EXPERIMENTAL AND COMPUTATIONAL RESEARCH OF NEW FILTER INNER LINEAR DESIGN

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Abstract. Air filters were designed for air cleaning. They extend the life of automotive and industrial devices, because they clean the incoming air from dust and other small particles. For example, small sand particles, ceramics and other abrasive particles. This study was based on the air filter construction, because for big air filters it is necessary to use some internal elements to increase the filter strength. This element is called the inner liner. The additional element changes the air flow trajectories and may affect the engine combustion parameters. To make sure that the vehicle characteristics will be the same or better, it is necessary to make experimental research and modelling for the designed elements. The air filter inner liner element was created using "Solid Works 2014" software and air flow modelling was done using "Flow Works" pocket. The experimental research was done using the "AEROLAB" wind tunnel. Exploring various options of inner liner models the best solution for the vehicle air filter element has been found. The newly designed element became lighter, stronger and allowed greater permeability.

Keywords: air filter, inner liner element, air flow.

Introduction

Many scientists investigate air flow calculations, because sometimes it is impossible to measure the air flow trajectories. The information about inner liner elements was found during the overview, which supports the importance of their mechanical stiffness and control of the air flow trajectories. However, this element may affect the permeability of the air filter, because it encloses the filtering material.

This study was based on the air filter construction, because the heavy weight vehicle air filter size is quite big. Therefore, it is necessary to use some internal elements to increase the strength of the air filter. This element must be strong enough that the force produced by the incoming air would not collapse it. However, it should not be forgotten that the additional element changes the air flow trajectories and permeability. In order to improve the new filter characteristics, it is necessary to make it stronger and with better permeability using the same type of air filtering material.

Vehicle filter construction review

The vehicle air filter consists of several elements [1]. Usually it consists of 5 items (Fig. 1). Some of them do the sealant function, filtering function and others support the structure and control the air flow.

After reviewing the existing air filters patents it was found that that usually various air filter plastic components or a complete structure are patented. Our research work objective is to create and develop the air filter inner liner element, which has big influence on the air flow for allowing better use of the filtering material. Searching for similar structures of the new idea three patents were found. In the US patent No. 3778985, 1973-12-18 [2] the inner liner element was described, which was twisted into a spiral and made from plastic via the form of a hollow cylinder shape. In JP patent No. 2011245482, 2011-12-08 [3] the inner linerelement was described, which is cone shape form with holes of the chain type. In the US patent No. 2009249756, 2009-10-08 [4] a cylinder shape air filter inner liner element was described, which has different diameters at the ends. This inner liner element surface has a perforated frame with irregular rectangular holes from metal or other material.

The known air filter inner liner element deficiencies are that the air flow distribution is not identical in all filtering material surface area. The bad air flow distribution does not ensure uniform function of the absorbing air cleaning, because not all filtering material surface area participates in this process. The filtering function is only partly used for cleaning. This reduces the filtration efficiency, because the filtration material surface area is not uniformly contaminated. This reduces the filtering material lifetime.

Fig. 1. **Air filter construction [1]:** 1 – radial seal gasket; 2 – flexible outer edges; 3 – filtering material; 4 – inner liner; 5 – end cap

Vehicle air filter inner liner element modeling

The air filter inner liner element was designed for heavy weight vehicles. This choice determined the size of the air filter and difficult working conditions. Using "Solid Works" software in computer environment a lot of different design inner liner elements were developed. According to the air filter manufacturer requirements and existing patented structures only one option, which showed the best calculation results, was chosen. The new design inner liner was compared with the existing one (used in "DAF" company air filters). This selection is shown in Fig. 2.

a) b)

