Design of system cooling using DC axial fans

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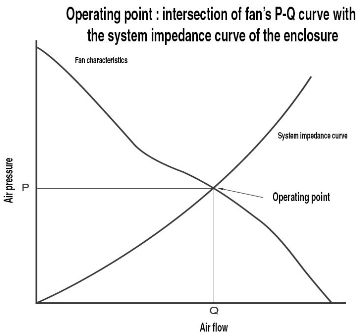
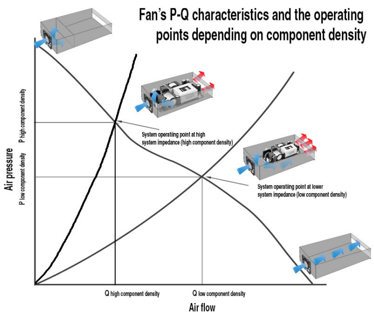
In the previous part of our series of articles, we reviewed the issues of selecting and operational point adjustment of axial DC cooling fans in order to ensure that the heat generated in our electronic system is dissipated as efficiently as possible by forced airflow. We presented the calculation of the required amount of air and, knowing the static pressure – air flow (system impedance) curve of the device, determined the static pressure range that the fan must overcome to provide the minimum air flow required for cooling. In most cases, in the manufacturer's catalog we can find a fan that can deliver the required amount of air at this pressure level, but what can we do if for some reason this device cannot be used, for example, there is not enough space for its installation? In this article, we will review the methods by which we can influence the amount of airflow that can be transported and the available air pressure when using a given device. We look at the possibilities of controling the speed and the cases in which we arrive at a satisfactory solution using more than one device.

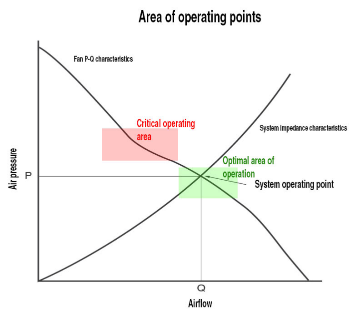
In a system cooled by airflow, the principal two characteristic curves are the fan's P-Q airflow curve and the system impedance curve of the cooled system. The intersection of these curves defines the operational point of the fan. The system impedance curve, defined by the component density, is constant, and the fan must be chosen to be able to operate preferably in the optimal area shown in the third figure at a given (usually at nominal) speed. To achieve this, as discussed in the previous part of this series of articles, the designer needs to define the minimum required amount of air, and then choose a fan, which can carry it at the pressure value determined by the system impedance curve. (The amount of air that can be transported during free flow decreases as a result of the component density – the impedance – of the system grows). Another criterion for selection is the relationship between the available space and the permissible noise level. The larger fan can be used to transport the same amount of air, the lower the speed at which it must be run, which helps to reduce noise. When choosing, it is worth prioritizing the medium or small volume types within the given size range, that still can carry sufficient air, so that in case of a possible increase in cooling demand later, we can easily replace the insufficiently functioning fan with a larger capacity version of the same size. If this is not possible, then additional cooling capacity can only be realized with a more serious redesign. Resize the chassis to accommodate a larger cooling fan and improve flow conditions to ensure lower component density or better ventilation is usually a difficult task, Thus, it is often necessary to choose other methods. This can include applying speed control, as noise can be reduced at low revs, or higher static pressure can be overcome and a larger amount of air can be supplied at higher speeds. For DC fans, this is relatively easy to implement, as the supply voltage is proportional to the number of revolutions, with simple voltage regulation we can operate. We will review the methods later. It is possible that we cannot set the desired working point by using a single cooling fan, in which case it may be justified to use several fans at the same time. This, while increasing costs, increases also the noise level and the fan motor impairs the efficiency of cooling due to its own heat generation, in some cases it is inevitable and due to redundancy, the system has an increased reliability so it is at the end a beneficial effect.



