mechanicalservicecorporation

41 South Jefferson Road
Whippany, New Jersey 07981
Tel > 973.884.5000
Fax > 973.884.5060

www.mscnj.com

Project Report

8/6/17 Project number: 17-2306

Overview

This report pertains to heat recovery unit HRU-4. This unit was reported as not operating in a stable condition. It was further explained that the BMS cannot provide a stable negative static pressure condition in the exhaust duct upstream of the HEPA filter bank. This unit is equipped with a VI as the volume control method. This report outlines the observations and steps taken to attempt to identify and correct the problem. Extensive records were provided to Engineer as proof that fan selections were the cause.

Scope of work performed

1. 7/23/17

   The VI was reported on this unit to be hunting. Examined the VI, controller, linkage, etc., and determined that the VI was hunting at approximately 3.7 VDC at the electric to pneumatic transducer (EP). Measured the command voltage at the controller and at the EP and found that the voltage at the EP was hunting while the controller output was not. Using the same wire, we connected a signal generator and found the same condition. Installed a temporary cable outside of the conduit and found a stable signal at both ends with the signal generator and the BAS contractor controller. Traced the problem to a ground loop which was causing interference in the conduit Disconnected the cable shield drain wire and the problem ceased. The cable should be replaced.

2. 7/24/17

   a. Began testing HRU-4 in auto mode. At startup the VI and the VI signal was steady. During this time, the negative static pressure in the unit inlet plenum moved plus and minus approximately 0.5” w.c. as the VAV boxes adjusted. Checked the BAS contractor’s signal to several boxes and found it steady but the actuators were hunting up and down slightly.

   b. Al tested the inlet guide vane (IGV) problem reported on the adjacent HRU-5. This device was reported to be hunting as well. Al observed dithering at a few points in the operating range. He checked the electronic signal, the pneumatic signal and found that the positioner was causing the dithering as it tried to bring the IGV into position. This was corrected by installing a 0.007” restrictor because of a similar complaint. The two complaints were not related.

   c. Tom started the area 15 system (AHU and HRUs). Both HRU-4 and HRU-5 came up to operating pressure smoothly. We videoed HRU-4 through the startup. The HRU-4 system continued to operate smoothly.

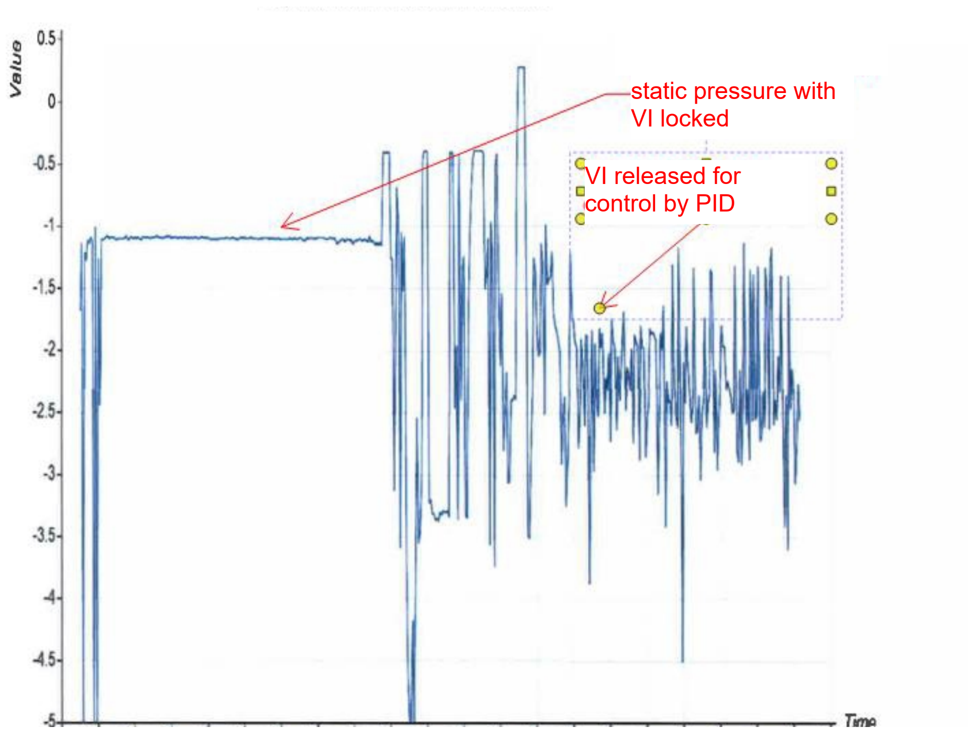
d. At 12:30 PM, Tom reported that HRU-4 was again spiking the exhaust static pressure. We videoed this condition and it appeared that the VAV boxes were hunting and upsetting the VI.

