ENGINEERING
TOMORROW

High Speed Motor Test Rig
Spring Presentation 1

Team 4: Francisco Barreto, Matthew Ketchum,
Thyeasha Joseph, Durval Marques, Leonardo Branco.

Sponsor: Danfoss
Liasain: William Sun
Faculty Advisor: Dr. Patrick Hollis
1-21-16

Project Background

- Danfoss is looking to build a motor-generator rig to test the compressor motors.
- Compressor uses magnetic bearings.
- Motor-generator rig couples the drive-shaft of one motor to another motor shaft which acts as a generator (back driven).
- Danfoss TT-Series motors run between 20,000-40,000 rpm (depending on the model).
  - High amount of misalignment must be minimized.
  - High chance of misalignment calls for high precision for alignment process.

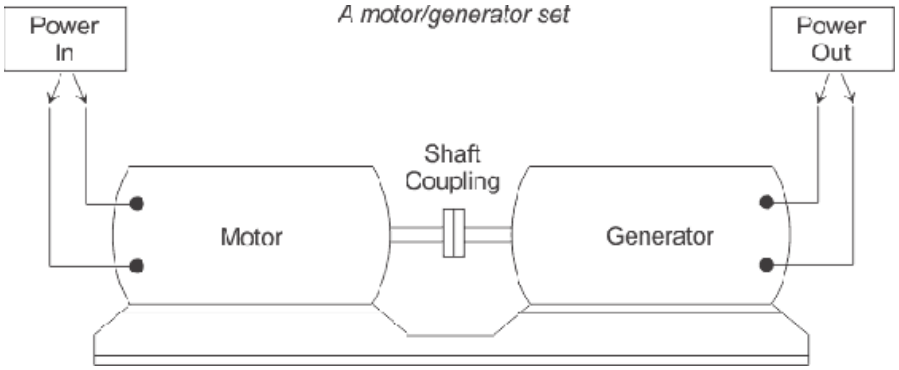


Figure 1. Motor-generator

Frank Barreto

Problem Statement

- Danfoss desires a system to qualify their compressor motor performance specifications.
  - Power
  - Efficiency
  - Heat Management
- Needs to be able to qualify all TT-Series compressor motors
  - Torques and Angular Speeds vary between models
- System alignment process must also be qualified

Frank Barreto

Final Design

- Test rig components:
  - Rigid couplers
  - 20 mm diameter steel dowels
  - Flexible Bellows couplers
  - Torque transducer (Magtrol 308/311)
  - ¼ inch thick 2x2 inch steel tubing
  - Transducer stand to be welded to frame
  - Steel tubing to be fastened with ½ inch hex bolts
- Shims and set screws will be implemented for horizontal and vertical alignment
- TKSA 31 laser alignment tool will be used to qualify the alignment process

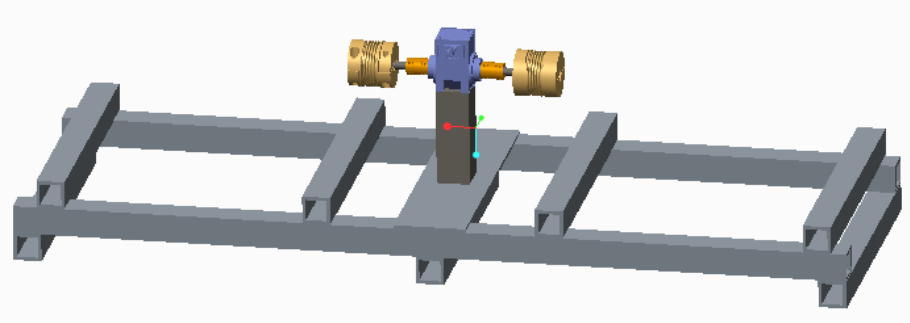


Figure 2: Final test rig design (compressors not shown)

Frank Barreto

Design Challenges

- Selecting components to withstand motor performances.

