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Noise testing of multi-disc fan

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Abstract The impeller of a multi-disc fan was made of rotating smooth discs spaced close together. The concept of such a machine came from Nikola Tesla in 1909. The fluid, based on the principle of friction against the rotating surfaces of the discs, flows outwards from the disc pack into an outlet. According to the literature, such a design is characterized by low noise emissions. Based on calculations, a prototype of a multi-disc fan was designed and then manufactured. Tests were carried out for the sound power level emitted from the fan's outlet. The examination was performed in a reverberation chamber according to the ISO 3741:2010 standard. The noise source was visualized using an acoustic camera. The aerodynamic characteristics were also determined experimentally according to the ISO 5801:2017 standard. The aim of this study is provide insight into the acoustic and aerodynamic characteristics of a multi-disc fan.

Keywords: aeroacoustics, multi-disc fan, experimental test.

1. Introduction

In 1909, Nikola Tesla applied for a patent in the United States of America for a turbine [1] and a fluid propulsion system [2]. Both patents were granted in 1913. Tesla wrote in his patent that in order to achieve the greatest economy, the changes in speed and direction of the fluid should be gradual. In the machines of the time, such speed changes, shocks, and vibrations were inevitable. Devices with pistons or blades have numerous disadvantages and limitations, complicating their design and increasing the manufacturing and maintenance expenses of the machine.

A multi-disc fan impeller consists of rotating discs spaced close together. The fluid flows outwards from the disc pack into a manifold due to friction against the rotating surfaces of the discs. The frictional losses in the flow between two discs rotating at the same speed are considerably less than the analogous losses for a disc rotating in a stationary casing [3]. Disc fans have a significant pressure build-up at low airflow. This means that these fans have a low-speed ratio.

The author describes in his book [4] that this design, due to the lack of blades is characterized by low noise emission. The author of the paper [5] writes that multi-disc turbomachines can run quieter than conventional machines, and that the noise is similar to white noise with no dominant frequencies. The article [6] on the Tesla turbine mentions its low noise level as an advantage. The literature often mentions that Tesla's turbine, pump, and fan designs are characterized by low noise generation. However, the authors of these works do not cite any results of noise measurements, nor do they present their own measurement results. This paper presents the results of acoustic and aerodynamic measurements of a proprietary multi-disc fan design according to Tesla's patent.

2. Fan design

A prototype multi-disc fan was designed to allow future testing of different disc sizes and configurations. A volume flow rate q_V of 27.8 dm^3/s at a fan total pressure increment p_f of 100 Pa was taken as the design operating point. Flow calculations in the impeller were carried out using CFD and the rest of the structure was calculated using one-dimensional calculation methods from the literature [7]. A computer programme was written in the Python programming language that searches for the optimum fan dimensions for a given operating point.

The designed structure has an impeller with an external diameter of 250 mm, consisting of sixteen discs with a thickness of 1.5 mm and a distance between them of 1.5 mm. The nominal speed is 1450 rpm. The motor speed was varied using an inverter. The fan design is shown in Figure 1.

Figure 2 shows the impeller disc. The impeller is made up of fifteen such discs and one like it (closest to the motor), but with only one hole for the shaft.