1| Determination of the operational point



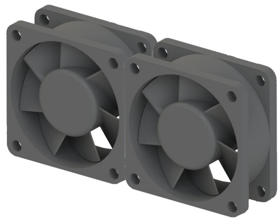
2| The operational point for a given type at a given speed is determined by the component density



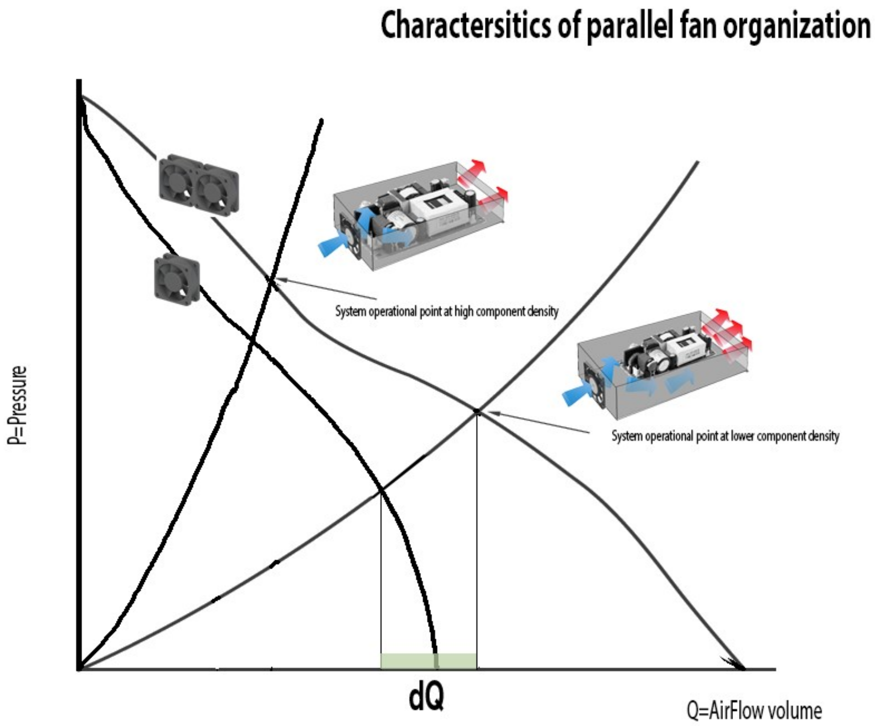
3| Area of optimal operation

Using multiple fans – parallel operation

When we switch several fans in parallel, then the joint system's air moving capacity is increased in the range of low static pressures. On the following curve, it can be observed that when used concomitantly, the idle air flow is increased. In practice, this means that we can operate with such an arrangement if the component density of the system to be cooled is low, so the operation point can be set at a low static pressure level. Of course, the new working point is also associated with a slightly higher air pressure, however, where a significant increase is observed it is the air flow. In the case of higher system impedance, this arrangement does not bring much benefit, since the additional investment does not result in a significant increase in airflow.