e. With a steady voltage command the VAV actuators continued to dither. These are supposed to be driven to a specific position and remain stable (no dithering) to allow the internal volume controls to hold the commanded exhaust volume. It was noted that most of the VAV terminals on this system experience the same dithering. Through this test, the VI appeared to remain in position.

f. Prior to leaving for the day, Tom locked the VI for HRU-4 in position (not permitted to modulate) and also set a constant volume command to the VAV terminal. Noted that the HRU inlet static still became unstable at times but seemed to settle out and then repeat. At times we heard a “whooshing” sound which was likely one of the terminal units cycling open and closed but we couldn’t trace it to a specific terminal.

3. 7/25/17

a. Tom reported that the system locked overnight, there were no reported static pressure excursions in the trend log (see below). The trend log for this is a 15 minute window.



b. Shut down the system, disconnected the BMS signal from the EP controlling the VI and installed our signal generator.

c. On restart we found several of the positive close off relays energized (8 of 12) in the BAS panel. These relays are controlled by the pressure differential switch on each VAV box and serve to latch open and break the feedback signal to the BMS to indicate a problem (this is a new program loaded only on the zone 15 system). The BAS contractor checked the wiring for these relay, confirmed that they are dry contact relays and labeled the relays for the supply and exhaust VAV boxes.

   During the startup sequence (once the VAV boxes were released by the BMS), the suction static spiked to 4" w.c. And then dipped below 1" w.c. and continued to do so. It appears that the pressure differential switches open and latched during one of the dip cycles. This has been reported to be happening.

d. Investigated other VAV valves on this system with the BAS contractor and found three valves in service mode. The BAS contractor reset the three boxes.

e. Investigated the operation of the three bubble tight dampers that cross connect to the adjacent HRU. Confirmed proper operation with the BAS contractor but the isolation BTD for the last two VAV valves on zone 15 had the actuator indicator installed incorrectly. The BAS contractor corrected and confirmed the correct feedback to the BMS.

f. Tom restarted the system and changed the static pressure setpoint from -1.4" to -2.0" w.c. to try to prevent the pressure differential switches from energizing the latching relays during low points in the static pressure dip cycle.

g. With the system in automatic (VI control by BAS contractor), we observed the HRU inlet plenum pressure repeated cycle between -3.25" and -1.25" as the control system tried to maintain stability. With the lower static pressure setpoint, the VAV boxes did not dip to the trip point.

h. After a short time, Tom locked the VI signal and the hunting stopped. The hunting cycle started with a 0.1 psig pressure change to the VI actuator. Small changes in VI position (0.1 psig) repeatedly cause the static pressure cycling to start.

i. Tom made a program change in the VI control loop to create a dead band. The intent was for the VI not to move when the negative static pressure was within the dead band. Al removed the pneumatic restrictor previously installed and Tom tuned the PID without it. With this change, the plenum pressure appeared to stabilize faster following an upset. Still not satisfactory.

j. We removed the EP and swapped it with another to remove the possibility that the EP is faulty. No change.

k. We found that VAV box E-109 seemed to be hunting more than the others. We disconnected that actuator and allowed the box to fully close for the night.

l. Continued checking by upsetting the system (opening HRU doors slightly, changing exhaust box setpoints, etc.) and the system seemed to recover and stabilize.

m. Noted that when HRU-4 was hunting, it appeared to affect the pressure in HRU-5 exhaust.

