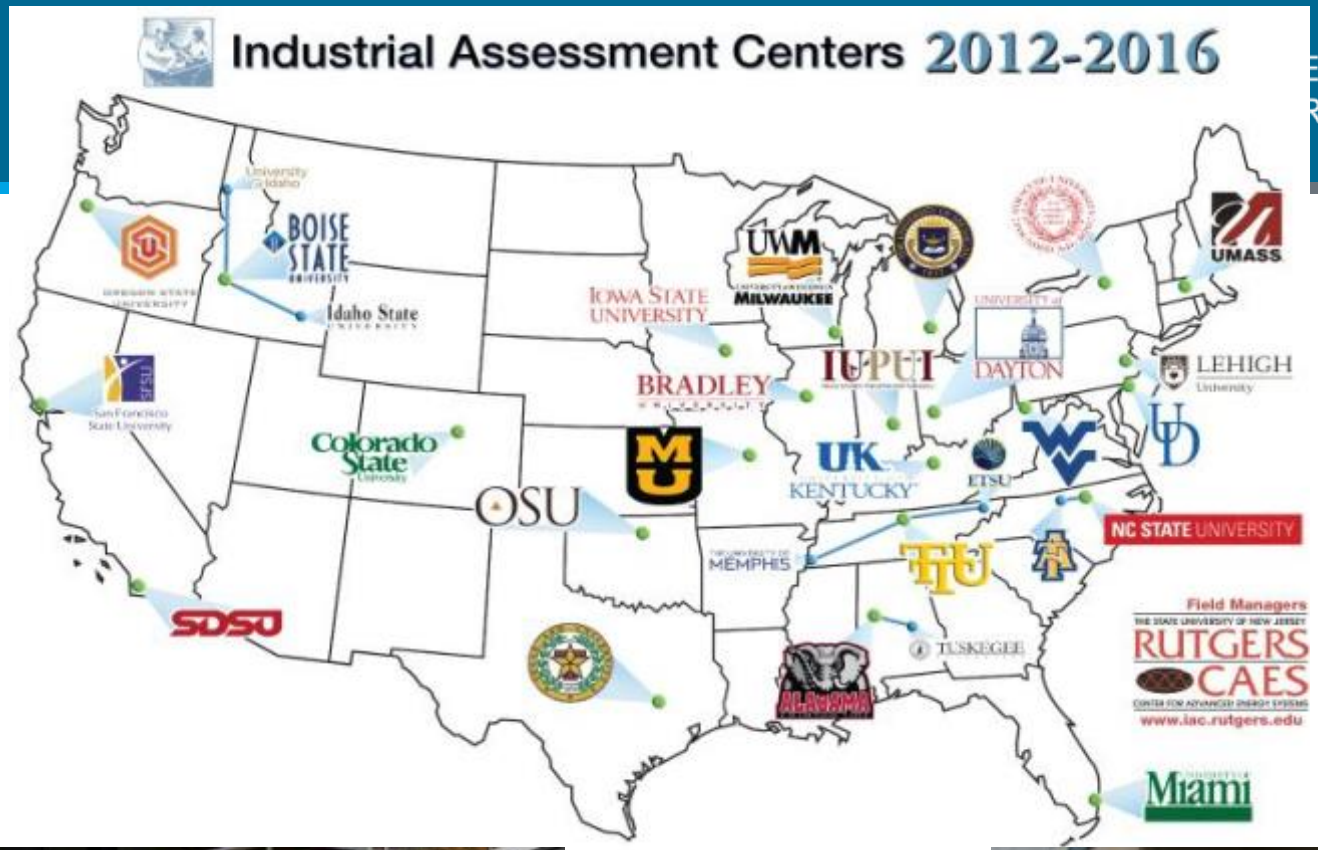
# IAC Student Collaboration Webinar

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

**Thomas Wenning, PE**
Oak Ridge National Laboratory

**IAC Student Webinar Series**
**March 2016**


Industrial Assessment Centers 2012-2016
University of Idaho
BOISE STATE UNIVERSITY
Idaho State UNIVERSITY
OREGON STATE UNIVERSITY
San Francisco State University
Colorado State University
OSU
SDSU
IOWA STATE UNIVERSITY
UWM
MILWAUKEE
BRADLEY UNIVERSITY
IUPUI
UNIVERSITY of DAYTON
UMASS
LEHIGH University
UD
UK
KENTUCKY
ETSU
NC STATE UNIVERSITY
MEMPHIS
TUSKEGEE
ALABAMA
Miami
Field Managers
RUTGERS
CAES
www.iac.rutgers.edu

# IAC Student-Led Webinars Intro

- Alternative to student meeting
- Monthly student-led webinars
- Proposed Structure:
  - 40 min student presentation
  - 20 minutes of Q&A/open dialogue
- Allow students to connect

# Webinar Series Purpose

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- Mechanism for IAC-to-IAC student collaboration
- Possible topics:
  - Relevant items for day-to-day IAC operations (client recruitment, report writing, etc.)
  - New technologies and innovations
- Rotate speakers and topics each month
- Each center will lead or contribute a presentation to a future webinar

# Feedback

We want your feedback (date, time, topics, etc)!

….and Volunteers!

# Feedback

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

## Webinar Survey

1. Did you find this webinar helpful (1 being least helpful and 5 being most helpful) ?

   1 ○ 2 ○ 3 ○ 4 ○ 5 ○

2. What topic or topics would you like to see addressed in future IAC student-led webinars?

3. Would you be interested in leading a future webinar?

   ○ Yes

   ○ No

4. If interested in leading a future webinar, please list your name and contact email.

# On to the Speaker…

- **Topic**: Overview of Cogged V-Belts vs. Standard V-Belts
- **Who**: Chad Dunkel, University of Idaho IAC

dunk1833@vandals.uidaho.edu

University of Idaho

# Overview of Cogged V-Belts vs. Standard V-Belts

Presented by: Chad Dunkel
On behalf of the Industrial Assessment Center

Department of Biological and Agricultural Engineering
University of Idaho

# Presentation Objectives

- Background
  - Belt types
  - Factors effecting belt drive efficiency
  - Belt drive maintenance
- Belt Upgrade Recommendation
  - Prevalence
  - Methodology
  - Site visit insights/observations
  - Client feedback
  - Cost effectiveness
- V-belt vs Cogged Belt Energy Savings Experiment
  - Percent savings validation

# Background

According to DOE belt drive tip sheets:

- Approximately 1/3 of electrical motors in industrial and commercial sectors use some form of belt drive.
- Proper Design of Belt Systems provide:
  - High efficiency (95-98%)
  - Low noise
  - No lubrication
  - Low maintenance
  - Inexpensive
  - Flexibility in the positioning of motors

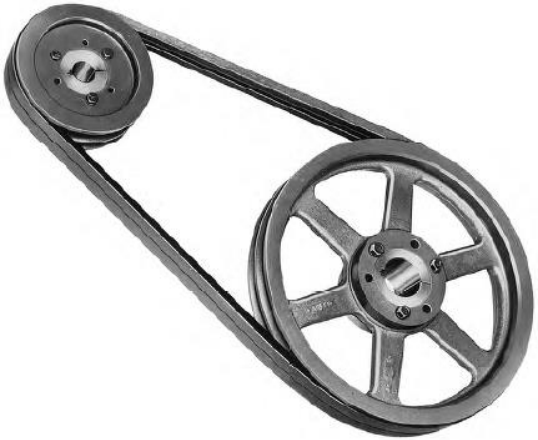
# Background

What is a belt?

Loop of flexible material that is used to mechanically link two or more rotating shafts to transmit power.

What is a pulley (also called sheave)?

Wheel on a shaft that supports movement and change of direction of a belt along it circumference. Can be smooth or have notched teeth.



# Energy Losses in Belt System

Torque loss

- Torque losses are typically due to losses incurred from the stresses (bending) that are imposed as the belt goes around the pulley or sheave.

