EC FANS
ANNEX

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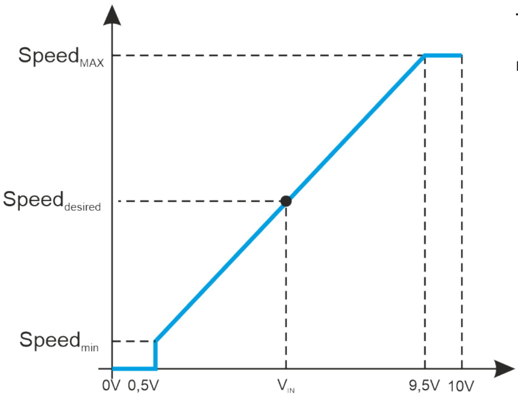
1. ANALOG SIGNAL CONSIDERATIONS

1.1 Voltage and speed



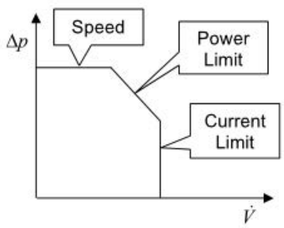
Pict. 1

This paragraph shows the way to find the voltage V_{IN} required to achieve the Speed$_{Desired}$ using the diagram Signal/Speed of figure aside.

$$V_{IN}=\frac{Speed_{Desired}-Speed_{min}}{Speed_{MAX}-Speed_{min}}\cdot 9V+0.5V$$

1.2 Voltage signal rescaling

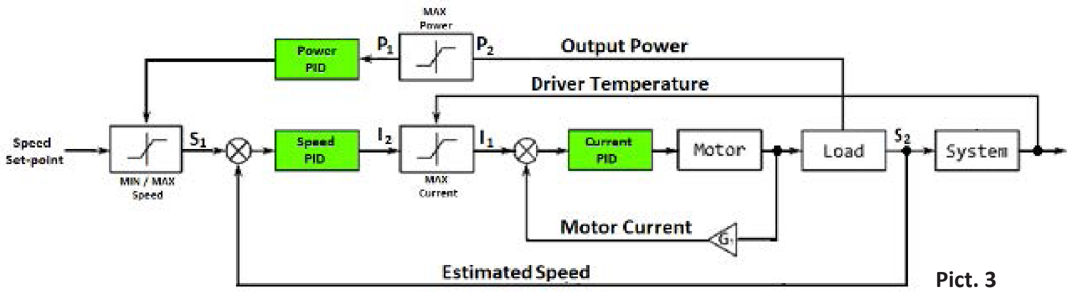
Each fan performance is defined and limited by its own Safe Operating Area.



Pict. 2

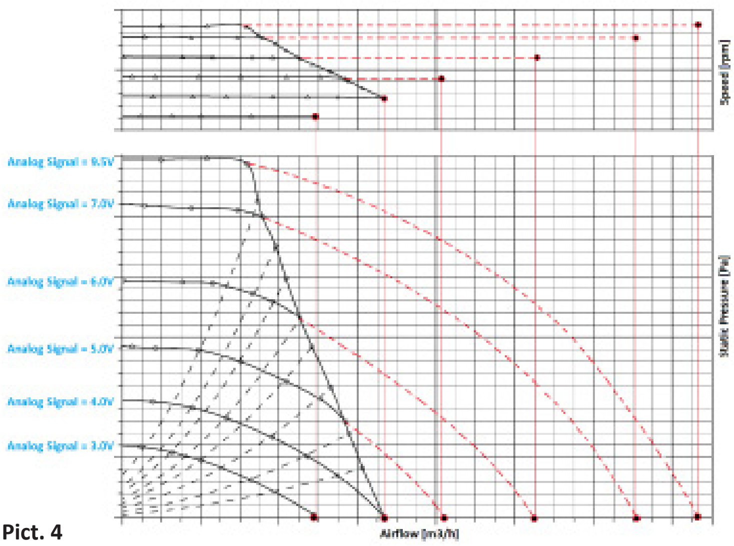
The Speed is limited by the fan impeller
The Power is limited by the fan driver.
The Current is limited by the fan motor.

The motor current, the absorbed power and the driver temperature represent the process, while the speed represents the set-point of the system. Therefore, the driver control loops reduce the speed whenever a process variable exceeds its own limit.



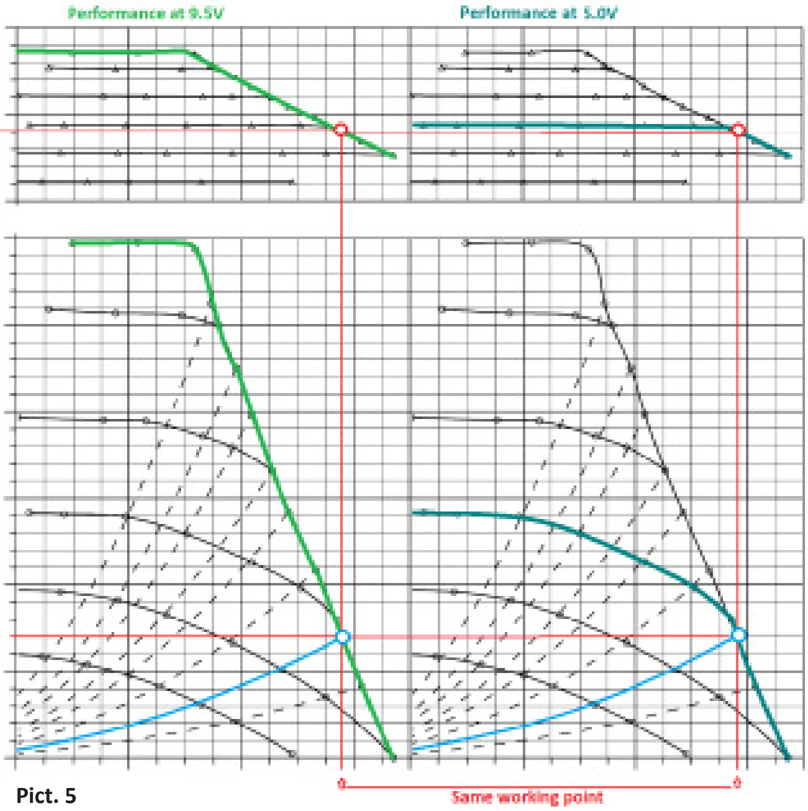
Pict. 3

In the following figure, the performance of a DDMP 7/7 Tight has been extended (red curves) supposing to have no limitation of power, current and heating.



Pict. 4

Each fan is configured by default at its own max possible values (Fan Speed, Motor Current and Absorbed Power).

