American Society of Heating , Refrigerating, and Air-Conditioning Engineers

Volume 46, Issue 6

February 2011

QUAKER CITY CLIMATE

INSIDE THIS ISSUE:

Dave & Busters

325 N Columbus Blvd
Philadelphia, PA 19106
(215) 413-1951
For Directions : Click Here
Parking is $12 ($5 coupon)

Dinner Fees are based on online reservations and prepayment ($45 without online reservation):

- Philadelphia Chapter Members: $30
- ASHRAE Members - Non-Chapter Members : $40
- Non- ASHRAE Member : $40
- Young Engineers (35 and under): $25
- Students: $10

HVAC NOISE AND VIBRATION CONTROL

Our next meeting is scheduled for Thursday, February 10, 2011 at Dave & Busters. Followed by YEA social. The event schedule is as follows :

- Social Hour with Cash Bar 5:00pm-6:00pm
- Dinner 6:00pm-6:45pm
- HVAC Noise and Vibration Control Presentation 6:45pm-7:45pm
- Afterwards: YEA Social

Presentation Overview:

The two most common complaints about new HVAC installations are temperature and noise. A basic understanding of acoustics and relevant terminology, acceptance criteria, noise control engineering techniques, spec strategies for compliance, cost considerations, and HVAC noise suppression methods and examples will be presented to help minimize the risk of noise complaints and the higher costs of remediation vs. design

Certificates of attendance will be provided at the end of the presentation to help those members who need to document their professional development hours as part of the PE renewal process in Pennsylvania (or other states that use the NCEES model.)

Presenter's Biography

Bruce W. Majer, Vice President of BRD Noise and Vibration Control, Inc., has nearly 30 years of experience in vibratory noise control, with strong concentrations in acoustics and machine reliability. Prior to joining BRD in 2002, he worked as Field Service Manager and then Sales Manager at VSC. During that time he developed and maintained machine reliability programs for industrial and military facilities throughout North America. He is currently participating in development of certain noise criteria for the Navy's DDG 1000 program (the new US Navy multi-mission destroyer).

Bruce has also designed training courses in sound and vibration analysis, while delivering them throughout this hemisphere and abroad. He has been published in journals Sound & Vibration, P/PM Technology, Vibrations, ASNE Intelligent Ships, and ASNE Fleet Maintenance Technical Proceedings. He attended Spring Garden College and earned certifications from PMC Beta, Quest Technologies, Technical Associates of Charlotte, International Research and Development, and the Vibration Institute. He is currently a practicing member of the American Society of Naval Engineers and the Acoustical Society of America and is serving on a committee to rewrite an IEEE standard.

PRESIDENTS MESSAGE:

The ASHRAE Philadelphia Chapter is off to a good start to the New Year. We had a well-attended social event in January at a Flyers game and have several upcoming events in February. Our February 10th dinner meeting will bring us back to Dave and Busters, a venue with plenty of opportunities to network and socialize both before and after the dinner and presentation. I also encourage you to attend the balancing seminar on February 26th that is held at the Local 19 Sheet Metal Workers training center. This is a particularly helpful seminar for those of you looking to have a better understanding of how the air and water sides of HVAC systems are balanced.

February 20-26 is Engineers Week and there are a number of events here in the Delaware Valley during the week. Please take a look at the Delaware Valley Engineers Week website for more details (www.dvec.org.)

Best Regards,

John Pardekooper
215-436-5802
c21@ashrae.net

Fan Balance and Vibration

This article was submitted by Rob Innes of Mutimer Company on behalf of New York Blower. Articles highlighting novel HVAC technologies should be submitted to Chapter Technology Transfer Committee Chair Mark Maguire (c021bog4@ashrae.net) for consideration in future newsletters.

Introduction

Vibration always has been a good indicator of how well a piece of equipment was designed, installed and maintained. With sophisticated, computerized, preventive maintenance programs, vibration can now also be used as a precursor of future maintenance requirements.

Fans are subject to vibration because they have a high ratio of rotating mass to total mass, and operate at relatively high speeds. Unlike most mechanical equipment, there are two major causes for vibration in fan equipment. These are aerodynamic (having to do with airflow) and mechanical (having to do with rotating components, fasteners and structural support). This article will discuss both causes of vibration and provide guidelines for their reduction.