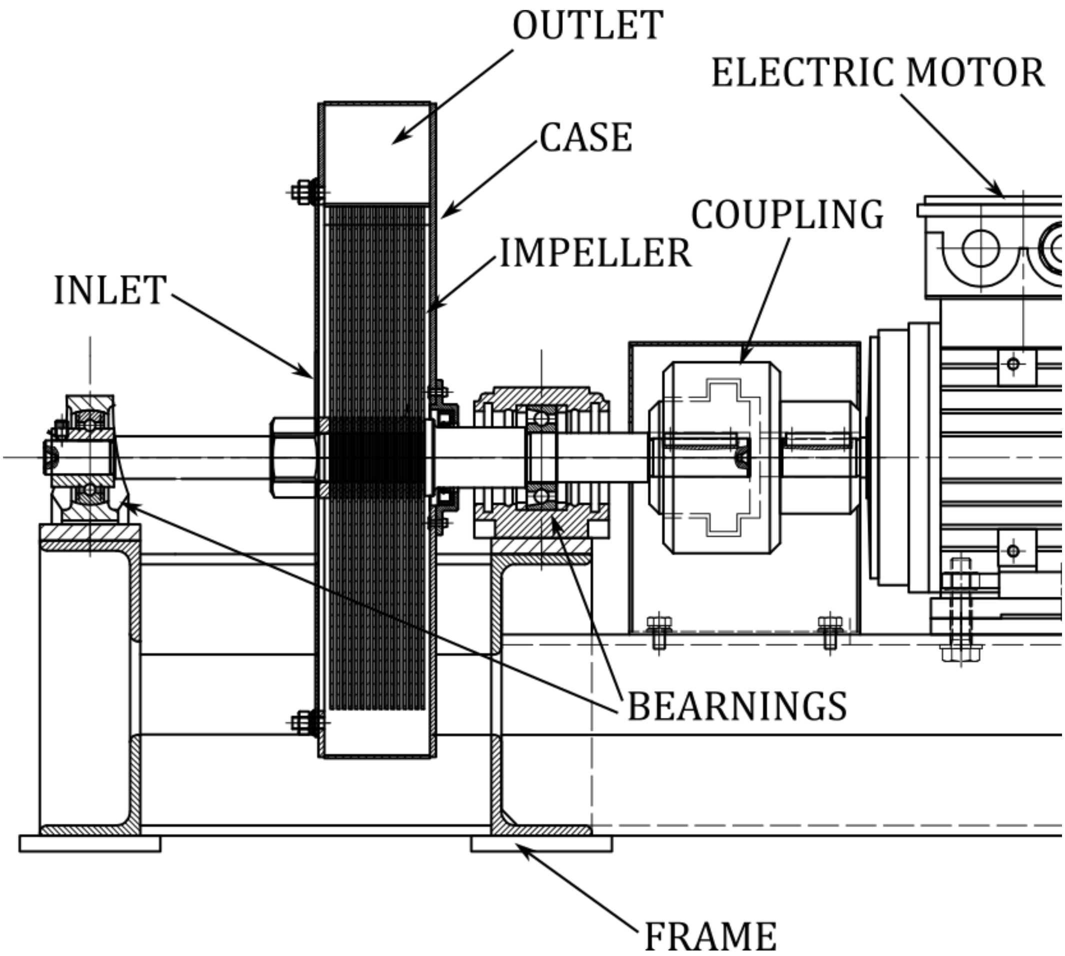

Figure 1. Technical drawing of a prototype multi-disc fan.

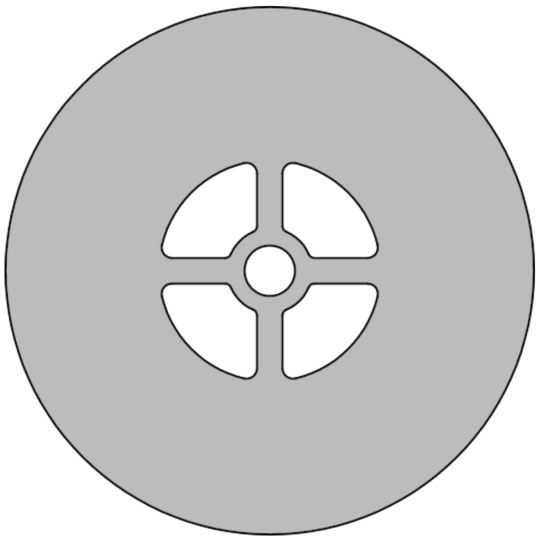

Figure 2. Impeller disc used in the fan.

