LINEAR INDUCTION MOTOR

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Electrical and Computer Engineering

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Project Advisor: Professor Steven Gutschlag

3/3/2016

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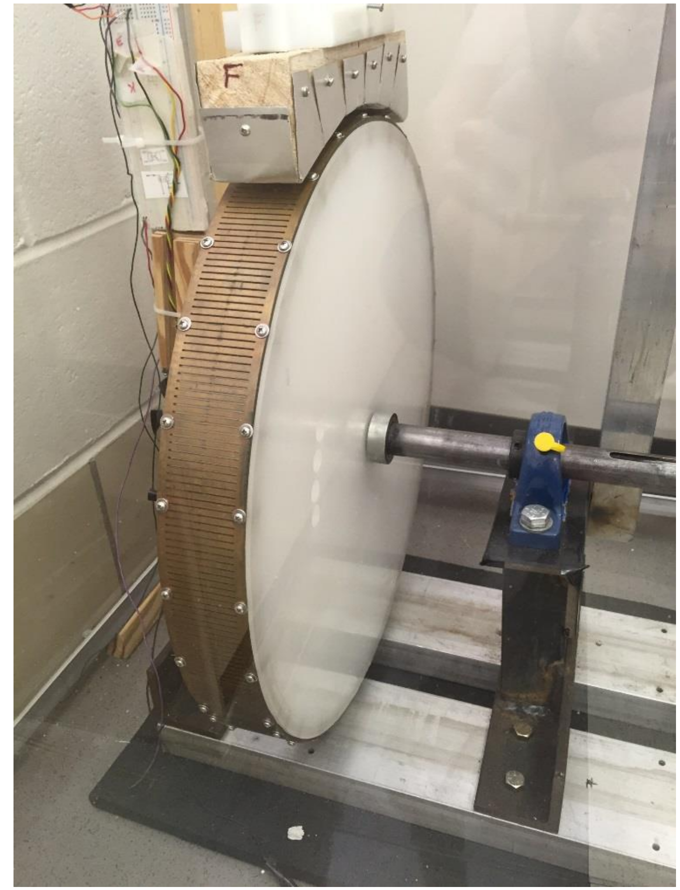
Project Overview

- Bradley University's Department of Electrical and Computer Engineering's Senior Project
- Design, construct, and test a linear induction motor (LIM)
- Run off of a three-phase voltage input
- Rotate a simulated linear track and cannot exceed 1,200 RPM
- Monitor speed, output power, and input frequency



[1]

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Linear Induction Motor Background

- Alternating Current (AC) electric motor
- Powered by a multiple phase voltage scheme
- Force and motion are produced by a linearly moving magnetic field
- Used to turn large diameter wheels

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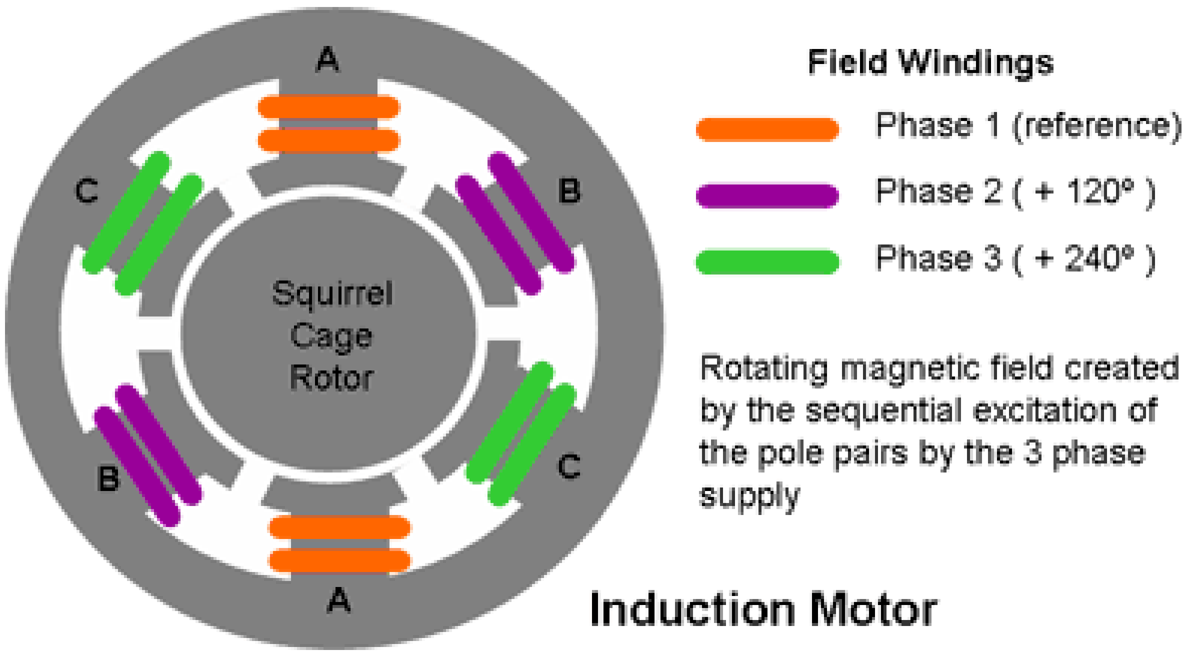
Alternating Current Induction Machines