Aerodynamic Vibration

Aerodynamic vibration occurs when a fan operates to the left of its peak static pressure point. The vibration frequency is at a frequency other than the wheel rotation speed. This area of operation is illustrated in Figure 1. In this region the fan wheel does not move enough air to fill the blade passages. Aerodynamic vibration is most easily identified by increasing the volume of air flowing through the fan, thereby moving the fan's point of operation to the right. If the cause is aerodynamic, the vibration will usually disappear or be reduced significantly. Increasing the airflow is accomplished by opening dampers, cleaning filters and coils, or as a test, removing a section of duct near the fan. These actions will reduce system pressure and correspondingly, increase airflow.

Because of their inherent wheel geometry, some fans are more susceptible to pulsation when operating to the left of the peak on their static pressure curve. Centrifugal fans utilizing forward-curved or flat, backwardly-inclined blades are particularly subject to this phenomenon. However, fans with backwardly-inclined airfoil blades are designed to be stable left-of-peak.

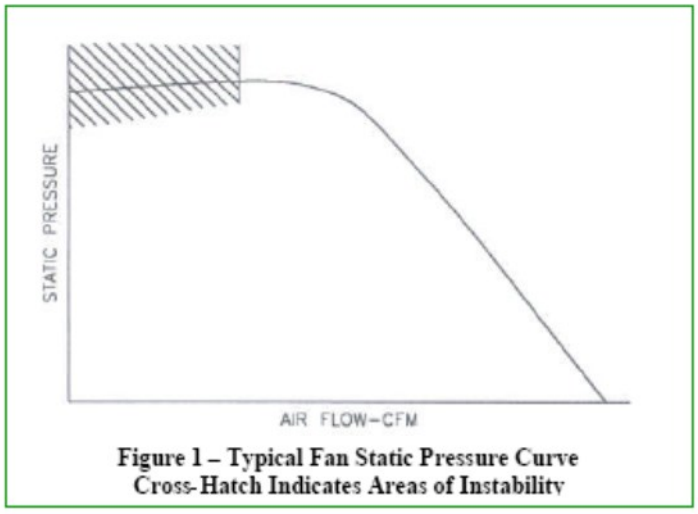

Figure 1 – Typical Fan Static Pressure Curve
Cross-Hatch Indicates Areas of Instability

For the remainder of this article go to page 9.

Philadelphia Future City Competition

One outreach program of the National Engineers' Week is the Future City competition. Teams of middle school students simulate their vision of a city of a future, develop an essay and an abstract, build a tabletop model and make a 7-minute presentation in a regional competition. Each team consists of an engineer/mentor, a teacher and three students.

There were 40 middle-school entries in the 2011 Philadelphia regional competition, which was held January 22 at the Sheet Metal Workers Union Hall.

The regional competition winner advances to the national competition in Washington, DC during Engineers' Week in February. The ASHRAE Philadelphia Chapter is a bronze-level sponsor of the program and awards the Best Indoor Environment Award to the team which incorporates an innovative solution to controlling the indoor environment.

The intent of the program is to steer young students toward engineering by associating the profession with an enjoyable competition. The students also learn presentation, writing and team-building skills.

St. Cecelia School from Philadelphia won the Best Indoor Environment Award. The team sited their city underwater and incorporated desalination, a tidal energy plant and water purification by electrolysis. Buildings in the city were heated by ground-source heat pumps.

ASHRAE Fellow John Kampmeyer is the regional coordinator for the event. Chapter member Mark Maguire was a special-awards judge, and Jeff Crozier was a team mentor.

The competition needs volunteers to sustain the effort on an ongoing basis; please check their Website (futurecityphilly.org) for additional pictures and volunteer opportunities.

Chapter Technology Award Competition 2011

The Technology Award Program recognizes members for innovative designs, communicate that technology to other members, and highlight achievements to other professionals.

The Chapter Technology Transfer Committee will be accepting applications for the Chapter Level competition in March 2011 in the following categories:

- Commercial Buildings, New and Existing
- Institutional Buildings, New and Existing
- Health Care Facilities, New and Existing
- Industrial Facilities or Processes, New and Existing
- Public Assembly Facilities, New and Existing
- Residential Buildings, New and Existing (Single Family and Multi-Family)

Alternative or Renewable Energy Use

Entries will be judged on energy efficiency, indoor air quality and thermal comfort, innovation, operation and maintenance, cost effectiveness, environmental impact and quality of presentation.

