

# Modeling dynamic blowers in Simscape® for mechanical ventilation

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*Abstract: This contribution focuses on modeling dynamic blowers by forming a Wiener model in which the linear dynamics of the rotational speed and the non-linear static relationship of differential pressure and volume flow is regarded separately. Two isolated identification processes were conducted to parameterize the model which was created upon pre-existing Simscape® elements. For validation purposes the model was placed in a pneumatic circuit equally to a hardware test bench and results are presented for two operating points. In the future this model approach could serve as the basis for model-based control tuning of blowers for mechanical ventilation.*

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## I. Introduction and aim

Mechanical ventilation is crucial for patients with respiratory failure as it supports or substitutes the breathing work while providing a sufficient minute volume with an increased level of precisely dosed oxygen. In many ventilator designs, centrifugal blowers are used as actuators which supply compressed ambient air. Depending on the blower's performance and the selected ventilator's topology, they are either operated with constant rotational speeds for pressure supply while the dosage is conducted by downstream valves or they generate feedback controlled pressure or flow trajectories by pulsed dynamic changes in rotational speed. As blowers come with electrical, mechanical and pneumatic characteristics, it is challenging to model the behavior. Furthermore, the resulting flow of the pressure source is also depending on the connected pneumatic load following Bernoulli's principle. In order to achieve a desired minute or tidal volume, blowers are therefore often operated in adaptive modes such as pressure regulated volume control (PRVC) which adjusts the rotational speed for a required differential pressure over time. Real physical components with multiple domains can be replicated in Simscape® (The MathWorks, Inc) and publicly available models already focus on mechanical ventilation, however by using only ideal volume flow sources [1]. The integration of real pressure sources for ventilation is missing but present for related research areas [2]. Therefore, the aim of this work is to choose a simplified yet representative model architecture which allows the isolated identification of key characteristics. These are then to be implemented by pre-existing blocks in Simscape® wherever possible and parameterized. Finally, the model will be validated against the hardware setup in the same pneumatic circuit.

## II. Material and methods

The intended architecture is shown in Figure 1. A Wiener model [3] is formed by the assumed linear

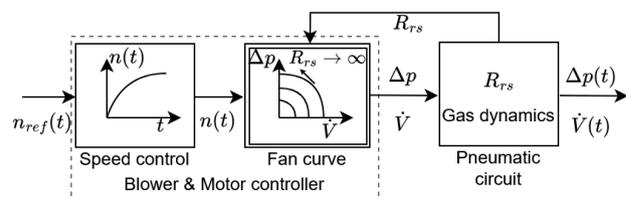


Figure 1: Proposed model for the blower. Rotational reference speed is mapped to the differential pressure and volume flow.

dynamics of internal controlled rotational speed  $n$  followed by the non-linear relation of differential pressure  $\Delta p$  and volume flow  $\dot{V}$  for velocity and resistance  $R_{rs}$ . Its output is then fed into the pneumatic circuit.

### II.I. Hardware setup

The hardware setup consisted of the examined blower Micronel U65HN-024KS-6 (Micronel AG, Tagelswangen, Switzerland) driven by a motor controller (ESCON 50/5, maxon motor gmbh, Munich, Germany) and a microcontroller (STM32 Nucleo-F767ZI, STMicroelectronics, Geneva, Switzerland). At its outlet the volume flow (SFM3300, Sensirion, Stäfa, Switzerland) and pressure (AMS 6915, Analog Microelectronics GmbH, Mainz, Germany) were measured. A manually adjustable pneumatic resistance was incorporated for the continuous variation of the restricted area.

### II.II. System identification

Two aspects of the motor controlled blower were investigated: First, the dynamic response to a set reference speed and secondly, the non-linear static relation between differential pressure  $\Delta p$  and volume flow  $\dot{V}$  for constant rotational speeds and varying resistances. The dynamic behavior of the internal controlled system was examined via its (increasing) step-responses at different reference speeds and approximated by a linear first-order transfer function (PT<sub>1</sub>) with unity static gain and a time constant of 0.06 s. The reference speed (0 to 57.000 rpm) was mapped to the duty cycle (DC) of a pulse-width modulated signal

(PWM) between 10 % and 90 % driven by the microcontroller.