- Most common AC machine in industry
- Produces magnetic fields in an infinite loop of rotary motion
- Stator wrapped around rotor



[3]

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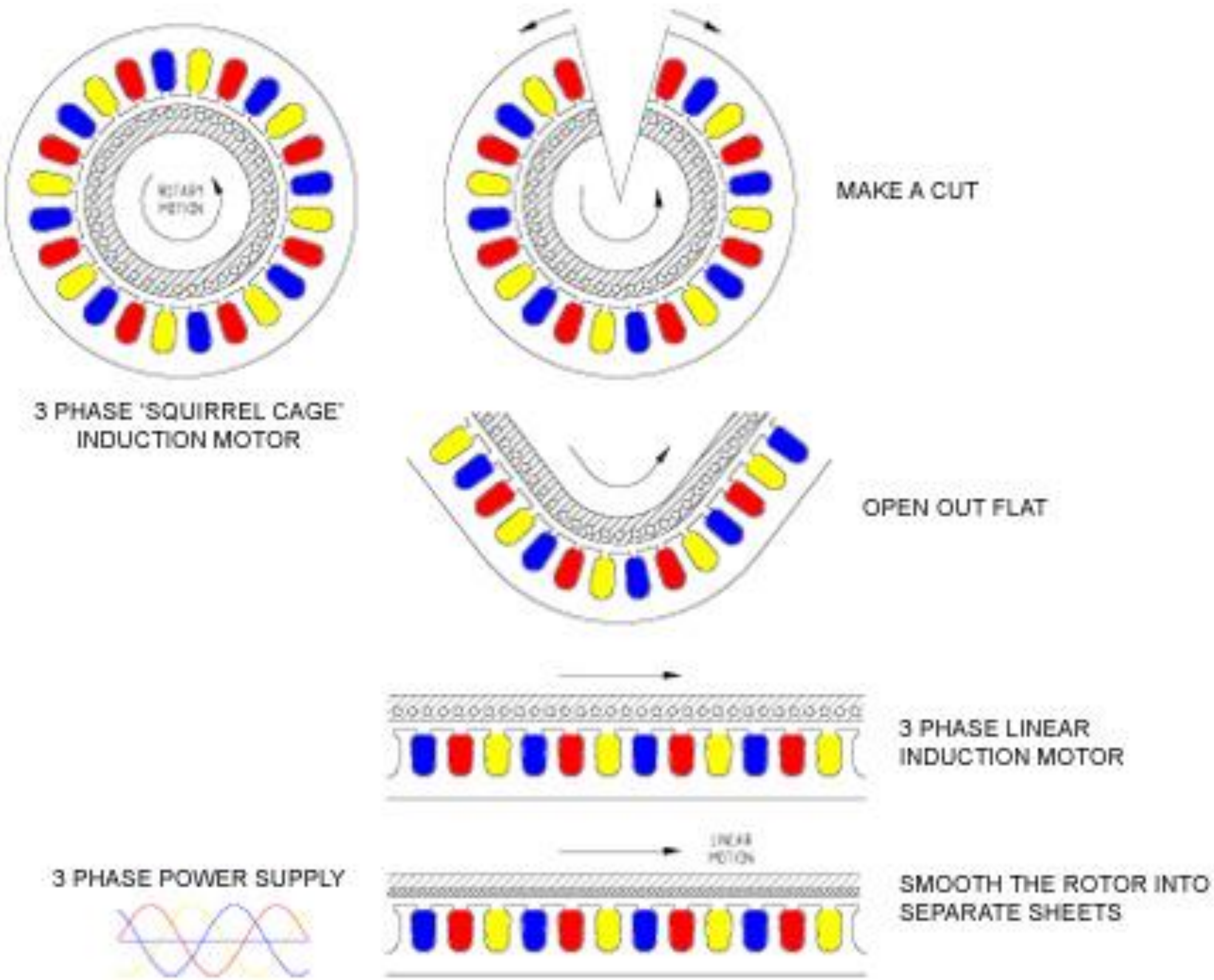
Rotary To Linear