Frictional Loss

- Belt/Pulley Interface
- Drag (imposed by air friction)

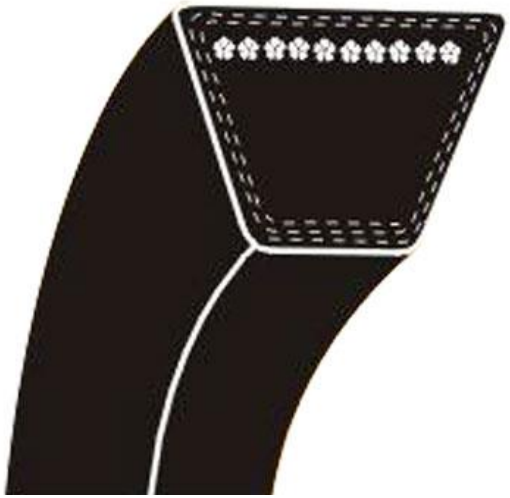
Speed Loss

- Belt slippage and creep

*__Total energy losses__ effecting efficiency will be lost in the form of heat

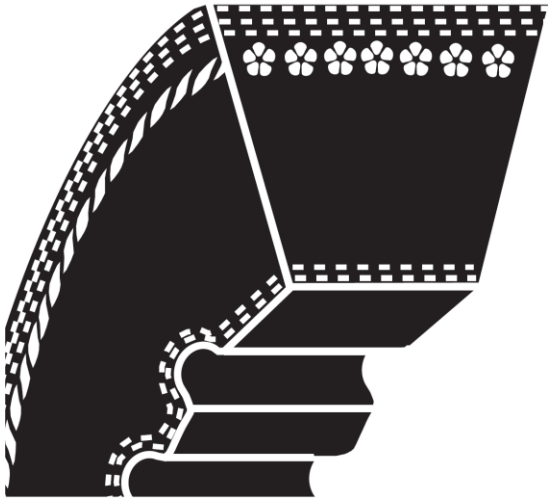
# Types of Belts

- Traditional V-Belts
  - Trapezoidal
  - Shape creates wedge inside pulley to increase friction and effective transfer
  - Reduction in efficiency in high torque applications due to slippage
  - Inexpensive
  - Still common in many industrial applications



# Types of Belts

- Notched Belts
  - Grooves that run perpendicular to belts length
    - Reduces internal bending stresses
  - Can use same pulleys as standard v-belts
  - Benefits:
    - Run cooler
    - Longer lifespan
  - Disadvantages:
    - Slightly higher cost



# Types of Belts

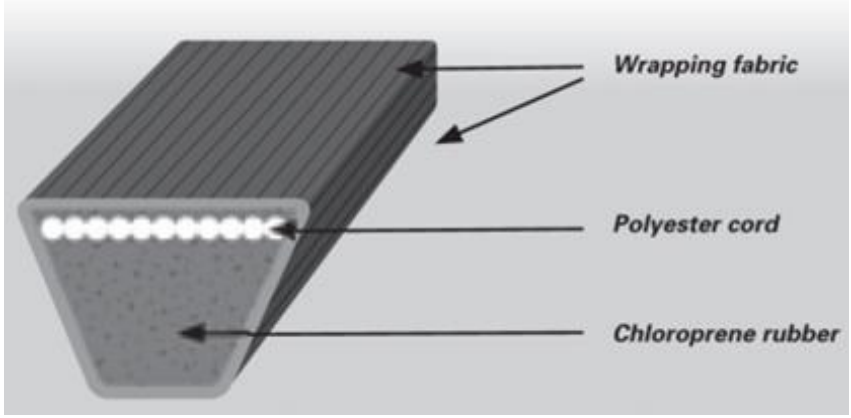
- Synchronous Belts
  - Toothed belts that run on mated grooved sprockets
  - Operate with consistent efficiency (~98%)
    - Maintained over varying loads
  - Low maintenance
    - Minimal retensioning
    - Operate in wet environments
    - Very low slip
  - Disadvantages
    - Noisy
    - Not good for surge loadings
    - Transfer vibration (due to belt stiffness)

# Types of Belts

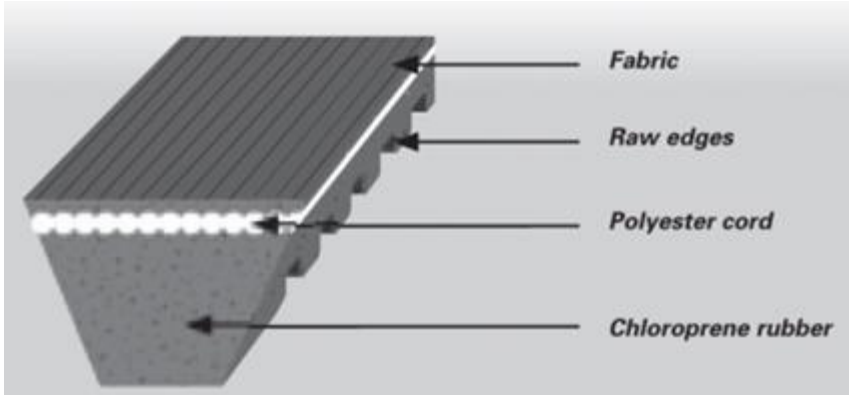
- Linked V-belts
  - Claim to be stronger than traditional belts
  - Vibration resistant
  - Versatile
    - Can be replaced without equipment disassembly
    - Size can be adjusted by add/subtracting links
    - Can join two belts together

# Belt Construction

V-Belt




Cogged Belt



Link V-belt

# Factors Effecting Belt Efficiency

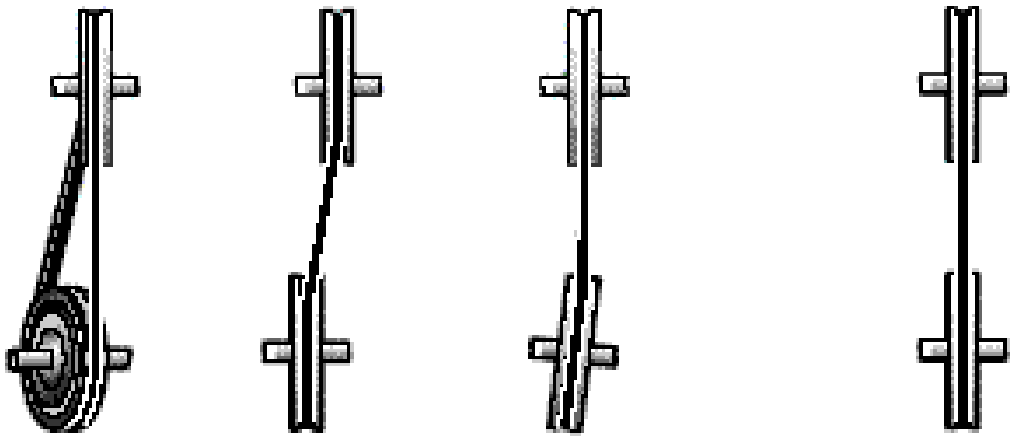
- Peak belt drive efficiency can be up to 95%-98% (new belt)
- Nominal efficiency is typically around 92%
- Key factors that effect belt drive efficiency:
  - Belt type
  - Belt tension
  - Pulley size
    - Small pulleys typically exhibit greater internal belt stresses
  - Pulley wear
  - Belt condition
  - Belt alignment
  - Torque produced
  - Improperly sized belts (for required load)
  - Environmental conditions (heat, dust, moisture, etc.)