The process for the ASHRAE Technology Awards starts right here at the Chapter level. Chapter Competition winners will be judged in the Regional Technology Award Competition. Regional winners will then submit a long form application for the Society Technology Award Competition. Winners of the Society Competition will also be featured in the ASHRAE Journal.

More information on the Technology Award Program will be coming soon.

Mark M. Maguire, PE
Chapter Chair – Technology Transfer
c021bog4@ashrae.net

Prizes to Include

- First Place
- Second Place
- Third Place
- Longest Drive
- Closest to the Pin

Lunch/Registration: 12:00 PM
Shotgun Start: 1:00 PM
Format: Scramble
Dinner/Awards: Following Golf

Please contact Jim Piscopo at jpiscopo@aeceng.net with any questions

SPONSORSHIP OPPORTUNITIES

Stay tuned...details will follow

REGISTRATION DETAILS

Stay tuned...details will follow

Chapter Technology Transfer Committee

ASHRAE Milton W. Garland Award

ASHRAE offers two competition-based awards encouraging the design of innovative refrigeration systems. The Milton W. Garland Commemorative Refrigeration Award for Project Excellence recognizes non-comfort refrigeration systems. The Refrigeration Comfort Cooling Award for Project Excellence is oriented toward comfort refrigeration systems.

The Philadelphia Chapter Technology Transfer Committee is currently accepting applications for both competitions for 2011.

The Garland Award competition is open for the design of mechanical refrigeration machinery for applications other than human comfort: e.g., food processing/preservation, industrial/manufacturing processes, life support in extreme environments, recreational facilities.

The Refrigeration Comfort Cooling Award competition is open for the design of mechanical refrigeration machinery for human comfort applications.

Both submissions must be made within 36 months of the initial operating date of the system, and will be judged on the following criteria:

- Complexity of Problem
- Solution Concept
- Architectural Integration
- Originality
- Achievement of Performance Criteria
- Energy Effectiveness
- Budget Compliance

Ease of Maintenance

Additional information can be obtained from Mark Maguire, Chapter Transfer Technology Chair (c021bog4@ashrae.net).

ASHRAE Offers Certification: Building Energy Assessment Professional

With growing emphasis on energy consumption reduction and cost savings, there is a recognized need for credible information to help in the assessment and modeling of energy use in buildings.

A new certification program from ASHRAE will help fill that need, recognizing individuals' ability to audit and analyze residential, commercial and industrial buildings. The Building Energy Assessment Professional (BEAP) certification complements ASHRAE's Building Energy Quotient program as well as its Building Energy Modeling Professional certification. Together, the programs provide a valuable toolkit when it comes to the evaluation and reduction of building energy use.

The BEAP program certifies individuals' ability to audit and analyze residential, commercial, and industrial buildings including determining project scope, collecting data, analyzing building performance, interpreting results, evaluating alternatives, submitting recommendations for energy conservation measures, and assisting with the implementation of these recommendations.

The program will launch February 2, 2011 with a pencil and paper examination in conjunction with ASHRAE's 2011 Winter Conference and AHR Expo in Las Vegas. Approximately six weeks after the first exam administration, the exam for that program will be available on computer at proctored testing centers through Applied Measurement Professionals, Inc., which has testing centers in Center City Philadelphia, Wilmington, DE and Robbinsville, NJ.

This is in addition to the five certification programs currently available:

- Building Energy Modeling Professional;
- Commissioning Process Management Professional;
- Healthcare Facility Design Professional;
- High-Performance Building Design Professional;
- Operations and Performance Management Professional.

Additional information is available on the ASHRAE Website at www.ashrae.org/certification. Or you can email the Philadelphia Chapter Technology Transfer Chair (Mark Maguire) at c021bog4@ashrae.net.