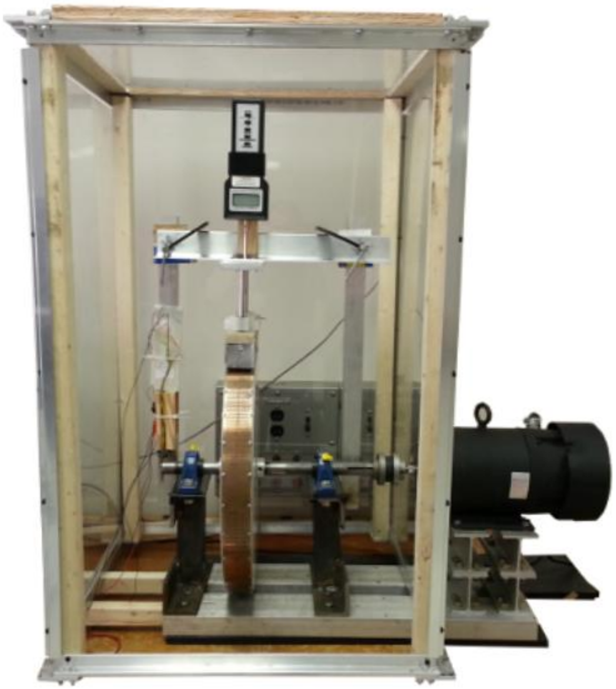


[4]

Previous Data

TABLE I: PREVIOUS DATA FROM MAGNETIC LEVITATION SENIOR PROJECT

Rotational Speed (RPM)	Output Power [W]
1106	510.78
1343	619.16



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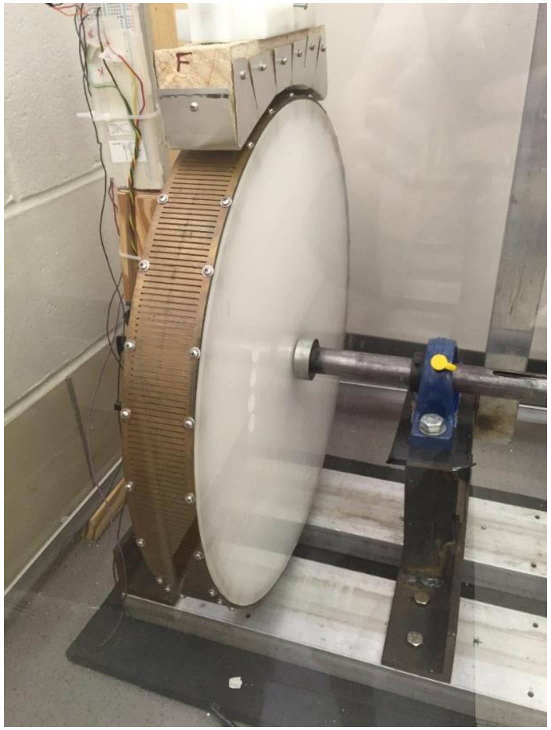
Linear Track Run-off

TABLE II: Total Run-off of Simulated Linear Track

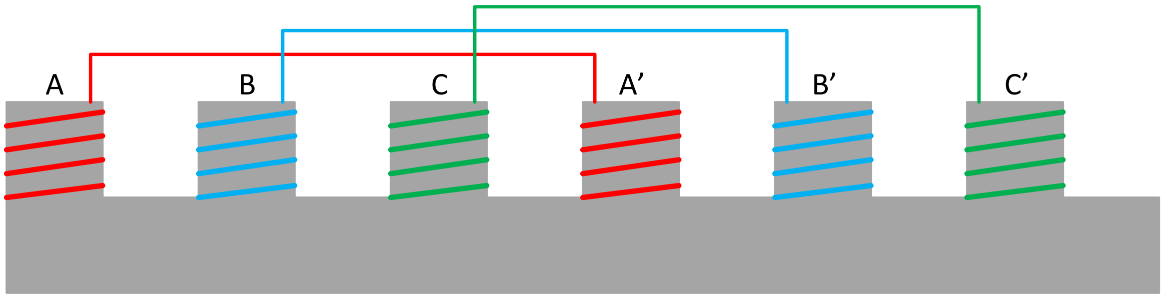
Side	(+) Run-off	(-) Run-off	Total Run-off
Right	+ 0.015”	- 0.015”	0.03”
Middle	+ 0.016”	- 0.013”	0.029”
Left	+ 0.018	- 0.012”	0.03”



