) allowed the optimal selection of gap size between itself and the conical unit with regard on efficiency of inertial catching of particulates into pocket. However, the turbulent diffusion of soot into insulators of electrodes still made the continuous work of device impossible. The conception of supplying working part of reactor with high voltage by means of three electrodes shielded with long liners, which moved insulators of electrodes away from duct conveying the exhaust gas, turned out to be unfavorable. Results achieved by practicing the discussed arrangement were unsatisfactory, worse than those obtained previously in case of flat arrangement. The change of geometrical configuration of reactor units did not permit considerable extending of device's operation time. As formerly, insulators of electrodes became covered with the soot in spite of considerably moving of with liners covered insulators away from the channel conveying the fumes. The linking of electrodes casings with chassis has been considered as unfavorable; the casings having negative electrical potential, same as chassis, attracted the positive charged particulates, permanently favoring the pollution of electrode's insulators and reducing the catching effectiveness of particulates carried in exhaust gas.

The next attempt to increase the efficiency of cleaning device was the new idea for supplying the units generating the corona discharge with high voltage: instead of three cantilevers - the single one was applied, playing simultaneously the part of insulator.

3. Variants of devices with single insulator

The updated device had a single cantilever, being simultaneously an insulator (2). Central casing (1) was not bounded with chassis and could have positive or "indifferent" electric potential. The location of reactor's blades (6) has been altered as well, in relation to "cantilever (4) - electrode (3)" assembly, supplying the device with high voltage (Fig. 2). At the end of central casing the swirler of exhaust flux was placed in order to throw away the particulates by inertial manner in the direction of exhaust gas flow channel walls (5), which reduced the penetration of soot into the depths of central casing and weakened the contamination process of being there part of insulator. The device was provided with an altered catcher of particulates having form of concentric mesh filter (8). The forces of inertia called out by fume's spin movement on blades (9) together with electrostatic force acting on particulates additionally charged close to edges of blades, counteracted the settling down of soot on the outer surface of insulator.

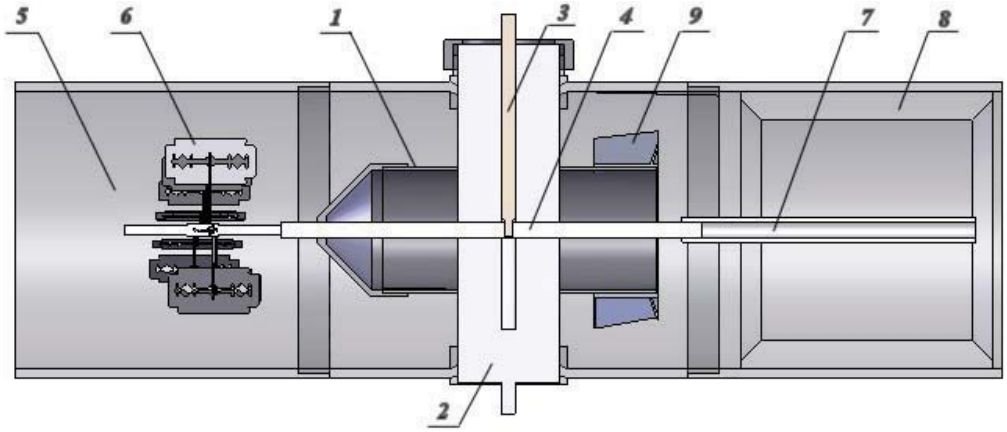

Fig. 2. Fundamental parts of reactor after described modifications

These modifications did not assure long-lasting operation of the device (Fig. 3). The insulator of electrode conveying the high voltage got quickly dirty with soot, and effect of particulate's catching was still unsatisfactory. Quick coating of insulator with soot made testing of device impossible by applying the working voltage higher than 12 kV. Newly - designed insulator, being simultaneously the main cantilever in plasma reactor, fulfilled his task with regard on mechanical and thermal strength. The next step was a transfer of reactor's blades (1) beyond the sleeve covering an insulator. In order to increase intensity of exhaust gas' spin a different kind of blades (2) was applied. All described changes are presented on Fig. 3. Another variant of device was given an examination also, in which corona discharges were generated on the meshes of thin wires fixed on two module cantilevers.