Philadelphia Chapter Programs Calendar 2010-2011

Date	Location	Topic	Theme	Joint Meeting
12/9/2010 Breakfast	Union League	Energy Simulation Programs, presented by ASHRAE Distinguished Lecturer Drury Crawley, PhD		
1/20/2011	Wells Fargo Center	Flyers VS Ottawa Social		
2/10/2011	Dave & Buster's	Noise & Vibration	Member-ship/YEA/Student Night	
3/10/2011	Fisher's Tudor House	Design Build for Green Buildings	Trade Show	SMCA
4/13/2011	Holiday Inn (4th & Arch)	VAV System Design by ASHRAE Past President & Distinguished Lecturer Bill Coad, PE	Student Night	
5/12/2011	Holiday Inn (4th & Arch)	Variable Primary Flow Chilled Water Sys-tems, presented by ASHRAE Vice Presi-dent and Distiguished Lecturer William Bahnfleth, PhD, PE	Past President's Night	
TBD	NVCC	Golf Outing		
TBD	TBD	2011-2012 Planning Meeting		

*** Program calendar is subject to change. Please refer to ASHRAE Philadelphia Website for up to date infor-*

Young Engineers Social Events

The next YEA Social will be after the ASHRAE meeting on February 10th at Dave and Busters. If you're 35 years or under, stick around after the meeting for a time of hanging out and playing pool with other young engineers.

Young Engineers Social:

Come join other young engineers in the area to celebrate Engineers Week 2011 at the Young Engi-neers Social. Hosted by the Engineers Club of Philadelphia, this happy hour style celebration will be Tuesday, February 22nd from 6:00 to 9pm at The Field House Sports Bar in Philadelphia. The event will recognize Angela Fante, the 2011 Young Engineer of the Year, and provide a venue for young en-gineers of the Philadelphia area to network and socialize. Guests will enjoy appetizers, drink specials, dinner and networking opportunities in a relaxed setting.

For more information, go to page 8.

Contact Ashley Lester at alester@klingstubbins.com for details and questions.

ASHRAE Philadelphia has a YEA Facebook page. Check it out Here.

The Philadelphia Chapter of the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc.

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ASHRAE Philadelphia Website

 Any member with material to submit for inclusion in the *Climate* can send the information to:

Matthew Trinsey
Clive Samuels & Associates, Inc.
1 Independence Way
Princeton, NJ 08540
(P) 609-627-7983
c021ne@ashrae.net

Material can include letters to the editor, member news, upcoming events, comments on chapter programs or issues, etc.

Affiliate Membership

What is the Affiliate Membership Grade?

Affiliate Membership is for young professionals who are age 30 or younger and are brand new to ASHRAE.
Affiliate Members can take advantage of discounted dues for their first three years of membership for a total savings of $330.

- First Year - $50
- Second Year - $70
- Third Year - $90

At the end of year three Affiliate Members are converted to full dues paying Associate Members.
Affiliate Membership includes all Member benefits except for the ASHRAE Handbook and the opportunity to vote in the Society annual ballot.
Though Affiliate Members can't hold positions in the Chapter or Society, they can serve on local Chapter committees such as Membership Promotion and Technology Transfer to learn the volunteer role.
Click Here to register as an affiliate Member today. Please note you must enter your date of birth in order to receive the Affiliate option.
If you know a young professional 30 years of age or younger please share this information with them and encourage them to take advantage of what ASHRAE has to offer.

James Piscopo
Membership Promotion Chair

Membership Promotion

I would like to encourage all members to go online and verify that the contact information in their bio is up to date. The primary email and mailing addresses listed in your bio at www.ashrae.org are what we use to contact you with invitations to all monthly meetings and special events.

Please do not hesitate to contact me if you have any questions about updating your contact information or your membership in general.