# Belt Tensioning

- Belt tension is critical in maintaining efficiency. Belts that are too loose or too tight result in inefficient power transmission, belt wear/failure, motor bearing wear.
- Belt tension should be such that the belt delivering power should not experience slip around pulley during peak/maximum loadings.
- In order to ensure belt is properly tensioned, the following tools can be used:
  - Tension meter
  - Infrared tools to identify over-tension (heat)
  - Vibration analyzers
  - Tachometers

# Belt Alignment

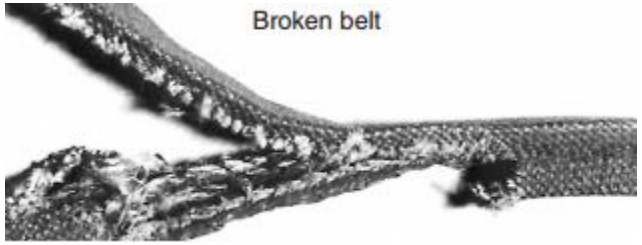
- In order to maximize efficiency and to minimize excessive wear to the belt system the belt pulleys should be aligned correctly.
- Pulleys should be in line and parallel with each other
- There are laser tools on the market that show if pulleys are aligned



Incorrect Alignment

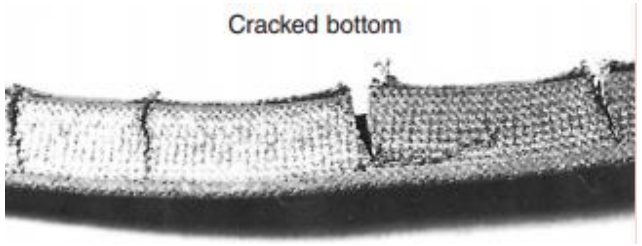
Correct Alignment

# Belt Failure and Cause




Broken belts can be a result of end of belts lifespan or due to foreign objects introduced in the belt drive

Sidewall wear is typically a result of a damaged/worn pulley or from pulley misalignment




Cracked belts can be a result of using a pulley that is too small (diameter), excessive slippage, and high temperatures

# Maintenance

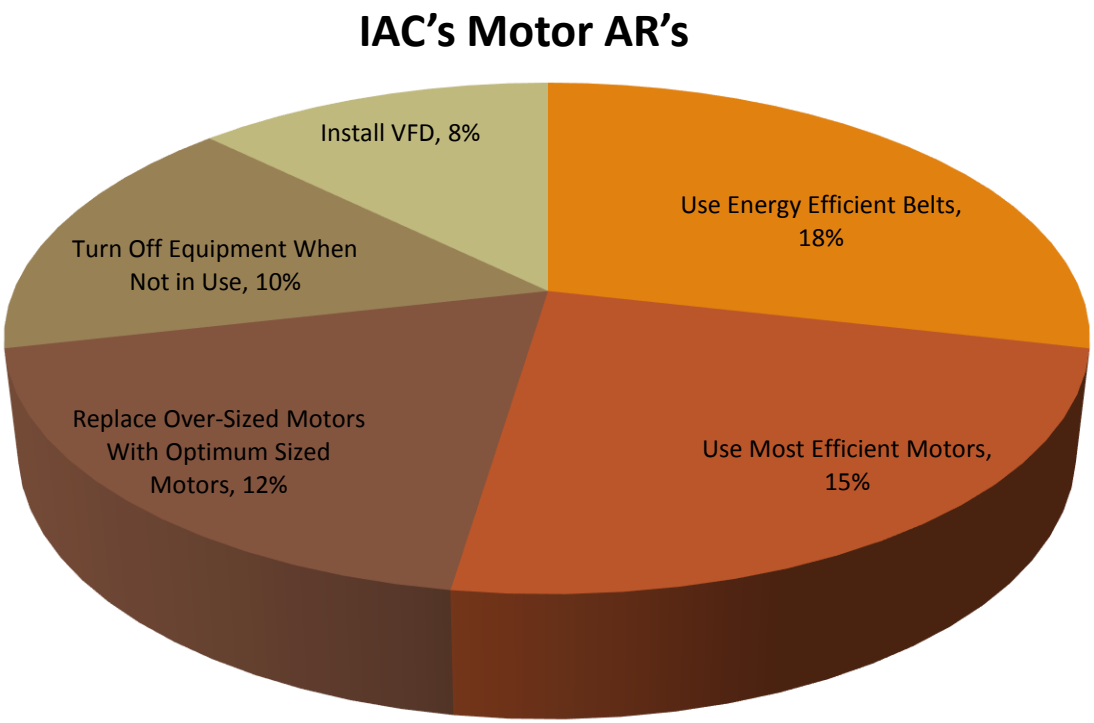
In order for belt drives to continue operating at maximum efficiency, ensure the following:

- Belts are properly tensioned
  - Over or under-tensioning of belt will cause inefficiencies and/or wear
    - Under tensioned belts result in power transmission loss due to slippage
    - Over tensioned belts cause excess stress and friction in belt drive system and bearing loads
  - Belt is properly tensioned when there is no slip during peak loads
  - Belt tension should be checked every 3 to 6 months depending on application.
- Pulleys are aligned correctly
- Pulleys are not worn and are void of moisture and debris
- Belts are not excessively worn

# Belt Upgrade Recommendation: Prevalence and Methodology

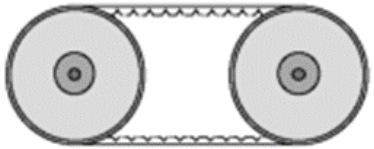
# Prevalence in IAC Database

By looking at the 5 most prevalent motor recommendations in the IAC database, the recommendation to implement the use of energy efficient belts accounted for 18%



# Prescribed Methodology

Methodology for belt drive change out found in DOE Self Assessment Workbook.



**Anticipated Savings**

Studies have shown that typical well-maintained industrial V-belts are about 92% efficient. Field tests of cog belts for both large and small drives show gains in efficiency from 2.0% to 5%. Conservative values for gains in efficiency range from 1% - 3%[4]. For our calculations, we will use (and recommend) a conservative value of 2.0%. We can calculate the yearly electric consumption savings using the following formulae:

$$PS = \frac{HP}{\eta} \times LF \times S$$

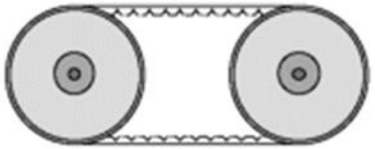
$$ES = PS \times H$$

| | | |
|---|---|---|
| PS | = | the anticipated reduction in electric power in kW. |
| ES | = | the anticipated energy savings (kWh/yr) |
| HP | = | the total horsepower for the large motors using standard V-belts in the plant. This is estimated to be 212.5 HP based on the equipment list contained in the plant background section. |
| $\eta$ | = | average efficiencies of the motors (0.85) |
| LF | = | average load factor (80%). |
| H | = | annual operating time (8 hrs/day x 5 days/wk x 52 wks/yr) |
| | = | 2,080 hrs/yr |
| S | = | estimated energy savings (taken here as either 2% for cog belts) |

# On Site Assessment

Requirements for Recommendation Calculations

- Tabulate the following for all motors eligible for belt upgrade:
  - Motor horsepower
  - Annual operating hours of each motor
  - If measurable, percentage of rated load
    - Instantaneous electrical measurement



**Anticipated Savings**

Studies have shown that typical well-maintained industrial V-belts are about 92% efficient. Field tests of cog belts for both large and small drives show gains in efficiency from 2.0% to 5%. Conservative values for gains in efficiency range from 1% - 3%[4]. For our calculations, we will use (and recommend) a conservative value of 2.0%. We can calculate the yearly electric consumption savings using the following formulae:

$$PS = \frac{HP}{\eta} \times LF \times S$$

$$ES = PS \times H$$

# On Site Assessment

<u>What to look for:</u>

- Load characteristics
- Large motors
  - Greater energy savings
- Belt selection
  - V-belt
  - Cogged
  - Synchronous
- Environmental Conditions (moisture, dust, heat, etc.)

