Preventive to Predictive Maintenance

Authors: Hagmeyer, Simon; Mauthe, Fabian; Dutt, Marcel; Zeiler, Peter
Institution: Hochschule Esslingen - University of Applied Sciences
Research Department: Reliability Engineering and Prognostics and Health Management
Contact information: simon.hagmeyer@hs-esslingen.de, fabian.mauthe@hs-esslingen.de

Date: 16. June 2021

Description of the test bench:
This data set originates from a practice-relevant degradation process, which is representative for Prognostics and Health Management (PHM) applications. Data sets are generated for various practice-relevant data situations which do not correspond to the ideal conditions of full data coverage. These data sets are uploaded to Kaggle by the user "Prognostics @ HSE" in a continuous process. The observed degradation process is the clogging of filters when separating of solid particles from gas. A test bench is used for this purpose, which performs automated life testing of filter media by loading them. A schematic of the test stand's basic operating principle can be seen in Figure 1. Due to various physical filter models described in the literature, it might be beneficial to support the actual data-driven models by integrating physical knowledge respectively models in the sense of theory-guided data science or informed machine learning (various names are common).

Filter medium:
The object to be tested is a filter mat made of randomly oriented non-woven fibre material. These filter mats are cut out of a flat material, which is fixed in the middle of the filtration chamber. The test material has an effective square flow area. Figure 5 shows a cut filter mat after a life cycle test, which is loaded with the test dust. The properties of the filter media are:

Mean fibre diameter	23 µm
Filter area	$6131\ \mathrm{mm}^2$
Filter thickness	20 mm
Filter packing density	0.014-0.0165
Clean filter pressure drop	25 Pa at flow of $1080\ \mathrm{m}^3/(\mathrm{h}\cdot\mathrm{m}^2)$

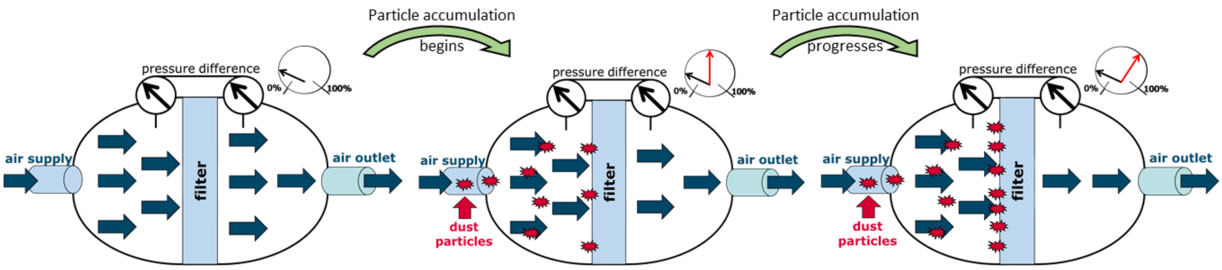

Figure 1 Basic operating principle of the test bench

Test particles and particle feeding:
For testing the filters life, standardized Arizona test dust (ISO 12103-1) in the particle sizes A2, A3 and A4 are used for their loading. These dusts have a defined distribution function with regard to particle size and chemical composition. The distributions of the particle sizes of the test dust batches used are shown in Figures 1-3 and given in the files:

- Particle size distribution_ISO_12103_1_A2_Fine.mat
- Particle size distribution_ISO_12103_1_A3_Medium.mat
- Particle size distribution_ISO_12103_1_A4_Coarse.mat

The dust particles are induced into the compressed air system of the test bench by a nozzle for powdery solids based on the Venturi principle. The test dust is contained in a cylinder. This is fed to the nozzle by an electrically driven spindle actuator as shown in Figure 5. Thus, the load profile can be adjusted by the velocity of the spindle actuator. By adjusting the velocity, the amount of particles added per time unit is set, independently of differential pressure and flow. In the data set, the current material feed is given in mm^3/s. Together with the bulk density of the dusts of,

A2 Fine Test Dust	$0.900\mathrm{g/cm}^3$
A3 Medium Test Dust	$1.025\mathrm{g/cm}^3$
A4 Coarse Test Dust	$1.200\mathrm{g/cm}^3$

the mass of the fed dust can be calculated.