4. 7/26/17
    a. Met with BAS contractor technician and had him print the static pressure trend log from the overnight. The static pressure did not remain steady and began its cycle shortly after we left. The trend log also showed that when the VI was locked (the previous day) that the static pressure was much more stable (still had a small saw tooth).
    b. Went up to HRU-4 and confirmed that it was hunting. Walked the space and discovered that E-109 had come off its seat from the previous night and was surging. Al locked the actuator closed for the remainder of the day and reconnected it prior to leaving.
    c. Went to supply boxes S-114 and S-115 and found both boxes dithering (same as the exhaust boxes). The BAS contractor connected the VAV software and put box S-114 into manual mode. The actuator dithering stopped. Confirmed that the position signal was locked on the BMS.
    d. The inlet static pressure on HRU-4 continued to fluctuate. After approximately 30 minutes it stabilized at -2.5" w.c. (setpoint -2.0" w.c.) Where it found a new balance point. At the same time we noticed that the supply and exhaust boxes stopped dithering.
    e. We opened the HRU inlet door slightly to create a small upset and the cycling started. We checked the two supply boxes and they were not moving.
    f. Went to exhaust box E-111 and found it hunting. Measured the command voltage from the BMS at the box terminals and found a steady 4.209 VDC signal from the BMS. The actuator was hunting but there was no vibration or movement on the box that could upset the potentiometer.
    g. Checked exhaust box E-110 and found it hunting. Checked the voltage output signal and found 1.832 VDC steady. Checked the output from the board to the actuator and found that it was not steady enough to read as the actuator was hunting. Input steady, output moving. After approx. 15 seconds the command voltage moved to 1.782 VDC momentarily and then returned to 1.832 VDC.
    h. Took control of the VI with a signal generator. With the system steady, we increased the signal to the EP by 0.1 VDC. This caused a plenum pressure immediate swing to -1.5" and then up to -3.0" w.c. This small change caused instability.
    i. Removed the EP and installed our test regulator with a .007" restrictor, a pneumatic gauge and a 0-5" w.c. magnahelic gauge in the plenum to manually command the VI directly. The VAV valves were operating as before with slight movement. The following are test results. Note that the pressures noted do not correspond to the expected pressure for a small change in volume.

Regulator pressure (psig)	HRU inlet plenum pressure (inches w.c.)	Comments
13.3	-3.4	
13.4	-1.4	
13.4	-1.5	
13.3	-1.5	
13.2	-4.1	
13.2	-4.6	Changed box E-107 volume command from 927 CFM to 727 CFM
13.2	-3.75	Changed box E-107 volume command from 727 CFM to 927 CFM
13.2	-2.75 to -3.35	Changed box E-107 volume command from 927 CFM to 1127 CFM. SP dropped, hunted and then worked up to -3.35" w.c. with no VI adjustment
13.2	-4.1	Changed box E-107E volume command from 1127 CFM to original 927 CFM

5. 7/27/17
    a. Obtained a 25 HP test VFD and assembled into a test cart with flexible cables.
    b. Reviewed the HRU submittals and reviewed fan performance at various wheel widths.

6. 7/30/17
    a. Installed a temporary portable VFD for testing.

b. A representative from VAV box manufacturer arrived on site to check the actuator hunting reports on the VAV boxes served by the HRU-4 air handler. The VAV rep checked all terminals, observed the dithering and determined (through discussions with VAV engineering department) that the unstable duct static pressure is causing the internal piston to rapidly cycle and hit against the actuator arm which causes movement and then a correction by the actuator.

c. We lowered the fan speed to 45 Hz (75% speed) and observed operation. The system negative static pressure settled and became stable. The VI was being controlled by the BAS controller.

d. Tom returned the PID loop to its original speed but left the dead band in. The static pressure remained stable.

e. We locked out terminals E-110 and E-107 (total 1,140 CFM) and observed the system response. The VI adjusted slowly and steadily and the system smoothed out.

f. Continued testing as outlined below at 45 Hz (75% speed). The system proved to operate in an orderly and stable manner. No hunting of the VAV terminals was present. We ran the system through several stability tests at 45 Hz.

g. Set up a new test intended to allow us to select a sheave change. The intent was to test the system at the highest speed possible without causing instability or until the negative static

Test #	Date	Time	VAV box volume total from BMS	Number of boxes in total reading	Neg pressure at BMS sensing point (HEPA inlet)	Pressure differential across HEPA (Mag reading)	Neg pressure in HRU cabinet fan inlet (in w.c.)	VI air pressure	VI %	Motor Hz	Motor amp draw on VFD
1	7/30/17	14:37	4,391	12	-1.15	4.20	6.45	3.00	100.0%	49.0	15.0
2	7/30	15:15	4,144	10	-2.90	3.00	6.61	6.50	70.8%	49.0	14.1
3	7/30	15:27	4,139	10	-2.85	2.00	5.62	8.00	58.3%	49.0	13.5
4	7/30	15:27	4,150	10	-2.80	0.50	-3.98	9.30	47.5%	49.0	12.7

i. Test #1: Twelve VAV terminals connected (includes the two from zone 16 that are able to be cross connected to HRU-4). The box volume totals from the BMS were 4,391 CFM with decon closed and the information not available for S-106 and S-105 which are both 70 CFM setpoint terminals. We set the pressure differential across the HEPA to 4.2" w.c. using the inlet damper to simulate end of life filters. The HEPA filters were reported to be installed. During this test the system static pressure remained steady.

