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Editor
Komarytskyy M.L.
Ph.D. in Economics, Associate Professor

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LOCAL WEAR MECHANISM IN THE MODERN CAR ENGINES DUE TO DUST CENTRIFUGATION IN INLET SYSTEM

Khrulev Alexander
Ph.D, senior researcher
International Motor Bureau
Ukraine

I**ntroduction**. It is known that abrasive particles in the size range of 5-30 microns cause abrasive wear of friction pairs, and the size of 10-20 microns is the most destructive for engine parts [1]. However, the question remains which processes in the intake system can be affected by particles from the specified range if air filters in operation do not capture all particles.

It is obvious that any particle with mass, when changing the direction of air flow, can lag behind the current lines as a result of the action of inertial forces. In this case, we should expect a redistribution of particles over the channel cross section when the flow turns. It means, the particles will be displaced by inertia towards a larger radius, i.e. particle centrifugation and their local redistribution will occur [2].

Indeed, such design elements, in which centrifugation of abrasive particles is possible, are quite widely used in the intake systems of modern internal combustion engines [3]. These are various distribution pipes for supplying air to the rows of cylinders, as well as manifolds with pipelines supplying air directly to the cylinders (Fig. 1a).

Aim. The purpose of the work is to determine the uneven distribution of dust particles in the branching channels of the intake system of a car engine. To achieve this purpose, it is necessary to simulate the flow of air with dust particles in branching elements of typical intake manifold.

Materials and methods. The simulation was carried out using the ANSYS software package [4] in several stages [5]. First, to construct the finite element mesh, the element size of the flow region was set to 4 mm, after which the entire region was divided into elements with this size. Next, the number of layers of the boundary layer was specified (12), then the dimensions of the boundary layer elements were obtained. After this, a mesh with 168267 elements was generated (Fig. 1b).

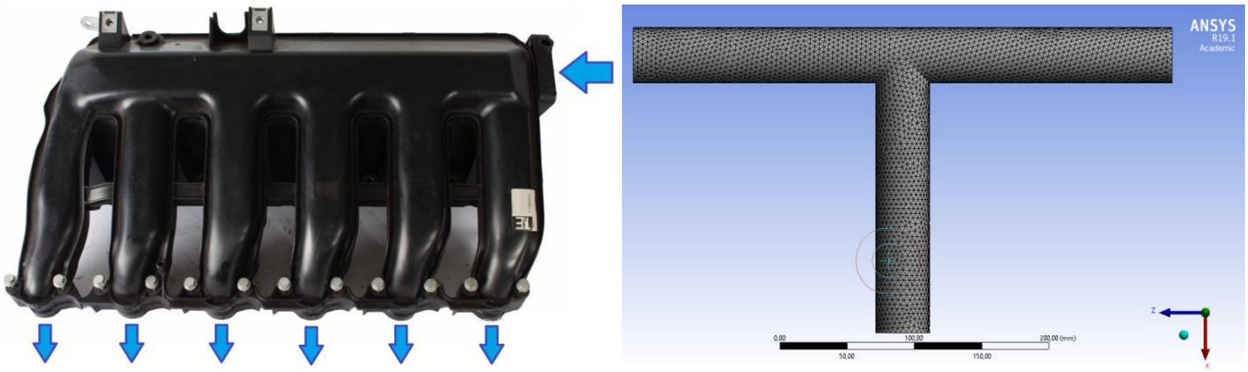

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Fig. 1. The engine intake manifold, in which we can assume the presence of centrifugation of dust particles when the air turns into the side outlets (a), and a finite element model of the flow with branching (b).

The calculation model was created in the standard Fluent module of the ANSYS software package, which meant: choosing a material (there are two of them in the task: air and dust particles), choosing a flow model, setting boundary conditions, and setting up the calculation module (solver).

When calculating the air flow, the standard k-e turbulence model was specified [6]. As boundary conditions at the inlet, the air flow velocity was set (in the range of 5-20 m/s), which was assumed to be the same along the inlet section and directed normally to it. The air flow rate in the outlet sections was assumed to be the same.