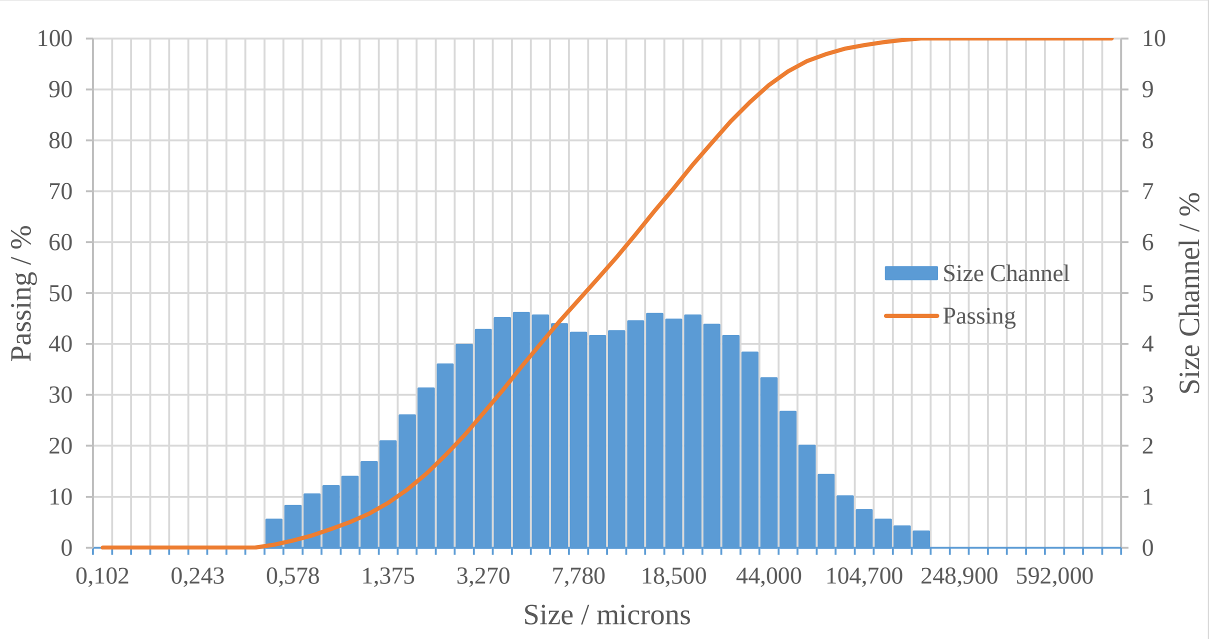

Figure 2: Particle Size Distribution: ISO 12103-1, A2 Fine

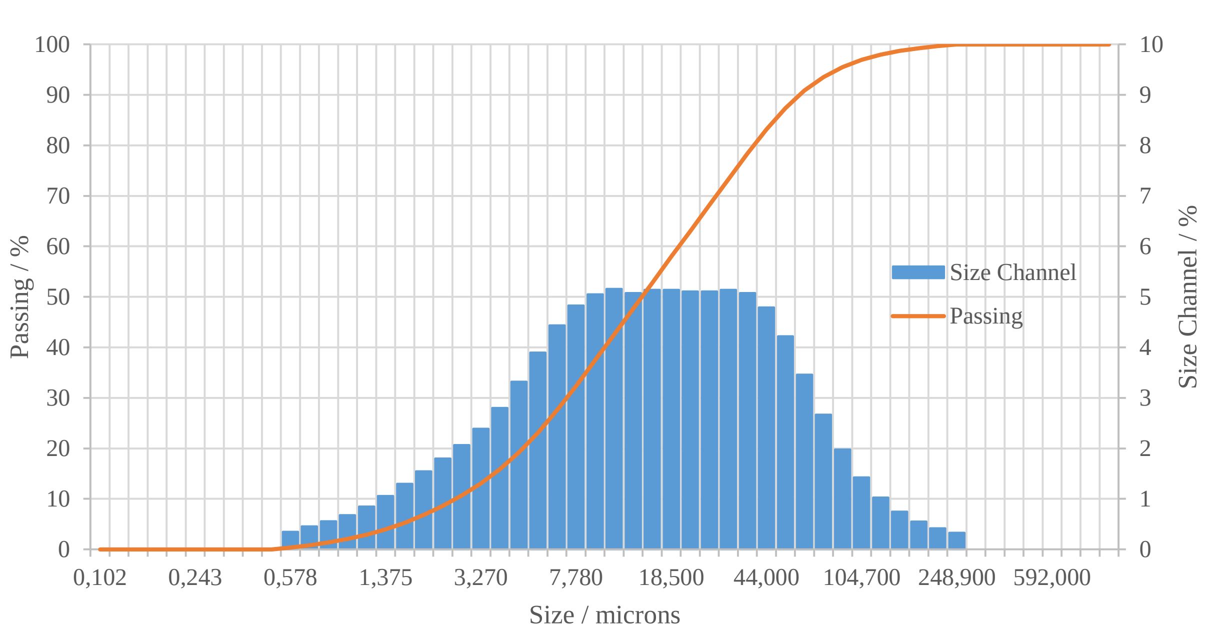

Figure 3: Particle Size Distribution: ISO 12103-1, A3 Medium

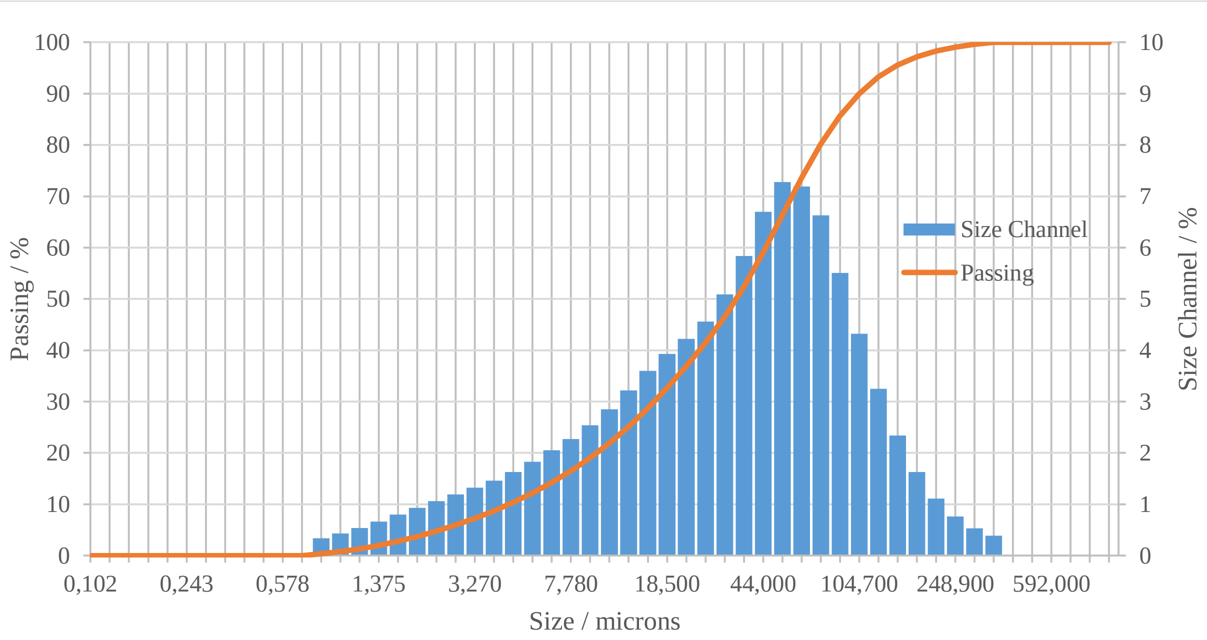

Figure 4: Particle Size Distribution: ISO 12103-1, A4 Coarse

Sensor:

In this test bench, the flow rate and the differential pressure across the filter are recorded during a lifetime test. Here, the flow sensor is located upstream of the particle feed, which leads to a falsification of the flow. The impact of this falsification is determined experimentally and a compensation function is modelled to correct it. The given measured values in the data are the corrected values. Thereby, the flow sensor indicates the flow rate for atmospheric pressure. The differential pressure sensor has a measuring range of 0 to 2500 Pa.