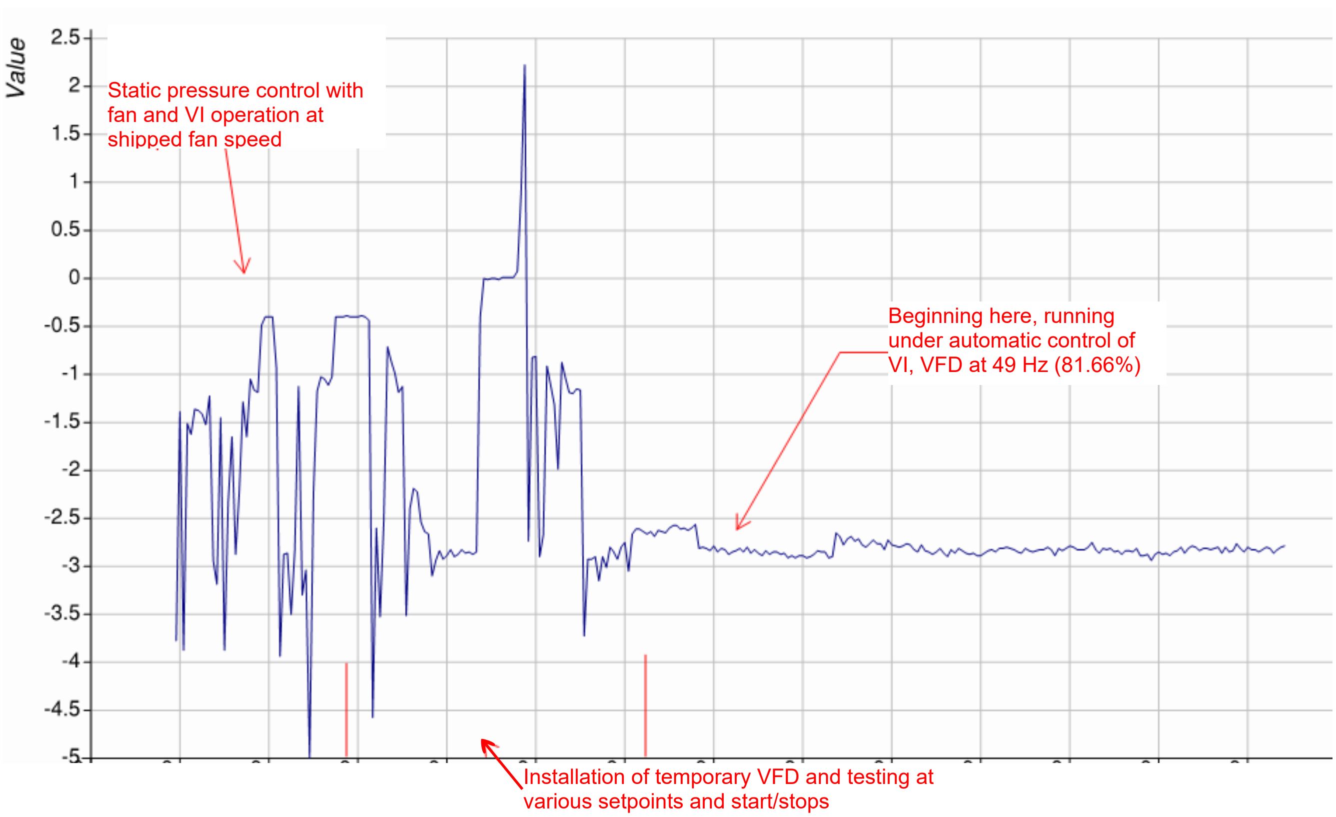
ii. Test #2: Closed the bridge damper to zone 16 to leaving the ten (10) VAV terminals dedicated to HRU-4 connected with the VI in automatic. The VI slowly backed down in a stable manner to 70.8% open and maintained the static pressure setpoint of 2.2" w.c.

iii. Test #3: Reduced the pressure differential across the HEPA bank to 2.0" w.c. with the VI in automatic. The VI backed down to 58.3% open and maintained a steady negative static pressure.

iv. Test #4: Opened the HEPA inlet damper fully, reducing the pressure differential to 0.5" w.c. The VI moved to 47.5% and remained stable.