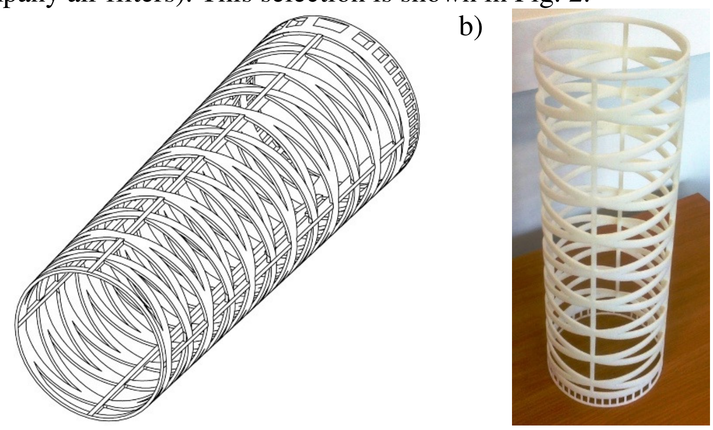

Fig. 2. **New design inner liner element:** a – 3D model; b – printed model

The air flow and stiffness calculation results are shown in Figure 3. The calculations show that the designed inner liner element is 15 g lighter and has 4 times lower displacements compared with the "DAF" air filter inner liner element. The flow calculations showed that the vehicle air filter box design was not very good. First of all, the air intake hole was very close to the outlet hole. Therefore, the air flow travels to the shortest path and does not use all area of the air filter box. Also, the air intake hole is designed to avoid creating vortices. Therefore, the incoming air does not use all area of the air filter box. The inner liner element with increased permeability was chosen. The designed inner liner element (Fig. 2) increased the area of the filtering material by about 10 %, which creates lower resistance for the vehicle air intake system.

a) b) c)

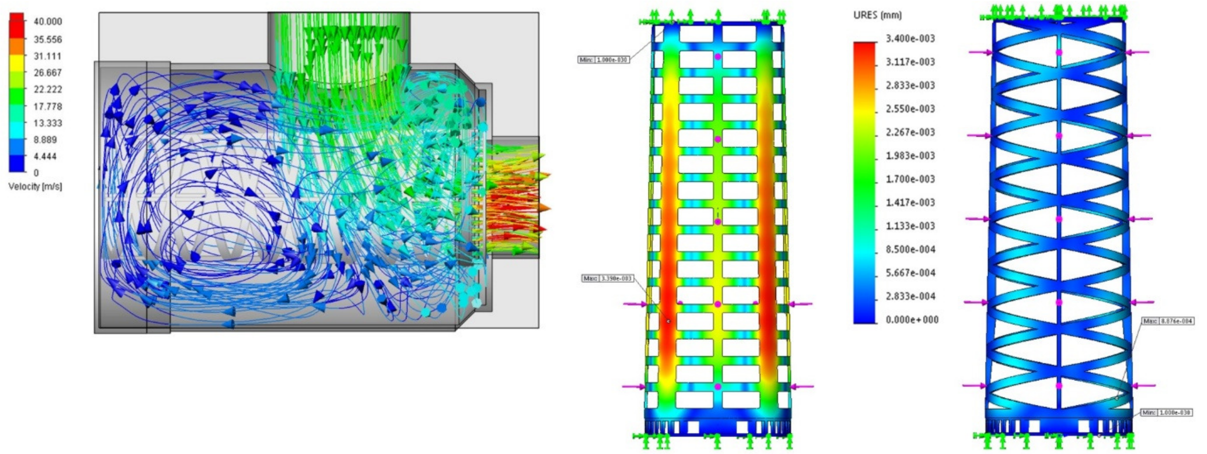

Fig. 3. **Air flow and rigidity calculation results:** a) – air flow distribution in the vehicle air filter box; b – displacements of the inner liner element used in “DAF” company air filters; c – displacements of the new design inner liner element

Experimental research of air filterswith different inner liner elements

The air filters and air filter box (housing) models were made for the experiment. These models were 2 times smaller than the real ones. The measurement results for two filters were compared. One with the inner liner element used by the “DAF” company, and the second one with the new design inner liner element. The measurements were made using the “AEROLAB” wind tunnel [5] (Fig. 4a) and the static pressure probe with accuracy of ±0.005 mbar. The wind tunnel and models are shown in Fig. 4b.The wind tunnel is capable of reaching the air flow speed of 45 $m \cdot s^{-1}$ at the inlet. This filter requires debit of 0.45 $m^3 \cdot s^{-1}$, which corresponds to 18 $m \cdot s^{-1}$ speed at the inlet. Because the model size was reduced two times, to maintain the same Reynolds number the speed was increased to 36 $m \cdot s^{-1}$, which is at 80 % power of the wind tunnel.

a) b)