Compressor	Max Torque (Nm)	Max Speed (RPM)
TT300	22.8	37,762
TT350	38.0	30,598
TT400	37.2	25,091
TT700	73	17,000

- Danfoss will not supply funding for the torque transducer
  - Roughly $8,000 for each transducer
- New "mock transducer" part will be designed in CAD as a back up
  - Could cause a potential issue with the alignment process
  - Necessary modifications to help alignment will be made

Frank Barreto

Key Design Component: Flexible Coupler

R&W BKC 150 Coupling:

- 150 Nm rated torque
- 80,000 RPM rating
- Safety Factory=2.11
  - 80,000RPM/37,762RPM

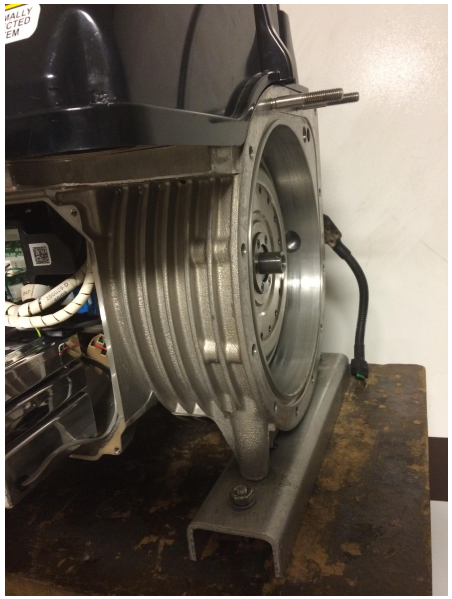


Figure 3. Compressor shaft (left) that will be coupled to flexible coupler (right).

Misalignment Tolerances:

- 0.2mm lateral, 1° angular, and 1mm axial

Frank Barreto

Key Design Component: Alignment System

- Step 1. Attach TKSA alignment tool
- Step 2. Vertical alignment with shims
- Step 3. Lateral Alignment with set screws

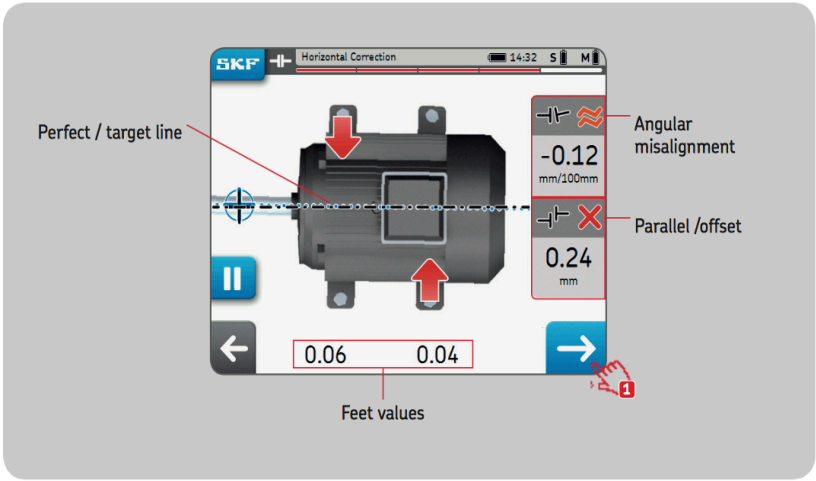


Figure 4 (left to right). Alignment tool set up, shim, alignment tool screen.

Frank Barreto

Alignment System: TKSA 31

- Measuring error less than 5%
- Accuracy of $10\mu m$
- Live values for vertical and horizontal machine position correction; Laser soft foot tool.
- Cost: $3,595.00

Figure 5. Alignment tool set up.

Frank Barreto

Alignment System: Shims

- Shim material: 304 stainless steel
- Shims thicknesses: 10, 25, and 250 μm.
- Angle (θ) and elevation (y) induced by shim width (a):

$$\theta = \tan^{-1}\frac{a}{b} \qquad y = \mathrm{c} - \cos(\theta) \cdot c$$

  - Ex. @ $a = 250\ \mu m, \theta = 0.03°, y = 0.027\ \mu m$
- b, distance between front and rear compressor mounts. c, shaft height above mounting surface.