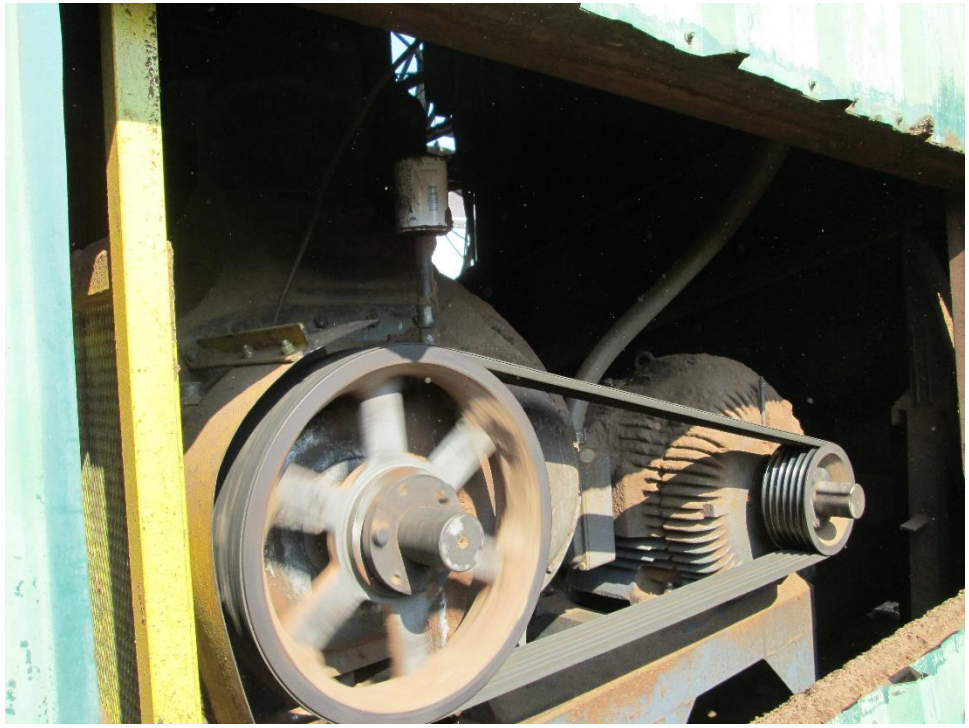
# IAC Belt Upgrade Recommendation

Recommendation Components

- Background Information
  - Information regarding motors with belt drives and operations that could benefit from belt upgrade
- Recommended Action
  - The suggested action/belt replacement that is recommended to the client
- Anticipated Energy Savings
  - Motor information (hp, runtime, load factor, efficiency)
  - Current energy use calculation or measurement (demand and consumption)
  - Proposed energy use using estimated energy use reduction (DOE uses 2%)
  - Energy savings = Current – Proposed
- Implementation Cost Estimate
- Simple Payback Period = Implementation Cost/Cost Savings

# UI IAC Site Visits

- Belt upgrade recommendations are increasingly more common in our reports
  - Easy to collect data
  - Low implementation cost
  - Easy calculation
  - Small payback period (typically <1 year)
  - Easy to implement
  - Wide availability



# UI IAC Site Visits

Common Industries with large quantity of belt drives:

- Lumber Mills
- Food Processing
- Manufacturing

Common Applications

- Conveyors
- Fans/blowers
- Pumps

# UI IAC Belt Upgrade Recommendations Overview

| Industry | Assessment Recommendations | Annual Resource Savings | Annual Cost Savings | Capital Cost | Balance of Project Cost | Simple Payback Period |
|---|---|---|---|---|---|---|
| Composite Manufacturing | Utilize Cogged V-belts on Dust Collectors | 29,820 kWh<br>42.5 kW | $1,903 | $120 | $80 | < 1 year |
| Lumber Mill | Upgrade V-Belts | 156,947 kWh<br>268.8 kW | $9,395 | $0 | $84 | < 1 year |
| Food Processing | Upgrade V-Belts | 77,853 kWh<br>256.4 kW | $12,633 | $40 | $832 | < 1 year |
| Manufacturing | Upgrade V-Belts | 4,643 kWh<br>6.4 kW | $305 | $0 | $20 | < 1 year |
| Municipality | Replace V-Belts with Cogged Belts | 1,616 kWh<br>2.3 kW | $143 | $0 | $60 | < 1 year |
| Lumber Mill | Replace V-Belts with Cogged Belts | 6,300 kWh<br>26 kW | $629 | $0 | $15 | <1 year |

# Client Feedback

Clients have been skeptical regarding savings achieved by upgrading belts or have explicit reasons for not upgrading

- High heat environments result in shortened life span when using notched belts
  - “Traditional v-belts last longer in hot applications”
  - Facility used link belts
- Complaints regarding increased noise levels when using notched belts
  - “We don’t use cogged belts due to the noise”

# Cost Effectiveness

- For the best cost effectiveness of implementation it is typically recommended that belt upgrades be done at end of v-belt life
  - Many clients are reluctant to throw away “working” belts
  - Run old belt until it needs replacing and then simply replace with notched belt
- Although cogged belts are slightly more expensive, they last longer and are more efficient that traditional v-belts
- If synchronous belt system is suggested, belt and sprocket should be designed such that proper speed and torque is delivered.

# Research Question

Can the energy efficiency improvements attributed to belt drive upgrades be experimentally validated?

# Expected Results From Literature Review

DOE  Office of Industrial Technologies Motor Tip Sheet 3

- V-belt*
- Peak efficiency of 95% to 98%
- Nominal efficiency of 93% (Environmental conditions, slippage, and wear)

IAC Self Assessment Work Book Example Calculation 4.1

- Notched belt**
- 1% to 3% efficiency improvement over traditional V-belt

* http://www.nrel.gov/docs/fy00osti/27833.pdf
** http://iac.rutgers.edu/technicaldocs/Self Assessment Manual

# Useful Formulas for Experiment

1) $Efficiency = \frac{Power\ Output}{Power\ Input} \times 100$

2) $Power\ Output = Torque\ Output \times RPM\ Output$

3) $Power\ Input = Measured\ value$

# Test Stand Development

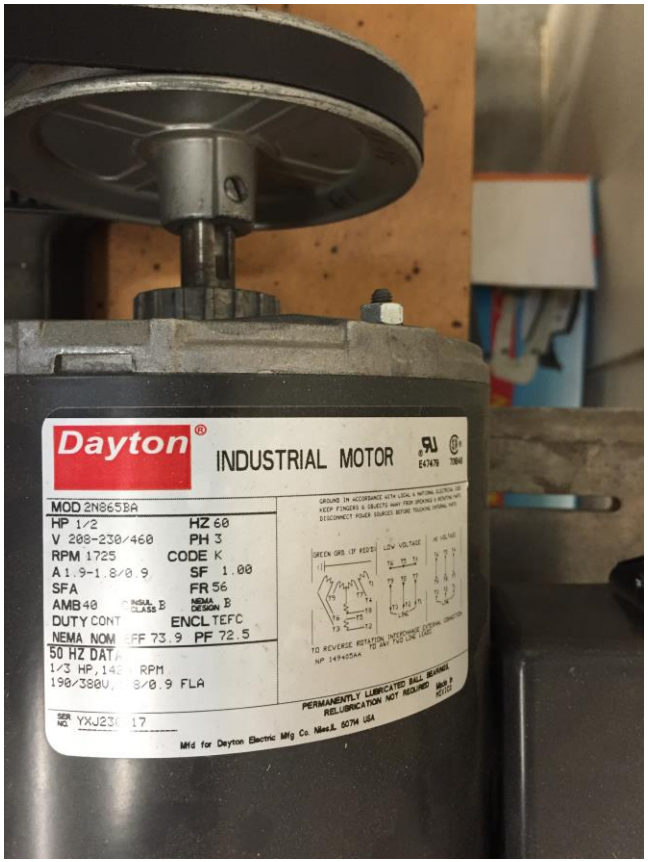
Required Components

- Electric Motor
- Traditional V-belt
- Notched belt
- Ability to Generate Load on Motor
- Ability to Measure Torque Imposed by Motor Belt Drive
- Ability to Measure Electrical Input to Motor

