TWENTY SEVENTH EUROPEAN ROTORCRAFT FORUM 2001

MAIN DIRECTIONS OF EFFICIENCY IMPROVEMENT OF DUST SEPARATOR INERTIAL WITH CENTRAL BODY OF A TYPE AS MEANS OF INCREASE OF AN OPERATING TIME OF TURBOSHAFT ENGINE OF THE HELICOPTER IN OPERATION IN A DUSTY AIR ENVIRONMENT

by

V. Sushentsov,
S. Tcherenkov,
K. Vlasov,
S. Dibkaljuk.

Russia,

30 Central Research Institute of

Defense Ministry

September 11-14, MOSCOW, RUSSIA

Main directions of efficiency improvement of dust separator inertial with central body of a type, as means of increase of an operating time of turboshaft engine of the helicopter in operation in a dusty air environment

Summary

The unsatisfactory activity of inlet dust particles separator (DPS) inertial with central body of a type, detected at special tests of the helicopter Ka-32 in a dusty air, had required development of measures till it to improve. On this purpose it were executed the analysis of a dusty flow in a zone nearby and inside of DPS, the trajectories of motion of dust particles and paths of their ingestion in the engine were determined. It's made it possible to reveal the reasons of a low overall performances of DPS of given a type and to offer paths them to increase. By a computational way it has been obtained and confirmed experimentally expected improvement degree of dust separation efficiency by the expense of implementation of offered measures. An evaluation of efficiency of offered measures as means of increase of helicopter 's turboshaft engine accumulated burn time in operation in a dusty air environment is executed as well.

Introduction

As it is known, the helicopters frequently are applied at ground air stations and unprepared platforms, and also frequently work in conditions of proximity of ground. Thus in engines the plenty of sand and dust enters, that calls erosive wear of elements of engines, deterioration of their performances and premature removal out of operation. In order to avoid the occurrence of events of this kind, dust and sand particles must be prevented from the engine. Main basic direction to do it is the installation DPS. There are statistical data indicating, that the mean running time of engines TV3-117 without DPS makes about 60-100 hours. After the installation DPS the mean operating time to removal increases up to 300-400 hours, however, it is evident, that DPS installation does not provid resource of engines between repairs and the engines are removed prematurely. Now, in connection with tendentious of essential increase of resources of an engines TV3-117, the problem of DPS performances improvement acquires the special urgency.

On domestic helicopters in Russia, including helicopters of a new generation, usually installed DPS of the axial inertial with central body of a type where central body profile reminds a mushroom, fig. 1. DPS of given a type is designed as the two-stage scheme. The first stage is the central body together with the lip, the second stage - unit of inertial separators. Function of the first stage of DPS is to direct maximum of dust particles to the unit of inertial separators, as the not entered in separators particles then become ingested by an engine. Function of the second stage is to extract overboard of the helicopter maximum of particles entered in it (i.e. the second stage represents the inlet of scavenge system).

Basic performance of an DPS is described by , its capacity to remove particles from the engine air . The figure of merit for removing particles , usually called separation efficiency η (degree of clearing), may be calculated in different ways. One of them is as follows:

$$\eta = 1- m_{de} / m_{dps\ inl} ,$$

where m_{de} - weight of dust finally ingested in the engine;

$m_{dps\ inl}$ - weight of dust entered DPS ' inlet.

In bench conditions providing that an axisymmetrial DPS blowing presents at passing of quartz dust large size particles, the separation efficiency makes up about 75%. As have shown researches, the values of a separation efficiency essentially depend on value and direction of speed of an oblique flow. Speed of oblique flow is created by a flow of the main rotor of the helicopter and a speed of helicopter movement or/and speed of wind and may be calculated as a vector sum of these speeds.

The field experience of helicopters confirms, that in operating conditions efficiency of DPS of given a type is insufficient. On the purpose of the problem investigation, "Kamov" company has conducted the special tests of the helicopter Ka-32 in a dusty air environments, during which port engine was fitted with DPS, and starboard engine was without DPS. The measurements of an erosive wear of compressor rotor blades before and after tests were made. The outcomes of tests have confirmed unsatisfactory DPS efficiency, that has required consideration of activity of each stage. In the given paper the technique of calculation of a dusty flow in a zone nearby and inside DPS is represented, the outcomes of analysis of a dusty flow in a zone nearby and inside DPS are resulted, the reasons of its ineffective activity are determined, the measures of separation efficiency increase are offered. The basic of latters is installation in a flowing part of DPS thin partitions (dividing walls). The expected improvement of separation efficiency of DPS is determined. The evaluation of increase of turboshaft (with axial compressor) engine's operating time in a dusty air is executed as well.

1. Calculation technology of a dusty airflow in a zone of proximity of DPS and inside DPS.

1.1 Analysis scheme, basic data, coordinate system

On majority of operational modes of the helicopter the dust in a zone of input devices of engine comes from above, that is stipulated by an oblique flow. This condition is incorporated in the computational scheme of research of

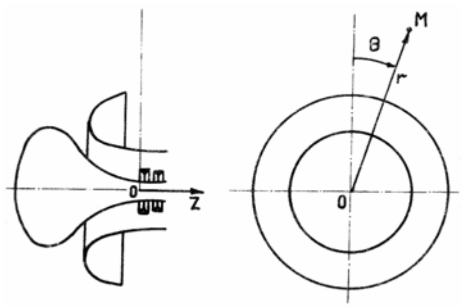


Fig. 1. Scheme of the DPS and system of coordinates.

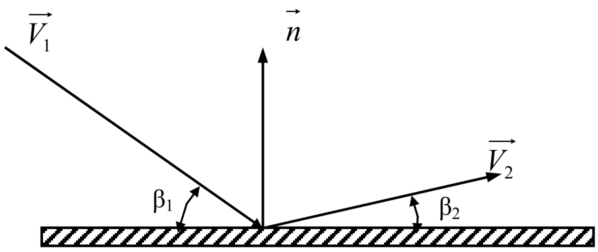


Fig.2. Scheme of particle impact on a construction unit.

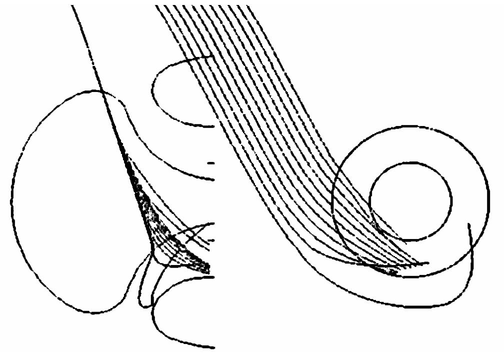


Fig.3a. Trajectories of particles movement.