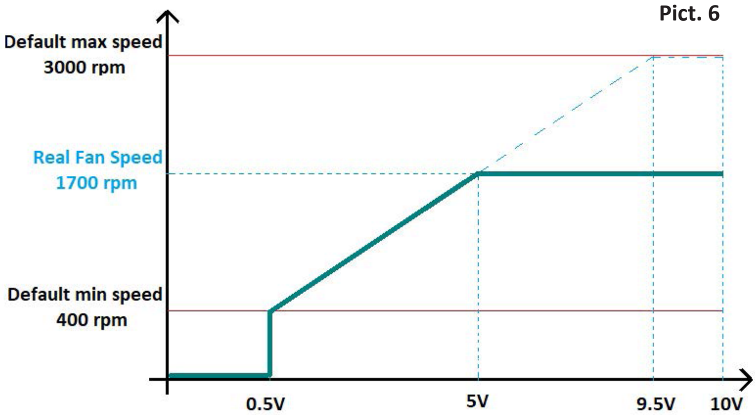


Pict. 5

For example, the max speed of the DDMP 7/7 Tight is 3000rpm represented by the performance at 9.5V of figure 19 (light green).
While dark green line represents the performance at 5V that corresponds to a speed of 1700rpm
The blue parabola represents a working point where the fan is in a current limitation.
Therefore, the fan performance is the same in both cases of 9.5V and 5V
For this reason, reducing the voltage signal from 9.5V to 5V at that working point doesn't change the fan speed.
This situation occurs also when the fan is configured in Modbus mode, even if the max speed is set, the real fan speed will be 1700 rpm.

This situation could cause discomfort when a potentiometer is used, the loss of signal dynamics is translated into no fan reaction when the potentiometer is rotated.

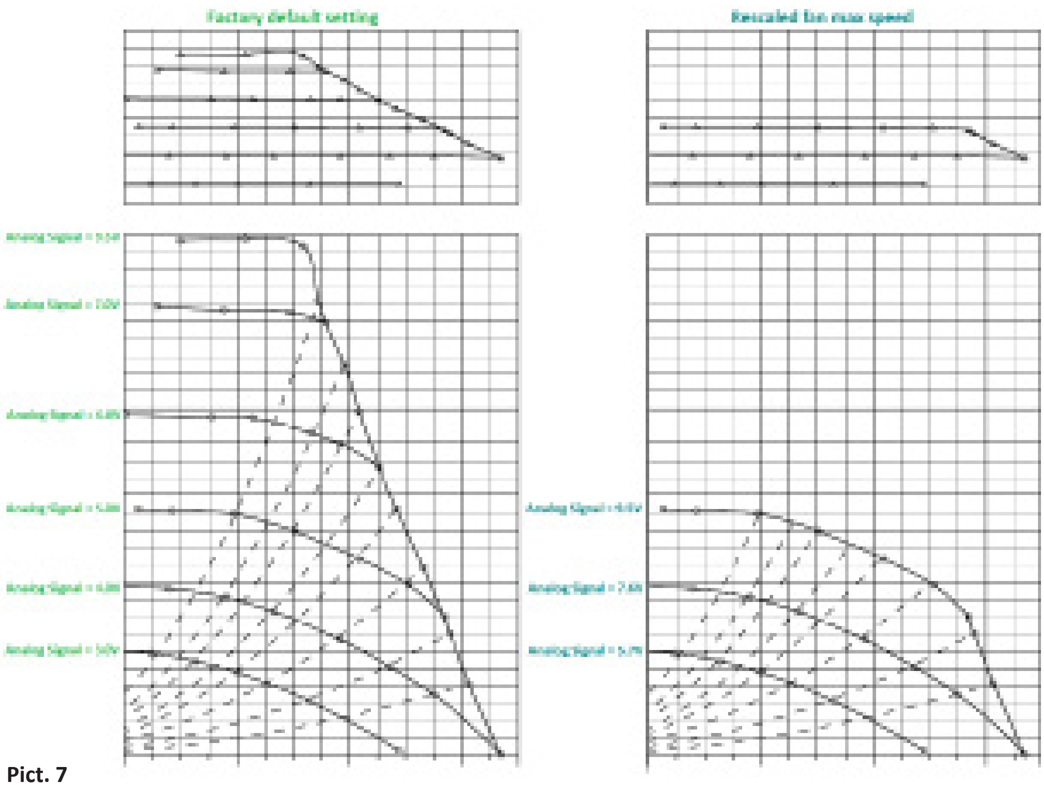
Pict. 6



To avoid this problem is enough to rescale the max speed of the fan. The procedure is simple and requires the Modbus connection:

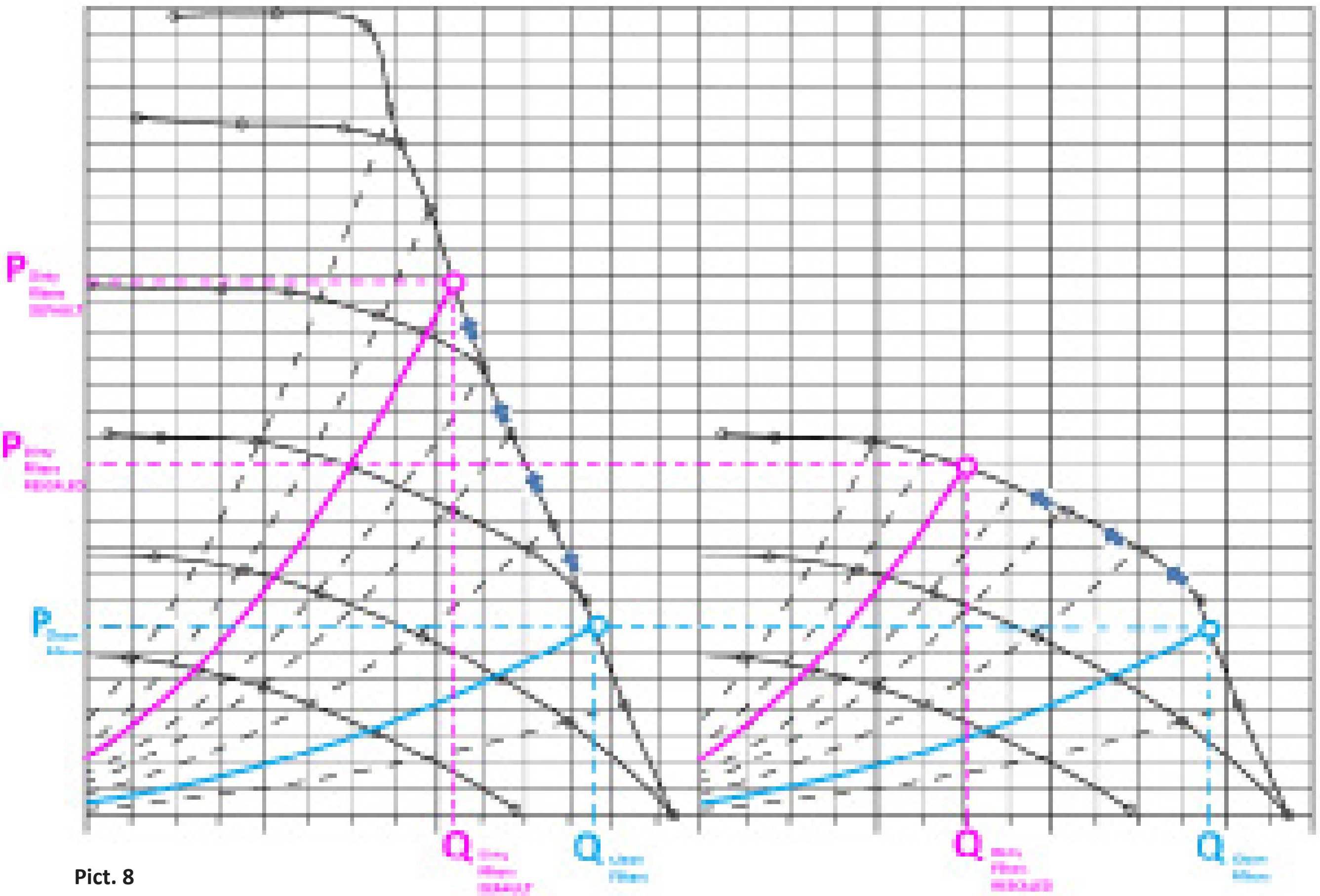
- Install the fan inside the unit at the same condition of the final application.
- Start the fan at its max speed.
- Read the real speed from the Input Registers n°3.
- Set the max fan speed by changing Holding Register n°2 at the previously read value.

