April 2017

TTM-07: Back to the basics – fan laws

An introduction to fans laws and where they can be used

1. Introduction

Fans are used in a wide variety of applications including air conditioning, refrigeration, medical and transport applications. EC (Electronically Commutated) fans are becoming increasingly popular due to their improved energy efficiency compared to AC (Alternating Current) fans and energy-conserving speed controllability. With increased interest in speed-controllable fans, there is a growing need to understand how speed-control affects the fan behaviour in AC and EC fans differently.

Fan laws are a useful set of tools to develop statistically sufficient estimates on how the performance of an EC product changes when the speed-control feature is used. These fan laws do not apply to AC products due to the different mechanisms used in speed control. This paper will explain the fan laws and show the effects of speed control on EC and AC products based on the example of a 190mm backward curved fan.

2. Speed control of fans

The speed-controlling of fans has been around for a very long time. AC products are typically speed controlled by external devices such as triac controllers or VSDs (Variable Speed Drive). Each of these devices has a different effect on the performance of the AC product and certain precautions have to be taken to prevent possible damages to the fan and motor, such as overheating. These external speed-controlling devices influence the slip and efficiency of the motor and cause power transfer losses. As a result fan laws do not apply for AC speed controlled fans and motors.

With ebm-papst EC products, speed control is a lot simpler as the speed control electronics are integrated into the fan. Speed control can be managed, for example, by applying a 0-10V or PWM (pulse width modulation) signal to the control input, influencing the fan speed and thereby the input power of the fan product. The minimal impact on motor slip or efficiency means that ebm-papst EC products typically follow fan laws.

3. Fan laws

If fan speed increases, so does the air flow, back pressure and power consumption of the fan. The following formulas apply:

$n \sim q_V$
$n \sim p_{fs}^2$

Fan air power is the product of air flow and total pressure (static and dynamic component).

$P_u = \frac{q_V \times p_t}{3600}$ where $p_t = p_{fs} + p_d$

Variable	Parameter	Unit
n	Speed	[rpm]
q_V	Air flow	[m3/h]
p_{fs}	Fan static pressure increase	[Pa]
p_t	Total pressure	[Pa]
p_d	Dynamic pressure	[Pa]
P_1	Fan input power	[W, kW]
P_u	Fan air power	[W, kW]

Therefore:
$n \sim P_u^3$

The relationship between air power and input power is:
$P_u = \eta \times P_1$ where η is the efficiency of the fan-motor-combination

Therefore:
$n \sim P_1^3$

Air Volume at reduced speed

$$\frac{n1}{n2} = \frac{V1}{V2}$$

Input power at reduced speed

$$\frac{n1}{n2} = \left(\frac{p1}{p2}\right)^3$$

For noise, the relationship between speed and sound is not proportional. The following formula for sound increase / decrease applies:

$$\Delta Lp = 50 \times log10\left(\frac{n1}{n2}\right)$$

Based on above discussed relationships and formulas, it is easy to calculate how a change in speed in an application theoretically affects air performance, input power and noise for EC products. As an example (Figure 1a and 1b): when reducing fan speed by 50%, the input power is reduced by a staggering 87%. Noise is reduced by 15dB(A). This is an impressive reduction as well as a reduction of 3dB(A) is considered to be a reduction of noise by half.