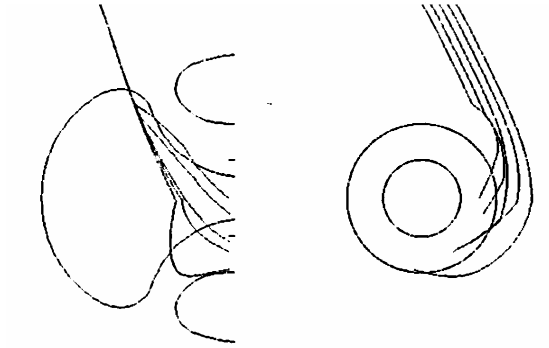


Fig.3b. Trajectories of particles movement .

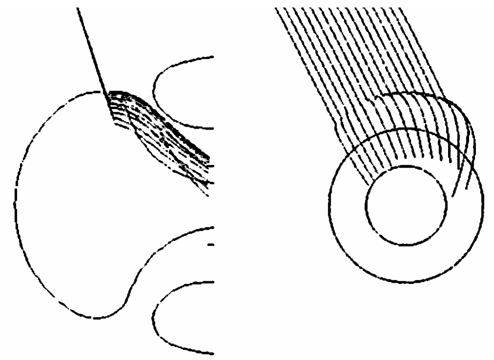


Fig.3c. Trajectories of particles movement.

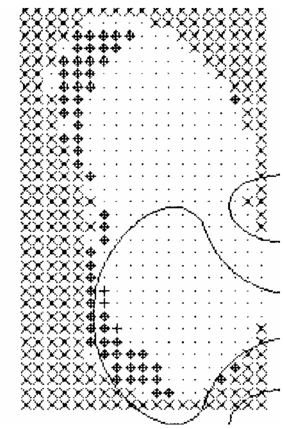


Fig. 4a. Distribution of particles by size 40 μ in plane of particles initial positions.

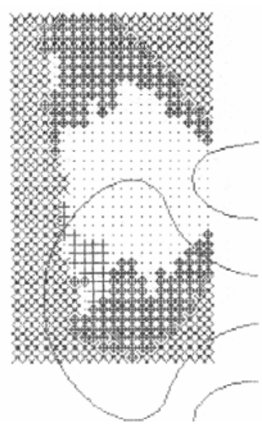


Fig. 4b. Distribution of particles by size 160 μ in plane of particles initial positions.

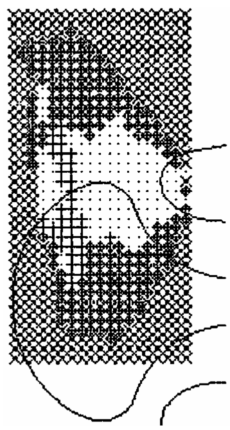


Fig. 4c. Distribution of particles by size 320 μ in plane of particles initial positions.

activity of DPS. The initial positions of dust particles were set under a plane of rotation of the main rotor in immediate proximity of it. The difference of values of speeds of particles $\overline{V}$ and speed of an air flow $\vec{C}$ was taken into account by a factor of sliding, $\frac{\vec{V}}{\vec{C}}$. The directions of vectors $\vec{V}$ and $\vec{C}$ were considered identical. In analysis the influence of an airflow created by the main rotor to a structure of a dusty flow was taken into account, however possible particles impacts on the main rotor were not taken into account. The influence of a fuselage and adjacent engine was not taken into account as well. As a basic data were taken the flow velocities of the main rotor, geometric sizes DPS and air mass- flow ratio through him, all with reference to the helicopter Ka-32. The calculations of an air flow and dust particles motion in a zone nearby and inside DPS were executed in cylindrical coordinate system r, q, z, fig. 1, where the axis z is directed along longitudinal axis of an engine. Point z = 0 coincides with an input edge of the unit of inertial separators. The positive directions of axes and of an angle q are shown in a fig. 1.

1.2 Basic assumptions

The review of references concerning two-phase flows, and also works, concerned dusty airflows, allows to accept the following assumptions.

- The particles of dust mechanically do not interact one another and do not influence against each other.
- At calculation of particles motion the forces of an aerodynamic drag and gravity are taken into account only.
- The air flow is considered as stationary.
- The rebound characteristics of particles impacting on DPS construction are considered equal to their sample mean.
- The influence of a fuselage to a structure of a dusty flow is not taken into account.
- The impacts of particles with the screw are not taken into account.

The analysis was based on a definition of the separator aerodynamic flow field (speed and flow direction), then a point-by-point calculation of individual particle paths through the flow field was carried out. At calculation of a flow of particles the method of statistical tests was applied. So the definition of parameters of motion of a flow of particles was made by statistical processing of appropriate parameters of separate particles, which motion was calculated sequentially. The factor of an aerodynamic drag force Cx in the unsteady motion of dust particles was determined on a standard curve of resistance of a single rigid sphere moving at a constant speed in stationary isothermal incompressible fluid of an infinite extension [1].

1.3 Equations of particles motion in an airflow

Equation of motion of a rigid particle with adopted above assumptions is possible to record as follows:

$$m\frac{d\vec{V}}{dt} = \overrightarrow{F_{ad}} + \overrightarrow{F_g}$$

The forces of an aerodynamic drag $\vec{F}_{ad}$ and weight $\overrightarrow{Fg}$ are determined by the following expressions:

$$\overrightarrow{F_{ad}} = \frac{1}{2} C_x \ \rho \ \ /\vec{C} - \vec{V}\ /(\vec{C} - \vec{V})S \ ;$$

$$\overrightarrow{F_g} = m\vec{g},$$

Where S - midsection of a particle,

$$C_X = \frac{24}{\text{Re}} \quad \text{when Re} < 10^{-1},$$

$$C_x = \frac{24}{\text{Re}}\left(1 + 0{,}125\,\text{Re}^{0{,}72}\right) \text{ when Re} = 10^{-1} \ldots 10^3,$$

$$C_x = 0{,}48, \text{ when Re} > 10^3,$$

when $\text{Re} = \frac{\rho \cdot d \cdot \left|\vec{C} - \vec{V}\right|}{\mu}$,

Where, Re - Reynold's parameter, definited on relative speed of a particle.
Substituting in place of a particle of the incorrect shape particle of spherical one with equivalent diameter d, we can record expressions for mass m and midsection S of a particle as follows:

$$m = \frac{1}{6}\pi d^3 \rho_p \ ;$$

$$S = \frac{1}{4}\pi d^2 \cdot$$

In cylindrical coordinate system r, q, z (see fig. 1) we can receive set of simultaneous equations of motion of a single rigid particle :

$$\frac{dV_r}{dt} = \frac{V_\theta^2}{r} + \frac{1}{2m} C_x \rho \left|\vec{C} - \vec{V}\right|\left(C_r - V_r\right)S - \text{g}\cos\theta,$$

$$\frac{dV_\theta}{dt} = \frac{V_\theta V_r}{r} + \frac{1}{2m} C_x \rho \left|\vec{C} - \vec{V}\right|\left(C_\theta - V_\theta\right)S + \text{g}\sin\theta,$$

$$\frac{dV_z}{dt} = \frac{1}{2m} C_x \rho \left|\vec{C} - \vec{V}\right|\left(C_z - V_z\right)S,$$

$$\frac{dr}{dt} = V_r,$$

$$\frac{d\theta}{dt} = \frac{V_\theta}{r},$$

$$\frac{dz}{dt} = V_z,$$

Where Vr, Vq, Vz – components of a vector of particle speed $\vec{V}$ in cylindrical coordinate system; Cr, Cq, Cz - components of a vector of an airflow speed $\vec{C}$ in cylindrical coordinate system.

