

Development of an Air Filtration Software

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ABSTRACT

The air filters in an air intake system permanently remove foreign particles such as dust, dirt and soot from the intake air, thereby maintaining the performance of the engine and protecting it from damage. The filter performance is typically a trade-off between pressure loss, load capacity and efficiency. Exhaust gas regulations and customer requirements such as filter duration always determine air filter development.

For this reason Röchling Automotive has developed a new software tool for estimating air filter lifetime which simplifies and significantly shortens the pre-development of filter elements with regard to filtration and pressure drop. In addition, it is possible to compare the different filter geometries (number of pleats, height, paper etc.) in order to limit the number of different filter elements, for example for a complete series of cars.

By correlating the total air consumption with the average dust concentration typical for the environment involved, the air filter lifetime can be precisely predicted. The program utilizes input data such as the maximum flow rate, the condition of the ambient air, filter geometry, filter media and air consumption per kilometer. All of these data allow precise predictions to be made regarding filter duration, load capacity and maximum face velocity.

First, this paper explains how filter testing is usually carried out according to the ISO 5011 standard, and it describes the testing conditions and regulations with which the test rigs used have to comply. After some general facts on the software tool, the paper focuses on the basic mathematical principles behind it as well as its mode of operation. This is followed by a discussion of the input data required and of the output which the user can obtain in return. The paper finishes with an outlook on additional features in the future.

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INTRODUCTION

In the pre-development phase of filter elements and air intake systems, several simulation tools are already in use in certain fields:

1. 3D Fluid Dynamics (e.g. CFX): this provides data on system pressure drop, velocity distribution and design optimization
2. Engine performances & 1D acoustics (e.g. GT Power): this provides data on engine performance, intake noise and system refinement
3. 3D acoustics (e.g. Nastran): this provides data on 3D sound pressure, resonator design and vibroacoustics

In terms of air filtration there have been no simulation tools up to now. In order to obtain reliable data regarding air filter design, air filter performance and air filter lifetime prediction, it was necessary to develop a large number of realistic test setups (see [Fig. 1](#)) using various filter element prototypes. The

test setup is always realized according to the ISO 5011 standard, which defines an accurate filter test using precision measurements under controlled conditions.

ISO 5011

The ISO 5011 standard focuses on performance testing with regard to inlet air cleaning equipment for internal combustion engines and compressors. It specifies uniform test procedures, conditions, equipment, and a performance report to allow a direct comparison of the performance of different air filters in the laboratory. In general, the test procedure includes an air flow restriction/differential pressure test, an efficiency test and a capacity test. In addition, a pressure collapse test should be performed on the air filter element.

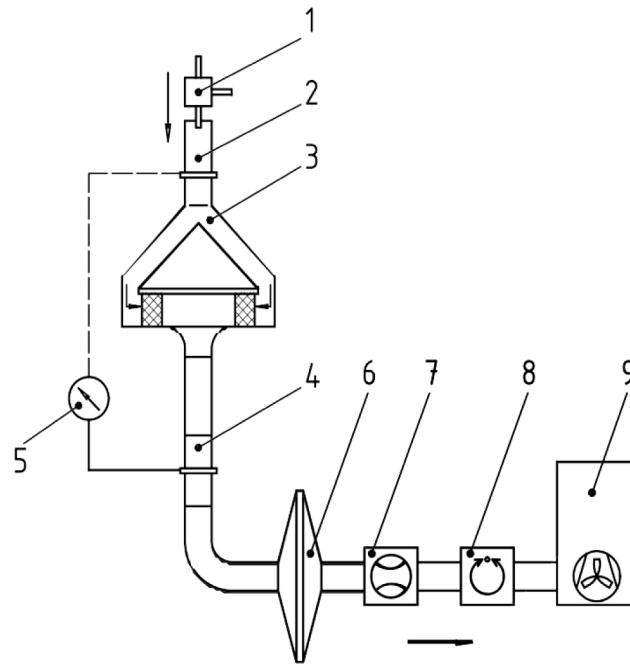


Figure 1. Filter element efficiency/capacity test setup. Key: 1. Dust injector, 2. Inlet tube, 3. Test shroud, 4. Outlet tube, 5. Pressure measuring device, 6. Absolute filter, 7. Air flow meter, 8. Air flow control, 9. Exhauster

