Performance Measurements on an Axial Flow Fan

Subject: BMEGEÁTAG03, M.Sc. in Mechanical Engineering

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1. Introduction

Axial flow fans are widely used in flow technological and thermal processes, e.g. in sucking cooling air through heat exchangers. Depending on the pressure drop through the heat exchanger, i.e. depending on the associated throttling effect, the air flow rate drawn through the heat exchanger by the fan will vary. Since the effectiveness of the cooling process highly depends on the air flow rate, it is of preliminary interest to know exactly the ***volume flow rate*** q_V delivered by the fan as function of its pressure increasing capacity, represented by the ***static pressure rise*** Δp_{st} performed by the fan.

An important indicator of loading of the fan-driving electric motor is its ***speed of revolution n***, as function of volume flow rate q_V, relative to its nominal speed n_N, specified on the data table of the motor. Speeds falling considerably below the nominal value indicate the risk of motor overloading.

From the viewpoint of loading of the electric network by the fan drive, it is of importance to determine the ***electric current i*** input to the motor, relative to the nominal current i_N, specified on the data table of the motor, as function of volume flow rate q_V. Excessively high currents, indicating motor overloading, may cause the emergency shut-off of the motor or the electric circuit (by over-current protection).

Finally, from energetic point of view, it is desirable to select the fan operating point close to its energetical optimum, indicated by its maximum **overall efficiency** η. For energetic judgment of fan operation, is therefore desirable to determine η as function of volume flow rate q_V.

The above suggest that before assembling a cooling system, it is recommended to check the following fan characteristics – being the subject of the present measurements:

- $\Delta p_{st}\,(q_V)$
- $n/n_N\,(q_V)$
- $i/i_N\,(q_V)$
- $\eta\,(q_V)$

2. Experimental facility and instrumentation (Fig. 1)

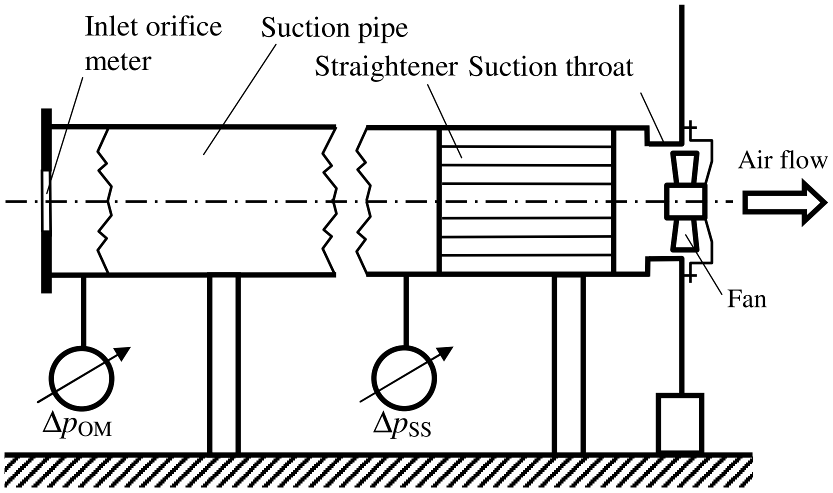

Figure 1. Experimental setup

The air enters from the surroundings into the suction pipe through an inlet orifice meter. A series of orifice plates with various diameter ratios $\beta = d/D$ have been manufactured. d is the orifice plate throat diameter, and $D = 400$ *mm* is the diameter of the suction pipe. The orifice plates with various β values represent various throttling effects. With use of the interchangeable orifice plates, the operating point of the fan, i.e. q_V, can be modified.

The air goes through the suction pipe. At the end of the suction pipe, a straightener is installed, in order to eliminate the apparent pre-swirl caused by the fan at more throttled conditions. Upstream of the straightener, static pressure taps are installed for measurement of the suction side depression compared to the atmospheric pressure. Downstream of the straightener, a suction throat is installed, as a continuation of the suction pipe. The fan under investigation is connected to this suction throat. The fan transports the air from the suction pipe into the free atmosphere.

The pressure downstream of the orifice meter, compared to atmospheric – Δp_{OM} – , and the suction side depression, compared to atmospheric – Δp_{SS} – are measured using digital manometers. The air temperature T at the fan outlet and barometric pressure p_0 are measured using an electric resistance thermometer and a barometer, respectively. The input current i is determined using an inductive clamp meter. The rotor speed n is monitored by means of a digital stroboscope.