The given set of equations allows to determine trajectories and speeds of rigid particles motion in an airflow, of known a structure.

1.4 Calculation of particles rebound

During a motion of dust particles in a flowing part of DPS their collisions with construction units of DPS and engine inlet duct are very probable, and for large size particles they are almost inevitable.
As have shown experimental researches, at impacts with a surface of a constructional material a particle loses a significant part of a kinetic energy, especially at large angles of impact β_1, fig. 2. The reduction of speed of a rebounded particle is characterised by a factor $\overline{V_2} = \frac{V_2}{V_1}$, where V_2 and V_1 - values of particle's speed after and before impact. The rebound angle β_2 (see fig. 2) essentially differs DPS an angle of impact. In executed earlier experimental researches for several aluminium alloys, it was shown, that the parameters $\overline{V_2}$ and $\overline{\beta_2} = \frac{\beta_2}{\beta_1}$ depend, mainly, on value of an impact angle and can be determined as follows:

$$\overline{V_2} = 0{,}981 - 0{,}01223\beta_1 + 0{,}5085 \cdot 10^{-4} \cdot \beta_1^2;$$

$$\overline{\beta_2} = 0{,}9609 - 0{,}01956\beta_1 + 0{,}2182 \cdot 10^{-3}\beta_1^2;$$

The particles rebound from construction units has probabilistic character stipulated by difference of the particles shape from spherical and a roughness of surface of construction units. The account of this fact complicates a little solution of a problem, however, as have shown computational researches, the neglect by probabilistic character of reflection of particles essentially does not influence results of calculation of a dust flow, definited in each case by motion a plenty of particles. Therefore parameters of particles motion after impact were received equal to their sample mean.
The vector speeds components of a reflected particle $\overrightarrow{V_{2r}}, \overrightarrow{V_{2\theta}}, \overrightarrow{V_{2z}}$ were determined in accordance with a condition of a complanarity of vectors $\overrightarrow{V_1}, \overrightarrow{V_2}$ and vector of normal to a surface $\vec{n}$:

$$\overrightarrow{V_1}\left(\vec{n} \times \overrightarrow{V_2}\right) = 0$$

By the solution of a set of simultaneous equations:

$$\overrightarrow{V_1}\left(\vec{n} \times \overrightarrow{V_2}\right) = 0$$

$$\overrightarrow{V_2}\vec{n} = V_2 \cos\left(90 - \beta_2\right),$$

$$\overrightarrow{V_1}\overrightarrow{V_2} = V_1 V_2 \cos\left(\beta_1 + \beta_2\right).$$

In a series of experimental activities it has been shown, that at speeds of impact lower than 70-100м/s the splitting of particles practically does not happens. As the speeds of impact of particles with construction units doesn't ever exceed 40 - 70 m/s, in the analysis it is accepted, that splitting of particles at impacts does not happen.
The calculation of an airflow structure is executed by a method of circumstances described in references [2,3]. The effect of an action of rigid wall on an air flow is imitated by effect of a vortex sheet. The vortex sheet is substituted by a system of discrete vortexes, and vorticity of every of them is determined from a condition of leaking-proof of a wall in checkpoints. An air mass-flow ratio through DPS is imitated by arrangement in output cross-section a system of drains. The method was applied to calculate airflow field structure inside axisymmetrial duct of an engine intake. Preliminary (in frameworks of separate investigation) method was upgraded (by substitution set of point vortexes by set of circular vortexes) and finally designed as a computer programme. The account of a flow of the main rotor implemented with use of experimental data on measurement of airflow velocities at various modes of the helicopter Ka-32 obtained in earlier conducted researches.
It is established, that the flow speeds in a zone of below the main rotor can reach 15-18 m/s, generally flow is directed top-down (75 – 78 ^{0} to a DPS centerline if to look at the helicopter in side) and from left to right (approximately 25^0 to a vertical if to look at the helicopter in front).
The reliability of a technique of calculation of an air flow is confirmed by comparison of outcomes of calculation to outcomes of model experiments.

2. Research of a structure of a dusty flow in a zone of proximity and inside serial DPS of the helicopter Ka-32

2.1 Analysis of trajectories of particles and determination of the reasons of their hit in the engine

In accordance to the adopted computational scheme, a plane of initial particles position (IPPP) was set above the engine, was parallel to a horizontal plane of a DPS symmetry and was removed DPS her on 0,5m. The initial particles speed was determined by expression $\vec{V} = 0{,}8 \cdot \vec{C}$, where $\vec{C}$ - vector of speed of an airflow in an initial position of particle, and particles distribution was set uniform. The main part of calculations is executed for 4 sizes of quartz sand particles: 40μ, 80μ, 160μ, 320μ. The small part of trajectories is plotted in a fig. 3.
The analysis of particles motion trajectories shows the following. In immediate proximity of IPPP vectors of speeds of particles and air differ insignificantly. In a zone of proximity of DPS as a result of the engine influence, streamlines turn toward the engine and part of the particles

(mainly of small and medium sizes) change their direction of motion, since its tend to follow the streamlines airflow. Simultaneously inertia forces tend to carry them in former direction, thus particles of large size are carried toward the lower part of DPS, and after impingement on lip or inner wall of intake or on an internal wall of a central body (see fig. 3a, 3b), bounce to centerline of inlet duct, and part of them passes below the unit of inertial separators, and thus, gets into an engine. Besides it, at high speeds of an oblique flow, some part of large particles moving toward the down section of DPS, impacts with the upper surface of inner wall of central body (see fig. 3 c), and bouncing toward longitudinal axis of DPS, passes above unit of inertial separators. However, the calculations show, that the share of such particles is insignificant. Basic reason of getting into an engine small-sized particles (less than 40 μ) are insignificance of their inertial forces and, therefore, the large susceptibility to effects of forces of an air flow, which main part is directed to the engine.