7. 7/31/17

a. Obtained #4 static pressure trend log graph from the BAS contractor for the overnight. See below. The log shows stable static pressure control with VI control under automatic control by the BAS contractor. For this trend beginning 7/30/17, the static pressure setpoint at the sensor location (exhaust duct upstream of HEPA bank) was set to maintain -2.75" w.c. with a 0.2" w.c. dead band (VI doesn't move when static pressure is within -2.55" to 2.95" w.c.).



b. Performed two additional tests for static pressure control at a lower static pressure setpoint as shown below:

Test #	Date	Time	VAV box volume total from BMS	Number of boxes in total reading	Neg pressure at BMS sensing point (HEPA inlet)	Pressure differential across HEPA (Mag reading)	Neg pressure in HRU cabinet fan inlet (in w.c.)	VI air pressure	VI %	Motor Hz	Motor amp draw on VFD
5	7/31	10:35	4,397	10	-1.41	0.50	-2.70	9.60	45.0%	49.0	12.6
6	7/31	11:05	4,380	10	-1.90	1.90	-3.20	9.40	46.7%	49.0	12.7

i. Test #5: This test was performed with the system static pressure setpoint set to -1.5" w.c. While the static pressure controlled properly and was stable, when the system was upset by reducing VAV box valve S-109 to 200 CFM, the static pressure did dip low enough to cause 109 to lockout on low flow.

ii. Test #6: This test was performed with the static pressure setpoint set to -2.0" w.c. VAV terminal S-109 was reduced by 450 CFM from setpoint. The terminal did not trip. We left the static pressure setpoint at -2.0" w.c.

c. We ordered a replacement motor sheave and belts for HRU-4 to permanently sheave the fan for 3,150 RPM to allow the system to operate for balancing.

8. 8/6/17

   a. We received and replaced the motor sheave.

   b. Final testing to be done 8/7/17.

Observations and technical notes

1. When reviewing the submittal, I noticed that the fan was sheaved for 6,000 CFM at 8" w.c. TSP. This is the "future" condition. The "present" condition is 5,000 CFM.

2. Assuming that the VAV terminal curves are correct, the ten (10) terminals connected to 4-1C totaled 4,380 CFM (our last test) with the following conditions.

   a. -1.9" w.c. at the BMS sensing point (steady).

   b. 0.5" w.c. pressure drop across the HEPA bank (we assume this to be the clean pressure drop).

   c. -3.2" w.c. pressure in the fan inlet plenum.

   d. 46.7% VI position.

   e. 81.66% fan speed (3,126 RPM).

3. The fan selection in the submittal indicates that the fan should have been sheaved for 3,714 RPM from the factory. Our measured fan speed at 60 Hz was 3,830 RPM and our measured motor speed was 3,566 RPM. The pitch diameters for the supplied sheaves were 5.6” for the motor sheave and 5.2” for the fan sheave.

Fan Type:	Plenum	Volume Control Type:	VIM
Fan Model Number:	16-QEP-1-III	Actual Wheel Width:	100.0%
Drive Type:	Belt	VIM Disc:	4.9%
Fan Class:	III	Net Wheel Width:	95.1%
Total Airflow Rate:	6,000 c.f.m.	Total Fan Power:	12.02 b.h.p.
External Static Pressure:	7.00"w.c.	Scheduled Fan Power:	12.70 b.h.p.
Total Static Pressure:	8.00"w.c.	Motor Enclosure:	ODP
Airstream Temperature:	70°F	Motor Speed:	3,550 r.p.m.
Elevation:	0' A.S.L.	Selected Motor Size:	20.0 h.p.
Fan Speed:	3,714 r.p.m.	Scheduled Motor Size:	20.0 h.p.
Maximum Fan Speed:	3,948 r.p.m.	Motor Position:	X
Tip Speed:	16,000 f.p.m.		
Static Efficiency:	69%		
Fan Rotation:	Clockwise		

		* VI	Adjusted to Desired Flow Rate
Total Airflow Rate:	5,000 c.f.m.	Total Fan Power:	9.82 b.h.p.
External Static Pressure:	7.00"w.c.	Scheduled Fan Power:	12.70 b.h.p.
Total Static Pressure:	8.00"w.c.	Motor Enclosure:	ODP
Airstream Temperature:	70°F	Motor Speed:	3,550 r.p.m.
Elevation:	0' A.S.L.	Selected Motor Size:	20.0 h.p.
Fan Speed:	3,714 r.p.m.	Scheduled Motor Size:	20.0 h.p.
Maximum Fan Speed:	4,131 r.p.m.	Motor Position:	X
Tip Speed:	16,000 f.p.m.		
Static Efficiency:	68%		
Fan Rotation:	Clockwise		

4. When observing operation at full speed, the VI operated between 25% and 28% open. Any small change in position in this area resulted in large swings in pressure. In this range, the VI disk was not able to adequately throttle air volume to maintain a static pressure setpoint.