Vertical correction – Side view – Shimming

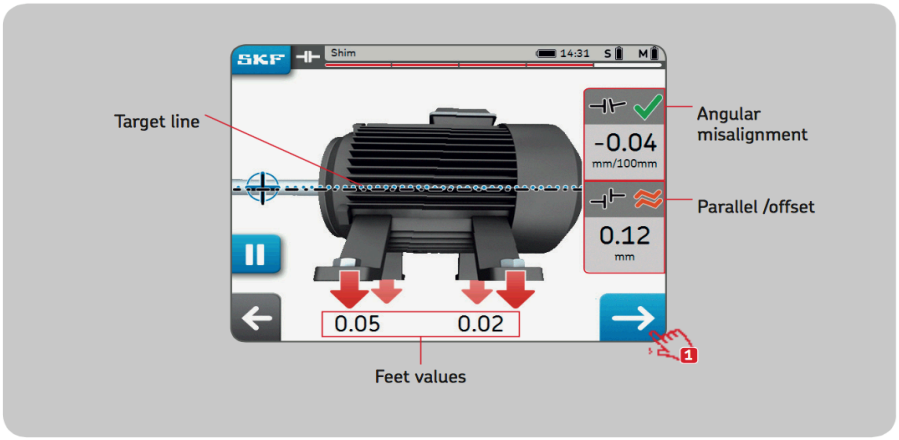


Figure 6A. Live guide for vertical adjustment

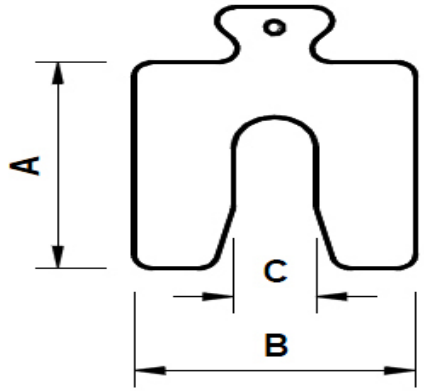


Figure 6B.Defining shim dimension (does not relate to equations)

Matt Ketchum

Alignment System: Set Screws

- Manufactured in house.
- Bolts to be purchased locally. 2 ¾” x ½”
- Will require steel plate to be cut, welded, and tapped.