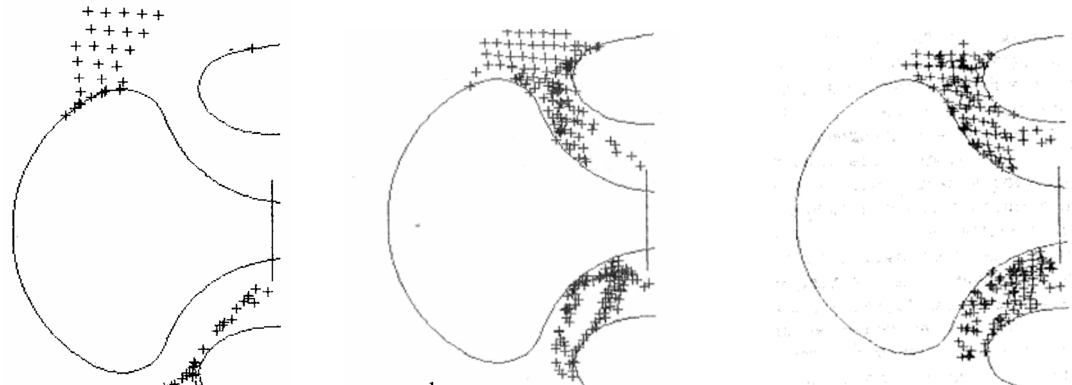
2.2 Analysis of dusty airflow structure in proximity of DPS and in a flowing path of DPS at various modes of the helicopter operation

For the analysis of a structure of a dusty airflow in a zone of proximity of DPS two horizontal planes were selected: IPPP and a horizontal plane of DPS symmetry (HPS). Within IPPP were established zones, from which the dust particle goes in an input of DPS, in the engine or in the unit of inertial separators. The boundaries and location of these zones are shown in a fig. 4 and 5. In fig. 4 is plotted IPPP, and in a fig. 5 - HPS. Following labels are used for marking of particles, distributed within this planes in fig. 4.: x - a particle which have not entered DPS; ⊗- a particle which has crossed a HPS and ingested by an engine, + - a particle which has not crossed a HPS and ingested by the engine, ● - a particle which has entered in the unit of inertial separators and extracted out of board. In a fig. 5 by label + are designated the particles which has crossed a HPS ingested in the engine.
As it is visible, in fig. 4 and 5, the main part of ingested in the engine particles crosses a horizontal plane. As it has been mentioned, the basic reason why part of dust avoid the unit of inertial separators is the oblique flow and conditioned by him particles displacement toward the lower part of DPS (see fig. 3a, b). These particles direction toward the second stage of clearing is possible by means of installation into flowing path of DPS thin partitions (dividing walls) between central body and inner wall of intake duct. Small part of particles ingested in an engine, has not crossed a HPS. Their trajectories are shown in the fig. 3c. Such particles separation by means of partitions installation is not supposed to be possible.
An analysis executed for different speeds of an oblique flow has shown their essential influence onto DPS efficiency: with oblique flow speed increase a separation efficiency reduces, fig. 6.
The described above character of particles motion is resulted in their irregular distribution in cross sections inside DPS passage. In fig. 7 and 8 it is plotted the particles distribution before the second stage of clearing of 40μ and 320μ sizes at speed of an oblique flow of 18 m/s and 6,8 m/s. The signs + show a point of particle crossing this plane.
As it is visible in fig. 7 and 8, the influence of speed of an oblique flow results in dust displacement in direction of a flow, i. e. in lower right-hand part of DPS (if to look at it in front). Displacement in this direction particles of large size (160μ and 320μ) is stronger, because of its inertial properties and smaller susceptibility to effects of forces of an airflow. Basic part of them passes below the unit of inertial separators and ingest in the engine. The reduction of the sizes of particles results in decrease of their inertial properties and smaller displacement abroad of unit of inertial separators (second stage of clearing).
The analysis of influence of speed of an oblique flow on distribution of particles before the second stage shows, that with reduction of speed of an oblique flow the effect of dust displacement downwards decreases, the structure of dusty airflow becomes more symmetrical concerning a centerline. However the share of large particles passing above the boundaries of the unit of inertial separators increases and as it has been mentioned above, their separation by means of installation of partitions is not supposed to be possible.
For making a confidence an analysis is true, it had been made comparison calculated zones of impact of various sizes particles on a central body DPS (at speeds of an oblique flow 15 - 18 m/s) and zones of erosive wear easy-wearing paint of a central body DPS of helicopter Ka-32, after flight test in a dusty air. The analysis has shown a rather high coincidence of zones' positions and size of obtained by a computational way and as a result of flight tests.

3. Expected improvement of separation efficiency of modified DPS at various operational modes of the helicopter

3.1 Reasons of separation efficiency improvement

To increase a DPS separation efficiency, originally was offered to install in a HPS inside DPS passage thin partitions approximately appropriate on size to zones of particles passing. The assumption was adopted, that the partitions, being thin, do not render influence to an airflow, but are impenetrable for dust particles. The executed research has shown, that at impacts on partitions a particles lose a significant part of its kinetic energy and become much more subject to an airflow, which in a curvilinear section of DPS directs them right to the second stage of clearing. Besides main part of particles is bouncing off in direction of the unit of inertial



a b c

Fig. 5. Distribution of particles ingested in an engine in horizontal plane of DPS symmetry: a - by size 40μ; b - by size 160μ; c - by size 320μ.

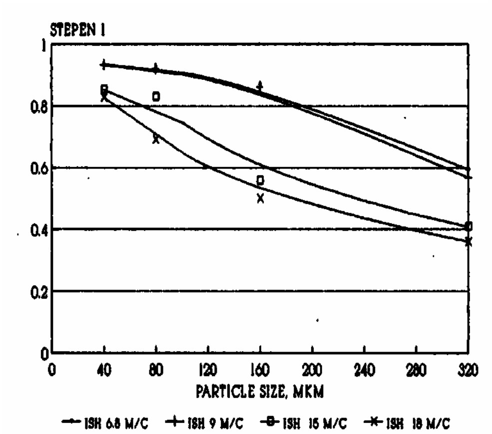
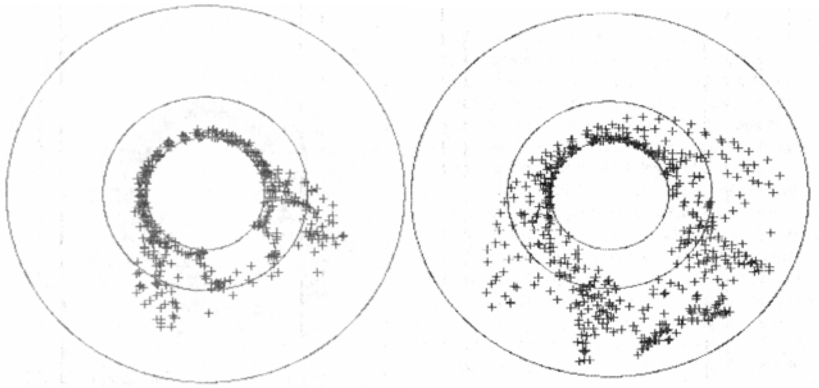


Fig. 6. Degree of clearing of first stage of DPS versus particles size at several speeds of oblique flow.



a b

Fig. 7. Particles distribution before second stage of clearing at oblique flow speed 18 m/s: a - by size 40μ; б - by size 160μ; в - by size 320 μ.