Due to the sensors used when measuring the differential pressure across the filter, this can be measured up to 2500 Pa. Since air flows along the sensor connections in the filter chamber, the sensor connections

were designed to minimise interference. A typical course of a measurement of the differential pressure from the filter application can be seen in Figure 6.
In addition to these sensor readings, the velocity of the particle feed is also recorded.

Operating modes:
In this test bench, during the life test, there is the possibility of selecting between two basic operating modes via the 5/3-way valve and the 3/2-way valve, which can be seen in Figure 7. Thus, during a test, it is possible to switch between flow and pressure control as needed. The respective operating mode is documented in the data of each life test. In the case of the "Preventive to Predictive Maintenance" data set, all life tests are carried out under flow control.

Procedure for a measurement:
In order to reduce the external influences, each measurement has the same start position of the spindle and same stop criterion. Therefore, the spindle with the cylinder containing the test dust is located at the lower limit switch. Also, the cylinder is filled with the same amount of dust. Before starting the measurement, the setting parameters such as feed rate of the spindle and the flow rate are defined in the user interface.

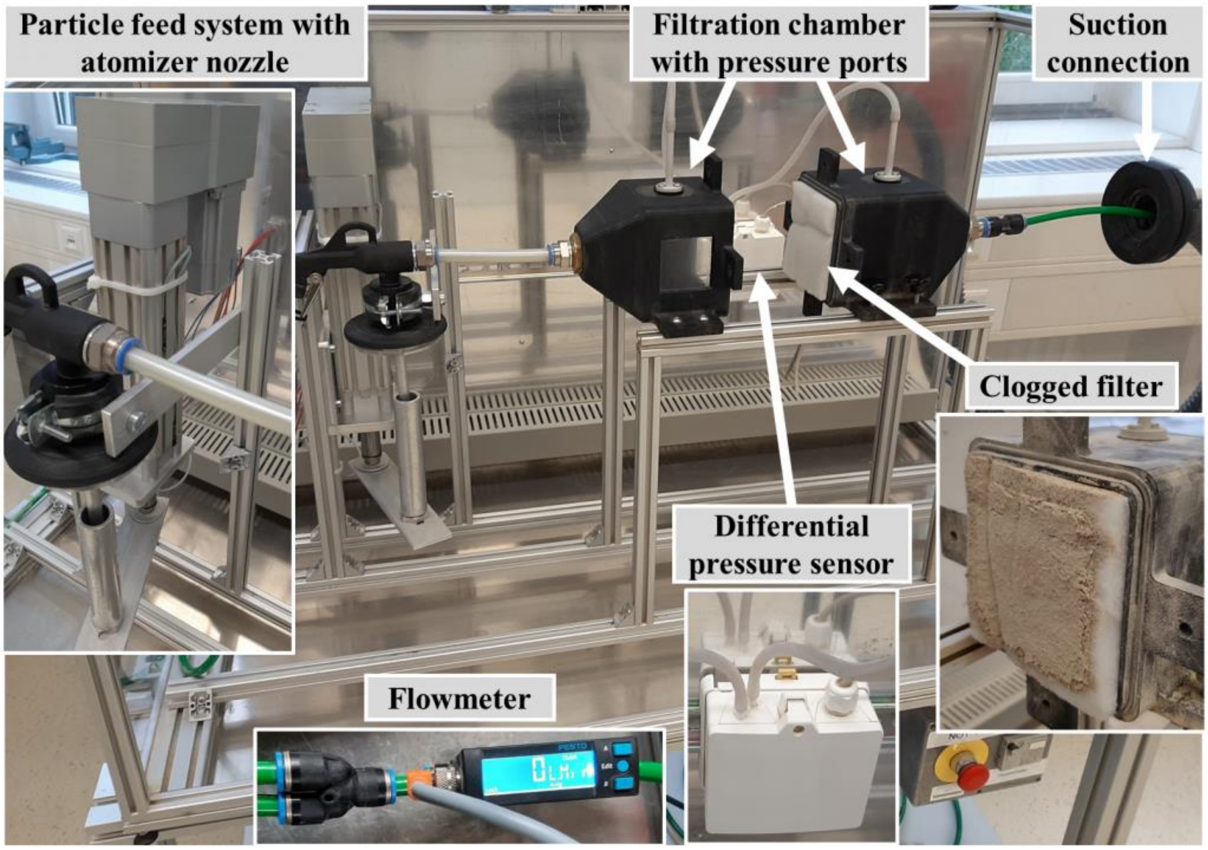

Figure 5: Filtration test bench with its particle feed system and filtration chamber