The situation after rescaling the speed is shown in the following figure:



Pict. 7

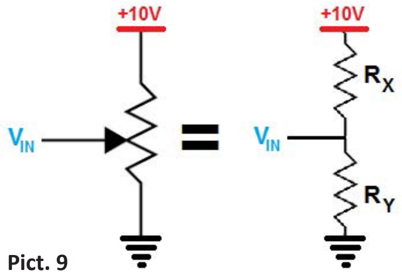
The rescaling obviously affects the behavior in case of change of the fan load (for example due to the dirt of the filters) and, at the same voltage of 9.5V, the default case has a lower loss of airflow compared to the rescaled one.



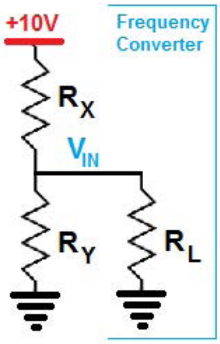
Pict. 8

1.3 Potentiometer setting

$R_{Pot} = R_x + R_y$ is the potentiometer resistance.
The input resistance of the driver is RL and the voltage power supply $V_+ = 10V$



Pict. 9



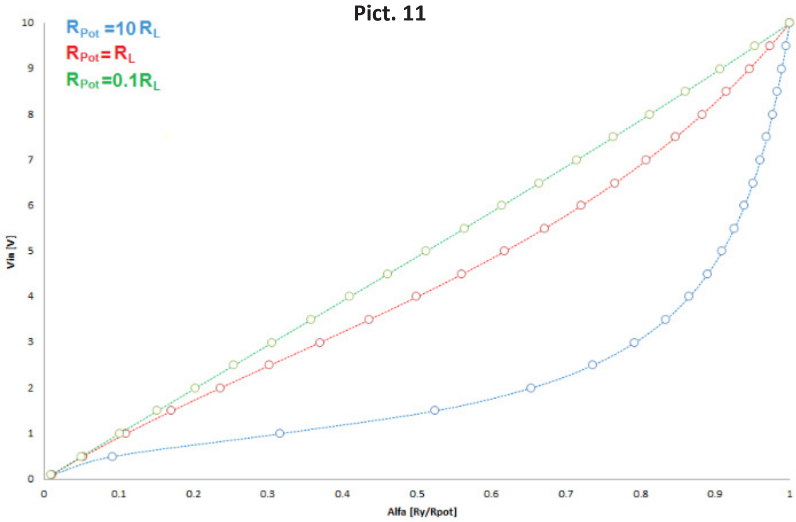
Pict. 10

Connecting the potentiometer to the driver analog input, the voltage value is

$$V_{IN} = \frac{V_+}{R_X + \frac{R_Y R_L}{R_Y + R_L}} \cdot \frac{R_Y R_L}{R_Y + R_L} = \frac{V_+ R_Y R_L}{R_X R_Y + R_X R_L + R_Y R_L} = \frac{V_+ R_Y R_L}{(R_{Pot} - R_Y) R_Y + R_{Pot} R_L} = \frac{V_+ R_Y R_L}{R_{Pot} R_L + R_{Pot} R_Y - R_Y^2}$$

$R_Y / R_{Pot} = \alpha$ represents the position of a linear potentiometer and the previous formula $\alpha^2 V_{IN} R_{Pot} + (10R_L - V_{IN} R_{Pot}) - V_{IN} R_L = 0$

Pict. 11

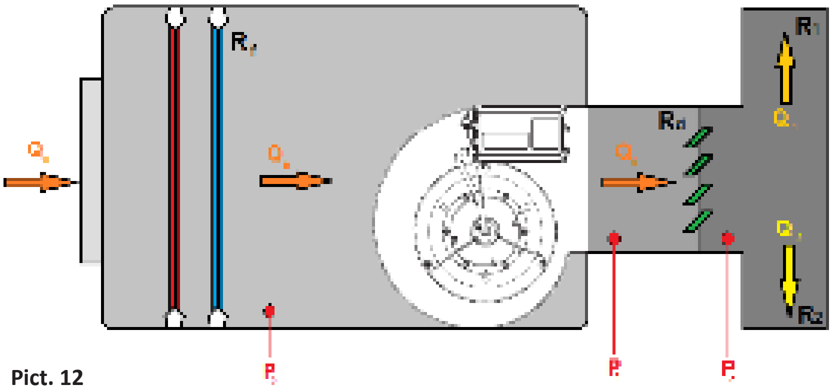


$R_{Pot} = 10R_L$	$V_{IN} 10\alpha^2 + (10 - V_{IN} 10) - V_{IN} = 0$
$R_{Pot} = R_L$	$V_{IN} \alpha^2 + (10 - V_{IN})\alpha - V_{IN} = 0$
$R_{Pot} = 0,1R_L$	$V_{IN} \alpha^2 + (100 - V_{IN})\alpha - 10V_{IN} = 0$

Observing the case $R_{Pot} = 10R_L$ at 90% of the potentiometer position the analog voltage value is still below 5V and therefore a very high sensibility to regulate the analog voltage value in the remaining 10% is required. This consideration must be done especially when N fans are connected in parallel where $R_{L\ parallel} = R_L/N$
Therefore, the choice of the potentiometer value is very important basing on the input resistance of the driver used. Unfortunately, another limitation when choosing the potentiometer value comes from the max current supplied by the +10V power supply of the drivers.
In this case the max available current is 5mA, above this value there is a significant voltage drop, therefore the minimum potentiometer value can be $R_{Pot} = 2k\Omega$.

2. SENSORLESS CONSTANT PRESSURE

In this paragraph there is an approximate explanation about why the Sensorless Constant Pressure is not applicable unless several compromises are accepted.