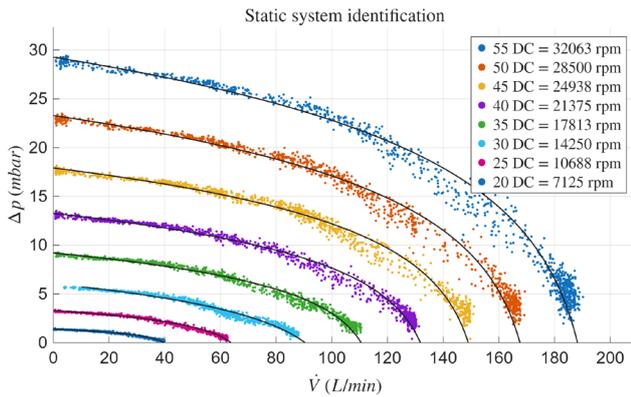


Figure 2: Identification of the static pressure-to-volume flow relation with constant rotational speed and varied resistance.

The static non-linearity was identified by setting constant speeds (see Figure 2) while varying the resistance from the finite value of the cross sectional area of the outlet to infinity whereas both flow and pressure were logged. The data points were interpolated by splines and sampled at constant flow intervals to create a matrix  $\Delta p^{50 \times 8}$  which gave the reference differential pressures for each volume flow  $\dot{V}$  and rotational speed  $n$ .

### II.III. Software model

The described setup in II.I was replicated in Simscape® while the blower was represented by the model approach shown in Figure 1. The linear dynamics were modeled by an ideal rotational source with its input signal fed through a linear transfer function. The gap between mechanical rotation and pneumatic domain was bridged by the FAN block [4] of the moist air library. The option “Fan parameterization” was set to “2D tabulated data” such that the previous obtained matrix could be inserted. The remaining pneumatic circuit consisted of two reservoirs for the ambient air conditions and a variable local restriction for the resistive load.

### III. Results and discussion

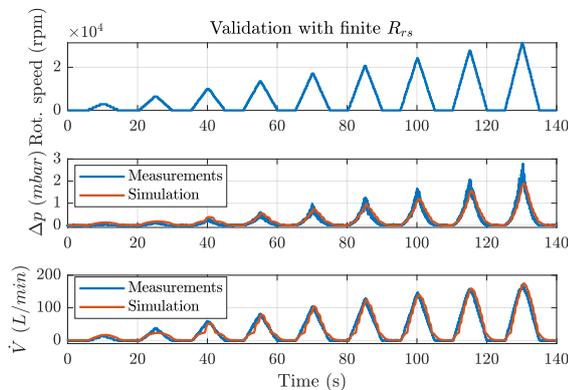


Figure 3: Validation with a finite resistance. Rotational speed (top), pressure (middle) with MAE = 0.1308 mbar and volume flow (bottom) with MAE = 11.14 L/min for all active intervals.

The blower model within the Simscape® environment was validated using triangular shaped input signals (see Figures 3 and 4) from 10 % to 55 % leading to a top speed

of roughly 32.000 rpm at two operating points of the (in)/finite resistances. The actual applied DC input signal from the microcontroller was logged and converted back to reference speeds for an equivalent input for the model over time. Both differential pressure and volume flow were measured and compared to the model’s output. Overall, the curves were aligned for most rotational speeds, however low values came with less precision. In Figure 4 only the pressure is shown as the volume flow equals zero. In comparison to Figure 3, there were deviations increasing with rotational speed and the simulated differential pressure lagged behind the measured one.

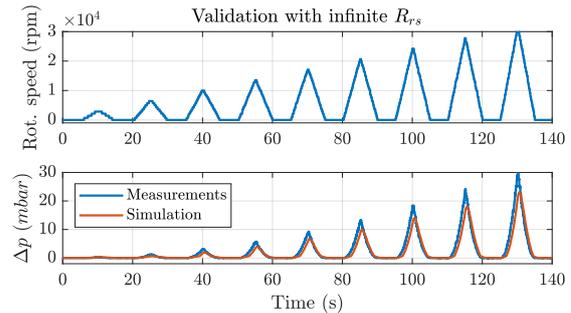


Figure 4: Validation with an infinite resistance. Rotational speed (top) and pressure (bottom) with MAE = 1.27 mbar.

### IV. Conclusions & Outlook

In this contribution a modeling approach of centrifugal blower based ventilation sources for mechanical ventilation was proposed. The principle of system identification and implementation was illustrated based on an exemplary blower. The validation of the model was conducted within a mirrored pneumatic circuit at two operating points and showed promising precision for pressure and volume flow. For future work the resolution of the matrix  $\Delta p^{50 \times 8}$  should be increased for low rotational speeds. Also, the validation could be extended to the full scope of the 2D area by varying known resistances both in soft- and hardware. The dynamics should be considered in more detail with appropriate excitation signals for both rising and falling edges. Finally, combining blower and lung models could support control tuning for mechanical ventilation.

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