5. With the fan running at the supplied speed (with the base or the base plus the cross connected load), a system upset as small as 200 CFM pushes the fan into an unstable condition which cannot be corrected by adjusting the VI position. To reestablish stability, the VI and the terminals must be locked down and the system must be permitted to ride the fan curve (with the VI at approximately 29% of travel or 1.16” wheel width).

6. We attempted to control the pressure manually using a signal generator and then by adjusting air pressure by 0.1 psig to the VI. Manual control was not possible.

7. Using the 6,000 CFM submittal future air volume, the fan is oversized by the following percentages when compared to the actual flows:

    a. Reported terminal flows from the BMS for area 15 only (normal operating condition) = 37% over-sized.

    b. Reported terminal flows plus cross connect load = 24% over-sized.

8. The fully loaded end of life HEPA bank filter pressure drop is listed in the spec. as 2.75” for the HEPA and 1.5” for the pre-filter for a total of 4.25” w.c. design pressure drop at 6,000 CFM. Our actual measured pressure drop with the filters are installed; we were told they were installed.

9. Following slowing of the fan, the BAS contractor added a 0.2” w.c. dead band. This allows the VI to fully stop which in turn allows the VAV terminals to adjust and remain steady. This improves performance and lessens wear and tear on system components such as EP’s, pneumatic cylinders, positive positioners and the VAV terminals.

10. The VI on this fan is slightly off center in the wheel which may contribute to uneven loading of the wheel especially below 30% VI position.

11. VI test data:

    a. The submittal data provided to us indicates that a TMI VI assembly was fitted to a Greenheck model 27 QEP fan and tested in an AMCA approved test chamber.

    b. The documents indicate that the tests were performed to determine the system effect on the fan for volume and static pressure with the TMI VI installed vs. the same fan with no VI.

    c. The tests were performed at 0% VI position, 30% VI position, 75% VI position and 100% VI position as the VI reduced the effective wheel width.

    d. The tests do not indicate whether the VI assembly was tested as it would be used for duct static pressure control.

Conclusions

1. The fan at the submittal speed (3,714 RPM) is over-sized for the current operating condition which includes the cross connected load of 470 CFM from zone 165 (terminals S-222 and S-105) when required. The condition is slightly exacerbated by the fan being supplied at 3,820 RPM.

2. The loss of pressure control and subsequent pressure fluctuations (system instability) appear to be caused by fan stall or rotating fan stall when the VI is in the 25%-30% range and at full speed.

3. When the fan moves into its unstable mode it is not possible for the control system to stabilize it regardless of what is done with the PID loop settings. This instability cannot be remedied with controls.

4. Reducing the fan speed by approximately 17% appears to eliminate the stall and moves the VI out toward the middle of its travel. Automatic pressure and volume control at reduced speed is smooth. Recovery following system upset is quick and stable.

5. The VI being slightly off center in the wheel may contribute to the condition when operating in the 25%-29% open range, but it does not appear to make an appreciable difference when the VI is out near the center of the wheel.

6. The fan capacity at the lower speed was able to meet the VAV terminal flow requirements (reported by the BMS) including the end of life filter loading (4.25” w.c.).

Path Forward

The best solution would be to retrofit each system with a VFD and allow the BAS contractor to control fan speed to satisfy the flow and pressure requirements. If VFDs are not an option, then each fan system should be tested to determine the point of instability and then the fans should be re-sheaved to a speed below the instability range. Additional testing and/or sheave changes may be necessary as the systems are balance.

General notes

Resources for this analysis include:

a. Fan Engineering (Howden Buffalo)

b. Surge stall and instabilities in fan (Twin City Fan FE-600)

Mechanical Service Corp.

Harry Hartigan

Harry Hartigan
President
Phone (direct): 973-929-6125
E-mail: hhartigan@mscnj.com