Pict. 12

All the airflow systems are assumed to be coherent with the approximate formula $P = kQ^2$
For this analysis, a simple analogy with electrical components can be considered: the sum of the Airflows in a node of the system is equal to 0 and the sum of the Pressures in a closed network is also equal to 0.

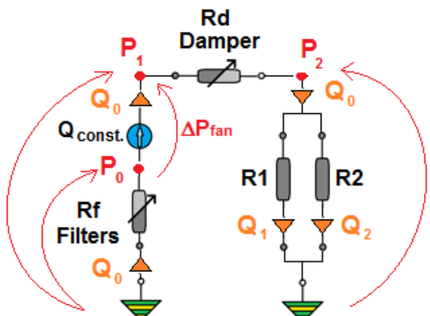
$\sum_{i=0}^{n} Q_i = 0$ and $\sum_{j=0}^{n} P_j = 0$

Here are used the symbols:

R_{Load}	$R_{Variable\ Load}$	$P_{Const.}$	$Q_{Const.}$	$P_{Stat} = 0$
Loads (channels)	Variable loads (filters)	Constant Pressure Generator	Constant Airflow Generator	Static Pressure = 0

Pict. 13

Considering the model of figure 12 the corresponding scheme when the fan is working in constant airflow mode is shown in figure 14.
The fan can keep the airflow constant ($Q_{const} = Q_0$) along the net independently from load conditions.
Using the law at the nodes:



Pict. 14

$$Q_0 = Q_1 + Q_2 = \sqrt{\frac{P_2}{R_1}} + \sqrt{\frac{P_2}{R_2}}$$

The R_1 and R_2 are not variable loads. Therefore, Q_1 and Q_2 are constant too.
Proceeding with the square of the equation:

$$Q_0^2 = \frac{P_2}{R_1} + \frac{P_2}{R_2} + 2P_2\sqrt{\frac{1}{R_1R_2}} = P_2\left(\frac{1}{R_1} + \frac{1}{R_2} + 2\sqrt{\frac{1}{R_1R_2}}\right)$$

$$P_2 = \frac{1}{\left(\frac{1}{R_1} + \frac{1}{R_2} + 2\sqrt{\frac{1}{R_1R_2}}\right)} Q_0^2$$

defining $R_{eq\_1} = \dfrac{R_1 \cdot R_2}{R_1 + R_2 + 2\sqrt{R_1R_2}}$ then $P_2 = R_{eq\_1} Q_0^2$

$$R_{eq\_PARALLEL} = \frac{1}{\left(\sum_{i=0}^{n} \frac{1}{\sqrt{R_i}}\right)^2}$$

Using the law at the networks:

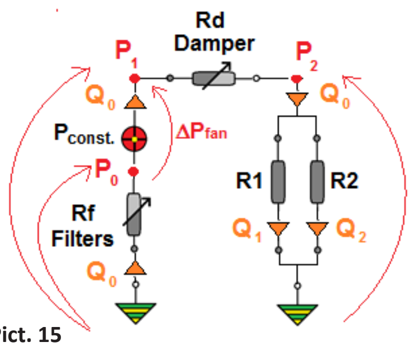
$$P_1 = P_2 + R_d \cdot Q_0^2 = R_{eq\_1} Q_0^2 + R_d \cdot Q_0^2 = (R_{eq\_1} + R_d \cdot) \cdot Q_0^2 \quad \text{defining} \quad R_{eq\_2} = R_{eq\_1} + R_d \quad \text{then} \quad P_1 = R_{eq\_2} \cdot Q_0^2$$

Assuming:

$$R_{eq\_SERIES} = \sum_{i=0}^{n} R_i \qquad \Delta P_{Fan} = P_1 - P_0 = R_{eq\_2} \cdot Q_0^2 + R_f Q_0^2 = R_{eq\_3} Q_0^2 \quad \text{Where} \quad R_{eq\_3} = R_{eq\_2} + R_f$$

The fan works keeping $Q_0 = const$ and changing its ΔP_{Fan}

Considering now the same model but with the fan working in constant pressure mode shown in picture 15:



Pict. 15

The fan can be programmed in the lab to keep the $\Delta P_{Fan} = const$

Generally, the fan in **Nicotra Gebhardt** laboratory is tested free inlet and ducted outlet. However, without knowing the final application for the constant pressure, it should be tested at free inlet and free outlet.

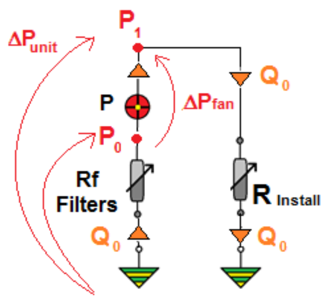
2.1 Considerations

The pressure in all the points of the installation must be calculated from the ΔP_{Fan} knowing all the load values of the final installation.

$P_1 = (R_d + R_{eq\_1}) \cdot Q_0^2$ so R_d changes and, therefore, P_1 cannot be kept constant.

A solution should be to create a customized sensorless constant pressure unit $\Delta P_{Fan} = const$ (see pict. 16)

(This would also imply that each customer should have to send each unit model to **Nicotra Gebhardt** laboratory for measurements).



Pict. 16

At time t = t_0 all data of customers' units are acquired when the value of R_f is R_{fs0}

Therefore $\quad \Delta P_{unit} = P_1 = \Delta P_{fan} + P_0 = \Delta P_{fan} - Q_0^2 R_{ft0} \quad$ with $\quad Q_0^2 = \dfrac{\Delta P_{unit}}{R_{install}}$

For a specific load condition $R_{install} = R_X$ the fan algorithm works on the value $\dfrac{\Delta P_{fan_X}}{Q_{0_X}^2} = R_X + R_{ft0}$

At time t = t_1 the status of the filters are changed into R_{ft1} and in the same load condition R_X, so the fan is not able to discriminate this change:

$$P_{1_{X_{t0}}} - P_{1_{X_{t1}}} = \Delta P_{fan_X} - Q_{0_X}^2 R_{ft0} - \Delta P_{fan_X} + Q_{0_X}^2 R_{ft1} = Q_{0_X}^2 (R_{ft1} - R_{ft0})$$

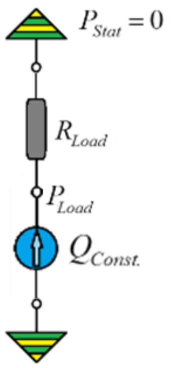
This means that the pressure P_1 gradually decreases depending on the status of the filters.