To obtain reliable results, it is absolutely necessary to monitor temperature and humidity of the test dust and air. The ISO standard prescribes the procedure as follows: "All tests shall be conducted with air entering the air cleaner at a temperature of $23^{\circ}\text{C} \pm 5^{\circ}\text{C}$. Tests shall be conducted at a relative humidity of $(55 \pm 15)\%$, the permissible variation at each weighing stage throughout each single test being $\pm 2\%$." [1] The continuous control of these conditions is extremely important as a small temperature change or a small change in humidity can cause a change in the mass of a filter paper amounting to several grams.

In addition, there are several other regulations regarding the ISO 5011 test, such as:

1. Grade of the test dust: two types of test dust are to be used; ISO 12103 - A2 (ISO Fine) or ISO 12103 - A4 (ISO Coarse); chemical analysis and particle size distribution should conform to ISO 12103-1.
2. Filter media: remarks on thickness, minimum density, fiber diameter and moisture absorption

All air flow measurements should be corrected to comply with a standard condition of 20°C at 1013 hPa (1013 mbar) in order to make all tests comparable. If the ISO 5011 standard is followed, a filter element tested in Germany can easily be compared with a filter element tested in the US, even if there are several years between both tests.

Until now, extensive test procedures with filter element prototypes were necessary, and it took a long time to compare the various elements under laboratory conditions during the pre-development phase. These tests have one big

disadvantage: the scenario they simulate is not realistic or authentic and is not comparable with everyday conditions in various countries. In contrast, it is a strictly theoretical approach. As a matter of fact, depending on the location, there are various conditions that cannot be pictured or even considered. For example, there are large regional differences regarding the dust load. Filter elements for the Brazilian market need a much bigger load capacity as the percentage of dirt roads there is a lot higher than it is in other countries such as France or Germany. For this reason, a reliable prototype test procedure should take local conditions of this kind into account.

Röchling Automotive has developed a software allowing observations such as these to be taken into account. The tool simulates a single measurement within hours whereas a realistic test setup with prototypes according to the ISO 5011 standard requires several weeks of preparation.

FILTER DESIGN SOFTWARE

In general, the software is primarily a tool for determining the ideal filter design, lifetime and performance. The program uses data taken from a database or provided by the manufacturer. Input data can be classified into three sections:

1. Customer or manufacturer input (see Fig. 2), for example input concerning engine data such as:
 - Vehicle speed profile
 - Transmission data
 - Vehicle data (e.g. gear ratios, drag and rolling resistance)
 - Targets such as the air filter lifetime required, load capacity etc.

2. Filter geometry input: e.g. paper medium, thickness, porosity etc.
3. Vehicle-dependent packaging input: e.g. pleat height and pleat step

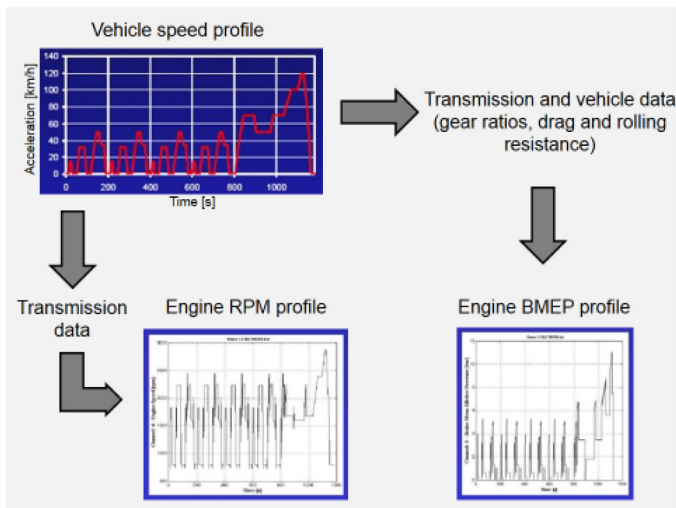


Figure 2. Necessary input data normally submitted by the OEM.

These data are all used to obtain the engine RPM and engine BMEP profiles necessary to create the engine air flow map (Fig. 3).