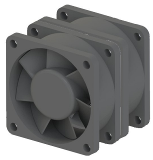


4| Use in parallel



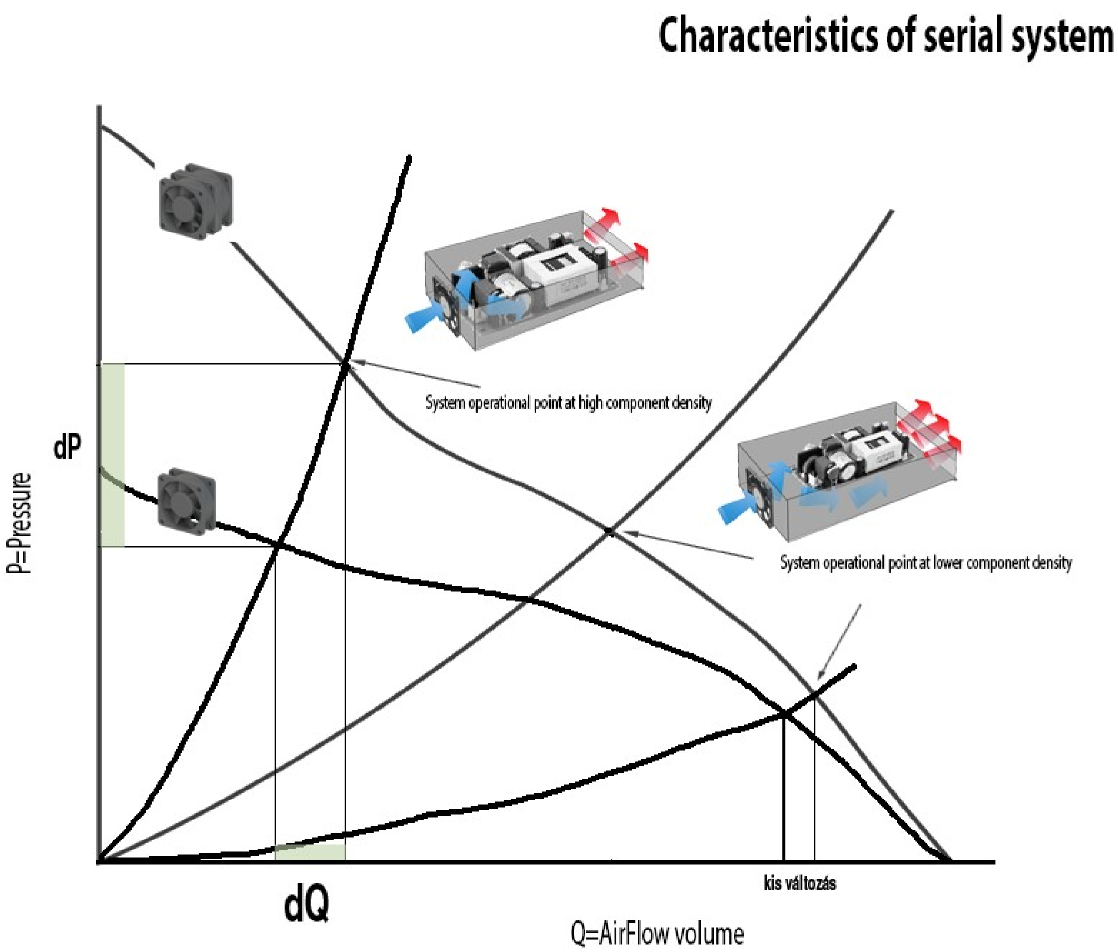
5| Comparison of the characteristic curves of one and two simultaneously coupled cooling fans