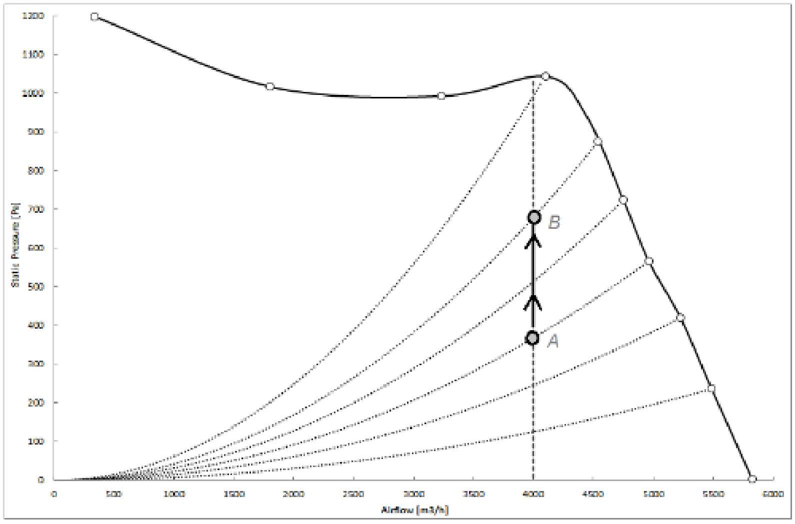
2.2 Conclusion

The sensorless constant pressure cannot be guaranteed and, therefore, not implemented into the **Nicotra Gebhardt** products.

3. SENSORLESS CONSTANT AIRFLOW

The fan working in Constant Airflow mode is ideally a generator able to maintain the same airflow independently from the applied load (pict. 17).



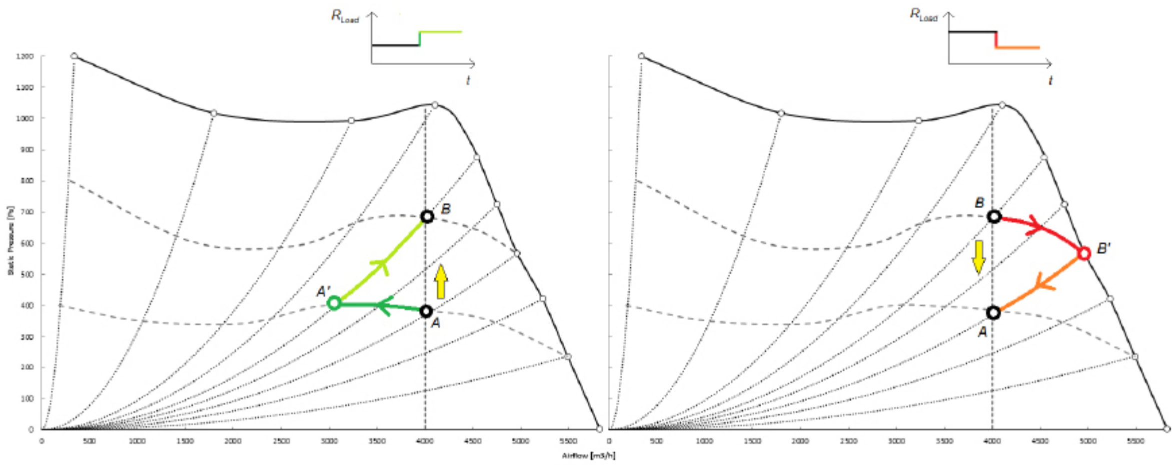


Pict. 17

P_{Load} changes depending on R_{Load} and in figure 17 is shown the ideal behavior from a working point A to B.
The step response in a real system when R_{Load} is suddenly increased first and then suddenly decreased to the starting value is shown in figure 18. The Sensorless Constant Airflow Algorithm of the fan works in terms of Speed (SX) and Power (WX).

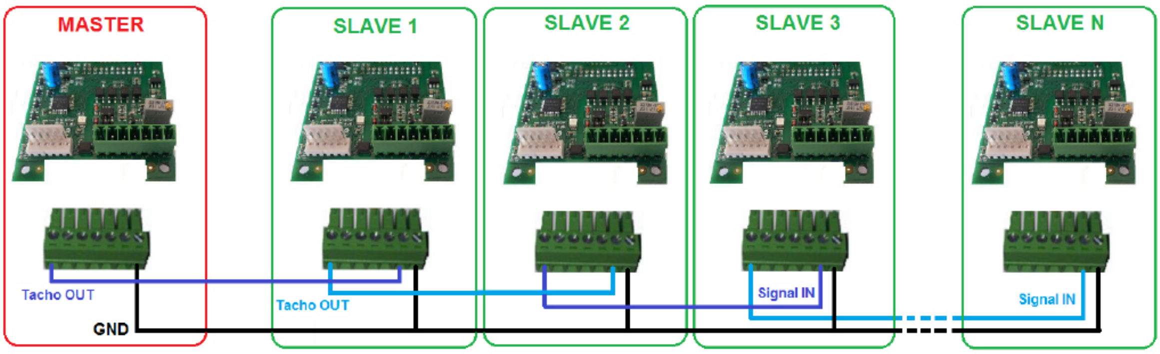
STEP UP
1) At the beginning, the duty point ***A* -> (S_A, W_A)** corresponds to the defined airflow value ***Q_{const}***
2) From *A* to *A'* the control had no enough time to react. Therefore, the speed is the same
3) In *A'* the absorbed power is **lower**. Therefore, ***A'* -> (S_A, $W_{A'}$)** corresponding to a different value of ***Q***
4) The control increases the speed up to duty point ***B* -> (S_B, W_B)** corresponding again to ***Qconst*** value

STEP DOWN
1) At the beginning, the duty point ***B* -> (S_B, W_B)** corresponds to the defined airflow value ***Q_{const}***
2) From *B* to *B'* the control had no enough time to react. Therefore, the speed is the same
3) In *B'* the absorbed power is **higher**. Therefore, ***B'* -> (S_B, $W_{B'}$)** corresponding to a different value of ***Q***
4) The control increases the speed up to duty point ***A* -> (S_A, W_A)** corresponding again to ***Qconst*** value



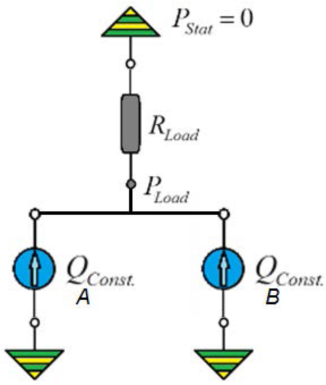
Pict. 18

4. MASTER & SLAVE CONSIDERATIONS



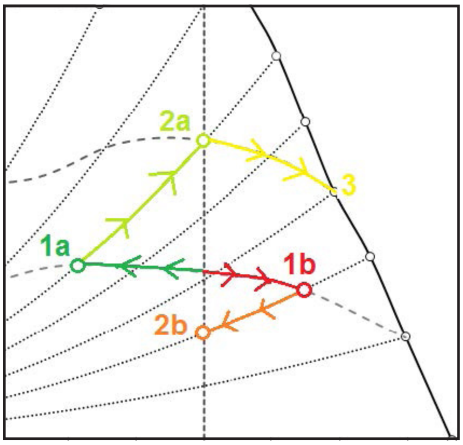
Pict. 19

When two fans (**A** and **B**) are put in parallel, configured in constant airflow mode and both blowing in the same plenum, they influence each other.