Figure 3 shows a manufactured prototype of a multi-disc fan. The impeller discs and housing were made of smooth steel. The entire fan including the electric motor has been placed on a frame.

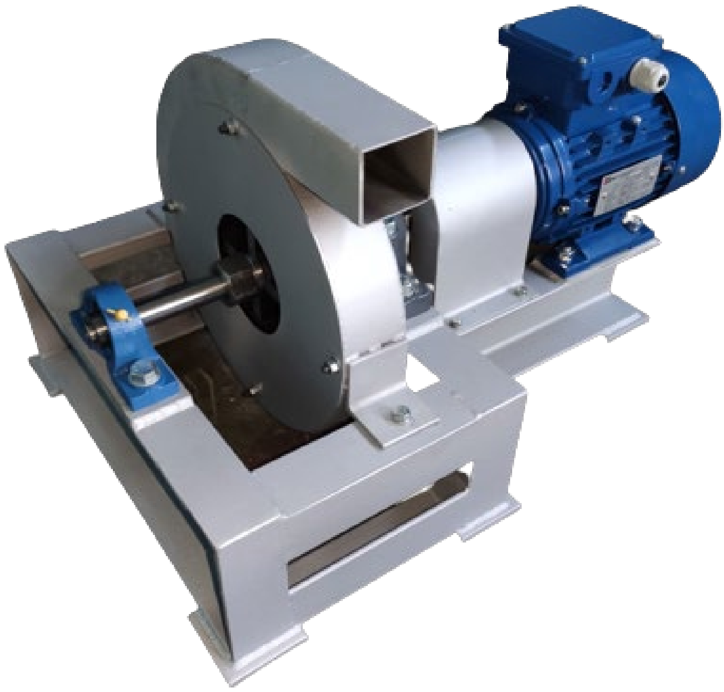

Figure 3. Photo of the fan after completion.

3. Measurements

3.1. Aerodynamic measurements

An aerodynamic test rig for fans was constructed in accordance with ISO 5801:2017 standard [8]. A type B test rig was chosen – a free fan inlet and a measuring duct at the outlet. The flow velocity in the duct was measured using a Prandtl probe at 18 points on a plane. An electronic differential pressure transducer was used to measure the pressure in the 80 mm diameter pipeline. Additionally, measurements of air temperature, relative humidity, and atmospheric pressure were taken at the fan inlet. The airflow for the constant speed of the electric motor has been reduced by closing the outlet from the stand. Figure 4 depicts the test rig utilized for the aerodynamic and acoustic tests.

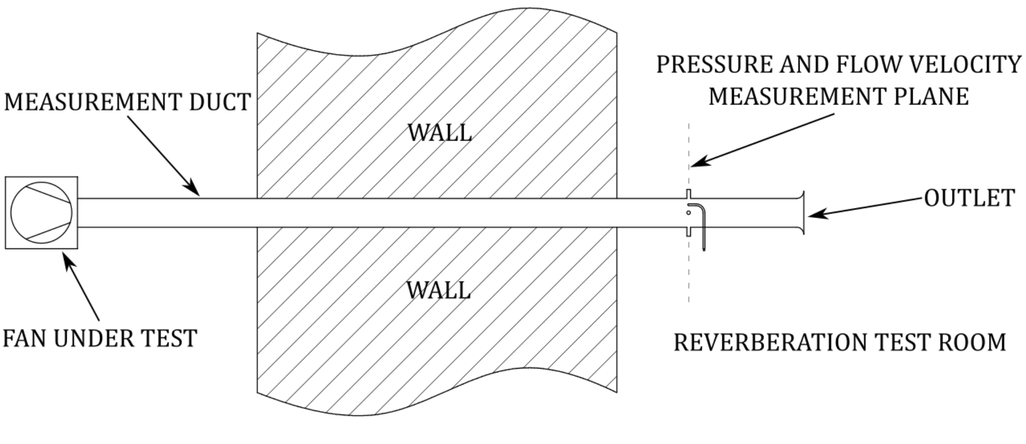

Figure 4. The test rig used to determine the aerodynamic and acoustic characteristics of the fan.