Instruments:

- Differential pressures: EMB-001 handy digital differential manometers. Uncertainty in 0-2000 *Pa* range: ± (2 *Pa* + 1.5 % of reading).
- Atmospheric pressure: MJL-B-506 barometer. Uncertainty: ± 2 *mbar*.
- Air temperature: GANZ DKH 1Pt-385 resistance thermometer. Uncertainty in 0-100 °*C* range: ± 0.5 °*C*.
- Speed of revolution: Voltcraft DT-2269 digital stroboscope. Uncertainty: up to 1000 *RPM*: ± (0.1 *RPM* + 0.15 % of reading), above 1000 *RPM*: ± (1 *RPM* + 0.15 % of reading).
- Input current: UNI-T UT201 digital clamp meter. Uncertainty up to 4 *A*: ± (0.1 *A* + 3 %).
- Dimensions (e.g. *d*): measuring tape. Uncertainty: ± 0.5 *mm*.

3. Determination of characteristics

The volume flow rate is determined as follows:

$$q_V = \alpha\, \varepsilon \frac{d^2 \pi}{4} \sqrt{\frac{2}{\rho} \Delta p_{OM}} \qquad (1)$$

Where $\alpha = 0.6$, $\varepsilon = 1$, the actual value of d is to be measured by means of a measuring tape, and ρ is determined from the universal gas law as

$$\rho = \frac{p_0}{RT} \qquad (2)$$

Using the measured atmospheric pressure and temperature data, and $R = 287$ *J*/(*kgK*) for air.

Considering that the kinetic energy of the free-exhausted air jet is fully converted to loss, the fan is characterised herein by the static pressure rise, calculated as the static pressure on the pressure side – being equal to p_0 – minus the total pressure on the suction side:

$$\Delta p_{st} = p_0 - (p_{SS} + \rho \frac{v_{SS}^2}{2}) \qquad (3)$$

Considering that the suction side depression, compared to atmospheric, is measured directly as Δp_{SS},

$$\Delta p_{st} = \Delta p_{SS} - \rho \frac{v_{SS}^2}{2} \qquad (4)$$

Where the dynamic pressure on the suction side is approximated with a suction-side air velocity calculated from the flow rate as

$$v_{SS} = \frac{q_V}{D^2 \pi / 4} \qquad (5)$$

Since the electric motor has a single-phase electric input, the electric input power is approximated as

$$P_{\mathrm{ELE}} = u\, i \qquad (6)$$

Where the line voltage is taken as $u = 230$ *V*.

The useful air technical performance of the fan is considered as

$$P_{\mathrm{USE}} = \Delta p_{\mathrm{st}} \quad q_{\mathrm{V}} \qquad (7)$$

The overall efficiency is calculated as

$$\eta = \frac{P_{USE}}{P_{ELE}} \qquad (8)$$

4. Estimation of uncertainties

Based on the uncertainty of the instruments specified above, a relative uncertainty e can be estimated for each measured quantity, over the entire measured range. (Relative uncertainty: absolute uncertainty divided by the nominal value.) Approximating the errors as random errors, the relative uncertainty of the measured quantities will propagate as described in the following section, being judged as a reasonable approximation.

For the air density (based on Eq. 2):

$$e_\rho \approx \sqrt{e_{p0}^2 + e_T^2} \qquad (9)$$

For the volume flow rate (based on Eq. 1):

$$e_{qV} \approx \sqrt{(2e_d)^2 + \left(\frac{1}{2}e_\rho\right)^2 + \left(\frac{1}{2}e_{\Delta pOM}\right)^2} \tag{10}$$

For the static pressure rise:

$$e_{\Delta pst} \approx e_{\Delta pSS} \tag{11}$$

For the overall efficiency (based on Eq. 8):

$$e_\eta \approx \sqrt{e_{\Delta pst}^2 + e_{qV}^2 + e_i^2} \tag{12}$$

Calculating these relative uncertainties over the entire measuring ranges, averaged *e* values are to be determined and ***reported – both in table format and indicated by error bars on the diagrams***.

5. Laboratory report

The report **MUST** contain the following data, in well-organized and easy-to-read format, providing a basis for reproducing the measurements if necessary:

- Title, names of measurement personnel, date and location.
- Measured air temperature and barometric pressure data, and the resultant air density.
- Type of fan under investigation; nominal motor data being significant from the viewpoint of the measurements (speed, input current, voltage).
- Schematic view of the experimental facility; dimensions, series of *d* throat diameters and β diameter ratios of orifice plates applied.
- Instruments applied, type numbers, serial numbers, measurement uncertainties.
- Description of determination (measurement, calculation) of characteristics (with equations as appropriate).
- The measurement data represented in 4 Excel diagrams of Δp_{st} (q_V), n/n_N (q_V), i/i_N (q_V), η (q_V), by indicating the quantities and their units in the axes, as well as indicating the experimental uncertainty by error bars. **Excel is exclusively accepted for processing the data and for generating the diagrams**. See Fig. 2 for example of diagram format.
- Detailed report on the experimental uncertainty, summarized in table format; accompanied by the details of the uncertainty calculation.
- Evaluation of results, conclusions, with special regard to the following aspects:
  - i) The operating range of the fan: measured q_V and Δp_{st} ranges for which the fan can be used,
  - ii) Variance of motor speed: are there operating points for which the speed falls down significantly?
  - iii) Variance of input current: are there operating points for which the input current exceeds the nominal value significantly?
  - iv) Efficiency: which Δp_{st} (q_V) range is mostly recommended from energetic point of view; what is the maximum overall efficiency for this range?

6. Administrative details

Participation and active contribution to the measurement is obligatory for each member of the group. Absence is not acceptable, except for officially proven medical reasons. No occasion for repeated measurements is offered.

Students MUST be prepared for the measurement. The precondition for the measurement is to pass a short-term oral examination at the beginning of the measurement. Those who fail this examination will not be allowed to participate, and no repetition will be offered for them (i.e. they receive a mark “Failed”).

The laboratory report is to be submitted by the laboratory leader, exclusively via email, in doc or pdf format, to vad@ara.bme.hu. The proper receipt of the report will be acknowledged via email. The deadline for submission of the final report: 10 working days after the date of measurement. No report will be accepted after this deadline.

Prior to the deadline, the report can be refined and improved during consultation with the representative, upon agreement of a facultative consultation date.

Dr. János VAD

Associate professor, Subsection Responsible

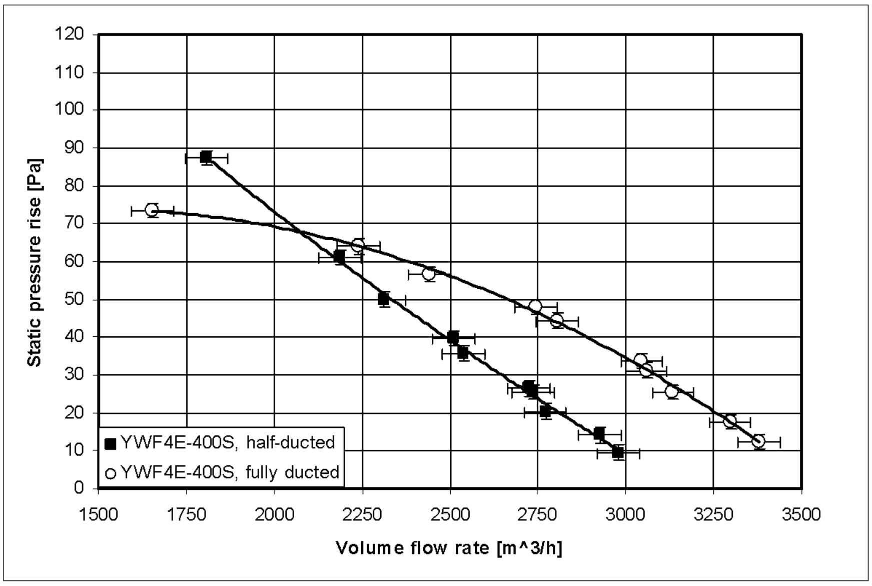

Figure 2. Example for format of the diagrams representing the results. Error bars MUST be provided.

7. List of symbols, units (SI units are to be used in each computation!)

Latin letters

d	[m]	orifice plate throat diameter
D	[m]	diameter of suction pipe
e	[-]	relative error
i	[A]	electric current
n	[$1/s$]	speed of revolution: revolution per unit time
P_{EL}	[W]	electric power input to the driving electric motor
P_{USE}	[W]	useful air technical performance
p	[Pa]	static pressure
Δp	[Pa]	pressure difference
Δp_{OM}	[Pa]	pressure measured downstream of the orifice meter, relative to atmospheric
Δp_{SS}	[Pa]	depression measured on the suction side, relative to atmospheric
Δp_{st}	[Pa]	static pressure rise of fan
q_{V}	[m^3/s]	volume flow rate
R	[$J/(kgK)$]	specific gas constant
T	[K]	temperature

Greek letters

α	[-]	contraction coefficient
β	[-]	throat-to-pipe diameter ratio for orifice plates
ε	[-]	expansion coefficient
η	[-]	overall efficiency
ρ	[kg/m^3]	fluid density

Subscripts

N	nominal value
SS	suction side (of fan)
0	atmospheric condition