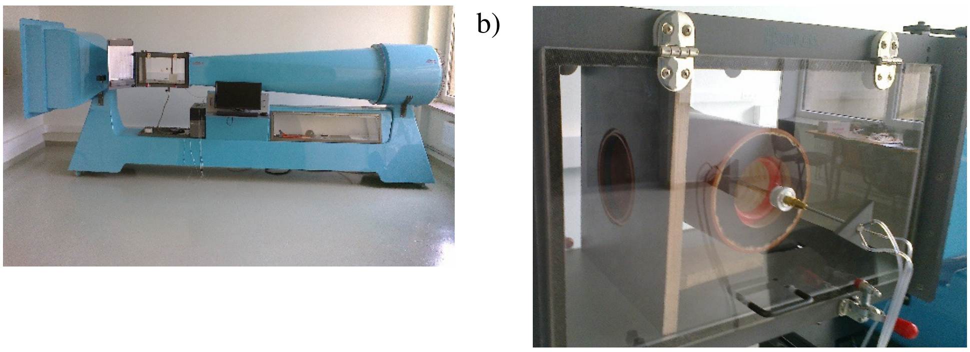

Fig. 4.**Test stand for measurements of different air filters:** a – “AEROLAB” wind tunnel; b – air filter housing model with installed air filter model

Usually air filter manufacturing companies make measurements of the debit or static pressure dropbetween the inside and outside of the filter [6; 7]. In our case, the following tasks were selected:

1. To measure the pressure drop along the filter, when the filtering material is clean;
2. Contaminate the filters via the same conditions with certified dust;
3. To measure the pressure drop along the filter, when the filtering material is dirty.

During the experiment the pressure drop was measured. The measurements were carried out using a special measuring probe. The scheme of these measurements is shown in Fig. 5. This figure shows the air filter box model with inserted air filter model. Here the incoming air flow crosses the air filter material, inner liner element and moves out. Fig. 5(b) shows how the measurement was done. The probe, which was inserted into the center of the model, was sliding along the air filter center line. The probe location was measured between the air filter box bottom and probe tip. The measured distance is marked in Fig. 5b and marked as "Probe distance".

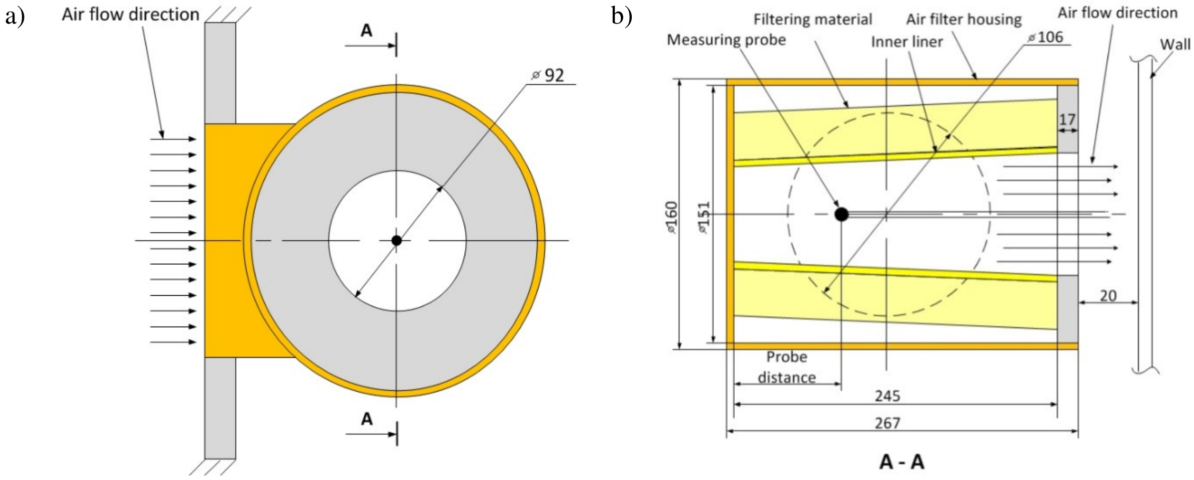

Fig. 5. **Air filter box model with installed air filter model:**
a – side view; b – cross section of air filter housing

In Fig. 6 the measured results of the pressure drop are shown. The measured air filter has the same air filtering material, with the same plot area. However, they have different inner liner elements. In both filters the pressure drop increases towards the end part of the filter. When the wind tunnel power is increased from 50 % up to 80 %, the slope of the pressure drop along the filter rises. When comparing air filters with different inner linearelements, the higher static pressure drop is observed in the air filter with the inner liner elementused by the "DAF" company. This indicates that less air flow passes through it.