3.2. Acoustic measurements

In order to determine the sound power level at the fan outlet, acoustic measurements were performed in a reverberation chamber according to ISO 3741:2010 standard [9]. Measurements were taken in the reverberation chamber where the outlet of the fan under test was directed. The whole fan with motor was placed outside the measuring room. The outlet of the measuring duct was led into the reverberation chamber. The reverberation room has a volume of 237.0 m^3 and an area of 231.5 m^2 with non-parallel walls. The outlet of the measuring duct was led into the reverberation chamber. The reverberation chamber with a visible outlet is shown in Figure 5.

Figure 5. Reverberation chamber with visible fan outlet.

The generated noise is determined by sound power level, measured and calculated under ISO 3741:2010 standard [9]. The Nor140 measuring set with the Nor850 software and the Nor265 rotary table was used for the measurements. The sound pressure was measured at twelve points in a circle with a radius of 1.7 meters (circumference of 10.7 m). Measured in 1/3 octaves in the range from 100 Hz to 10000 Hz. The measurement time is set to 30 seconds. Background noise was measured for a stand without flow to determine the background correction K_1. Reverberation was measured for four omnidirectional loudspeaker settings with three microphone settings and four speaker positions. All calculations of the sound power level were made using a previously made calculation sheet. Before and after all measurements were made, the background level was measured and calibrated using the Nor1256 calibrator. After measuring each setting, the temperature, relative humidity and atmospheric pressure necessary for calculating the sound power were recorded.

The final step in the research was to locate and visualize the noise source in the prototype fan using an acoustic camera.

4. Results of measurements

4.1. Aerodynamic measurements results

The results of the total pressure rise as a function of airflow for 725, 1450 and 2175 revolutions per minute (nominal and 50% lower and higher speed frequencies) are shown in Figure 6. The results of the measurements (airflow, pressure increase, fan mechanical efficiency) for different impeller speeds for the optimum operating point are presented in Table 1.