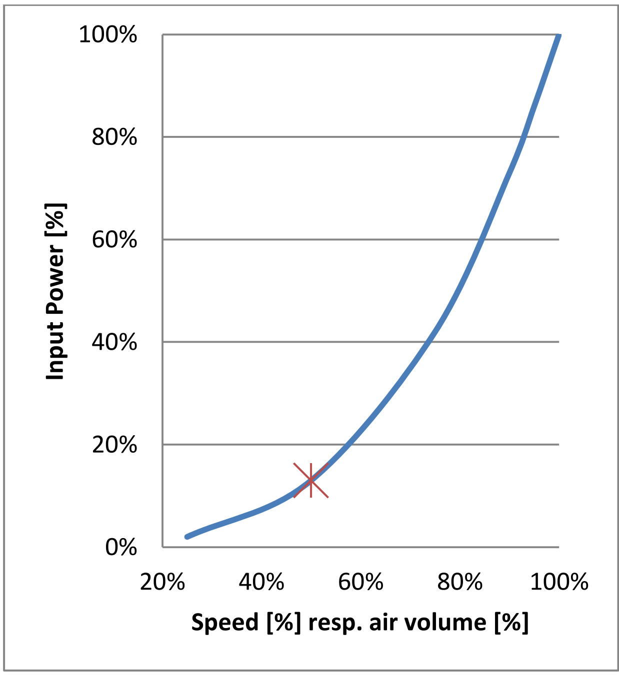

Figure 1a: Input power as a function of fan speed

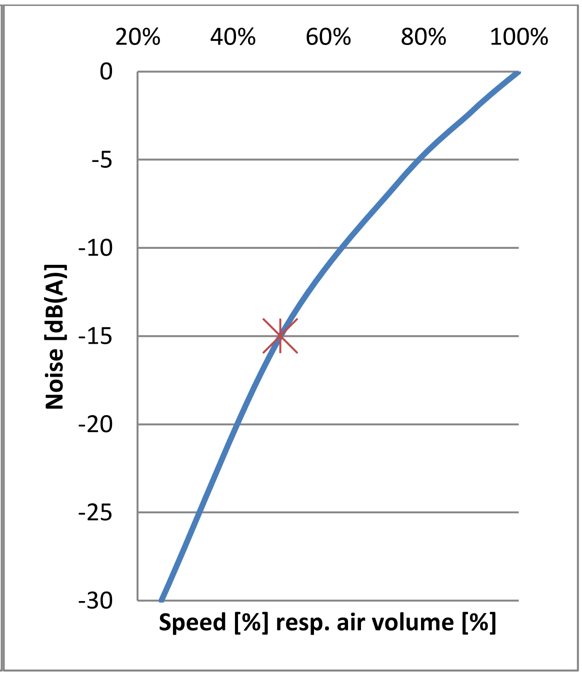

Figure 1b: Noise as a function of fan speed

3.1 Fan laws – an example

We measured an EC product and an AC product of similar size and performance on the in-house air performance test rig at ebm-papst A&NZ headquarters in Melbourne, Victoria.

EC product: R3G190RC0528 (EC190) – 190mm backward curved fan, speed-controlled by potentiometer
AC product: R2E190RA2664 (AC190) – 190mm backward curved fan, speed-controlled by triac controller, MC1-20112A