Pict. 20

If the fan **a** is perturbed for any reason (ex. by obstructing the inlet cone), it behaves like the step-up case from **1a** to **2a**. However, the **b** fan reacts as the step-down case (pict.21) from **1b** to **2b**.

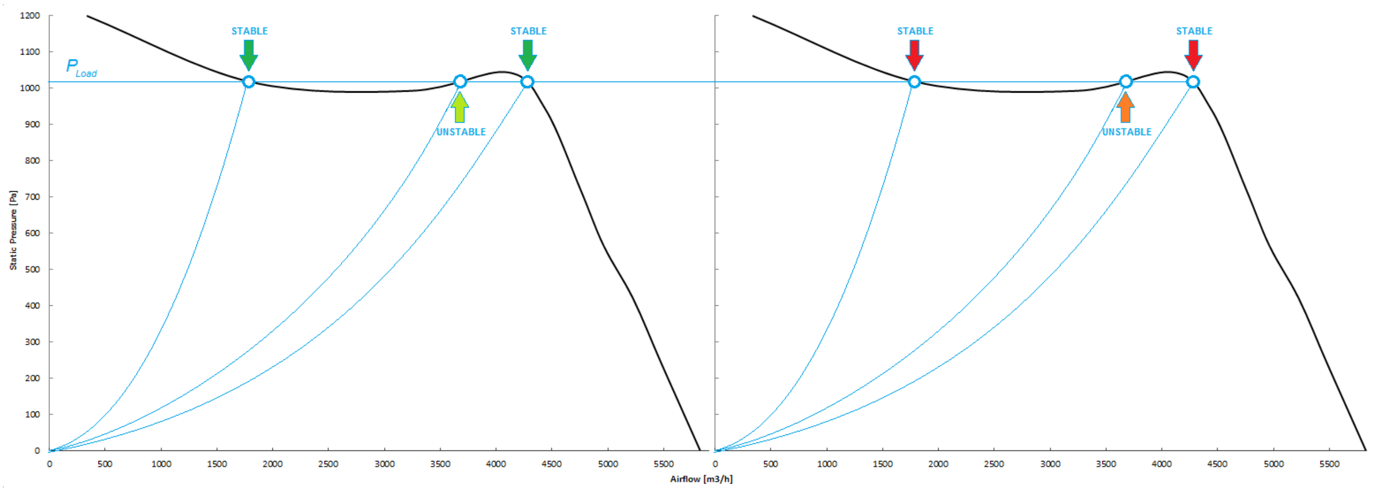


Pict. 21

When the obstruction is removed from point **3**, the **a** fan would return to the starting point, but the two fans would interfere each other.
The Master&Slave mode avoids this deep instability because the Master works in closed control loop, while the Slave works in open loop driven by the Master.

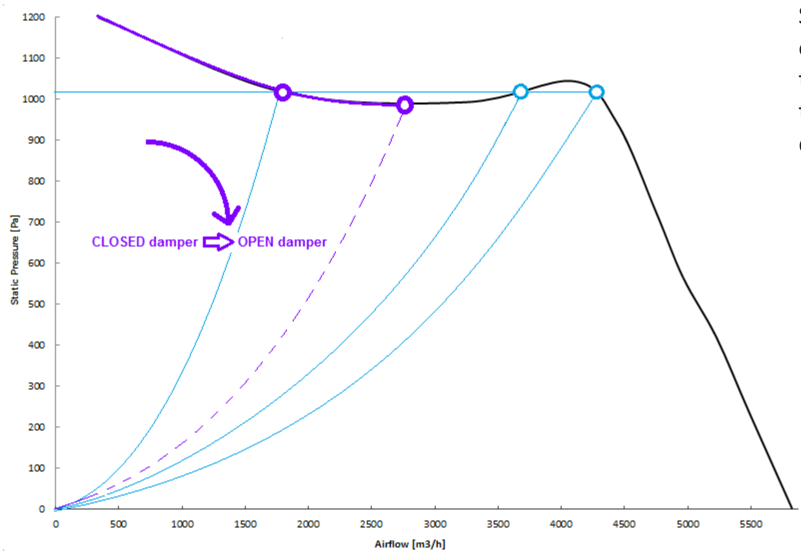
4.1 Characteristic of two forward curved fans in parallel at same speed

Two fans in parallel running at the same speed and blowing in the same plenum work at the same pressure.



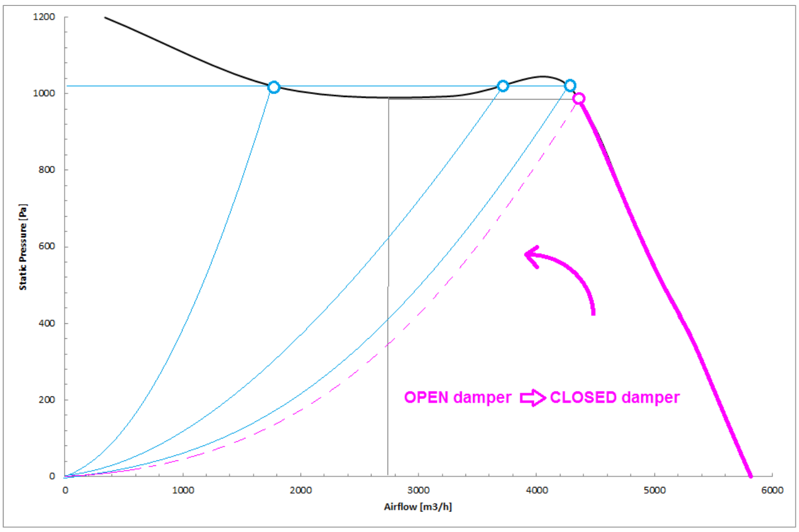
Pict. 22

Looking at the characteristic curve of a forward curved fan, at the same pressure there are three possible airflow points for each fan: two stable points and the unstable inflection area.



Pict. 23

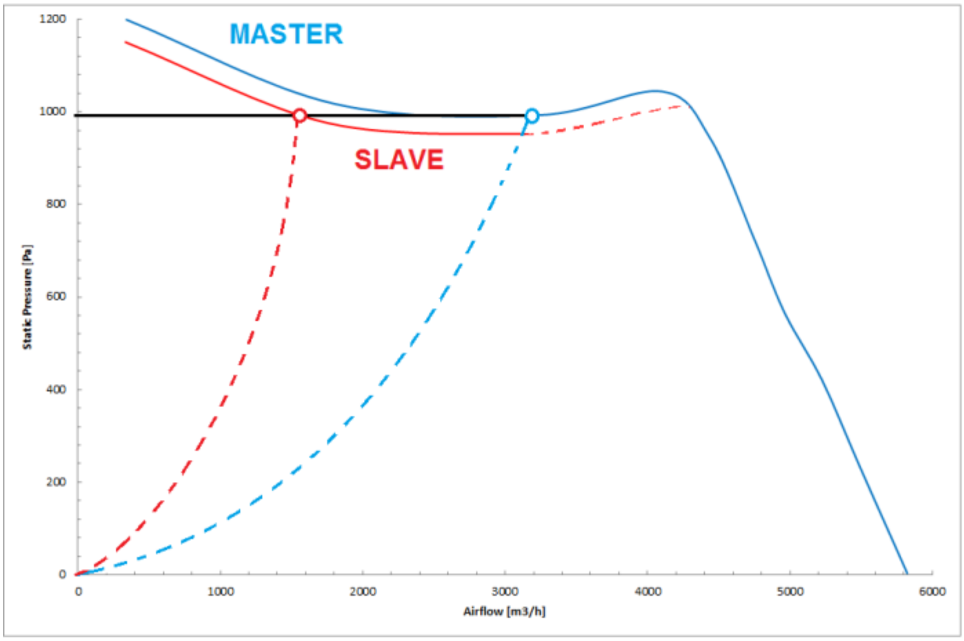
Starting from a totally closed plenum damper to a totally open one, the two fans have the same load curve until the minimum pressure point and, at a later time, a perturbation could force the two fans to have two possible different states.