# Test Stand Development

Electric Motor

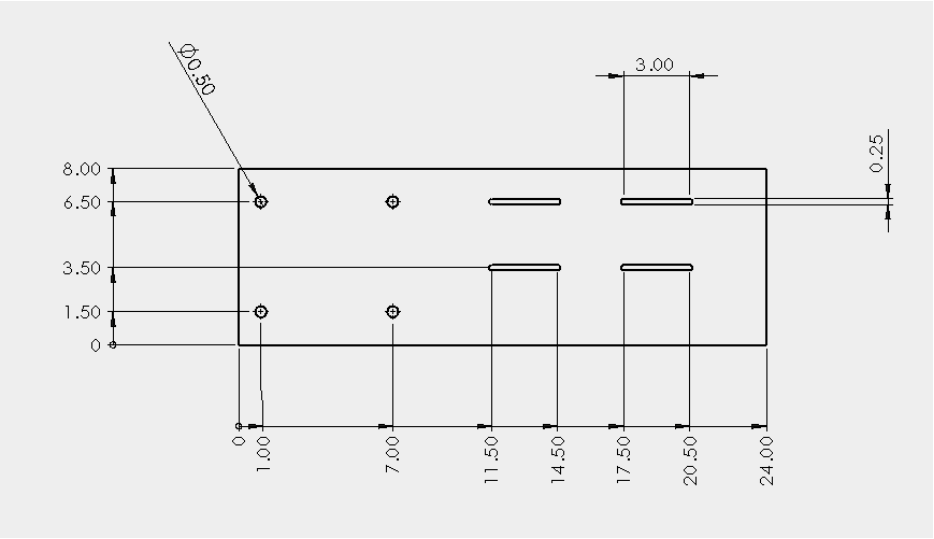
- Dayton Industrial Motor
- 3-phase
- 1/2 HP
- 230 Volts
- 1725 RPM
- NEMA Nom. Efficiency = 73.9%
- Power Factor = 72.5

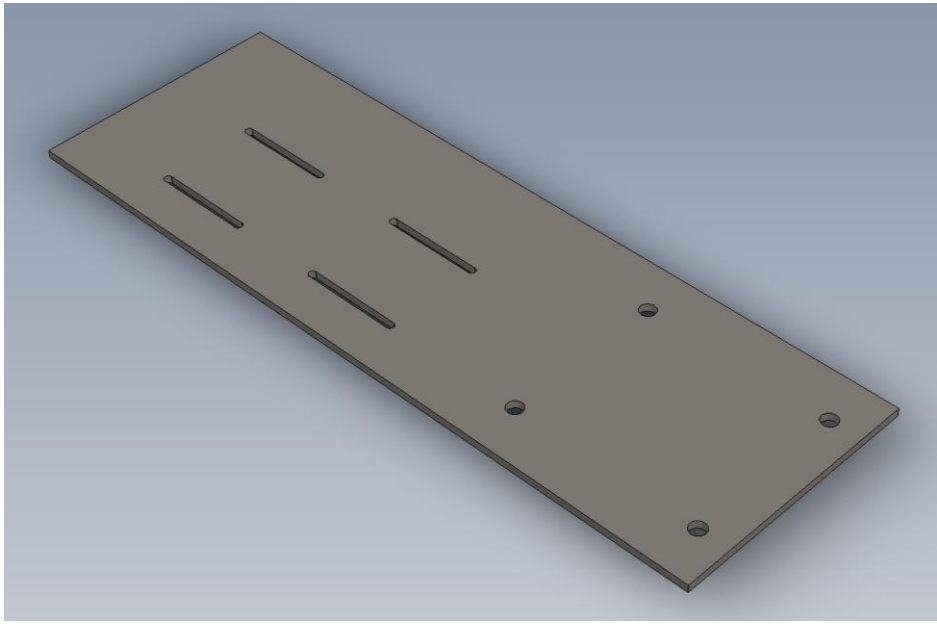


# Test Stand Development

Motor Adapter Mounting Plate

Adapter plate drawn in SolidWorks and manufactured to allow for motor/generator offset and belt tensioning. Plate also allows for multiple sizes of belt and pulley options.



# Test Stand Development

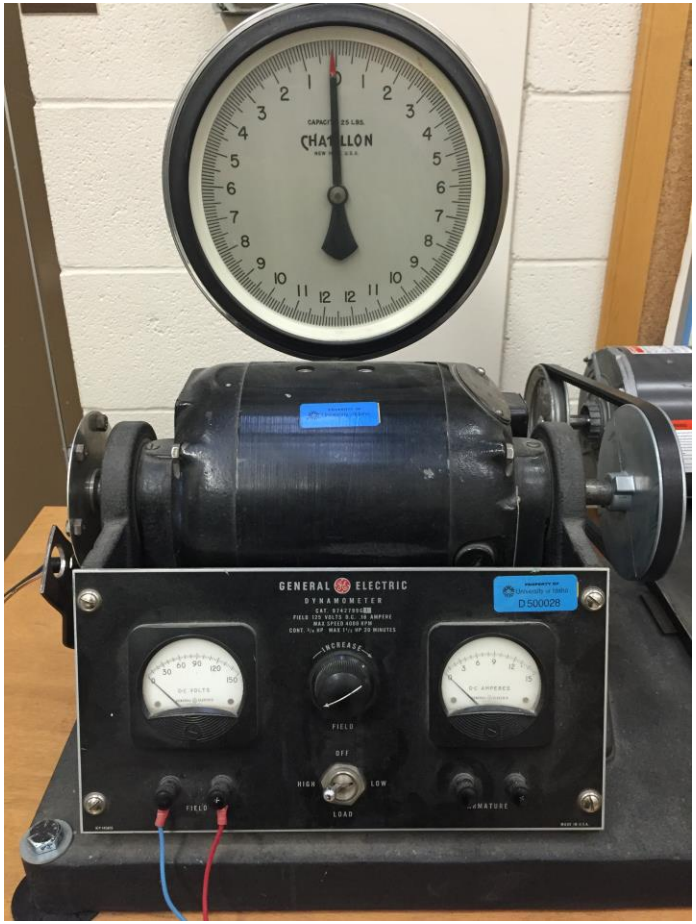
Motor attached to test stand using manufactured adapter mounting plate

Adapter plate manufactured to allow for motor/generator offset and belt tensioning.

# Test Stand Development

DC Dynamometer

- Provides resistance to simulate load on motor/belt drive system
- Bearings allow dynamometer to rotate as resistance is applied
- 6” long lever arm attached to dynamometer and scale provides a measurement of torque in ft-lbs