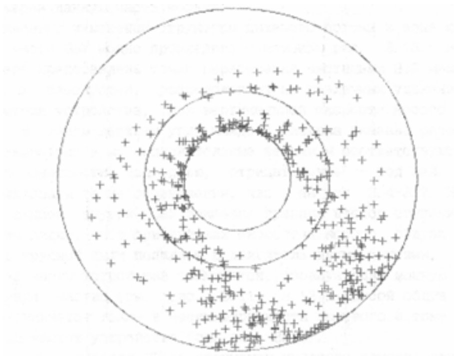
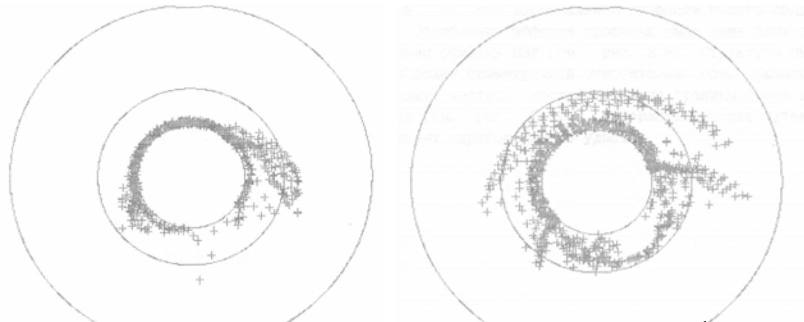


Fig. 7c.



a b

Fig. 7. Particles distribution before second stage of clearing at oblique flow speed 6,8 m/s: a - by size 40μ; б - by size 160μ; в - by size 320 μ.

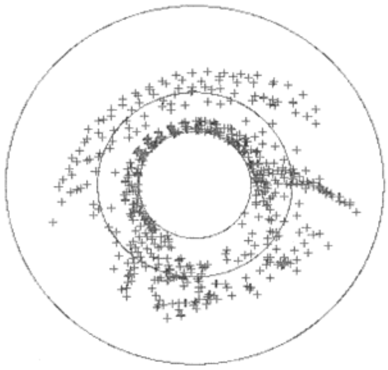


Fig 8c.

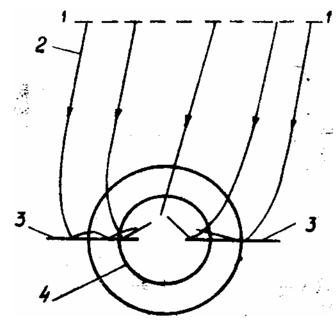


Fig 9. Scheme of particles movement in DPS at partitions presence : 1-plane of initial particles positions; 2-particles trajectories projects; 3-partitions; 4-second stage boundary.

separators, fig. 9. The results are shown in fig. 10 and 11 as relations of a separation efficiency of the first stage to the size of particles at various partitions positions for speeds of an oblique flow 6,8m/s and 18 m/s. Abbreviation "gor per" stands for its horizontal positions and "per per" stands for positions perpendicularly to obligue flow direction. As it is shown, the installation of horizontal partitions essentially increases a separation efficiency of the first stage and this effect amplifies with growth of speed of an oblique flow. It is necessary to mark, that the installation of partitions is especially effective means of increase of a separation efficiency during passing large particles having high inertial properties. And, on the contrary, at hitting of particles by size 40 μ modified and initial DPS have practically identical separation efficiency.

3.2 Selection of partitions optimum angular position and sizes.

With the purpose of further increase of a separation efficiency of the first stage the works were continued, thus within the limits of possible the sizes of partitions were increased, and also the researches by determination of their optimum angular position were executed.
The trajectories analysis shows, that a small part of particles entering the engine, not impact with partitions. So it was decided to increase up to greatest possible their sizes by means of displacement on 10 - 15 mm of a leading edge forwards (against a flow directed to the engine). The results of separation efficiency calculations shows, that any essential increase of a separation efficiency of the first stage has not taken place (the increase has not exceeded 3%).
For selection of an optimum position of partitions it was necessary to determine their efficiency at various angles of the installation. So, position of left partition (if to look at the helicopter in front) was fixed. It was considered, that it is installed in HPS, that is at an angle -90^0. The right of partitions placed under angles 30^0, 45^0, 63^0 (that corresponds to a direction, perpendicular speed of an oblique flow), 75^0 and 90^0 concerning a vertical. The computations were executed for particles by the size 40μ, 80μ, 160μ, 320μ and for speed of an oblique flow of 18 m/s. The latter is stipulated by fact, that at oblique flow speed 18 m/s efficiency of serial DPS is worst. The results of calculations are shown in a fig. 12 as relations of a separation efficiency of the first stage to the size of particles of dust for various angles of partitions installation. As it is visible in fig. 12, the least expedient position is the horizontal position -90^0, 90^0). The most expedient is the right partition installation at an angle 45^0. For more in-depth study is submitted fig. 13, which shows the relations of a separation efficiency of the first stage to an angle of the installation of right partition (at a fixed left partition position). On a horizontal axis in brackets the angle between speed of an oblique flow and partition is indicated. As it is shown in fig.13, the optimum arrangement of partitions depends on the size of particles: with size of particles increases the best angle between direction of an oblique flow and partitions reduces. So, for particles of size 40 μ the best angle makes about 90^0, for 80 μ - 80^0, for 160 μ and 320 μ - 72^0. It is necessary to mark, that curve in region of a maximum passes almost horizontally. It allows to recommend to design arrangement of partitions by such, that at basic operational modes of the helicopter the value of angle between partitions and direction of an oblique flow makes 72 - 80^0.
For confidence of this recommendation the monitoring calculation of the first stage separation efficiency was made at an angle of the installation of right partition 45^0, left — -105^0 concerning a vertical. The outcomes of calculation are shown in a fig. 14. As it has been seen above the maximum of separation efficiency was obtained at angles -90^0, 45^0. So the left partition has made an angle 63^0 concerning oblique flow direction, that is close to an optimum for large particles. However a separation efficiency at passing small and especially medium-size particles (80 μ) there were not maximum. Therefore even before fulfilment of the calculation it was possible to expect an increase of a separation efficiency, as it was obtained. The recommended angles of the installation have supplied a peak efficiency DPS.