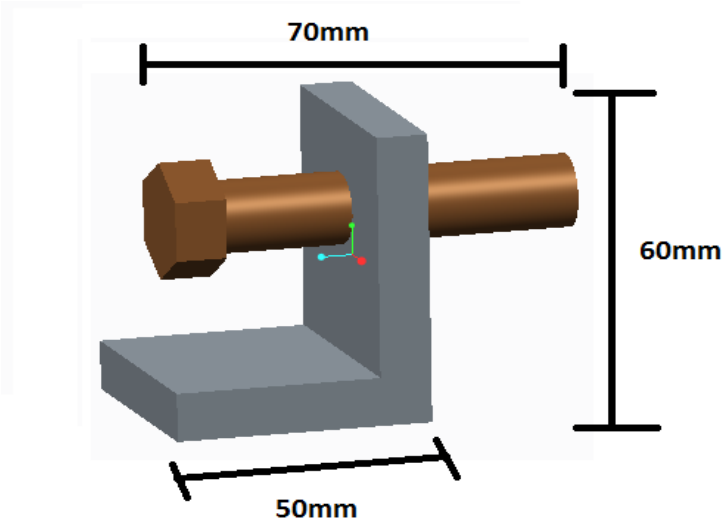


Figure 7. Lateral adjustment screw

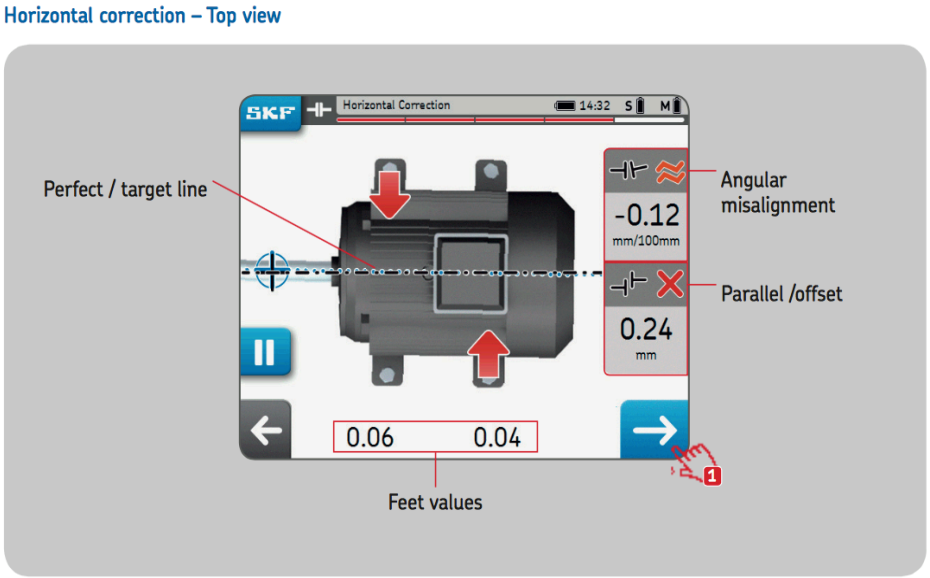


Figure 8. Live lateral adjustment guide

Key Design Component: Rigid Coupler

R2CC Rigid Coupler:

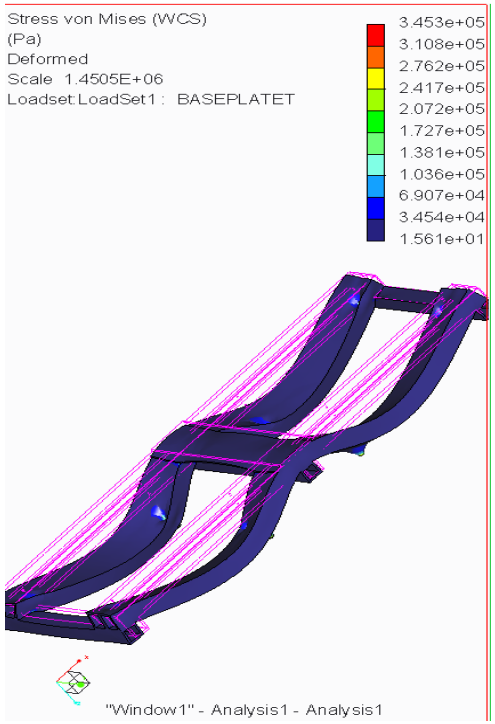
- Re-machinable: Will be balanced and bored by Danfoss
- Stainless Steel, ASTM A582
- Safety Factor: Unknown, must first be balance for maximum stability.
- OD: 1 ¾ in, Length: 2.625 in
- Couples to torque transducer and metal dowel from flexible coupler.