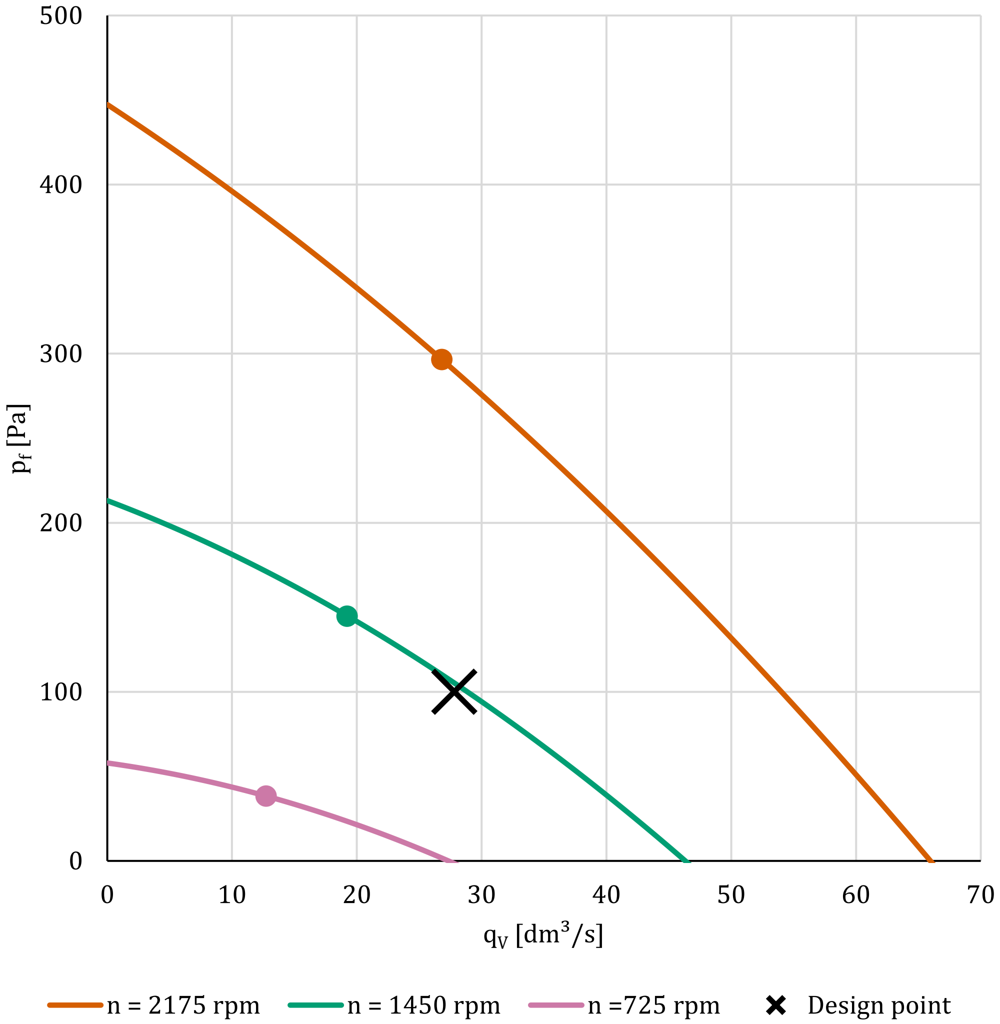

Figure 6. Characteristics of total pressure rise as a function of airflow rate for different motor speeds. The point of maximum fan efficiency is marked with a dot. A cross indicates a design point.

Table 1. Measurement results for different fan speeds at the point of maximum efficiency.

n [rpm]	q_V [dm^3/s]	p_f [Pa]	η [%]
725	12.7	38.4	31.5
1450	19.2	144.9	31.7
2175	26.8	296.7	29.9

4.2. Acoustic measurements results

Measured in reverberation room the sound power level emitted from the fan outlet is presented in one-third-octave bands for different impeller speeds as shown in Figure 7.