3.3 Expected efficiency of modification of the first stage

The high DPS separation efficiency is impossible without effective activity of each stage. Let's designate as η_{10} and η_{20} degrees of clearing of the first and second stage of serial DPS. Then the separation efficiency DPS as a whole equal $\eta_0 = \eta_{10} \cdot \eta_{20}$. And quantity of dust passing in the engine, is proportional to $\left(1-\eta_0\right)$ or

$$\left(1-\eta_{10} \cdot \eta_{20}\right).$$

Let's assume, that by the expense of the installation of partitions the of the first stage has become η_1, and one of the second, since it was not modified, did not change. Then quantity of the dust passing in the engine through modified DPS, is proportional to $\left(1-\eta_1 \cdot \eta_{20}\right)$. Let's designate through K the following ratio:

$$K = \frac{1-\eta_{10} \cdot \eta_{20}}{1-\eta_1 \cdot \eta_{20}},$$

which shows, how many times will decrease quantity of dust, going into the engine after modification DPS, in comparison with initial DPS. Approximately in as much times will increase engine's accumulated burnt time in a dusty air.

This parameter can be only esteemed, as value η_{20} is not known precisely. However, in the similar DPS of the helicopter Mi-24 at passing of large particles the value η_{20} makes up 0,8. In

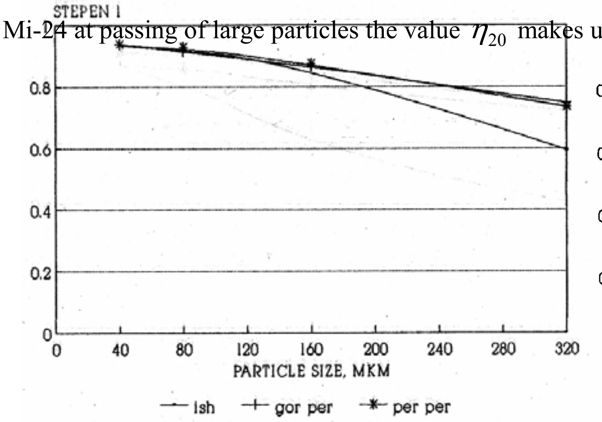


Fig. 10. Separation efficiency of the first stage of DPS versus size of particles at speed of an oblique flow 6,8 m/s (serial DPS and at partitions presence in positions horizontal and perpendicular to oblique flow direction).

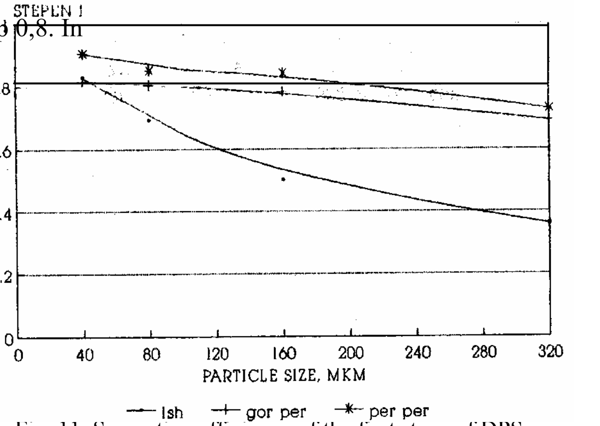


Fig. 11. Separation efficiency of the first stage of DPS versus size of particles at speed of an oblique flow 18 m/s (serial DPS and at partitions presence in positions horizontal and perpendicular to oblique flow direction).

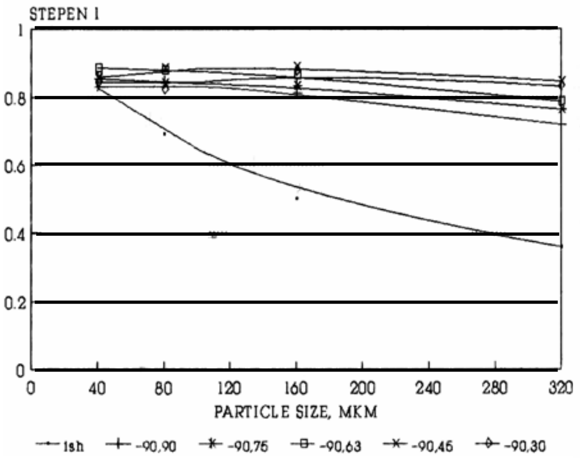


Fig. 12. Separation efficiency of the first stage of DPS versus size of particles at fixed an position of left partition and several positions of right partition. Oblique flow speed is 18 m/s.

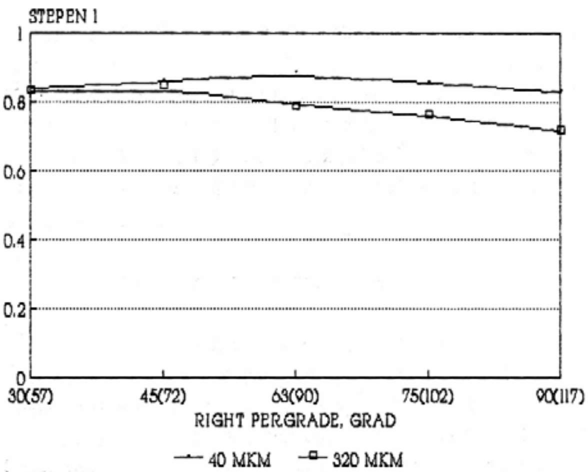


Fig. 13. Separation efficiency of the first stage of DPS versus right partition angular position at fixed position of left partition for particles by size 40µ and 320µ. Oblique flow speed is 18 m/s.

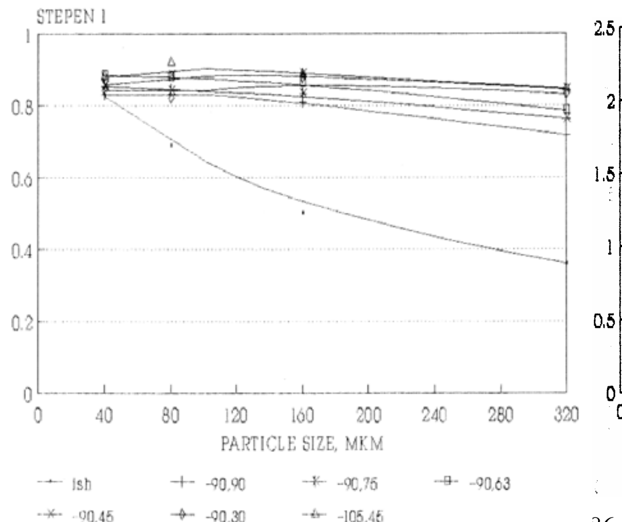


Fig. 14. Separation efficiency of the first stage of DPS versus size of particles at several partitions' angular positions including optimum arrangement, -105^0, 45^0, at oblique flow speed 18 m/s.

