Improvements in Air-Flow Management Using Fan Filter Units

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Fan Filter Units (FFU) form the backbone of most Cleanroom AirFlow Control for maintaining ISO standards for air exchanges and filtered air maintenance. The manufacturers and suppliers of FFU to the industry have been struggling to provide their cleanroom customers an ability to accurately supply the air-flow that is specified by their respective agency standards. Most cleanrooms are set over capacity to insure exceeding the standards as accurate regulated air-flow per FFU has remained elusive.

Smart motor algorithms to estimate the air-flow through motor loading was an accepted practice when the GE EC smart motor was coupled to a forward curve blower wheel. The introduction of higher efficiency backward curve fan-blades made this estimated approach not useable, so external sensors were introduced into the controls to provide measured air-flow data. NTC thermistor bridges were applied as well as traditional differential pressure sensors, culminating in the recent use of MEMS mass flow sensors to both accurately and cost-effectively monitoring FFU air-flow.

Successful optimization of Cleanroom Air-Flow to meet Agency standards can now be implemented to regulate the cleanroom environment in an energy efficient manner.
Cleanroom Control System

- **FFU Function** – AC, EC- Smart-motor, EC motorized Impeller
- **Cleanroom Control** - Console – Control FFU, Exhaust, Monitor Parameters
- **Facility Control** – Building Management System, HVAC

**Facility Management**

**Cleanroom Control**

**FFU Function**

- System Control
- System Monitor
- System Reporting

**Facility Control** (BMS)

Facility Monitor
Facility Control

**Cleanroom Control - Console**

- Control FFU, Exhaust, Monitor Parameters

**Facility Management**

- Facility Monitor
- Facility Control

**ESTECH 2019**
FFU Function: User, Network, FFU, Motor

Network Communications
- Speed adjust
- Status/fault
- System Integration
- Addressing

Monitor and Regulate
- Manual or Network
- Auto Adjust
- Airflow
- Power Consumption
- Temperature
- Filter Status (blockage)

User Interaction
- Display RPM/CFM
- Status/fault
- Manual Adjustability?

KEY NEXTGEN FEATURES
AirFlow Control
Power Monitoring
Display/LED indicators
AirFlow Control - Today

- Smart-Motor CFM estimator
  - ECM motor algorithm (rpm / current load)
    - Estimator based upon FFU characterization (static)
    - FFU actual performance varies w/ plenum and room pressure
  - Forward curve fan blade limitation
    - Forward Fan Blade allows for one data point per loading
    - Backward curve impeller has parabolic effect (2 data points per load)
    - Forward Curve Fan Blade uses 2-3x more power per CFM
- Field Installation and Certification
  - Each installation requires measurement and adjustment
  - As Environment and loading changes so does the actual to estimated CFM
  - VAV box control fights/negates CFM auto-control
  - External Sensor monitoring
    - Requires motor or external closed loop
    - Sensor cost and FFU calibration
    - Backward curve blade compatible
External AirFlow Control

BASIC Concept

**Total Air In through Venturi Inlet**

Measuring or Sampling Air-Flow in Venturi Provides accurate Air-Flow through FFU

**Total Air Out through Room Filter**
External Sensor Effort

Lowest Cost Sensor - NTC Thermistor
** one sensor in air-flow cools and second sensor provides no-air-flow base **

- limited linear operating range
- Poor consistency and sensitivity to turbulence
External Sensor Effort

Thermal sense with heat resistor
Analog Temp sensor (Linear temp vs. cooling)
Stable operation – linear air-flow sensing

Air-Flow for Open Plenum provides Good Results
Turbulence created by Ducted Systems creates poor results
Differential Pressure – K Factor

- Common use in Ventilation and HVAC
- Differential pressure sensor across FFU blower provides stable source for K-factor
Differential Pressure – K Factor

• Customize the FFU assembly – add pressure ports pre-/post FFU fan
• Stable measured results – open plenum / ducted plenum
• air-flow affected by Plenum/room pressure
• Higher cost of materials and electronics.
• *Viable option and potential for good results*
Back to the Future
Thermal Air-Flow through MEMS Technology

**Working Principle**

The MEMS sensor chip utilizes the calorimetric principle. It is packaged on a plate installed inside the flow channel, which provides additional flow conditioning from the boundary layer configuration resulting in a laminar flow. The mass flow measurement is established as the gas carries heat away from the heater leading to the redistribution of the temperature field. Accurate flow rate is obtained by calibration with standard gas at preset conditions.

- Sensor concept used by more expensive air-flow surface monitors used in flow hoods
- Sensors designed for monitoring clogged filters in automotive and other high-volume filter loading applications
- Can be repurposed for FFU application under right environmental conditions
- Lower cost platform with competitive results compared to Diff-pressure solution
Air-Flow Sensor Consideration

- Airflow Sensor – open plenum and ducted
- Design functions – has features for zero-null & Full flow scale
- On Venturi edge; in venturi flow; with ducted flow
- Variance and product variability
Across Venturi – AirFlow

For a given airflow:
- Air velocity forms S-Curve per travel across venturi opening.
- Velocity change greatest in first and last half-inch of 2-inch venturi opening.
Turbulence Impact – Across Venturi

SNR Data

Signal diminished by 13% when moving from venturi wall ($\Delta R=0$) to 1.5” across the venturi opening ($\Delta R=1.5$).

Zero airflow (offset) = ANA2 value of 144. Offset subtracted from signal to compute relative comparisons.

<table>
<thead>
<tr>
<th>Setpoint</th>
<th>Signal ANA2</th>
<th>Noise mVRMS</th>
<th>SNR</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta R=0$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100%</td>
<td>410</td>
<td>27</td>
<td>57</td>
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<tr>
<td>50%</td>
<td>322</td>
<td>45</td>
<td>33</td>
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<tr>
<td>20%</td>
<td>229</td>
<td>96</td>
<td>23</td>
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<tr>
<td>10%</td>
<td>208</td>
<td>138</td>
<td>17</td>
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<tr>
<td>$\Delta R=1.5$</td>
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</tr>
<tr>
<td>100%</td>
<td>375</td>
<td>28</td>
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<tr>
<td>50%</td>
<td>282</td>
<td>33</td>
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<tr>
<td>10%</td>
<td>217</td>
<td>55</td>
<td>26</td>
</tr>
<tr>
<td>1%</td>
<td>196</td>
<td>70</td>
<td>23</td>
</tr>
</tbody>
</table>
Flexibility of Air-Flow Sensor Placement

Moving sensor from venturi wall to within ½” of the motor does two things:

1. Reduces signal by 13% for Setpoint = 100%
2. Reduces exposure of sensor to turbulence, which increases the Signal-to-Noise Ratio for Setpoint values less than 80%, the SNR benefit increasing with decreasing Setpoint.
Air-Flow Sensor – FFU Assembly
Air-Flow Sensor Results

- Shows good results at venturi inlet for open plenum and in venturi flow for ducted
- Air-flow sensor acts well and tracks cfm – Forward Curve and Backward Curve Blade
- The center placement is a good place to situate the sensor. Improved turbulence and reduced flow average provide less hostile environment
- Variance and product variability have been evaluated and we expect tolerance
- Factory set-up and calibration provides field-ready FFU units that are calibrated and independent of plenum/room design.
Summary

• Present Technology Solution using Smart-motor algorithm for FFU control has limitations

• Air-Flow monitoring and control is a growing desire in next-gen FFU platforms

• Using pressure transducer and thermal air-flow will become viable options and improve air-flow control of “FFU function”
Thank you

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