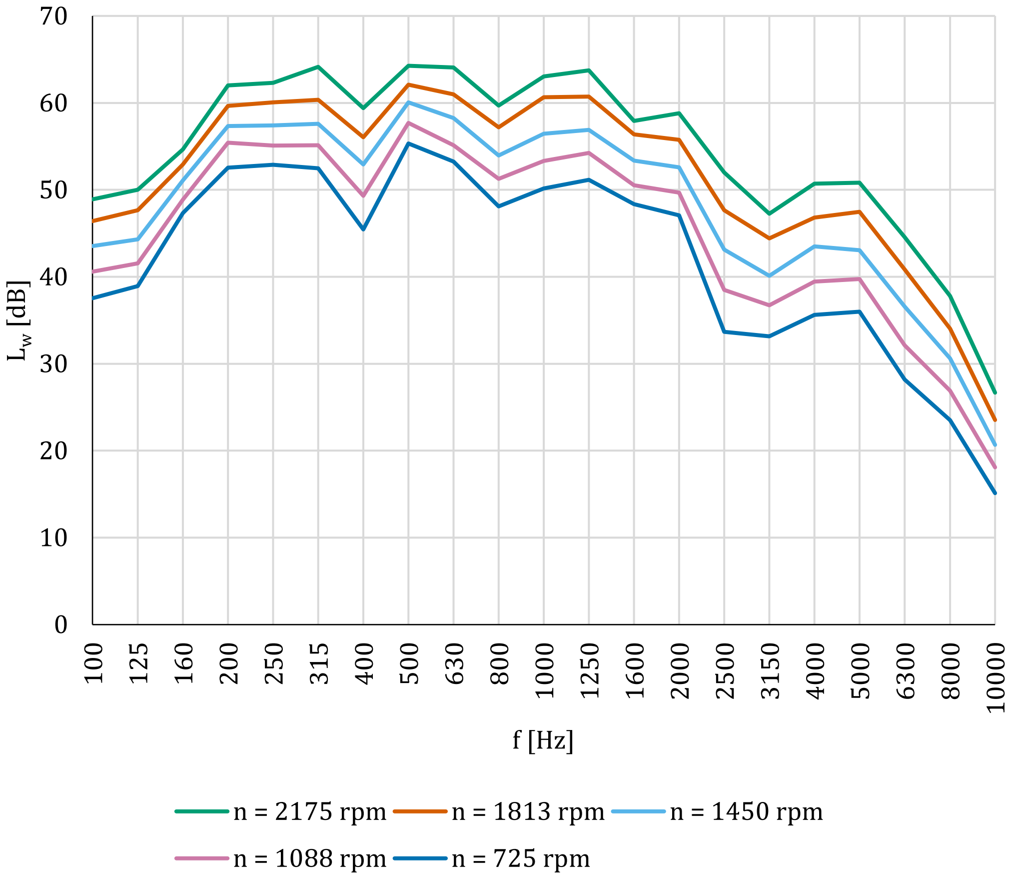

Figure 7. Sound power level at the fan outlet as a function of frequency for different impeller speeds.

Table 2 shows the results of the sound power level measurements in octaves and single A-weighted value for five different motor speeds.

Table 2. Measurement results of sound power levels in octaves for different rotor speeds.

	L_w [dB]				
f [Hz]	n = 725 rpm	n = 1088 rpm	n = 1450 rpm	n = 1813 rpm	n = 2175 rpm
125	34.4	36.0	38.3	40.4	42.2
250	49.0	51.6	53.9	56.6	59.7
500	54.9	57.2	59.9	62.3	65.1
1000	54.9	58.0	60.8	64.7	67.4
2000	52.0	54.4	57.3	60.5	63.0
4000	40.7	44.4	48.1	52.0	55.5
8000	29.2	33.0	37.3	41.5	45.2
A	59.4	62.0	64.9	68.1	70.8

4.3. Acoustic camera visualization

The SoundCam 2.0 acoustic camera was used to visualize the noise sources. Figure 8 shows the acoustic camera image from the fan outlet side and Figure 9 from the outlet side with the electric motor visible. The images were taken during operation at designed motor speed (1450 rpm). The figure shows the sound intensity level as a single number. The sound level at the fan inlet and outlet is similar, at around 67 dB. The noise from the inverter-controlled electric motor is no less than 3 dB compared to the sound from the impeller.

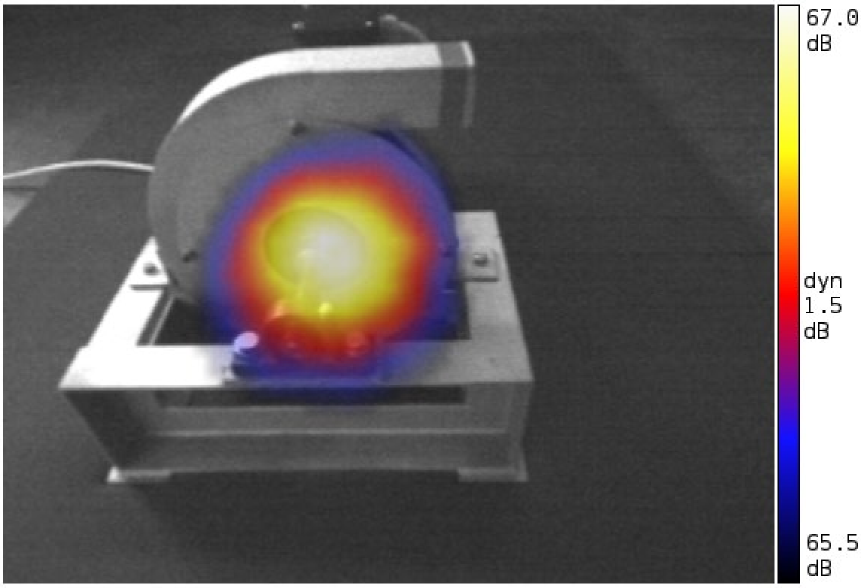

Figure 8. Acoustic camera image from the inlet side.