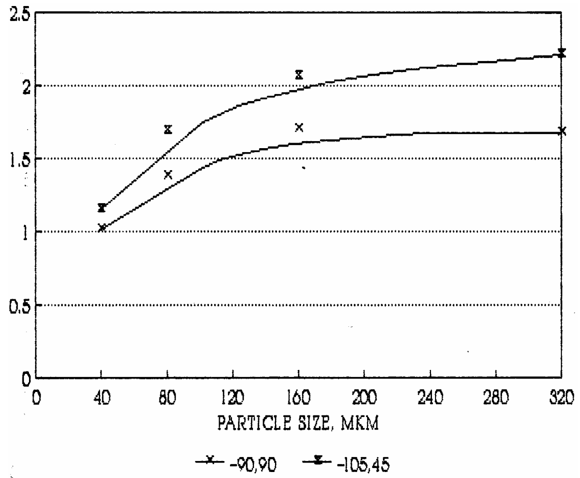


Fig. 15a. Increase (times) of an engine operating time in dusty air environments at assume that a separation efficiency of the second stage is 0,8 and at horizontal and optimal partitions' arrangement.

this case increase of engine running time in a dusty air can be evaluated as it is plotted in fig. 15a, which shows change of value K versus the size of particles of dust for two versions of the installation of partitions: horizontal and optimum. In fig.15 it is visible, that the engine running time increase in a dusty air at optimum version of the partitions installation is much greater than one at horizontal , especially at passing large size particles. However, the results of special flight tests of the helicopter Ka-32, which were spoken above, shows that separation efficiency of the second stage more probably makes up value about 0,5. In this case upgrade of the first stage will be less effective, (see fig.15b), as the second stage lets to pass in an engine a lot of dust. Such a case will require adaptation (change of geometry) second stage, and/or increase of air flow-ratio of the scavenge system.

4. Outcomes of tests, of serial and modified DPS

The basic goals of an experimental research consisted of the following.

1. To determine a separation efficiency serial DPS of the helicopter Ka-32 with account of its location on the helicopter (at the starboard or port engine), fig.16, at entry in its dust particles of a various size at various operational modes of the helicopter (at various speeds of an oblique flow).
2. To determine a separation efficiency modified DPS (by the installation of partitions) at entry in its of dust particles of a various size at various operational modes of the helicopter.
3. To complete the recommendations for DPS modification and conclusion about expediency of its introduction.

To achieve the goals was created experimental bench with special dusty chamber. The scheme of a bench is shown in fig.17. The features of a bench are following.

1. The bench allows to carry out tests of DPS.
2. The bench provides required speed and direction of an oblique flow (up to 15 - 18 m/s).
3. The bench provides required distributions, and speed of dust particles.
4. The required speeds of an oblique flow was created by the engine TV3 -117. Therefore at the given bench the speed of an oblique flow was directly proportional to the engine air-flow ratio and at engine's power setting maximum oblique flow speed achieves 15-18 m/s.

4.1 The results of tests of serial port and starboard DPSs

On the helicopter Ka-32 the arrangement of central bodies attachment struts (racks) of portside DPS and starboard one is not identical one another concerning an oblique flow direction (fig.16). The conducted tests have shown, that it renders essential influence to DPS' separation efficiency. So the results of portside and starboard DPS tests are shown separately. The separation efficiency of port DPS for dust particles of a various size is shown in table 1.

Table 1.

Power setting	Separation efficiency of serial port DPS, in %, at passing particles by the size	
	40 - 70 μ	140 - 200 μ
Maximum	58,5	37,0
Nominal	63,1	42,7
2-nd cruise	64,2	45,9

As it is visible DPS in table 1, reduction of the size of passing particles and power setting increase a separation efficiency η. It is explained by smaller displacement of particles downwards, abroad of inertial separators unit. The retests gave rather good recurrence of outcomes, the relative error does not exceed 2%.

Separation efficiency of starboard DPS is shown in table 2.

Table 2.

Power setting	Separation efficiency of serial starboard DPS, in %, at passing of particles by the size 140- 200 μ
Maximum	53,9
Nominal	55,4
2-nd cruise	57,1

As expected, the separation efficiency with the starboard DPS has appeared much above, than port one, that is explained by rather favourable arrangement of racks, which actually have executed the same role, as offered partitions. Thus, if in the mentioned above tests helicopter Ka-32 DPS had been installed on the starboard engine, the outcomes would have been considerably better. Increase of a separation efficiency at reduction of power setting is connected with change of speed of an oblique flow, which on the given bench, as was indicated, is proportional to the air-flow ratio through the engine.

4.2 The modified DPS tests results

As in the helicopter offered partitions and the racks will represent a unit, and their arrangement (at port and starboard engines) concerning an oblique flow direction will be identical, it was being tested only one DPS. To the basic outcomes of tests it is possible to attribute the following.

1. The offered partitions at all operational modes have essentially increased a separation efficiency of DPS. The comparison is made with initial port DPS and is shown in table 3.

Table 3.

Power setting	Separation efficiency initial port/starboard DPS, in %, at passing of particles by the size	
	40 - 70 μ	140 - 200 μ
Maximum	58,5 /68,4	37,0 / 68,1
Nominal	63,1 /68,5	42,7 / 60,1

2-nd cruise	64,2 /67,9	45,9 /61,6

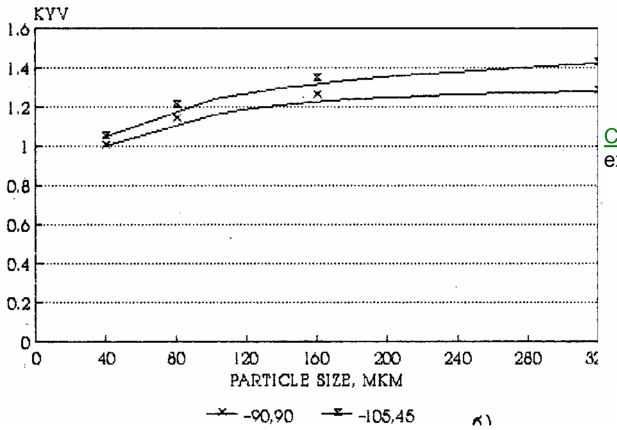


Fig. 15b. Increase (times) of an engine operating time in dusty air environment versus particles size at assume that a separation efficiency of the second stage is 0,5 and at horizontal and optimal partitions' arrangement .