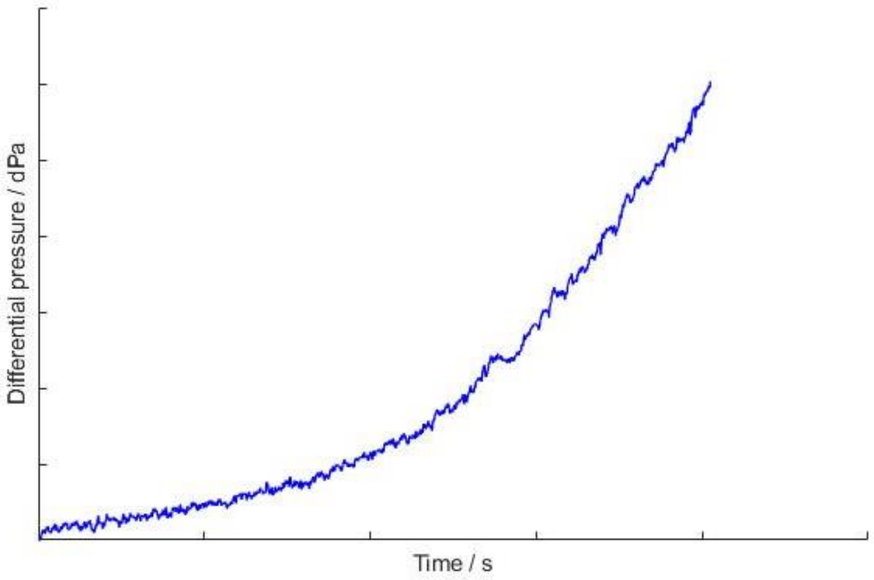

Figure 6: Typical course of a filtration test run

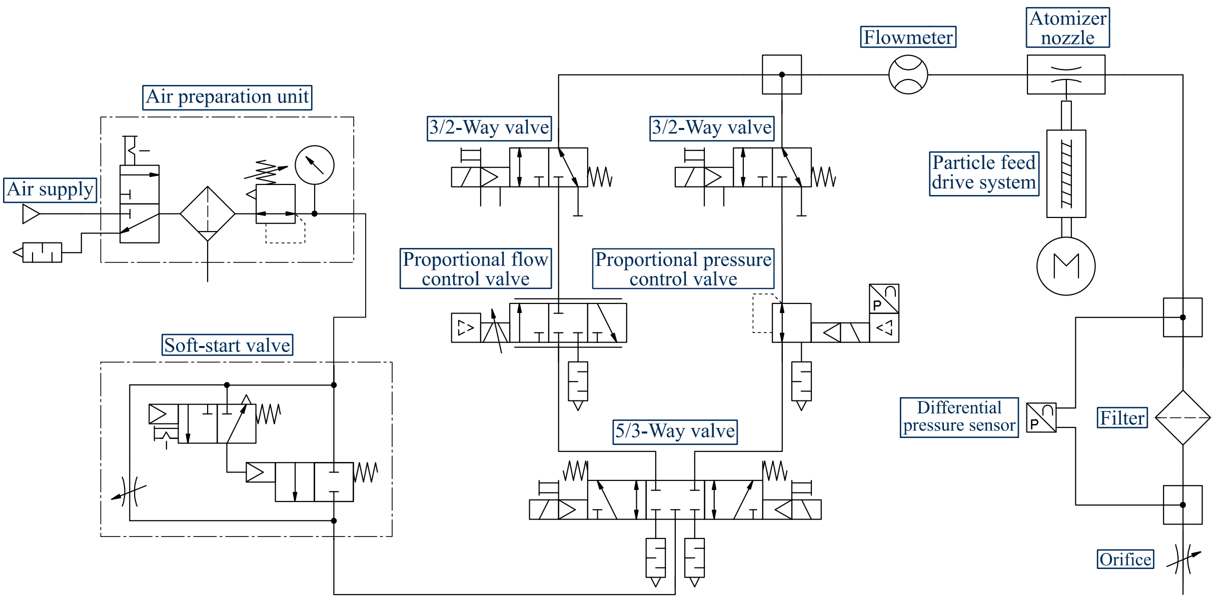

Figure 7: Pneumatic layout of the test bench

Given data situation:
The data set *Preventive to Predictive Maintenance* is about the transition of a preventive maintenance strategy to a predictive maintenance strategy of a replaceable part, in this case a filter. To aid the realisation of predictive maintenance, life cycles have already been recorded from the application studied. However, the preventive maintenance in place so far causes them to be replaced after a fixed period of time, regardless of the condition of the degrading part. As a result, the end of life is not known for most records and thus they are right-censored. The so given training data are recorded runs of the filter up to a periodic replacement interval.

When specifying the interval length for preventive maintenance, a trade-off has to be made between wasted life and the frequency of unplanned downtimes that occur, when having a particularly short life. The interval here is chosen so that, on average, failure is observed at the shortest 10% of the filter lives in the training data. The other lives are censored. The filter failure occurs when the differential pressure across the filter exceeds 600 Pa. The maintenance interval length depends on the amount of dust fed in per time, which is constant within a test run. For example, at twice the dust feed, the maintenance interval is half as long. The same relationship therefore applies to the respective censoring time, which scales inversely proportional with the particle feed. The variations between lifetimes are therefore primarily based on the type of dust, the flow rate and manufacturing tolerances. The filter medium CC 600 G was used exclusively for these measurement samples, which are included in this data set.

The data set contains a training and a test data set. The training data are recorded runs of the filter up to a periodic replacement. The test data contains complete run-to-failure measurements of the filter.

Task:
The objective of the data set is to precisely predict the remaining useful life (RUL) of the filter for the given test data, so a transition to predictive maintenance is made possible. For this purpose, the dataset contains training and test data, consisting both of 50 life tests respectively. The test data contains randomly right-censored run-to-failure measurements and the respective RUL as a ground truth to the prediction task. The main challenge is how to make the most use of the right-censored life data within the training data.