Using multiple fans – serial operation



6| Use in serial

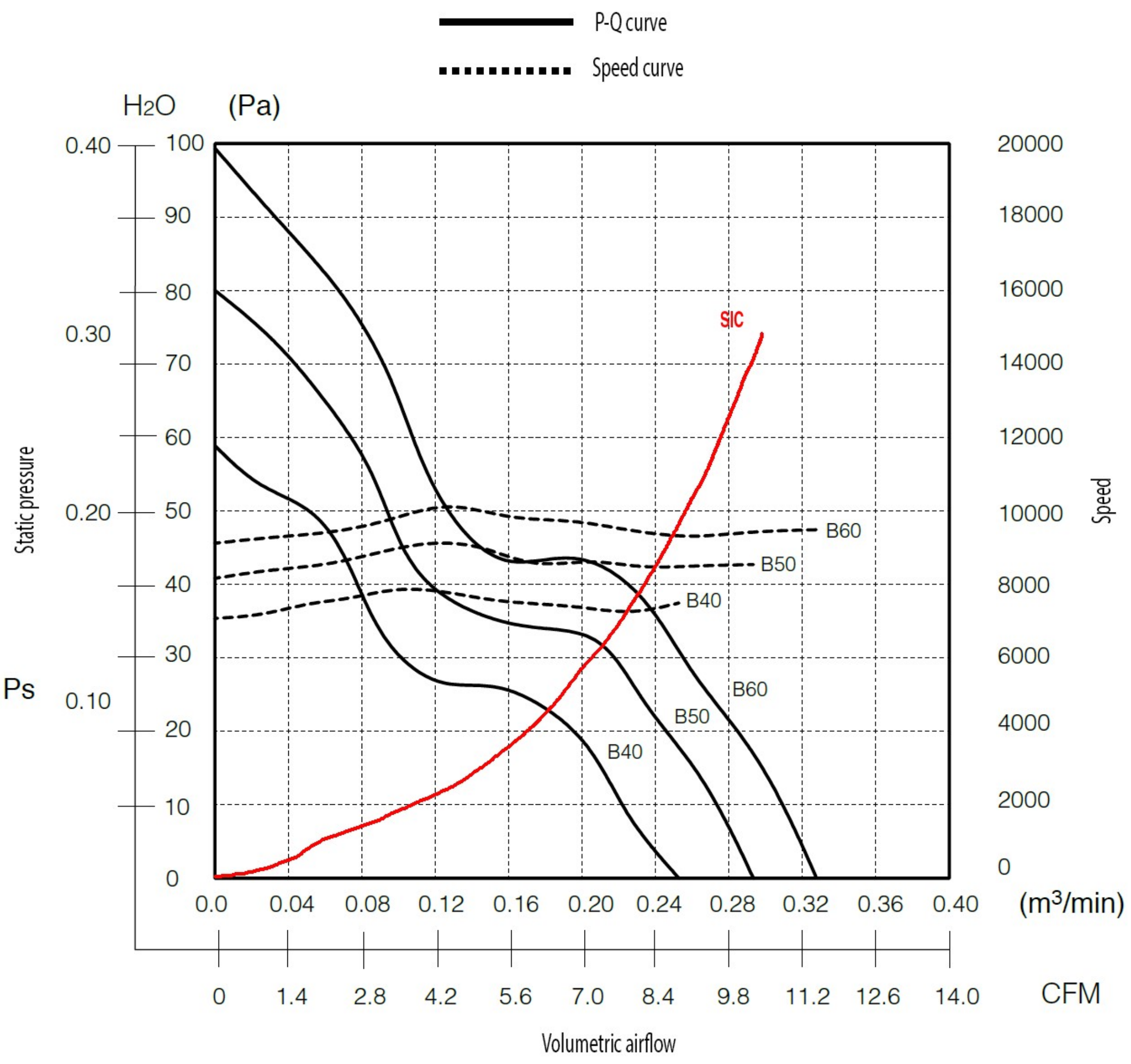
When several fans are connected in series, the airflow of the combined system increases significantly in the range of high static pressures, so with such an arrangement we can achieve a significant improvement in chassis with high component density and high system impedance. In this case, the operational point is in an area characterized by high static pressure, the serial arrangement is characterized by increased air flow even at higher air pressure. At low component densities, this additional pressure is not needed, so this arrangement cannot be applied economically, because the investment will not bring a significant increase in air flow.



7| Comparison of the characteristic curves of one and two series-connected cooling fans