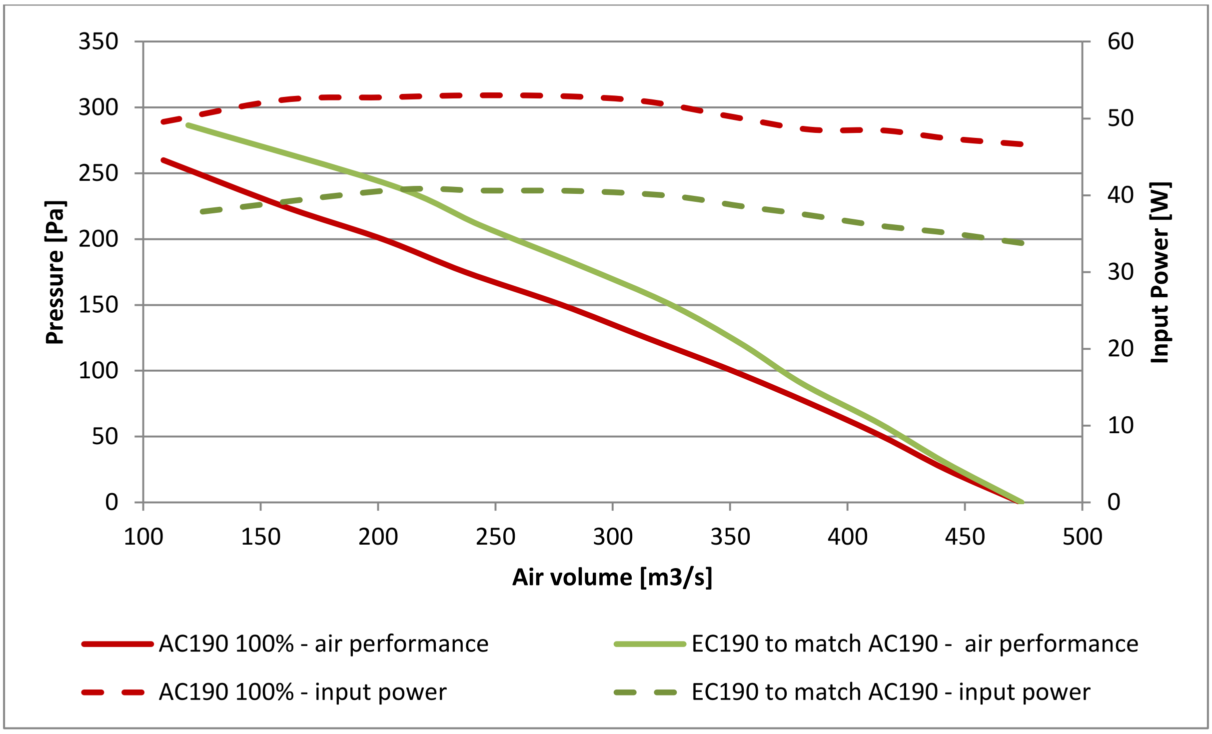

Figure 2: Test 1, comparing AC190 to EC190 pressure and input power at 100% AC performance of air volume

The first test (Figure 2) was to run AC190 at its maximum speed without speed control and to reduce speed of EC190 to match that performance. This needed to be done as EC190 is slightly stronger than AC190 at maximum speed. As EC products have a higher efficiency, the input power of EC190 is already lower than that of AC190.

The second test (Figure 3) was to reduce the speed of AC190 to 50% by using a triac controller and to reduce the speed of EC190 to match that performance by using a potentiometer.