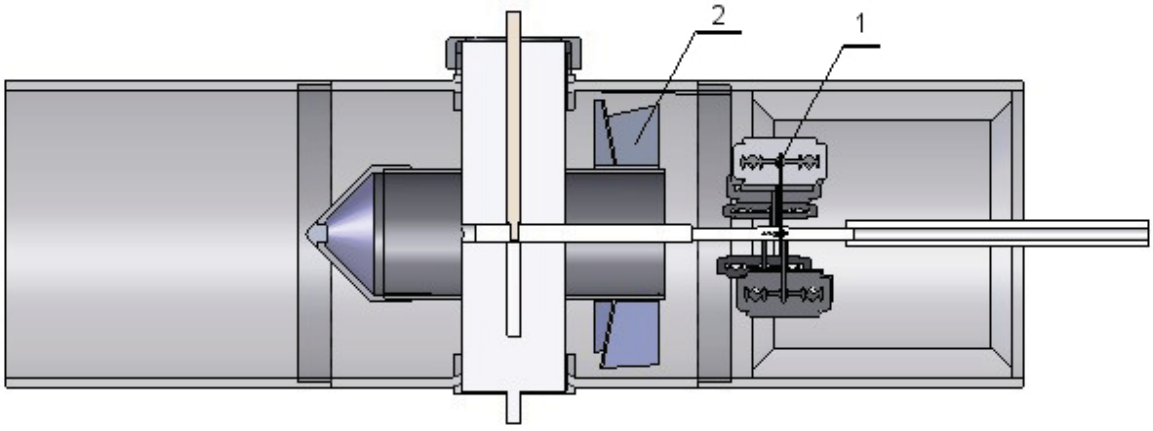

Fig. 3. Variant with single insulator

Increased dimensions and the changed slope of blades improved the intensity of fumes spin behind the shield of electrode. The essential (up to 40%) improvement of purification effectiveness of exhaust gas from particulates was obtained for both kinds of blades, but the soot penetration inside the sleeve screening the electrode was still considerable. The results of testing suggested, that during consecutive attempts of empirical shaping of corona discharge field the special emphasis should be put on growth of discharges intensity and purposeful formation of corona discharge's zone as well as electrostatic field. The possibility of feeding fresh air (4) inside the central casing (3) was the essential change introduced into the structure of device. Research works were implemented using another variant of device, where the central shield of electrodes has "indifferent" electrical potential. It order to achieve the possibility of shaping the air flow through the central shield, which prevented the settling down of soot on electrode's insulator, the combination of discs (1) and porcelain rings (2) was applied (Fig. 4).

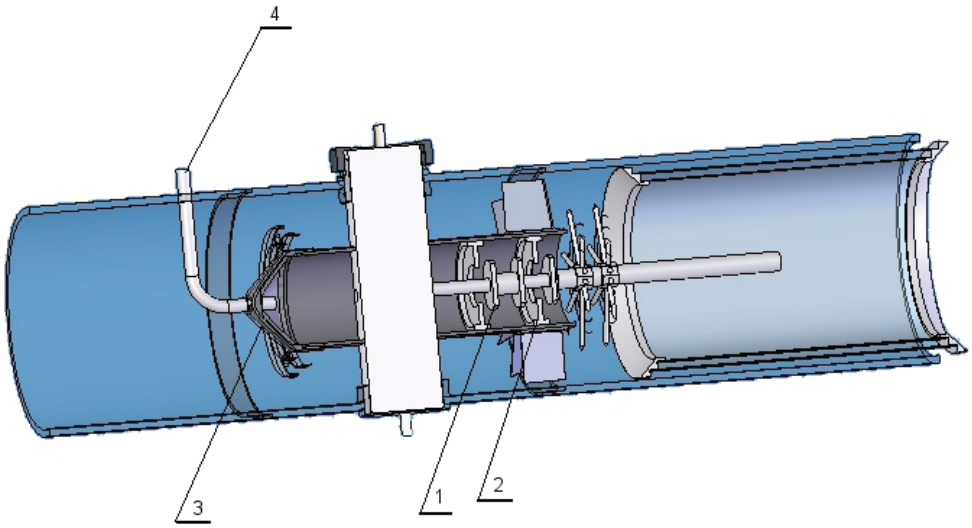

Fig. 4. Variant with air blow-in

The experimental optimization of blown-in air flow (about 3000l /h) as well as geometrical spacing of disks permitted an essential augmentation of device's time of operation and obtainment the essential improvement (above 45%) of effectiveness of fumes purification. This effect increased considerably as a result of location of special insert (1), which intensified air flow round insulator (Fig. 5).