Due to the detailed description of the setup and the various physical filter models described in literature, it is possible to support the actual data-driven models by integrating physical knowledge respectively models in the sense of theory-guided data science or informed machine learning (various names are common).

Data structure:

There are two data sets, the test data set and the training data set. These contain the individual measurement series of the life cycle tests. The individual life cycle tests have the same structural design. Therefore, they contain all necessary measurement data and setting parameters. The structure of a life cycle test is shown below:

– Train_Data	(table)
– Measured_Data	(table)
– Differential_pressure	(double)
– Flow_rate	(double)
– Time	(double)
– Sampling	(double)
– Dust	(char array)
– Dust_feed	(double)
– Data_No	(double)
– Test_Data	(table)
– Measured_Data	(table)
– Differential_pressure	(double)
– Flow_rate	(double)
– Time	(double)
– Sampling	(double)
– Dust	(char array)
– Dust_feed	(double)
– RUL	(double)
– Data_No	(double)

The Data.mat file contains all the training and test data, with the previously mentioned structure. The individual measurement series are contained in the training and test data, with the recorded data and the necessary setting parameters on the PLC. The dust used are specified. "Dust_feed" is the loading of the filter with dust per time (mm^3/s). "Sampling" indicates the frequency at which the measurement data is recorded (Hz). In the Measurement data table, the measured differential pressure and flow rate are listed at each point in time. In addition, the known RUL is specified for the randomly censored test data.

Acknowledgement:

Thanks go to Marc Hönig (Scientific Employee), Marcel Braig (Scientific Employee) and Christopher Rein (Research Assistant) for contributing to the recording of these life tests.

Data set Creator:

Hochschule Esslingen - University of Applied Sciences
Robert-Bosch-Straße 1
73037 Göppingen
Germany
Research Area Reliability Engineering and Prognostics and Health Management

Dataset Citation:
Hagmeyer, S., Mauthe, F., & Zeiler, P. (2021). Creation of Publicly Available Data Sets for Prognostics and Diagnostics Addressing Data Scenarios Relevant to Industrial Applications. *International Journal of Prognostics and Health Management*, Volume 12, Issue 2, DOI: 10.36001/ijphm.2021.v12i2.3087