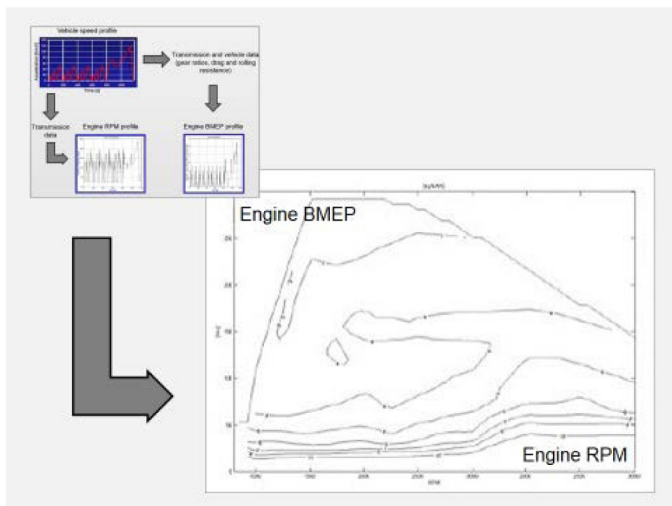


Figure 3. Engine air flow map.

Many factors play an important role in finding the ideal filter element, for instance stiffness and porosity in terms of the paper medium. The different paper values are summarized in a database so that they do not have to be newly acquired every time. In addition, the user is able to configure the main field of application within the software tool, i.e. he can define the conditions under which the filter has to function during its lifetime. This is important for the prediction of the filter lifetime as different environmental areas have varying dust concentrations (see Fig. 4).

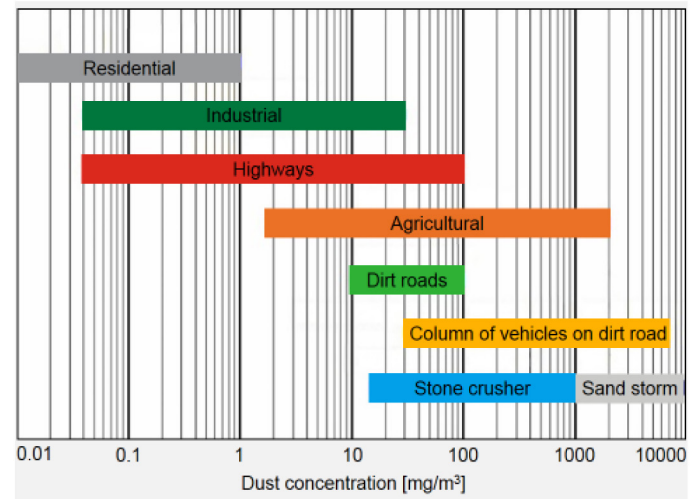


Figure 4. Overview of the dust concentration in various areas.

For example, if we determine that the filter will be used on highways or normal roads for 70% of its lifetime and in rural areas for 30% of it, this will have a different effect on its lifetime than if we determine that it will be used on dirt roads or in dusty areas for 80% of its lifetime and on highways for 20% of it. This means that the road types predicted have a direct influence on the lifetime and mileage of the filter element. The lower the dust concentration of the individual environment, the higher the possible mileage as well as the lifetime of the filter element.

Mathematical Principle and Mode of Operation

In general, the software tool indicates whether the desired specifications can be achieved or not. The calculation is carried out on the basis of mathematical formulas.

For example, one part of a calculation of this kind is used to determine the net frontal filter area as some parts of the filter do not work properly because the pleats are occluded by PUR foam or by glue on the edge. This fact makes the following calculations necessary:

Glue or PUR border:

$$s_{\text{glue}} = 5 \text{ mm}$$

Frontal filter area:

$$A_{\text{frontg}} = \text{width (mm)} * \text{length (mm)}$$

Net frontal filter area:

$$A_{\text{front}} = A_{\text{frontg}} - 2 * s_{\text{glue}} * (\text{width} + \text{length})$$

Many of the received values are used for further calculations. A_{front} can for example be used to determine the real average frontal velocity v_{front} :

$$v_{\text{front}} = \frac{q_{\text{nom}}}{A_{\text{front}}}$$