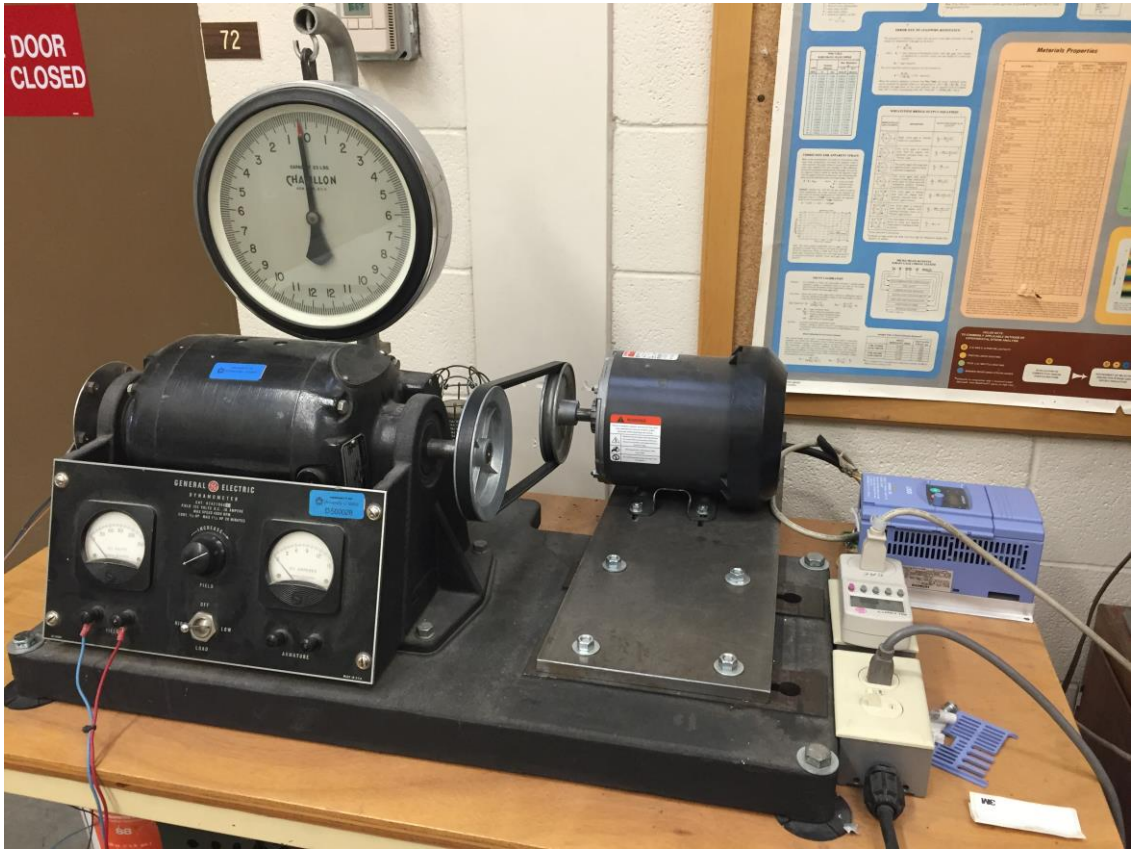


# Test Stand Development

<u>Additional System Components/Instrumentation</u>

- Kill-a-Watt
  - To measure power input to motor
- Variable Frequency Drive
  - To adjust frequency supplied to motor (Ran at 60 Hz)
- Handheld Tachometer
  - Used to measure motor and generator RPM

# Test Stand Development



# Experimental Results

Base Line Unloaded Condition:

**Unloaded:**

**V-Belt**

| Generator RPM | V_Gen(V) | I_Gen(A) | T(ft/lbs) | Motor RPM | Motor Power (W) |
|---|---|---|---|---|---|
| 1686 | 0 | 0 | 0 | 1715 | 181.3 |

**Cogged Belt**

| Generator RPM | V_Gen(V) | I_Gen(A) | T(ft/lbs) | Motor RPM | Motor Power (W) |
|---|---|---|---|---|---|
| 1692 | 0 | 0 | 0 | 1718 | 161.7 |

Loaded Condition:

**Loaded:**

**V-Belt**

| Generator RPM | V_Gen(V) | I_Gen(A) | T(ft-lbs) | Motor RPM | Motor Power (W) |
|---|---|---|---|---|---|
| 1485 | 136 | 7.2 | 3 | 1506 | 1313 |

**Cogged Belt**

| Generator RPM | V_Gen(V) | I_Gen(A) | T(ft-lbs) | Motor RPM | Motor Power (W) |
|---|---|---|---|---|---|
| 1487 | 136 | 7.5 | 3.1 | 1507 | 1145 |

# Experiment Conclusions

Determining efficiency in the system at a loaded state from the input power to the motor and the torque and rpm of the generator converted to power:

$$P_{out} = T * C_1 * C_2 * C_3 * \omega$$

Where,

| | | |
|---|---|---|
| $T$ | = | Torque induced in generator, ft-lb |
| $C_1$ | = | Conversion factor from m to ft, 0.3048m/ft |
| $C_2$ | = | Conversion factor from Newtons to pounds, 4.45N/lb |
| $C_3$ | = | Conversion factor from RPM to radians per sec, $(2\pi/60)$rad/s |
| $\omega$ | = | Shaft speed of the generator, RPM |

# Experiment Conclusions

For the standard V-belt:

$$P_{out} = 3[ft - lb] * 0.3048\left[\frac{m}{ft}\right] * 4.45\left[\frac{N}{lb}\right] * \frac{2\pi}{60}\left[\frac{rad}{s}\right] * 1485[RPM] = 632.8[W]$$

For the cogged V-belt:

$$P_{out} = 3.1[ft - lb] * 0.3048\left[\frac{m}{ft}\right] * 4.45\left[\frac{N}{lb}\right] * \frac{2\pi}{60}\left[\frac{rad}{s}\right] * 1487[RPM] = 653.9[W]$$

# Experiment Conclusions

$$\eta = \frac{P_{out}}{P_{in}} * 100$$

Where,

| | | |
|---|---|---|
| η | = | Efficiency |
| $P_{out}$ | = | Power out, W |
| Pin | = | Power in, W |

Efficiency for the Standard V-Belt:

$$\eta_s = \frac{P_{out}}{P_{in}} = \frac{632.8[W]}{1313[W]} * 100 = 48.2\%$$

Efficiency for the Cogged V-Belt:

$$\eta_c = \frac{P_{out}}{P_{in}} = \frac{653.9[W]}{1145\,[W]} * 100 = 57.2\%$$

Efficiency improvement with cogged belt: $\Delta\eta = \eta_c - \eta_s = 57.2\% - 48.2\% = 9\%$

# Sources of Error

- Tension on belt was not established by measurement
  - Over or under tensioning could result in excess friction losses or slip

- Accuracy of instruments used to measure RPM, torque, or power input
  - RPM : Tachometer calibration
  - Torque : Accuracy of scale used to measure lbs. of induced toque
  - Power input : Accuracy of input power meter

# Experiment Conclusions

- Using an *S* term of 2% in belt upgrade calculations prescribed by the Self Assessment Manual appears very conservative based on the results of our experiment.
- Due to possible experimental errors, it would be good to stick with an estimated savings of 2-5 %.
- Experimental results could be influential to client's decision to implement belt upgrades
  - Client may be more willing to follow through with upgrade after knowing there is potential 9% energy savings

# General Conclusions

- Use of cogged belts, rather than smooth v-belts, results in upwards of 9% energy savings and is usually a worthwhile upgrade
- Cogged belts may not improve efficiency if not maintained or in inappropriate environment.
- It is suggested that belts be upgraded at the end of previous belt's life
- Synchronous belt drives are most efficient
  - Synchronous belt drives may not be good in applications when vibration damping is needed or shock loads (can result in sprocket toother damage)
  - Synchronous belt drives are noisy.

# Questions?

# Q & A…

# 2016 IAC Distinguished Alumni Awards

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

**3rd Annual IAC Distinguished Alumni Awards**

– Presented to **3-5 IAC Alumni**

– For outstanding accomplishments in promoting the practices, principles and procedures of energy engineering in a professional or academic capacity

– Last year's awardee's:

- Dustin Pohlman (University of Dayton, 2013)
- Kevin Ng (San Francisco State University, 2009)
- James Eggebrecht (Texas A&M University, 1994)

- The deadline for the 2016 submission is **April 30, 2016**
- The nomination form can be found on the IAC Forum website at http://www.iacforum.org:8080/iac/news.jsp
- Please submit your nominations to: IAC@ee.doe.gov