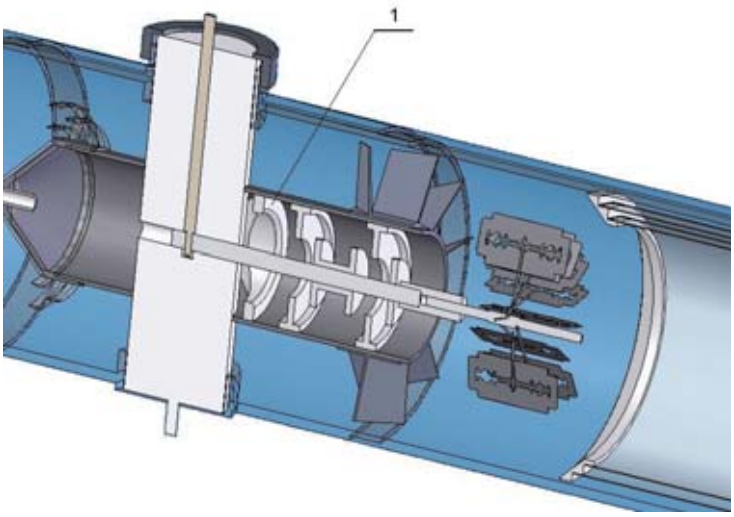

Fig. 5. Variant with special insert

Further extension of correct reactor's running was achieved by removing of blades. The variant showed in Fig. 6 presents the segment (1) located on the end of housing, which caused a rise of exhaust gas flow through the main channel and in consequence drop of static pressure outside the segment. Exhaust gas penetrating into this segment is sucked out outside them through the holes made in his cylindrical wall. The back-flow of exhaust gas improved the conditions of insulator's proper work and prevented the settling down of soot on his surface.

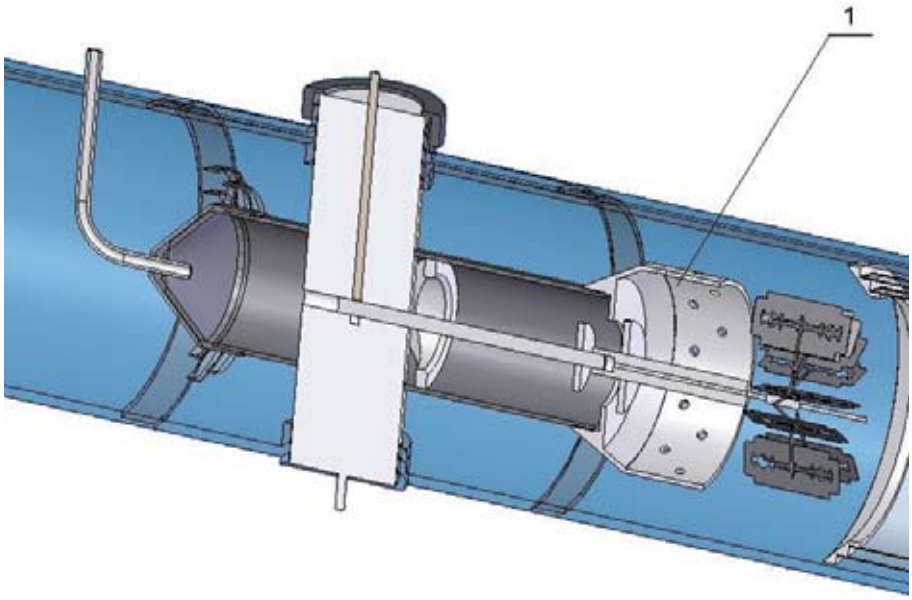

Fig. 6. Next modification of reactor

The series of tests confirmed the above mentioned reactor's configuration as the most profitable solution regarding its operation.

4. The final version of reactor

Considerable extension of reactor's work time forced the necessity of improvement of filtration module in order to better the collecting ability of caught particulates as well as through determination of intensity of current generating corona discharges and specifying of optimum geometric configuration of applied linear and mesh like blades. Examination of many combinations of geometrical blades location showed, that the linear blades arrangement is more advantageous then the thin wires mesh one. A double compact linear blades configuration, as the best arrangement, was chosen for subsequent researches. Additionally a new smaller ceramic insulator (2) was applied of diameter reduced to 40 mm. Insulator was encased in sleeves (3) and (4). For easier assembling the sleeve (4) was supported on disassembled bracket (6). The blown-in air (1) washed the unshielded part of insulator, which was closed in central casing and sleeves. The flow of fumes behind the plasma reactor was divided into two zones - the internal one containing the cleaned gas and the external, which included the particles positively charged in electrostatic field. Less purified fumes were subject to additional intensive whirl by means of blades (8) installed before filtering module, which threw them outside across the mesh (9) to container (12). The exhaust gas remaining in internal zone (4) swam round the electrode (7), which deflected the particulates in the direction of mesh (10), and flew into external zone. It was found after examination of many combinations of geometrical location of blades and several variants of corona discharge modules, that the arrangement of linear blades is more profitable then that of thin wires mesh.