Figure 9. R2CC Rigid Coupler

Matt Ketchum

FEA Analysis

Von Mises Stress



Maximum Displacement

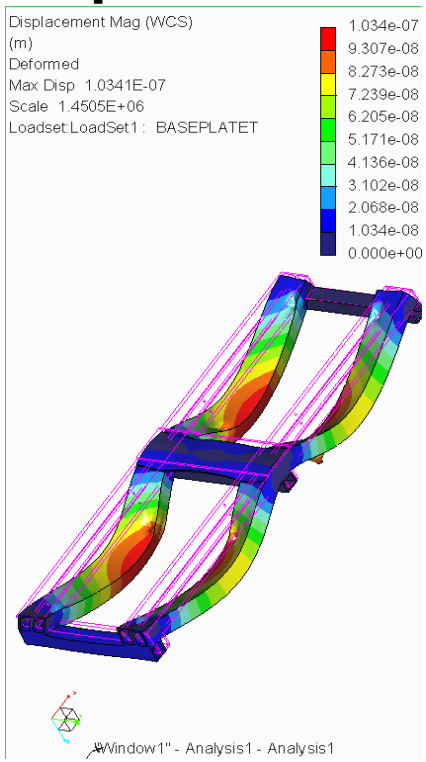


Figure 10. FEA Analysis

- Von Mises analysis shows a maximum stress of 6.9e04 Pa at the mounting hole locations.
  - A36 yield steel strength= 2.5e8 Pa.
- Maximum frame displacement of 1.034 e-07 meters.

Current Status

- Design was approved by Danfoss
  - Waiting for frame components to be purchased.
- During meeting on 1/15/16
  - Advised to use 80/20 Aluminum for safety shielding.
  - Polycarbonate instead of Plexiglass.
  - Torque transducer will likely not be purchased this spring.

Figure 11. 80/20 Aluminum

Matt Ketchum

Work Breakdown Structure, Spring Semester

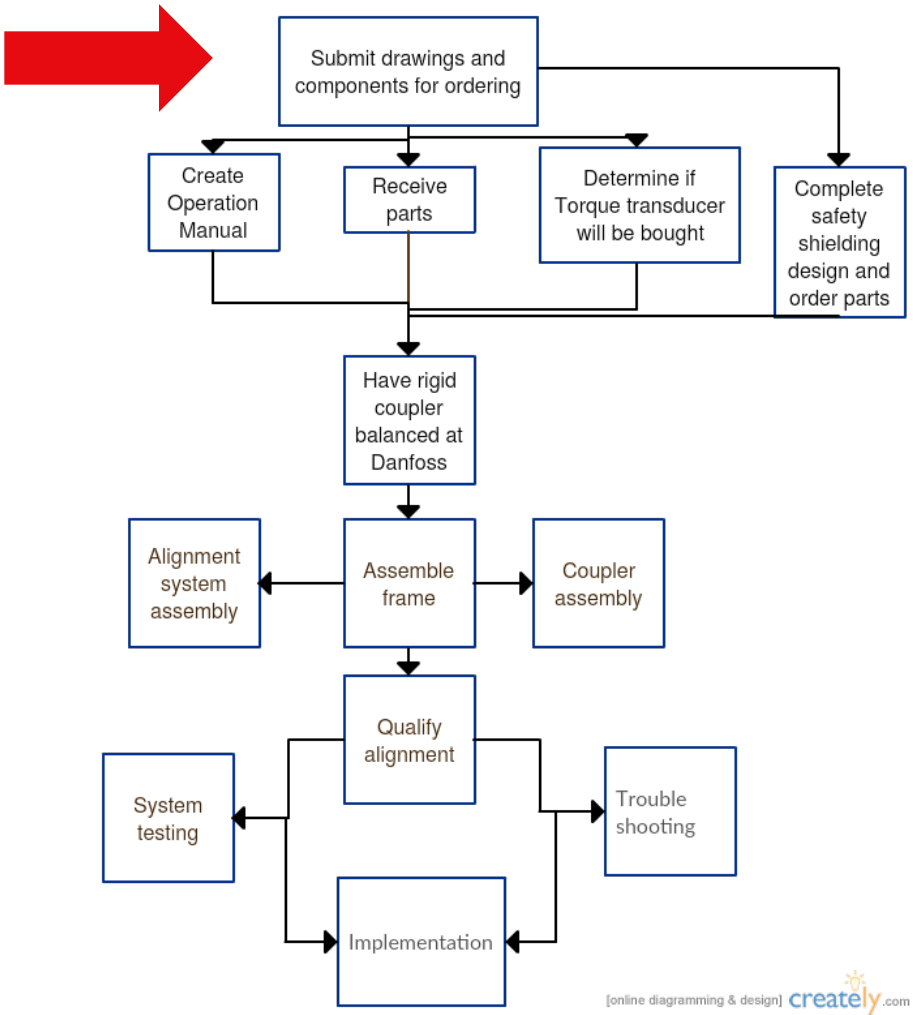


Figure 12. Work Breakdown Structure spring semester.