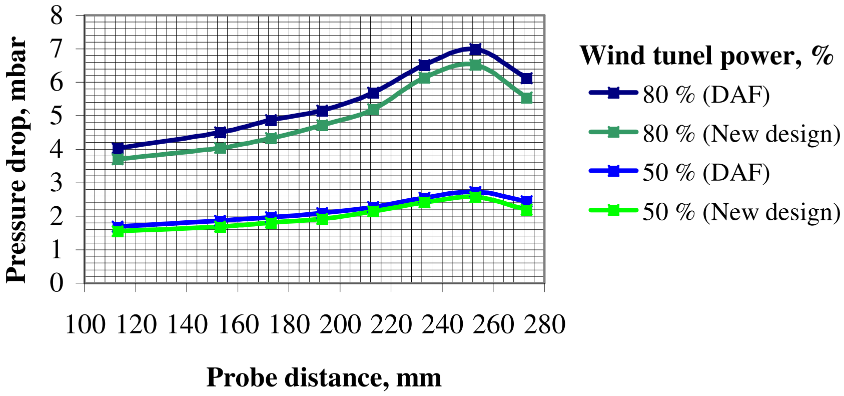

Fig. 6. **Pressure drop of air filters with different inner liner elements dependency on probe location at thepower of wind tunnel by 80 % and 50 %**

Contamination process of air filters with different inner liner elements

After measurements the filters were evenly contaminated with test dust (Fig. 7a). The test dust is made by "PTI Powder Technology, Inc."[8] and certified by the ISO 12103-1, A4 standard. The dust has different sized grains. For contamination "Coarse" type dust was used.

The contamination machine working principle is shown in Fig. 7b. The fan elevates and blows the dust, which flies around in a closed chamber. This contamination method allows to have the same conditions for both air filters. If the broaching method were used, the permeable air filter would catch more dust than the other and further measurements would be incorrect. During contamination the same quantity (60 ml for each) of dust were used. The contamination process took 30 minutes for one air filter. Before the second air filter contamination, the working chamber and the filter box model were thoroughly cleaned.

After the contamination process both air filters look like the same. Test dust mainly settles on the filtering material surface in front of the intake hole. Also more test dust sediments were observed at the opposite side of the filter. Everywhere else the sediments were very small. The contaminated air filter model is shown in Fig. 8.

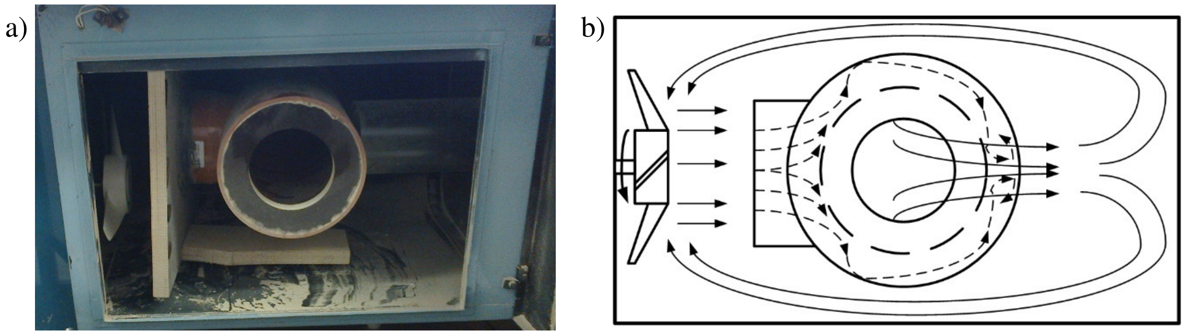

Fig. 7. **Contamination machine and its working principle:** a) contamination machine working chamber; b) contamination machine working principle