# www.IACForum.org

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

# Student Registry and Exit Interviews

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

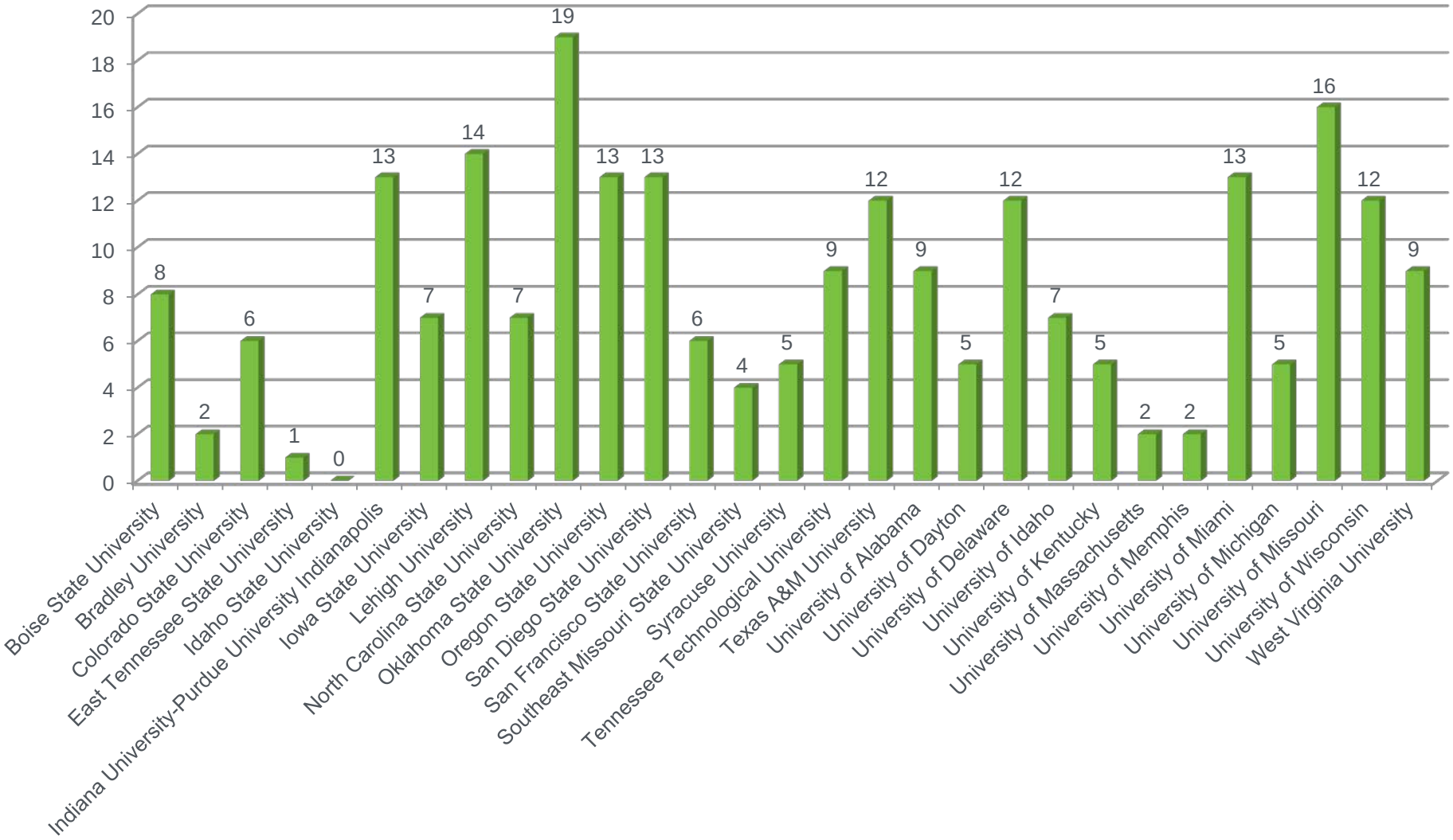
- **Lead Student Responsibilities**
  - Ensure all students complete registry entry
  - Ensure all students complete exit interview
  - Ensure that lead/active/inactive status is current
- Exit Interviews
  - Identify new lead students
  - Update contact information for alumni
  - Capture alumni career data

**http://www.iacforum.org/**

# Student Registry and Exit Interviews

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

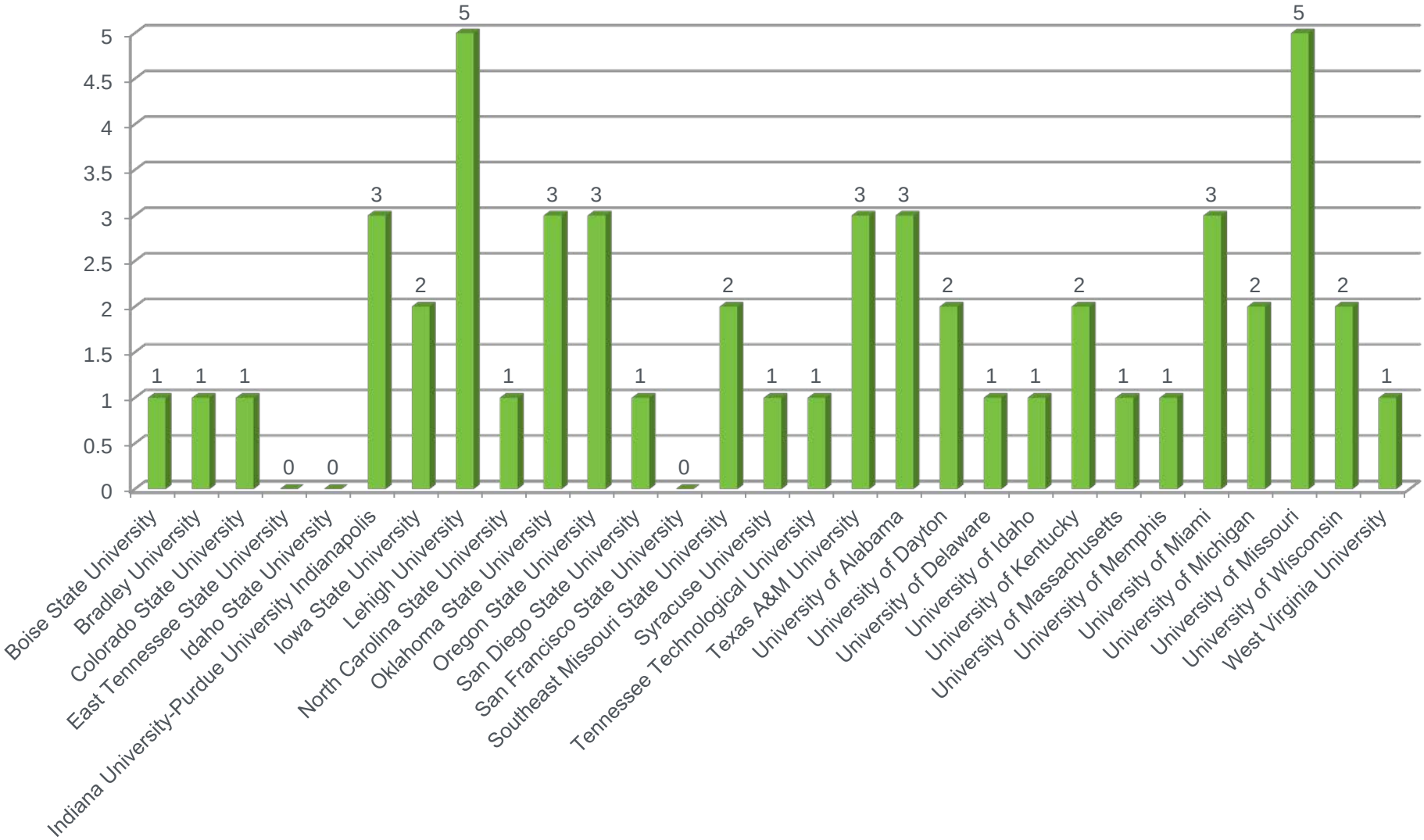
## Number of Students Currently Listed as Active in the IAC Student Registry