Gantt Chart

Task Name	Duration	Start	Finish
Order steel for frame	**11 days**	**Mon 1/18/16**	**Mon 2/1/16**
Order fasteners	3 days	Mon 1/18/16	Wed 1/20/16
Order alignment equipment	11 days	Mon 1/18/16	Mon 2/1/16
Frame assembly	3 days	Thu 1/21/16	Mon 1/25/16
Temporary assembly evaluation	4 days	Mon 1/25/16	Thu 1/28/16
Additional part order (If needed)	6 days	Mon 1/25/16	Mon 2/1/16
Integrate alignment system	5 days	Mon 2/1/16	Fri 2/5/16
Qualify alignment process	9 days	Fri 2/5/16	Wed 2/17/16
Order flexible couplers and rigid coupler	19 days	Mon 2/1/16	Thu 2/25/16
Balance rigid coupler and extension shaft	21 days	Fri 2/12/16	Fri 3/11/16
Integrate couplers	26 days	Tue 2/16/16	Tue 3/22/16
Order trandsucers if alignment is successful	47 days	Wed 2/10/16	Thu 4/14/16

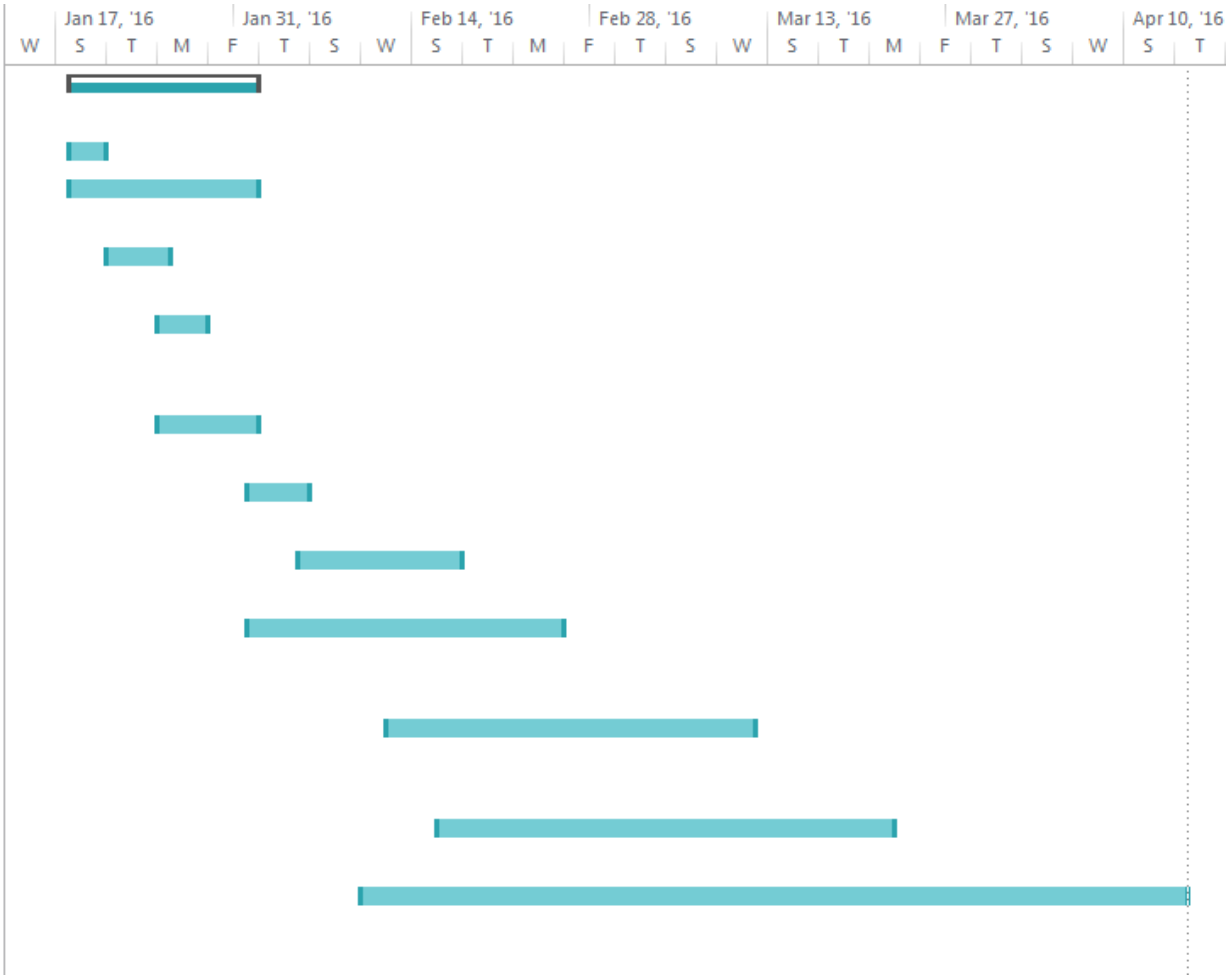