Pict. 24

The same happens from totally open to totally closed plenum damper, but in this case the two fans have the same load curve until the point corresponding to the minimum pressure.

The previous assumption is true if the speeds of the two fans are the same.
If for some reasons the Slave is slower than the Master, there is a unbalance condition forcing the system to a definite state as shown in picture 25.



Pict. 25

The same happens when the slave runs at higher speed, even if, in this case, the slave point is forced on the right.

5. PID TUNING PROCEDURE

Below are described some fast rules to set the PID parameters, according to the **Ziegler-Nichols method**.

It is a practical procedure to find the so-called "critical gain", from which the other PID parameters will be derived.

1) Connect the transducer output wires to the input connectors of the driver "GND" e "IN" (or "TRANSDUCER INPUT").
2) If the factory setting of the fan maximum speed is too high for your installation, adjust the maximum speed to a more appropriate value.
3) Determine the correct value of the signal from the transducer (between 0 and 10 V) corresponding to the desired value of the measured quantity (if it is pressure, temperature, air velocity, CO concentration or whatever). This value may be calculated knowing the full-scale reading of the transducer and the desired value, or simply read in **INPUT REGISTER 30**, with the fan running in a plain speed control mode, and adjusted to achieve the desired condition of the controlled system.
4) Set the driver operating mode by setting the **HOLDING REGISTER 34** to the correct value of "**INPUT TYPE**":
   a. 10 (PID mode with reference to the Analogue input signal),
   b. 11 (PID mode with reference to the volatile register **HOLDING REGISTER 66**) or
   c. 12 (PID mode with reference to the permanent register **HOLDING REGISTER 50**).
5) Set the target value for the transducer input signal, according to the chosen PID operating mode:
   a. If **INPUT TYPE = 10**, adjust the potentiometer output, using a multimeter of simply reading the value of **INPUT REGISTER 29** to the same value desired from the transducer,
   b. If **INPUT TYPE = 11**, set the desired value in the **HOLDING REGISTER 66**,
   c. If **INPUT TYPE = 12**, set the desired value in the **HOLDING REGISTER 50**.
6) Set the T_{PID} time constant to a plausible value for the system response time, e.g.:
   a. **Holding Register 54** = 100 (=100 ms).
7) The process must initially be controlled by an exclusively proportional controller; set K_I and K_D to zero by setting up:
   a. **Holding Register 52** = 0
   b. **Holding Register 53** = 0
8) The K_P gain of the proportional controller is gradually adjusted (preferably from a low value, which is progressively increased) until the fan speed oscillates with a constant period and amplitude of the oscillations:
   a. Set **Holding Register 51** = 100;
   b. If the fan accelerates directly to its maximum speed or oscillates with a progressively increasing amplitude, reduce the value of the gain in **HOLDING REGISTER 51** and try again;

c. If the fan slows down to its minimum speed, stabilizes to a constant value, or oscillates with a progressively reducing amplitude, slowly increase the value of **HOLDING REGISTER 51** and try again until stable oscillation is achieved.

9) The critical gain K_u is the value of the gain for which the controlled variable has sustained oscillations, that is, oscillations which do not disappear after a transient: this is a measure of the effect of the delays and the dynamics of the process.

10) Record the critical period Tu of sustained oscillations, e.g. by measuring the time required for ten complete oscillations, and then calculate the average oscillation period.

11) The constants for the PID controller are determined according to the following table, trying first the classic "classic PID" setting (first line in the table):

Ziegler-Nichols method:

Control type	K_p	T_i	T_d	K_i	K_d
Classic PID	$0.6\ K_U$	$T_U/2$	$T_U/8$	$1.2\ K_U/T_U$	$3\ K_U T_U/40$
Pessen Integral Rule	$7\ K_U/10$	$2\ T_U/5$	$3\ T_U/20$	$1.75\ K_U/T_U$	$21\ K_U T_U/200$
Some overshoot	$K_U/3$	$T_U/2$	$T_U/3$	$0.666\ K_U/T_U$	$K_U T_U/9$
No overshoot	$K_U/5$	$T_U/2$	$T_U/3$	$(2/5)\ K_U/T_U$	$K_U T_U/15$

12) Set the register values with the calculated values of the three control constants, K_P, K_I and K_D:
   a. **Holding Register 51** = K_P
   b. **Holding Register 52** = K_I
   c. **Holding Register 53** = K_D

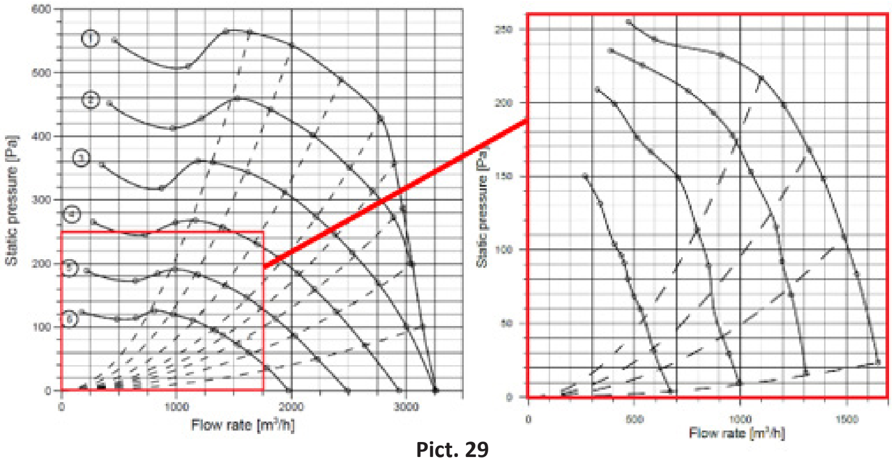
13) If the system behavior using this first setup is not satisfactory, try the other three settings shown in the table.

6. REPLACEMENT OF A FORWARD CURVED FAN EQUIPPED WITH AN ACIM MOTOR WITH A DDMP FAN

This chapter describes how to configure a DDMP fan in order to have the same performance of an old fan equipped with an ACIM motor that must be replaced.