# Student Registry and Exit Interviews

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

## Number of Currently Active Students Listed as "Lead Student"



# Student Certificates

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

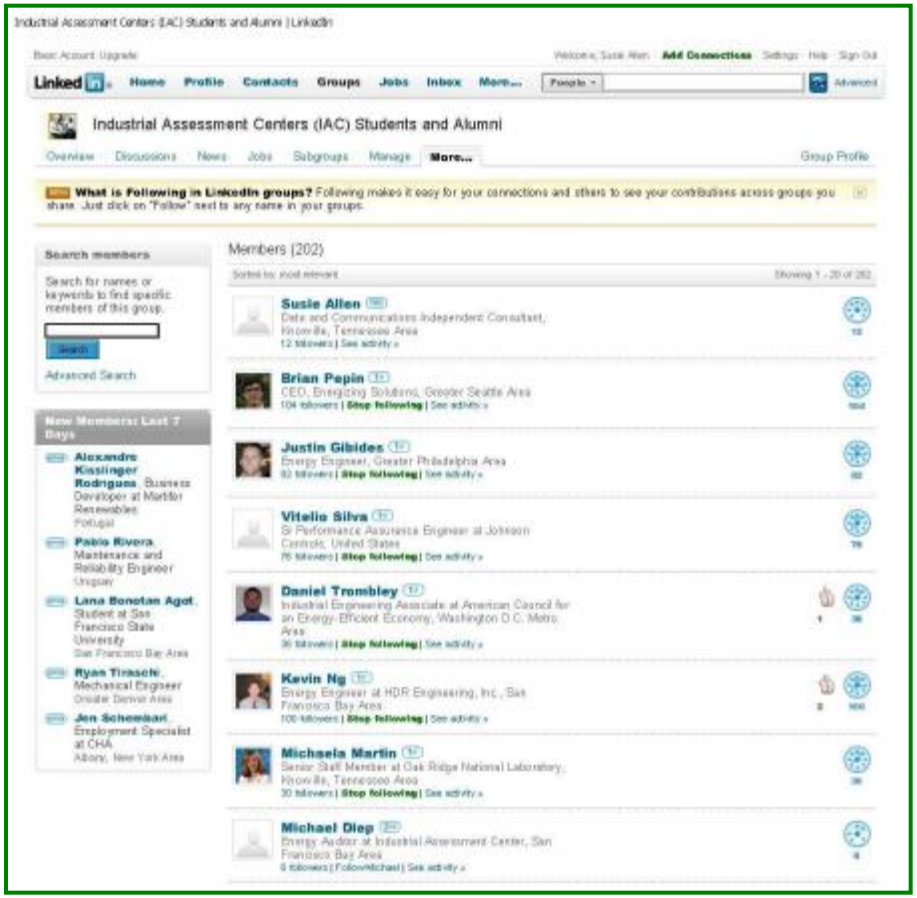
- On-line requests are processed through the certificates link on www.iacforum.org
- **Students and alumni must be in the IAC registry to receive certificates**
- Deadlines occur 3 times per year:
  - October 1, March 1, and July 1
- Certificate process
  - Student initiates request online,
  - Director/AD receives email notification with link
  - He/she completes the request online
  - Certificates arrive
- Certificates <u>are mailed to the Directors</u> within 30 days of deadline
- Applications for the March 2016 round of IAC Certificates are currently being processed and will arrive in IAC centers soon

Certificate of Participation
presented to
Name
For the completion of requirements mandated by the
U.S. Department of Energy's
Industrial Assessment Center Program at
Texas A & M University

# LinkedIn IAC Group

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

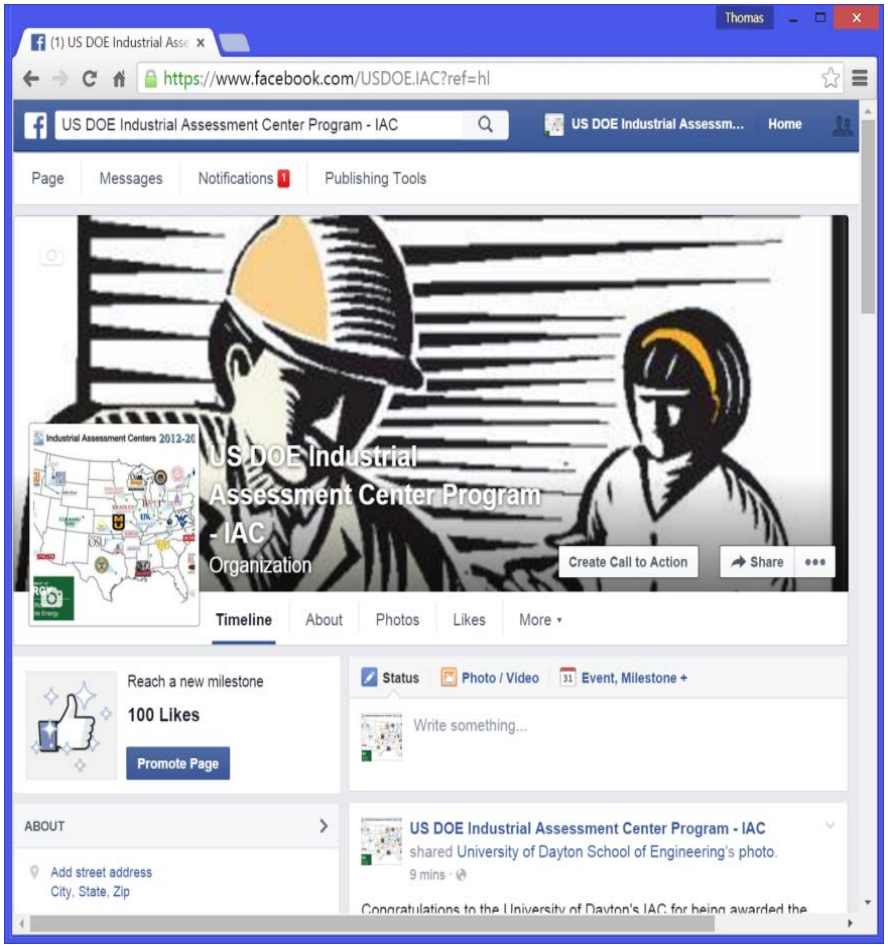
- Established in 2008
- Professional networking site for IAC students and alumni
- 595+ members
- News items, professional profiles, discussions
- **Please utilize for ongoing collaboration or technical questions**




**https://www.linkedin.com/grp/home?gid=912947**

# Facebook IAC Page & Group

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

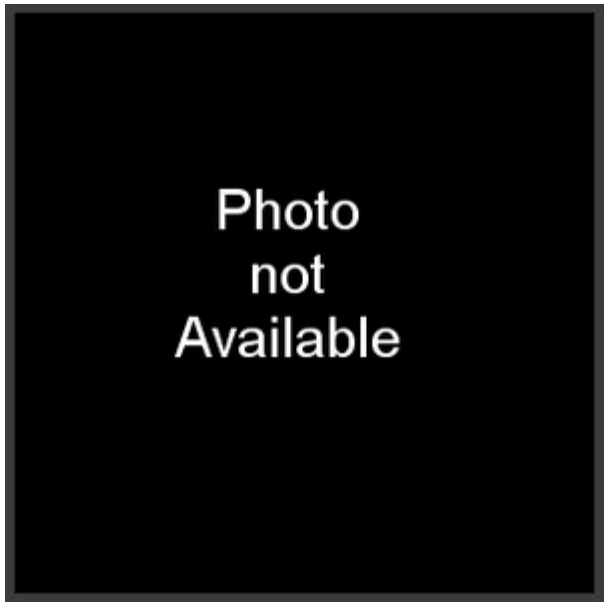


Page - https://www.facebook.com/USDOE.IAC

Group - https://www.facebook.com/groups/543916505784912/

# Request: Pictures, Video Clips, Articles & Stories

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Please send to:
[wenningtj@ornl.gov](mailto:wenningtj@ornl.gov)

# Looking ahead…April

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

- **Topic**: Pneumatics Best Practices
- **Who**: Jon Jensen, Energy Conservation Group, SMC Corporation of America
- **When:** Wednesday, April 13, 2016 @ 2pm ET

# Thank You!

**Thomas Wenning, PE**

IAC Student Activities Coordinator

Oak Ridge National Laboratory

865-946-1504, wenningtj@ornl.gov