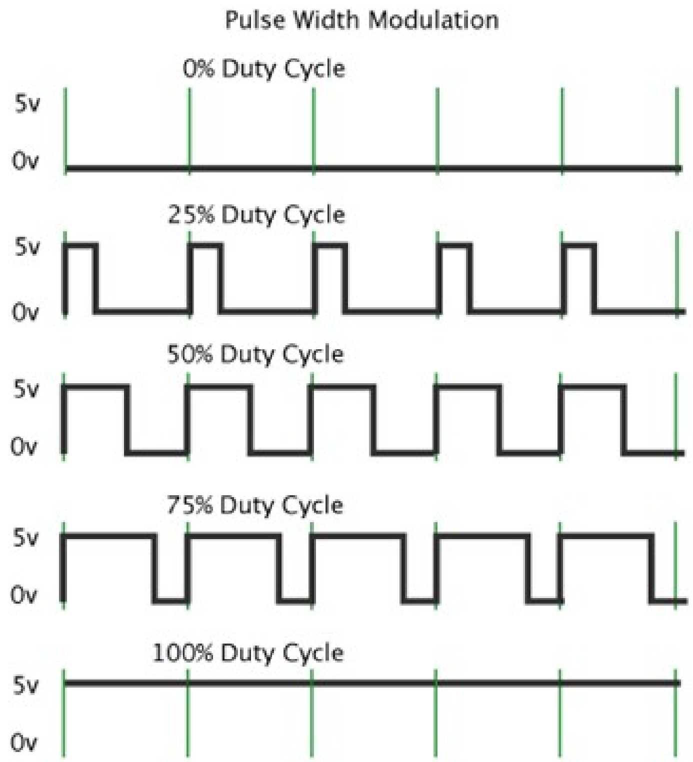
The effect of speed on air flow

DC axial fans have different P-Q characteristics for different nominal supply voltages, so they differ at nominal rotational speeds (see. Fig. 8), so when applied to the same system at a higher rotational speed, they can be used to achieve greater air flow and pressure. Assuming the impedance curve being a square function, the working points that are output for each rotational speed can be assigned to higher static pressure and air flow values, respectively. Variable speed can be achieved with external voltage regulation for two-wire fans, but of course there are built in RPM control functions at three- or four-wire fans. In the case of the former, the third wire is used to receive a high-frequency pulse width modulation (PWM) control signal, while in the case of the latter, a so-called additional tacho pulse supplied by a (HALL) transmitter is received from the motor on the fourth wire. The fan returns data about its rotational speed to the external control electronics. On this line, in addition to the usual data, a special distress signal, such as a warning of possible rotor jamming, may also be received.



8| Working points emitted by P-Q and system impedance curves at different speeds

Pulse width modulation speed control is actually a supply voltage control, the essence of which is that the DC voltage applied to the fan terminals is periodically alternated between the values of 0V and the rated voltage using transistor or FET-based electronics. The effective value of the terminal voltage is determined by the ratio of times spent in the two states (fill factor) as shown in Figure 9.



9| Explanation of PWM – the relationship between the duty cycle k and the RMS of the terminal voltage

In practice, there are a lot of rules for determining fan parameters under given conditions, the important of which are those that are used to determine volumetric air flow (CFM), pressure (P), power consumption (W) and noise (dBA) as a function of speed. The values interpreted at RPM_1 to RPM_2 can be converted as follows:

Air flow: $CFM_2 = CFM_1(RPM_2/RPM_1)$;

Pressure: $p_2 = p_1(RPM_2/RPM_1)^2$;

Power: $P_2 = P_1(RPM_2/RPM_1)^3$;

Noise: $N_2 = N_1 + 50\log_{10}(RPM_2/RPM_1)$;