Here are the steps to follow:

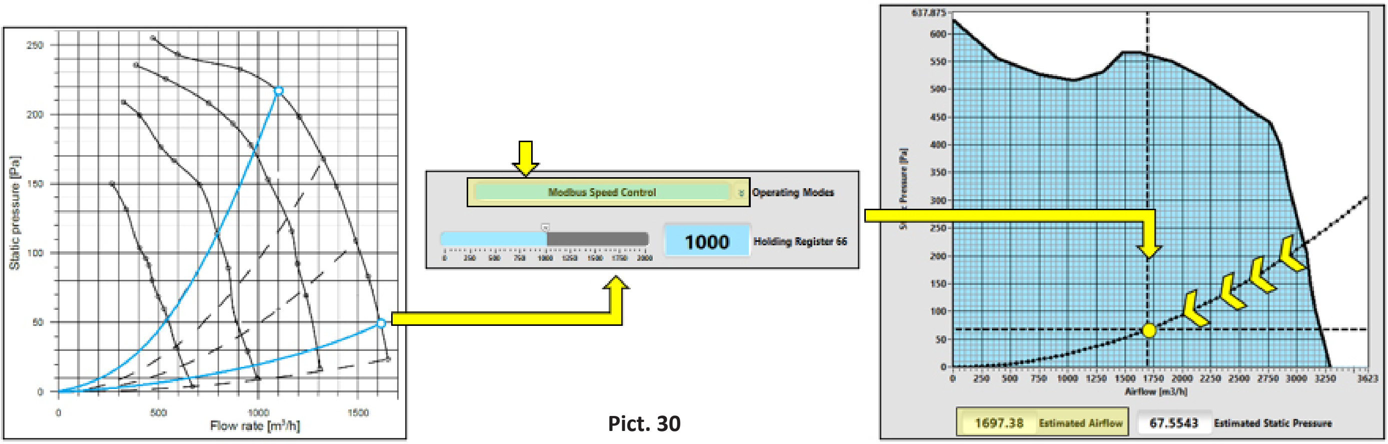
1) Check the performance curve of the fan to be replaced -> it must be a portion of the max performance curve of the chosen DDMP as shown in pict. 29.



Pict. 29

2) Choose two load curves from the AC fan performance curve:
   a. Towards free outlet -> i.e.: 1700m3/h @ 50Pa
   b. Close to the inflection -> i.e.: 1100m3/h @ 220Pa

3) Using the NG software, it is possible to configure the DDMP fan and check its performance and:
   a. Put the fan in a free outlet condition
   b. Configure the operating mode as Modbus Speed Control
   c. Set the speed to achieve approximately the performance of the AC fan at free outlet

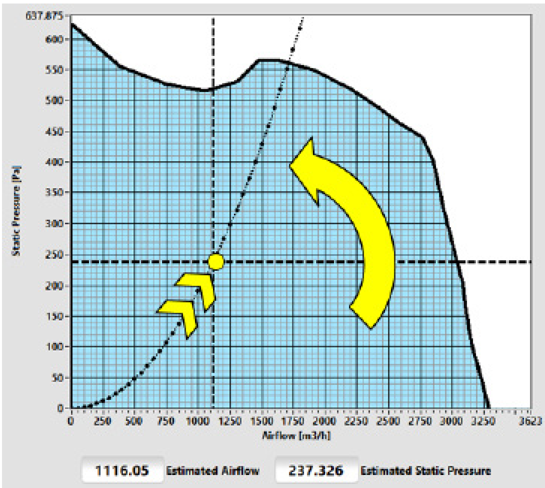


Pict. 30

4) Read the motor current value and set the equivalent Holding Register. This will be the max current limit of the DDMP.

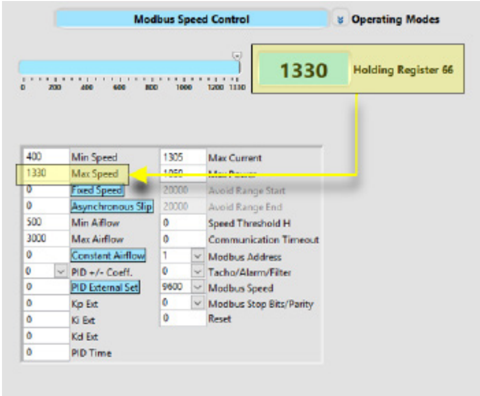
Pict. 31

5) Close the DDMP fan outlet until the load curve is close to the point after the inflection and increase the speed until the AC fan equivalent working point is reached.



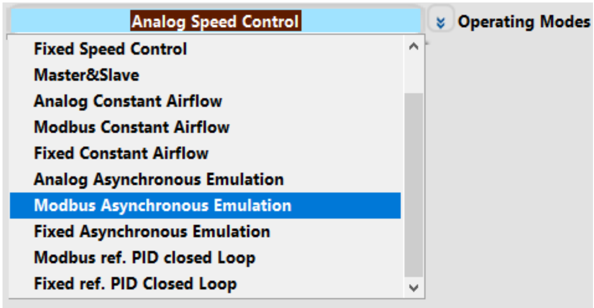
Pict. 32

6) Set the max speed value inside the related Holding Register.



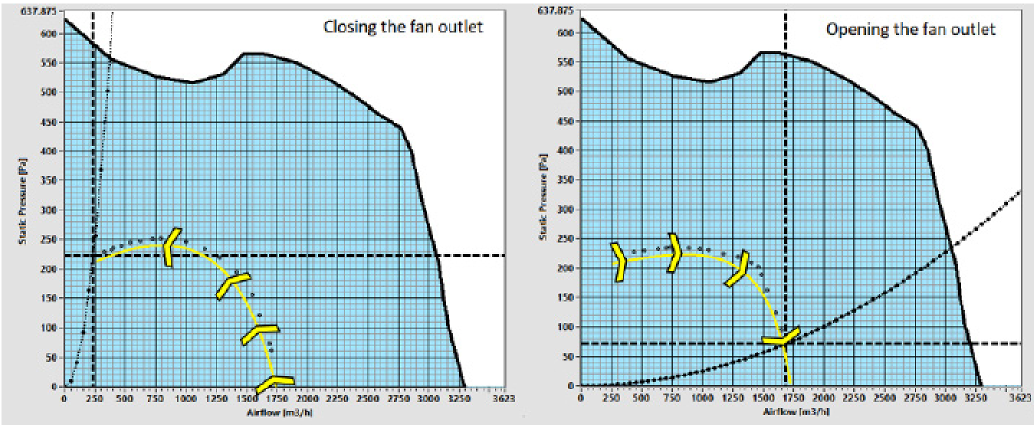
Pict. 33

7) Configure the fan operating mode in one of the three possible Asynchronous emulation modes.



Pict. 34

8) Verify that the final performance is correct by closing and opening the DDMP fan outlet.



Pict. 35

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