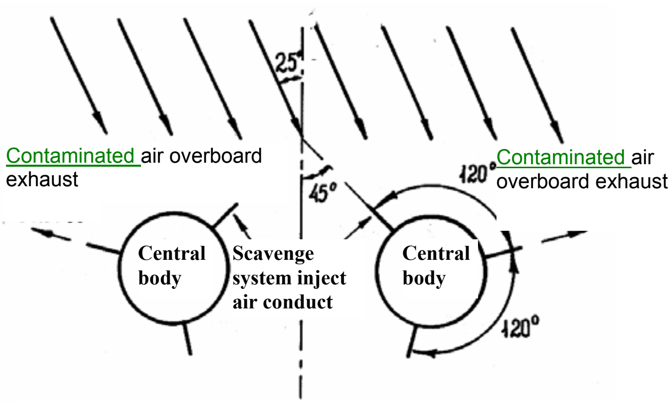


Fig. 16 Scheme of port and starboard DPS arrangement at helicopter Ka-32 (view in front)

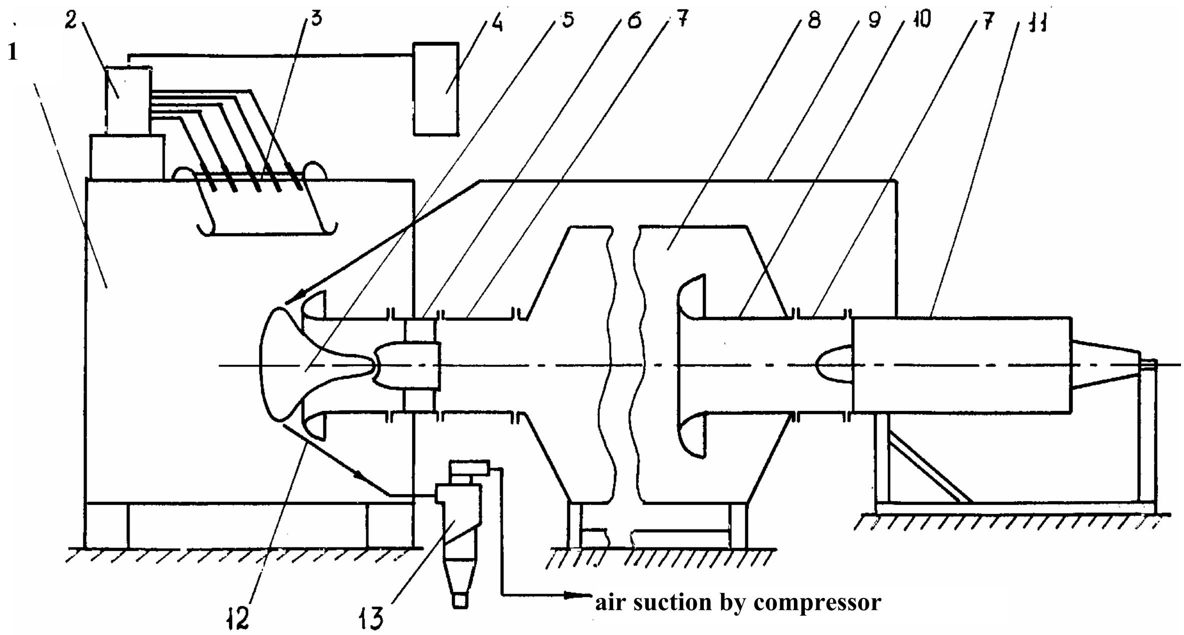


Fig. 17 Tests bench for DPS trials scheme: 1-dusty chamber; 2,3-dust distribution device; 4-dust dosage devise; 5-DPS; 6,7-elongation duct; 8 – receiver; 9-compressed air (scavenge system inject air) conducting line; 10-engine inlet duct; 11-turboshaft engine TV3-117; 12-extracting duct of scavenge air with entrained dust particles; 13-dust collector(dust-air separator).

2. As it is visible in table 3, the DPS separation efficiency practically has ceased to depend on power setting and, accordingly, on speed of an oblique flow in range 12 - 18 m/s.
3. At passing large particles modified DPS efficiency is a little bit lower. It can be stipulated, by fact, that a part of large size particles impacts on an upper inside part of a central body, and bouncing above the upper edge of the unit of inertial separators (see fig. 3c) and their separation by means of partitions installation is not possible. In connection with stated, possible way of further DPS efficiency improvement is extension of an upper edge of the unit of inertial separators on 8 - 10 mm.
4. The erosive wear of purposely covered paint on partitions made it possible to update their sizes.
5. As a whole, the erosive wear of paint coating on the unit of inertial separators, partitions and central body confirms described above character of motion of dust particles.

5. Proposals for DPS upgrade and evaluation of its introduction expediency

Executed computational and the experimental researches have allowed to develop the basic proposals for DPS of given a type upgrade.

1. A major direction of upgrade is the installation inside DPS thin partitions, or that is more rational, usage instead of them the racks of attachment of a central body, extended and located on other.
2. Possible further way to increase a separation efficiency of DPS is the extension up on 8 … 10 mm the upper edge of the second stage of clearing, that will allow to direct to the unit of inertial separators a main part of particles passing above it. The lower part of the unit of inertial separators should remain without changes.
3. The increase of a separation efficiency can be reached also by increase of scavenge system air-flow ratio. Executed earlier research at Moscow Helicopter Plant named after M. Mile have shown, that the increase of the scavenge system specific air-flow ratio (an air-flow ratio of scavenge flow as percentage of the engine air-flow ratio) from 1 % up to 1,5 % results in increase of a separation efficiency of the second stage at passing of large dust from 57 % up to 81%.

It is known, that at a high initial separation efficiency even small its increase gives essential increase of engine's accumulated burnt time in a dusty air. It is stipulated by large relative reduction of mass of dust, ingested in the engine. As it was shown above, the helicopter Ka-32 DPS upgrade only by the expense of the installation of partitions will cause to increase of accumulated burn time in a dusty air in 1,2 - 1,7 times. And the greater effect is reached on most erosive dangerous (high power settings) and at hitting of large size dust particles.

Said above evidently proves expediency of the installation of partitions and modified DPS implementation in the helicopter Ka-32.

Conclusions

1. Basic reason of reduction of a separation efficiency DPS of given a type is an oblique flow mainly creating by main rotor of the helicopter.
2. Main direction of increase of a separation efficiency is the installation in a flowing path DPS of cross-sectional (transversal) partitions. It is established, that for the helicopter Ka-32 the optimum angles between partitions and oblique flow direction make 72 - 80^0. In this case degree of clearing of the first stage of DPS makes 85 - 92 % at passing of particles by size from 40μ up to 320μ.
3. The bench tests of DPS have confirmed high efficiency of the installation of transversal partitions in conditions of an oblique flow: at passing particles of size from 40μ up to 320μ at various power settings the degree of clearing of DPS makes 60 - 68%.
4. The evaluations show, that the increase of running time of the turboshaft engine of helicopter before removal in operation in a dusty air by the expense of the installation of transversal partitions will makes 1,2 - 1,7 times.
5. Further increase of DPS efficiency on the helicopter Ka-32 is possible by the expense of the extension up on 8 - 10 mm the upper edge of the unit of inertial separators and increases of the air-flow ratio of scavenge system.

References

1. С. Соу. Гидродинамика многофазных систем, - М.: МИР, 1971.
2. Белоцерковский С.М Тонкая несущая поверхность в дозвуковом потоке газа. - М.: наука, 1965.
3. Федоров Р.М., Шимчак Я. Расчет течения воздуха в криволинейном канале ПЗУ методом дискретных вихрей. – В кн.: Научно-методические материалы по вопросам конструкции и систем управления силовых установок. – М.:ВВИА, 1982г.