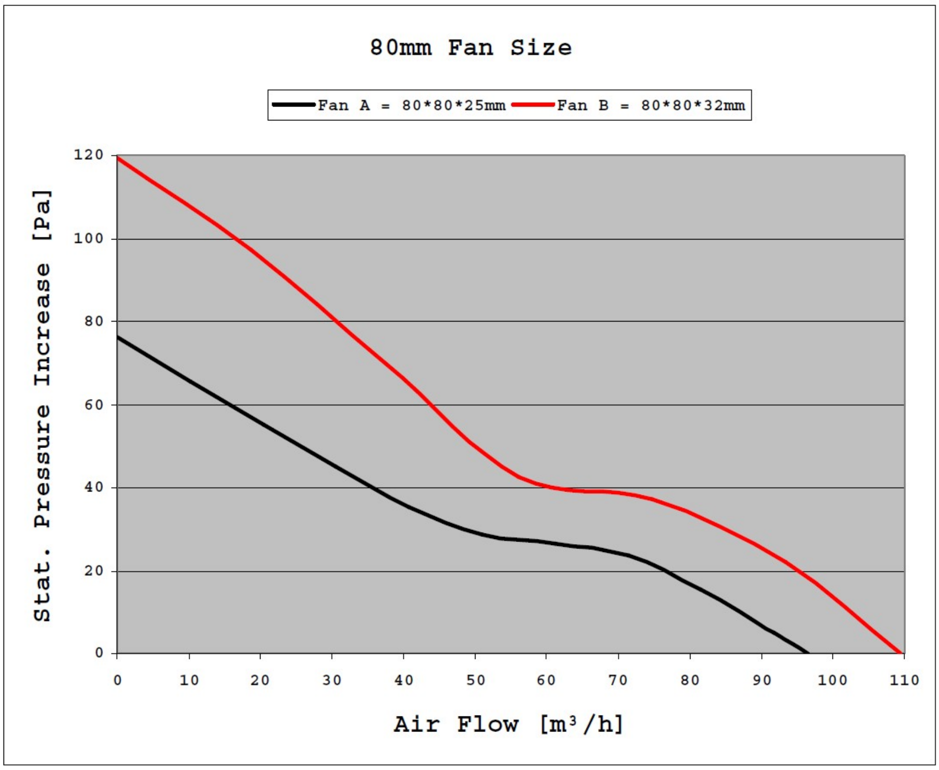
From the foregoing, some very important conclusions can be made, which must necessarily be taken into account when choosing a cooling fan.

With an increase in speed

- (+) the airflow increases
- (+) squared increase in pressure
- (-) there is a significant increase in noise,
- (-) significantly increase engine heating
- (+) the bearing load reduces the service life

We would like to show their significance through an example. Figure 10 shows the P-Q characteristics of two cooling fans. The parameters of the fans are as follows:

A:	B:
80x80x25 mm	80x80x32 mm
4200 rpm	4600 rpm
3.96W	4.20W
44 dB(A)	46 dB(A)



10| Comparison of two different fans

In the example above, in terms of the physical dimensions of the two devices, there is only a difference in their thickness. It is assumed that the device marked B would provide sufficient cooling for the system, but for space-saving reasons, we choose the thinner design (A). To ensure proper volumetric airflow and pressure levels, fan A is used at ~10% higher RPM, which results in 31.4% higher consumption, greater dissipation (heating), significant additional noise and significantly reduced service life due to the increased load on the bearing. The negative impact of warming further worsens life expectancy, which is really evident when you consider the fact, that - according to some experts - the fan motor‘s 10ºC durable temperature increase causes 20,000 hours (approx. 40%) reduction in lifespan.

From the above, it can be seen, when choosing cooling solutions for a particular system, it is worth making a reserve of the required airflow, using a cooling fan with the largest possible physical size, running at a speed even lower than the nominal one, if the design of the system allows it. If for some reason a higher static pressure or a larger volumetric air flow is required, depending on the layout, there are several options: you can raise the number of revolutions and/or apply more than one cooling fans (in serial or parallel arrangement). In all these cases, it is necessary to carefully examine the actual additional advantages of the given solution and how much investment it requires, because it often happens with poor designs that, for example, the self-heating of the applied several fans is greater than the extra cooling it offers for the system. In addition, the economy must also be examined, the price of the second, third fan, the increase in the mathematical probability of failure, the increase in consumption all affect the price and operating costs of the final product.

Bibliography used:

[1] Claudius Klose – Product Manager for Electromechanical Components – Endrich Bauelemente Vertriebs GmbH. – "Proper fan selection"

[2] NMB-MAT fan catalogue – "Fan engineering"