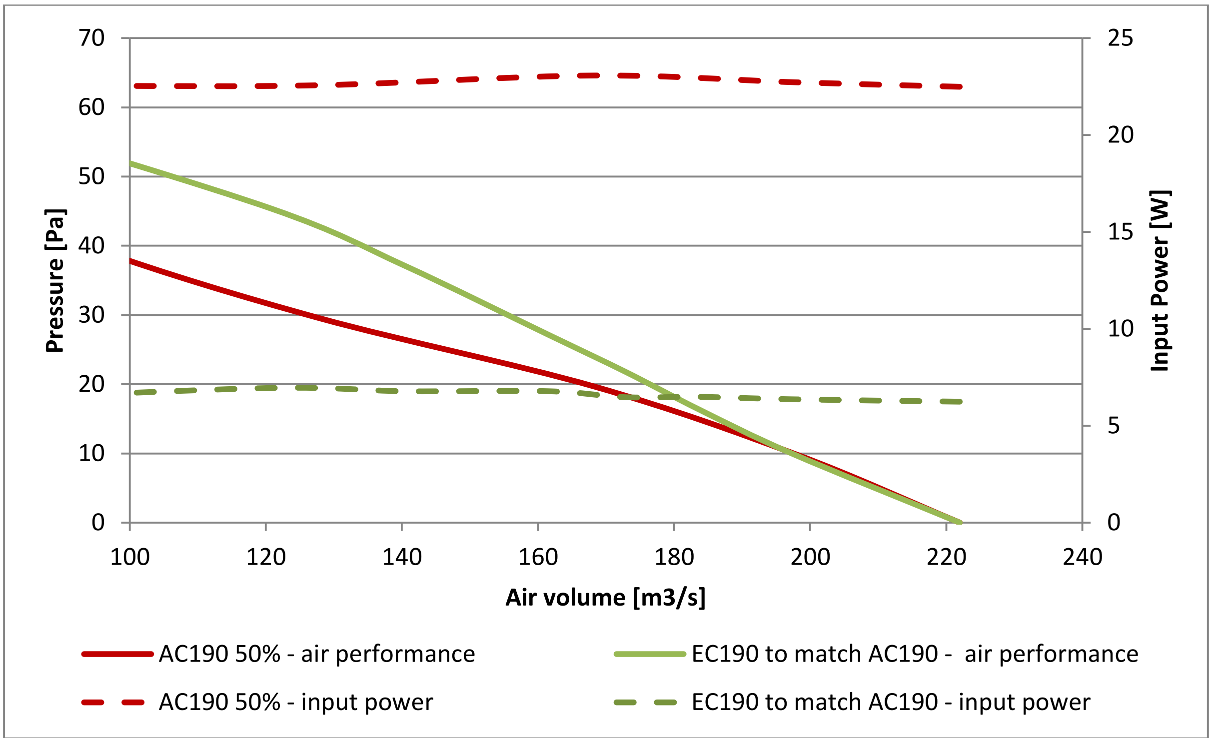

Figure 3: Test 2, comparing AC190 to EC190 pressure and input power at 50% AC performance of air volume

As expected, input power was reduced for both fan types in the second test due to reduced speed and performance. When comparing AC and EC input power, it becomes evident that the input power reduction is much higher in EC190 than in AC190. This is because EC products follow fan laws where as AC products with external speed control do not.

When reducing the fan speed to approximately 50%, following data was measured:

	input power [W]	
	AC190	EC190
100% speed – input power [W]	47	34
50% speed – input power [W]	23*	6
Difference [W]	24*	28
Difference [%]	51*	82

*These figures may be different if using a different speed controlling device.

By reducing AC fan speed to 50%, input power in this case decreased by 51%. However, input power for the EC fan at same speed reduction is significantly reduced, by 82%. This is due to the EC fans behaviour following the fan laws, compared to AC fans where the impact on motor slippage that occurs means that fans laws do not apply.

Comparing measured data with calculated data using fan laws:

	input power [W]			
	AC190 measured	**AC190 calculated**	**EC190 measured**	**EC190 calculated**
100% speed	47	47	34	34
50% speed	23	6	6	4
Difference [W]	24	41	28	30
Difference [%]	51	88	82	88

This comparison shows a difference between measured and calculated of 37% input power for AC190 using fan laws (51% vs 88% respectively). As previously mentioned, AC products do not follow fan laws due to the inefficient methods of speed control used in AC products, as is evident in this comparison.

Comparatively, the calculated and measured power reduction is very similar for EC190 with 82% measured compared to 88% calculated. The small discrepancy between calculated and actual input power is caused by the EC product also decreasing efficiency slightly when operated at reduced speed.

4. Conclusion

In summary fan laws are a great tool to estimate the performance of EC products at reduced speed. However, fan laws do not apply when speed controlling AC products with an external speed controlling device and therefore must not be used in these cases.

Fan laws, easy to remember:

$$\frac{speed\ 1}{speed\ 2} = \frac{air\ volume\ 1}{air\ volume\ 2}$$

$$\frac{speed\ 1}{speed\ 2} = \left(\frac{pressure\ 1}{pressure\ 2}\right)^2$$

$$\frac{speed\ 1}{speed\ 2} = \left(\frac{input\ power\ 1}{input\ power\ 2}\right)^3$$

And for noise:

$$\Delta Lp = 50 \times log10\left(\frac{speed1}{speed2}\right)$$