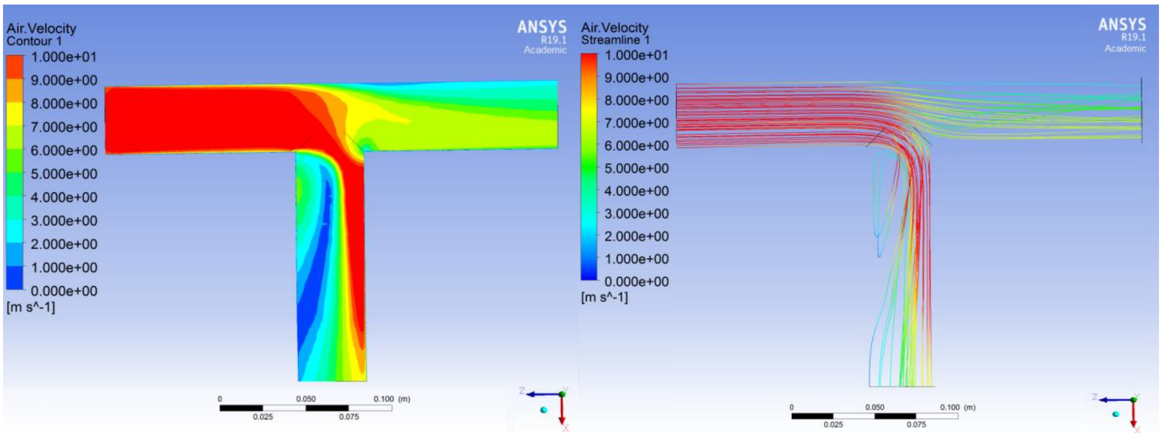

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Fig. 2. Velocity fields (a) and air flow lines (b) in branching pipes at an inlet velocity of 10 m/s

Results and discussion. As a result of the calculation, fields of pressure, velocity, temperature, as well as air flow lines were obtained (Fig. 2). At the next stage of the calculation, a two-phase flow model was added using the Eulerian calculation module. As the boundary conditions at the outlet for this model, only the pressure obtained when calculating the air flow is specified.

As a result, the problem is solved in the 2nd approximation, for which the following boundary conditions for air are specified: at the inlet it was the velocity, and at the outlet it was the pressure obtained at the 1st stage of the calculation. For dust particles at the inlet, their size and mass flow are specified (the velocity of the particles at the inlet was assumed to be equal to the air velocity).

Next, the trajectories of movement of dust particles are determined (Fig. 3).

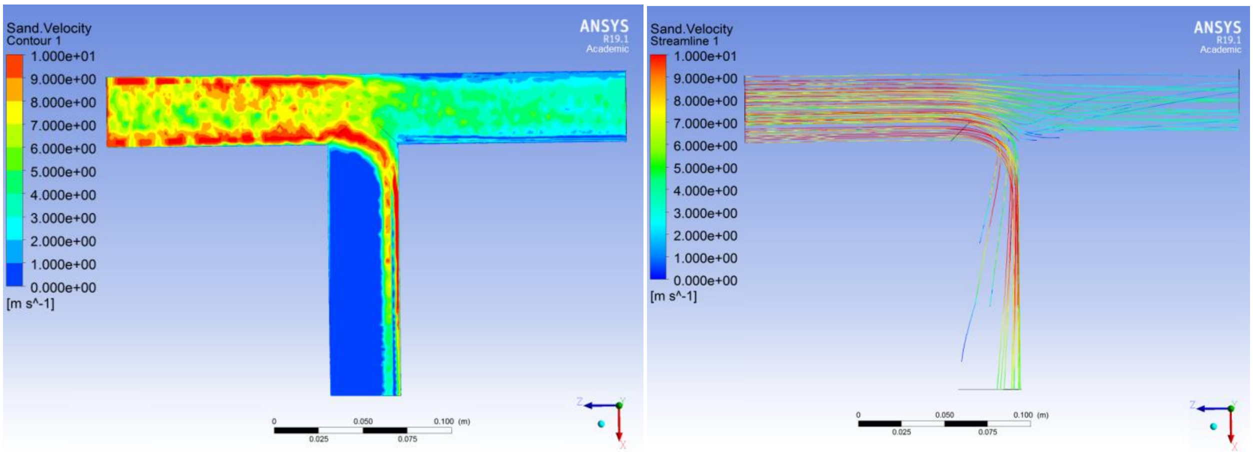

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Fig. 3. Velocity fields (a) and trajectories (b) of particles 10 μm size in air, the movement of which is presented in Fig. 2.

Then, using the built-in function of the calculation module, the number of particles and their speed (mass flow of dust), as well as the specified air flow rates at the direct and lateral exit are determined.

The obtained data from modeling a 2-phase flow in the range of air velocities of 5-20 m/s with a particle size of 5-30 μm shows that small particles (about 5 μm or less) move along air flow lines and do not detect centrifugation when the flow turns in lateral outlet (Fig. 4). At the same time, the larger the particle size and air velocity, the more particles do not enter the side outlet, “slipping” by inertia directly through the straight pipe. This conclusion coincides with the results of calculating the radial motion of a particle, including quantitative data on the particle redistribution [7].