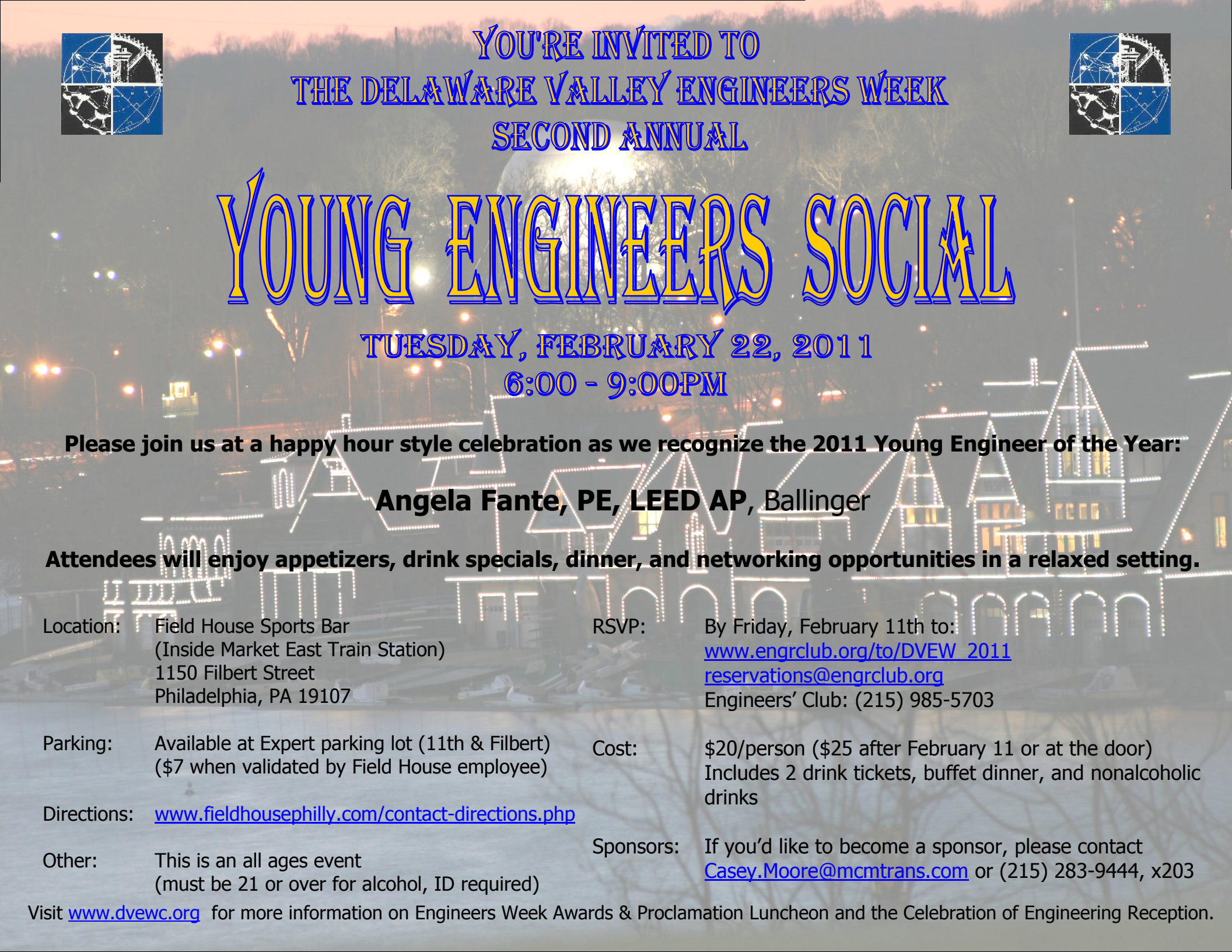
Chapter dues are waived for your first year of membership, however you will still receive all of the benefits of being a local dues paying member, including reduced fees for seminars monthly meetings.

James Piscopo, PE

Vice President

Membership Promotion Chair

Online Membership Application



You're Invited to
The Delaware Valley Engineers Week
Second Annual

Young Engineers Social

Tuesday, February 22, 2011
6:00 - 9:00pm

Please join us at a happy hour style celebration as we recognize the 2011 Young Engineer of the Year:

Angela Fante, PE, LEED AP, Ballinger

Attendees will enjoy appetizers, drink specials, dinner, and networking opportunities in a relaxed setting.

Location: Field House Sports Bar
(Inside Market East Train Station)
1150 Filbert Street
Philadelphia, PA 19107

Parking: Available at Expert parking lot (11th & Filbert)
($7 when validated by Field House employee)

Directions: www.fieldhousephilly.com/contact-directions.php

Other: This is an all ages event
(must be 21 or over for alcohol, ID required)

RSVP: By Friday, February 11th to:
www.engrclub.org/to/DVEW_2011
reservations@engrclub.org
Engineers' Club: (215) 985-5703

Cost: $20/person ($25 after February 11 or at the door)
Includes 2 drink tickets, buffet dinner, and nonalcoholic drinks

Sponsors: If you'd like to become a sponsor, please contact Casey.Moore@mcmtrans.com or (215) 283-9444, x203

Visit www.dvewc.org for more information on Engineers Week Awards & Proclamation Luncheon and the Celebration of Engineering Reception.