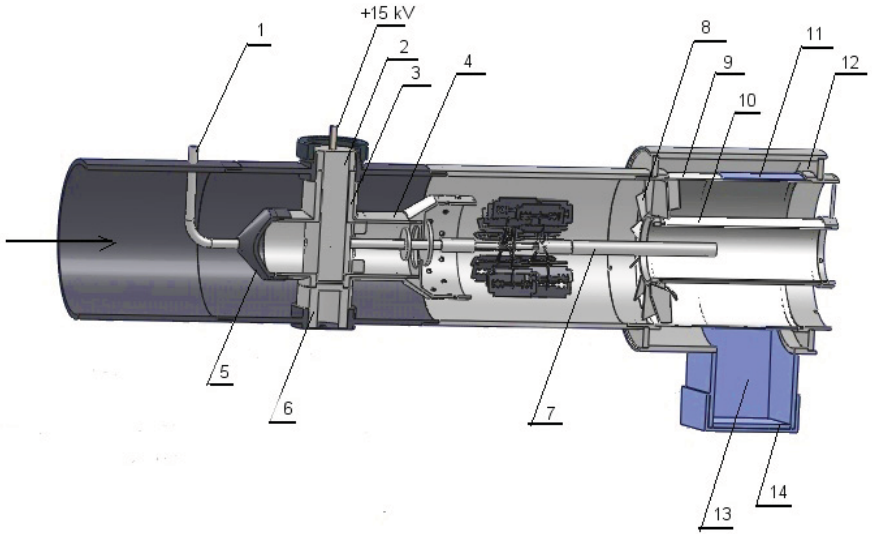

Fig. 7. Final version of axially-symmetrical device

Subsequently, the terminal part of mesh (9) was covered by the sleeve (11) made of thin metal sheet of length matched during preliminary and functional tests. The pocket (12) created in this way formed an inertial settler for particulates, having in its bottom part the sedimentary well (13). This well is furnished with sliding bottom (14), which enables removal of gathered particulates. This solution made possible periodical weighing of accumulated particulates, which can be an additional tool for inspection of cleaning efficiency. So far the separator was cleaned after every engine test. The constructional details of final version of reactor are shown on Fig. 7.

5. Tests results

Functional tests of depicted variant of device were carried out in Diesel Engines Certified Research Laboratory of Institute of Aviation, Warsaw. The role of particulates source played an experimental Diesel engine URSUS 4390. The following 8-phase toxicity tests of gaseous toxins and particulates have been realized using specially designed two way exhaust collector:

1. According to European directive 97/68/EC without purifying device (to achieve the reference level).
2. According to European directive 97/68/EC with inactive purifier.
3. According to European directive 97/68/EC with active purifying device - plasma reactor supplied with high voltage.

The comparative results of particulates' emission measured in 8-phase tests according to 97/68 EC Regulation, respectively for points 1, 2 and 3 are shown on Fig. 8.

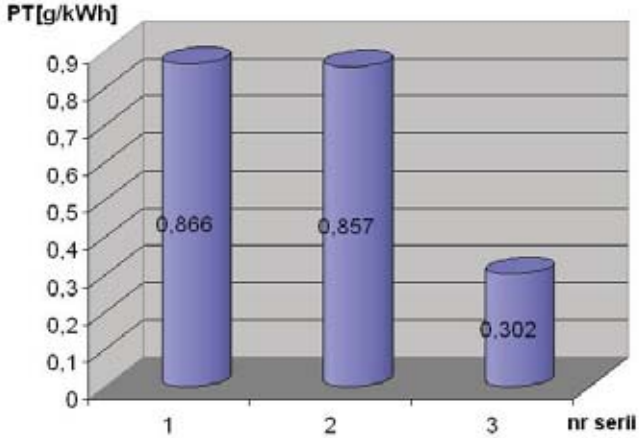

Fig. 8. Particulates emission in [g/kWh] in acc. with 97/68/EC Directive at 15 kV DC supply and without voltage

The tested cleaning device in described arrangement was characteristic of over 66% effectiveness of particulates separation.

6. Summary

- On the grounds of its functionality, the cleaning device run correctly during the research works.
- An over 66 % effect of particulates cleaning efficiency from exhaust gas in tests according to 97/68 EC was achieved
- The high voltage power supply unit does not present any technical problem. There are many small supplier for 24 V batteries accessible on market
- Depicted model device is a good basis for building-up of plasma prototype reactor on vehicle in order to run the exploitional tests. Regarding on necessity of applying of air blown up on electrode insulator it seems to be advisable to carry out the tests on turbocharged engine, which allow to use compressed air directly from compressor.

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