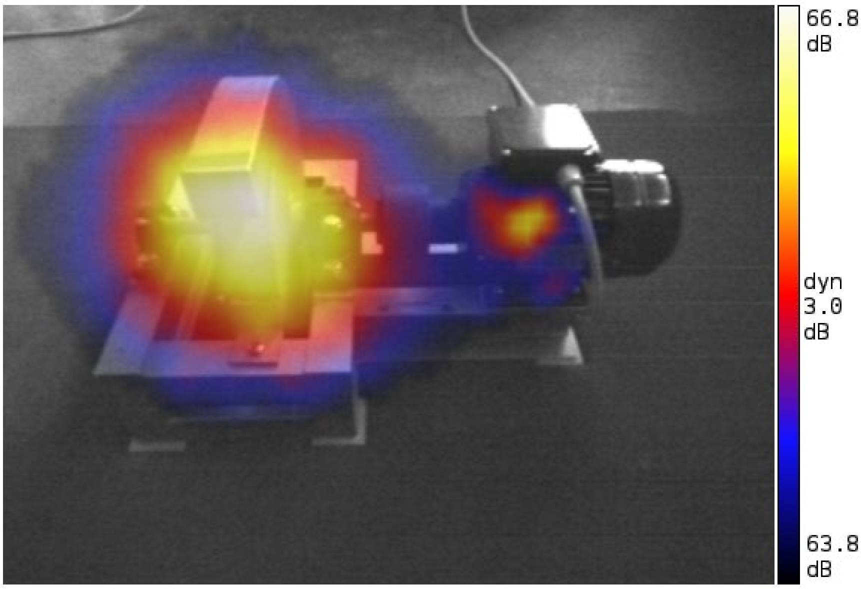

Figure 9. Acoustic camera image from the outlet side with the electric motor visible.

5. Conclusions

In this study, Tesla's multi-disc fan prototype was subjected to a series of aerodynamic and acoustic evaluations. These tests were necessary to verify the functionality of the prototype and to ensure that it met the design performance criteria in terms of aerodynamic dynamics and noise emission levels.

The aerodynamic characteristics of the prototype fan were assessed and found to be exactly as specified at the design operating point. This means that the actual performance of the fan in terms of airflow and pressure increment is very close to the theoretical models and expectations set at the design stage.

Table 3 compares the equivalent A-weighted sound power level at the outlet of the tested fan with a typical fan with the same nominal operating point (flow and pressure increase at maximum efficient) calculated in accordance with the standard VDI 2081 [10].

Table 3. Comparison of measurement results with a typical fan according to the standard VDI 2081.

n [rpm]	L_W [dB]	
	measured	calculated
725	59.2	52.7
1088	62.0	60.5
1450	64.9	66.1
1813	68.1	70.3
2175	70.8	73.7

According to the standard VDI 2081, the prototype multi-disc fan generates less noise than a typical fan with the same rating point at rotor speeds of 1450 rpm and above. However, below the design speed, the fan performs less satisfactorily in terms of noise generation. The acoustic camera images show that, in addition to the rotor itself, a large contribution to the noise generation of the design comes from the inverter-driven electric motor. The constant, significant noise generated by the inverter-controlled electric motor can be reduced by lowering or isolating it from the fan, which in turn reduces the measured sound power level of the fan outlet.

Additional information

The authors declare: no competing financial interests and that all material taken from other sources (including their own published works) is clearly cited and that appropriate permits are obtained.

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