Fan Balance and Vibration

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Fans are subject to vibration because they have a high ratio of rotating mass to total mass, and operate at relatively high speeds. Unlike most mechanical equipment, there are two major causes for vibration in fan equipment. These are aerodynamic (having to do with airflow) and mechanical (having to do with rotating components, fasteners and structural support). This article will discuss both causes of vibration and provide guidelines for their reduction.

Aerodynamic Vibration

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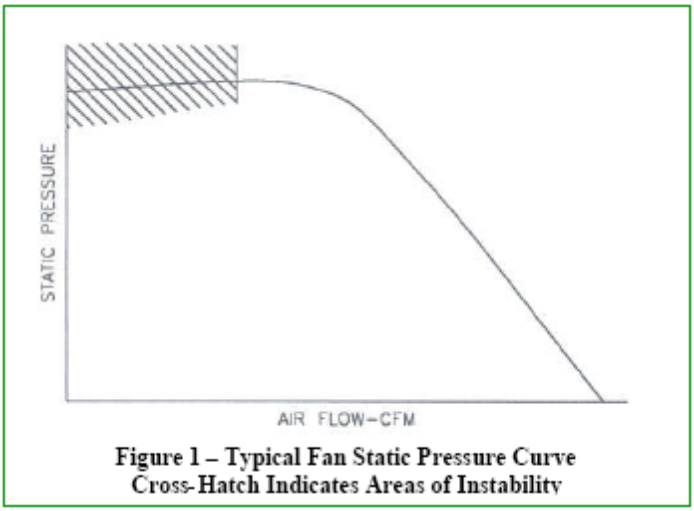

Figure 1 – Typical Fan Static Pressure Curve
Cross-Hatch Indicates Areas of Instability

Because of their inherent wheel geometry, some fans are more susceptible to pulsation when operating to the left of the peak on their static pressure curve. Centrifugal fans utilizing forward-curved or flat, backwardly-inclined blades are particularly subject to this phenomenon. However, fans with backwardly-inclined airfoil blades are designed to be stable left-of-peak.

Operation left-of-peak may be due to an error in system pressure calculations, less than optimal system installation, or poor maintenance practice. The fan's point of operation may have also changed because the process or system has been modified since installation. For example, a drying system may have initially been designed to pull air through a 2" bed of material. Subsequent system changes now require a 6" bed of material with a significantly higher pressure drop. This will cause the fan to operate at a different point on its curve which may be left-of-peak.

If a re-design of the system is not practical but current air volume is adequate and the fan in question is a centrifugal, it may be possible to eliminate or reduce pulsation by adjusting the fan wheel toward the inlet cone. As shown in Figure 3, by adjusting the wheel so the edge of the cone is inside the wheel front plate, additional air will recirculate in the fan. The fan wheel will now receive a sufficient volume of air, allowing it to perform without pulsating; however, the efficiency of the fan will be reduced. In general, increasing the overlap by a distance equal to 2% of the wheel diameter will eliminate pulsation.

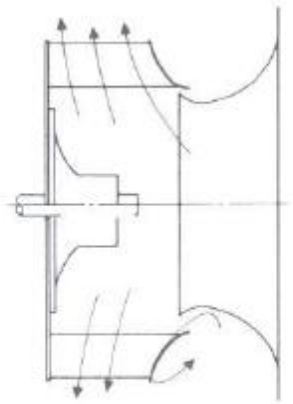

Figure 3 – Induced Air Recirculation

Aerodynamic vibration may also be caused by poor inlet connections to the fan. Inlet boxes and inlet elbows should be vaned to reduce losses. When air is forced to flow through a sharp turn as it enters the fan, it tends to load just a portion of the fan wheel. The result is always decreased performance but many times, pulsation as well.

The same phenomenon can also develop, though generally to a lesser degree, at the discharge of the fan. Fans do not discharge air at an even velocity across their entire outlet. They generally operate best when the air is discharged into a long, straight duct, the minimum being three duct diameters beyond the outlet of the fan.