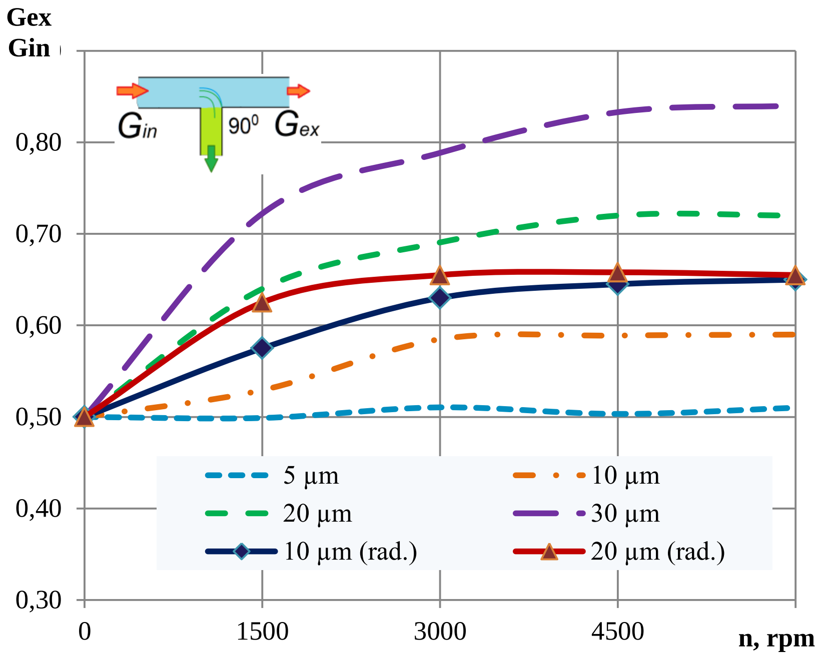

Fig. 4. Relative to the total number of particles at the inlet, the number of particles at the exit from the direct channel with dependence on the operating mode of the engine for various particle sizes, in comparison with the results of calculating the movement of particles along the radius (rad) [7].

Practice shows that due to dust centrifugation in branching channels, local abrasive wear in engines is possible [1]. This wear is especially pronounced even with minor breakage of engine maintenance regulations and untimely replacement of the air filter.

A strong influence of the particle inertia on their redistribution along the channels is observed in some designs of intake manifolds. Compact designs using cylinder recharging by changing the length of the channels (Fig. 5a) are characterized by high air velocity in the manifold.

As a result, so much dust can accumulate in one cylinder that the life of its parts (and the internal combustion engine as a whole) due to abrasive wear will decrease many times (Fig. 5b) compared to other cylinders, the life of which, on the contrary, will only increase. This can lead to premature internal combustion engine failures due to extremely severe abrasive wear in only one cylinder, even within the manufacturer's warranty period.

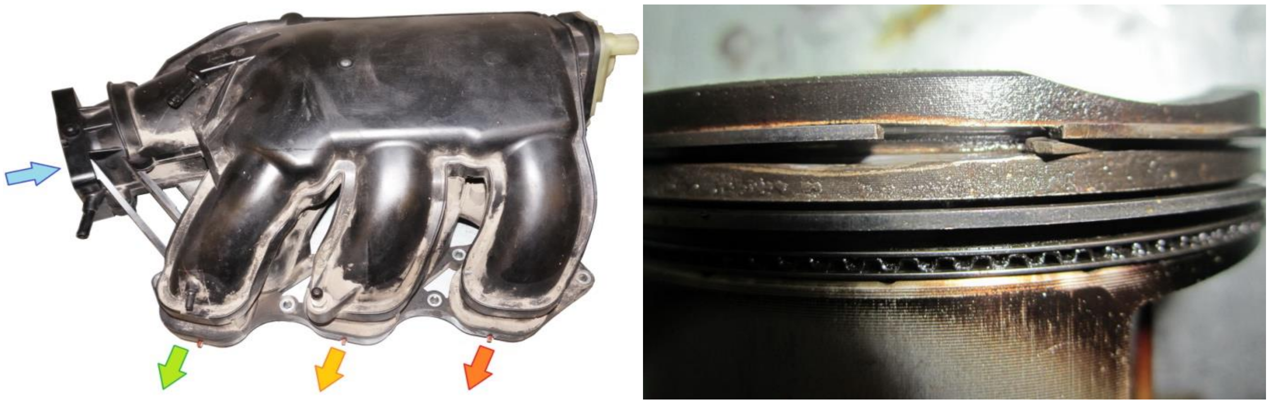

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Fig. 5. Intake manifold with variable channel length of a V-6 gasoline engine (a) and extremely strong local abrasive wear of piston No. 1 over 80,000 km [1], while there is almost no wear in other cylinders (b).

Conclusions. The study was the first to show that the durability of an internal combustion engine may depend not only on the efficiency of air filtration and wear resistance of parts, but also on the design of the engine intake system.

The developed model of a 2-phase flow of air with dust in the intake channels describes and explains the mechanism of the fault occurrence and development for certain types of operational damage due to abrasive wear. So, the model helps to determine the cause of the uneven local abrasive wear of parts of the cylinder-piston group and valve mechanism observed in practice in individual internal combustion engine cylinders, when more than 85% of incoming particles are locally concentrated directly downstream.

In addition, the study has found that local abrasive wear is actually an another wear mechanism, which depends on the number and size of particles passing through the air filter, the configuration of the intake system and engine operating conditions. This feature of the impact of particles must be taken into account when conducting expert studies of the engine technical condition in order to correctly determine the failure causes associated with breakage of operating conditions.

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