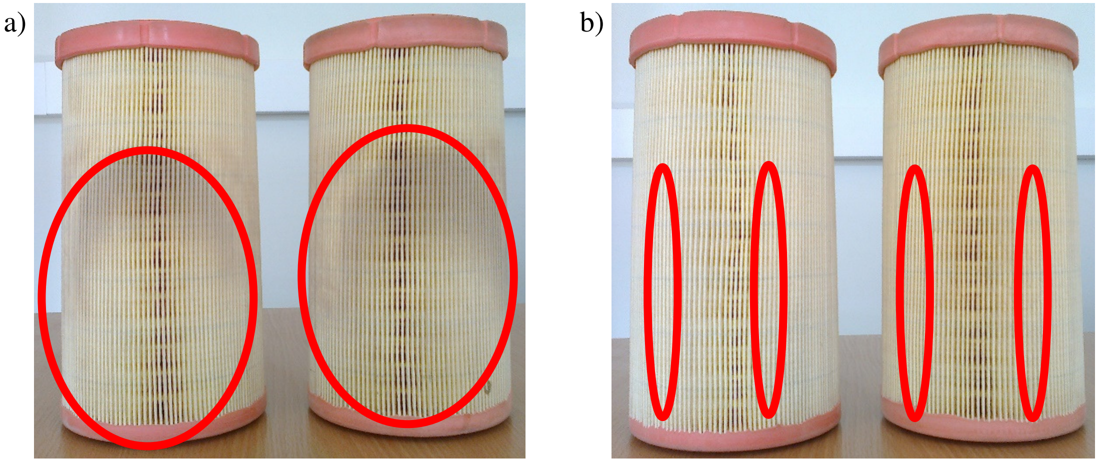

Fig. 8. **Contaminated air filter model:** a – front view; b – opposite side; round markers for contamination zones

Measuring results and discussion

The contaminated air filters were tested in the wind tunnel. The most visible measuring results were obtained at the wind tunnel power of 80 % (Fig. 9). Comparing the air filter measuring results it was found that the pressure drop increased by 1.1-1.2 % with measurement accuracy of 0.07 %.The air filter with the new design inner liner element had slightly better air flow permeability. That means that in this case the greatest impact on the air flow permeability is from the inner liner element.

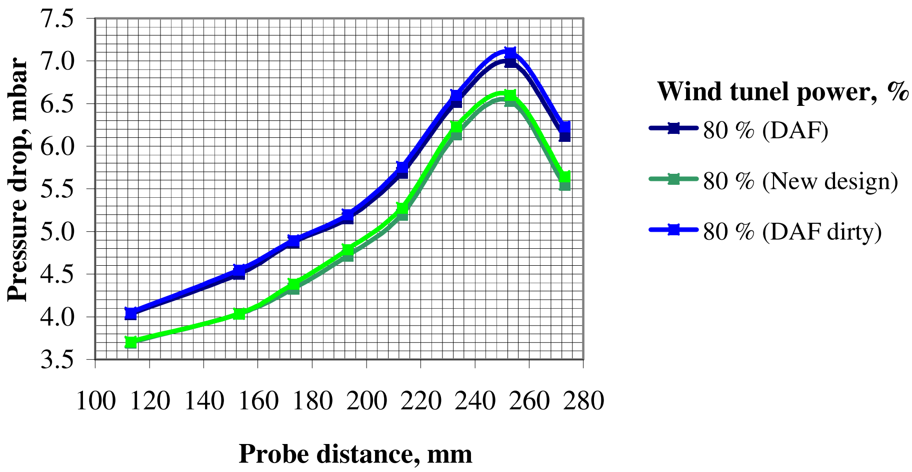

Fig. 9. **Pressure drop of clean and dirty air filters dependency on probe location at the power of wind tunnel by 80 %**

These experiments show that when the wind tunnel power is at 80% the difference between clean and dirty air filters is about 9.4 %. This result indicates that the new design inner linear element is significantly better than that used in the “DAF “company air filters. Also more experiments must be performed, including measurement of all spectrum of pressure inside the air filter and accurate debit measurements. This must be done not only for clean, but also for dirty air filters.

Conclusions

1. The new construction inner liner element has about 4 times better stiffness, comparing with the inner liner element used by the “DAF” company.
2. Comparing with the inner liner element used by the “DAF” company, the new construction inner liner element allows having about 9.4 % better permeability regardless of the filtering material cleanliness.
3. The new design inner liner element should allow using a bigger area of the filtering material.
4. Both inner liner elements have low influence distribution for the air flows. During the calculations and contaminations processes it has been observed that the airflow travels the shortest path towards the outlet.

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