Mechanical Vibration

Mechanical vibration is the most common type of fan vibration. It is caused by unbalanced wheels or other rotating fan components. Its negative impact is increased with loose fasteners and poor structural support. Two terms are important in understanding vibration.

Balance primarily refers to the fan wheel or other rotating components. The procedure of balancing involves adding or removing weight in an attempt to move the center of gravity toward the axis of rotation.

Vibration primarily refers to the complete fan. Fan vibration is measured during a "run test" and is the vibration amplitude at the fan bearings expressed in units of displacement or velocity. The vibration level for new fan

equipment is a result of the design and construction by the fan manufacturer. For operating fan equipment, the installation and subsequent maintenance practices can have a major effect on fan vibration.

There are a number of causes for wheel unbalance:

Construction – in new fan wheels, unbalance exists because of the nature of the fabrication and assembly process. Part and assembly tolerances, material density variations and warpage during welding all contribute to non-concentric wheel assembly. Balancing compensates for these factors.

Material Buildup – even a thin layer of dirt can cause a surprising amount of wheel unbalance. Using solvent, wire brushes, scrapers, etc., wheels can typically be cleaned and restored to a balanced condition.

Abrasion/Corrosion – in material conveying applications or applications handling corrosive fumes, abrasion or corrosion of the wheel will cause unbalance. For safety reasons, this condition is more serious than simple vibration and the fan manufacturer's representative should be contacted for repair recommendations, up to and including wheel replacement.

Drive Components – sheaves, belts, couplings and motors can have their own unbalance resulting in fan vibration. Check components for alignment, examine the grooves of sheaves, and check the surfaces of belts. Replace worn components. Couplings can shift even a few thousandths of an inch in shipment, causing misalignment and vibration.

Several drive components can be easily checked to determine if they are the cause of vibration. Disconnect the drive or coupling and run the motor with one sheave or half-coupling in place. If this assembly runs rough, remove the sheave or half-coupling and run the motor alone.

It is much more difficult to determine if the fan wheel or the driven sheave/coupling is causing the vibration without removing it and sending it to a balancing facility. Sheaves and couplings should have been dynamically balanced originally. Unless it is important to determine whether the wheel or drive component is out of balance, it is probably best to balance the wheel, shaft and drive component as an assembly.

Fasteners – wheel and drive component setscrews, bearing bolts and the fan base mounting hardware are all subject to loosening, especially when some vibration is present. Without attention, loose components will add to the overall fan vibration magnitude.

Structural Support – too frequently, fans are mounted on supports that have a natural vibration frequency near that of the fan. At this frequency, the structure will tend to continue to vibrate once it has been set in motion. Under such conditions it is almost impossible to balance all of the rotating components finely enough to prevent an objectionable amount of vibration. Adding mass or stiffeners will move the structure's natural frequency out of range of the operating fan.

Optimum mounting structures include thick concrete slabs, steel bases supported by isolators, or heavy, all-welded steel structures. Structures must have adequate sway bracing, with no long, unsupported spans. They should be designed to be heavier than if they were designed merely to support a static load. All vertical supports should be directly underneath the fan and the fan should not be located in the middle of beam spans.

Bent Shaft – can cause significant vibration which usually results in a vibration magnitude that is proportional to the amount by which the shaft is bent. Using a simple dial indicator, the shaft can be checked for trueness. It should not be out more than one or two thousandths of an inch on a short shaft or two or three thousandths of an

inch on a longer shaft. If the shaft is bent, it can be straightened, replaced or compensated for trueness by balancing.

Balance Criteria

Major fan manufacturers balance fan wheels prior to assembly on precision balancing machines. The balancing procedure involves detection of and compensation for ounce-inches of unbalance. For most HVAC, agricultural and industrial applications, an ISO balance quality grade of G6.3 is adequate. Using this balance grade, the permissible residual unbalance is calculated as follows:

$$\text{Uper} = \frac{6.01 \times G \times W}{N}$$

Where:

Uper = permissible unbalance per balance quality grade (oz.-in.)

W = wheel weight (lbs.)

N = wheel operating speed (RPM).

G = balance quality grade (6.3)

For example, using a Size 264 Series 20 DH wheel:

Where:

W = 78 lbs.