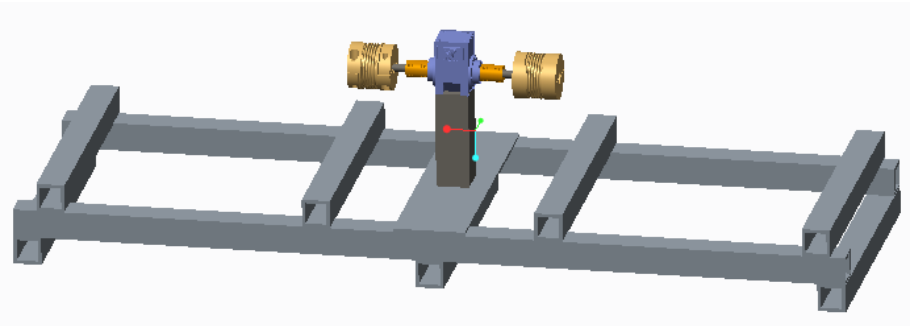
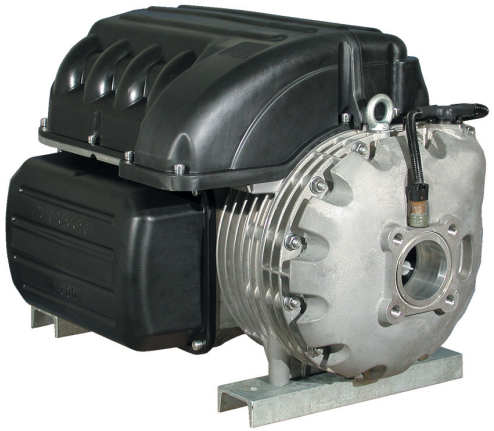


Figure 12. Gantt Chart, Spring Semester.

Conclusion & Future Work

- Frame material, couplers, and alignment equipment order will be placed through Danfoss.
- Assembly and manufacturing will be done at Danfoss.
- Dimensioning for safety shielding frame.
- Evaluate mock transducer alternatives.
  - 3 alternatives





Matt Ketchum

References:

1. http://www.magtrol.com/torque/torquemeter_transducers.html
2. http://catalog.climaxmetal.com/item/re-machinable-couplings/re-machinable-couplings-r2cc-series/r2cc-075-075-s
3. http://www.skf.com/us/products/maintenance-products/alignment-tools/shaft-alignment-tools/shaft-alignment-tool-tksa31/index.html
4. http://www.rw-america.com/products/bellows_couplings/bk/bkc/