N = 2280 RPM

G = 6.3

$$\text{Uper} = \frac{6.01 \times 6.3 \times 78}{2280}$$

Uper = 1.3 oz. – in.

Vibration Criteria

After wheel installation, assembled fans are “trim balanced” as a complete unit before shipment. Manufacturers have some limitations on what fans can be run-tested, based on electrical requirements, test speeds and customer-furnished components.

To perform a vibration run-test, the fan is mounted on a rigid base. The base may be more or less rigid than what the customer will use. Because of this difference, vibration limits determined from the factory vibration run-test cannot be used as a guarantee of the minimum level of vibration once the fan is installed in the system. To account for this difference in vibration-sensitive applications, more and more fans are being mounted on vibration-absorptive bases. These bases contain springs or rubber-in-shear isolation and may or may not be filled with

concrete for additional mass. The purpose of these bases is to allow the fan to vibrate without transmitting the vibration to the building structure.

Fan assembly vibration is typically measured in the horizontal direction with "filter in". *Filter-in* refers to the vibration being measured only at the frequency of interest. This method provides an accurate measure of wheel unbalance. Transducer orientation may vary by product and/or test stand configuration at the discretion of the manufacturer (Figure 6).

Major fan manufacturers have seismic vibration standards as part of their manufacturing/quality procedures. These limits will vary depending upon the fan manufacturer's test facilities, balancing equipment and fan type and size. As a guideline for fans in HVAC, agriculture and industrial applications, a peak velocity of 0.15 inches/second at the factory test speed is usually adequate.

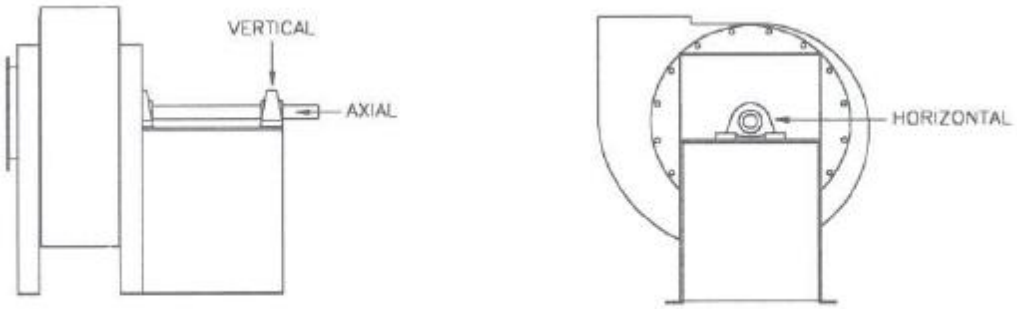

Figure 6 – Three Axis of Measurement

Displacement units can be converted to velocity units using the following equation:

$V = \pi fd/1000$, where

V = velocity (in/sec);

f = frequency (revolutions/sec);

d = displacement, peak-to-peak (mils = 0.001 inch).

Example: Convert 0.6 mils displacement to velocity in inches/sec with the fan running at 1200 rpm:

$V = \pi fd/1000 = [\ \pi(1200/60)(0.6)\ ] / 1000 = 0.0377$ inches/sec

<u>Conclusion</u>

System designers and specifiers should observe the following specifications to ensure minimum, acceptable levels of fan vibration:

1. Wheels should be dynamically balanced prior to installation in the fan assembly to ISO 1940/ANSI S2.19 Quality Grade G6.3.
2. Fans should be given a run-test and "trim balance" after wheel installation at the fan manufacturer's plant to decrease vibration caused by other fan components and the overall assembly process whenever the fan configuration permits it.

3. Mounting structures must be rigid and sufficiently heavy to properly support the fan. Structures must have a natural frequency that is well out of the fan's operating range.
4. For vibration-sensitive applications, special consideration should be given to spring or rubber-in-shear isolation, or inertia bases.
5. Utilizing computerized fan selection programs and the fan manufacturer's representative, fans should be selected to avoid unstable operating points and resulting aerodynamic pulsation.
6. Alterations to the overall system design should include consideration of changes in the fan's point of operation and possible aerodynamic pulsation.
7. Proper maintenance practice, including periodic wheel inspections and inspection of drive components and fasteners, will assure reduced vibration levels.