[1]

Initial Design

- 2-Pole machine
- Salient pole arrangement
- Laminated stator segments
- Operating at a max frequency of 120 [Hz]
- 16 AWG with current rating of 3.7 [A]
- Stator Tooth Length of 0.0762 [m]



[7]

Final Design

- 4-Pole machine
- Salient pole arrangement
- Laminated stator segments
- Operating at a max frequency of 120 [Hz]
- 16 AWG with current rating of 3.7 [A]
- Stator Tooth Length of 0.0889 [m] (3.5”)

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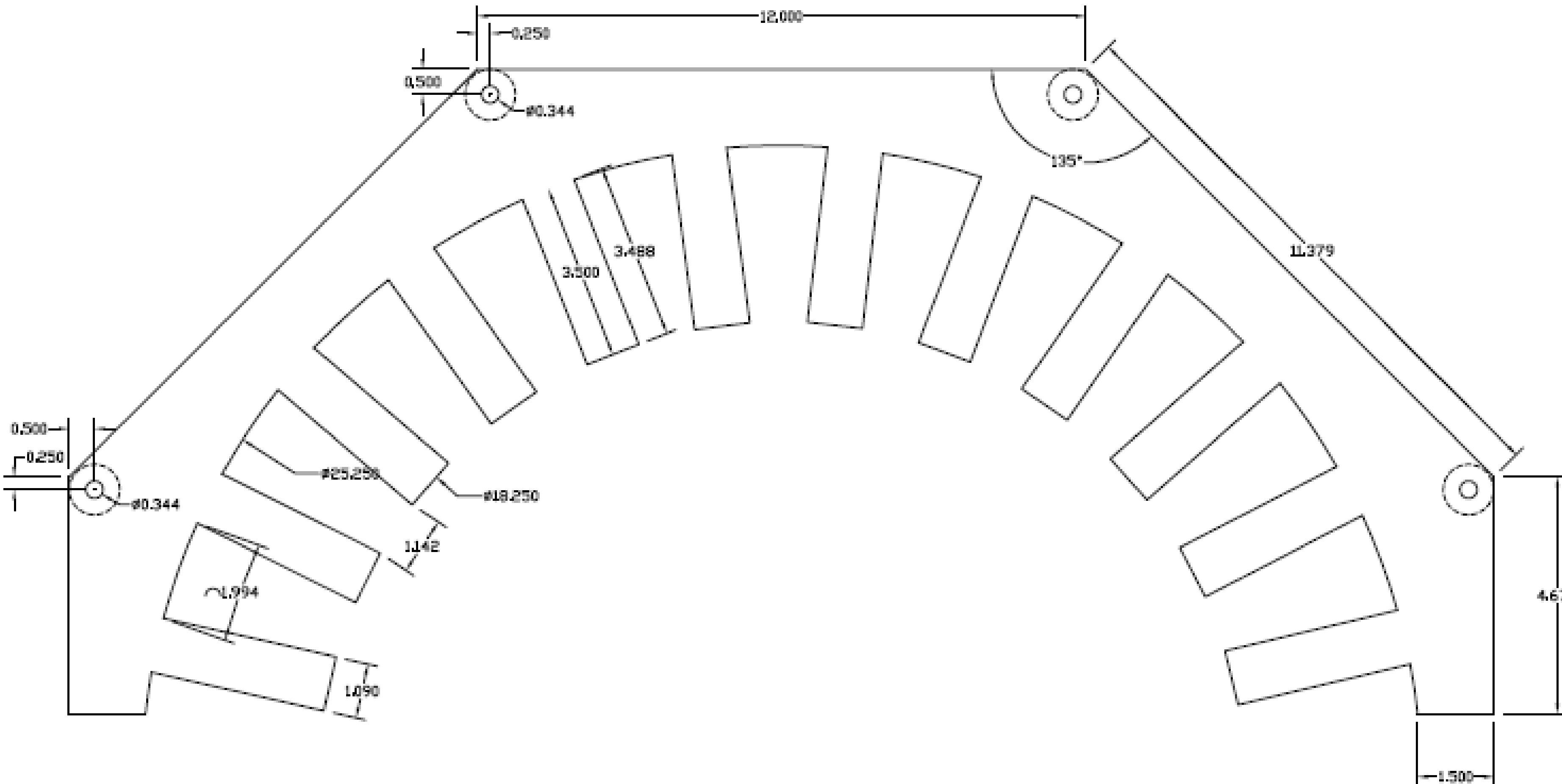
Final Stator Design



[9]

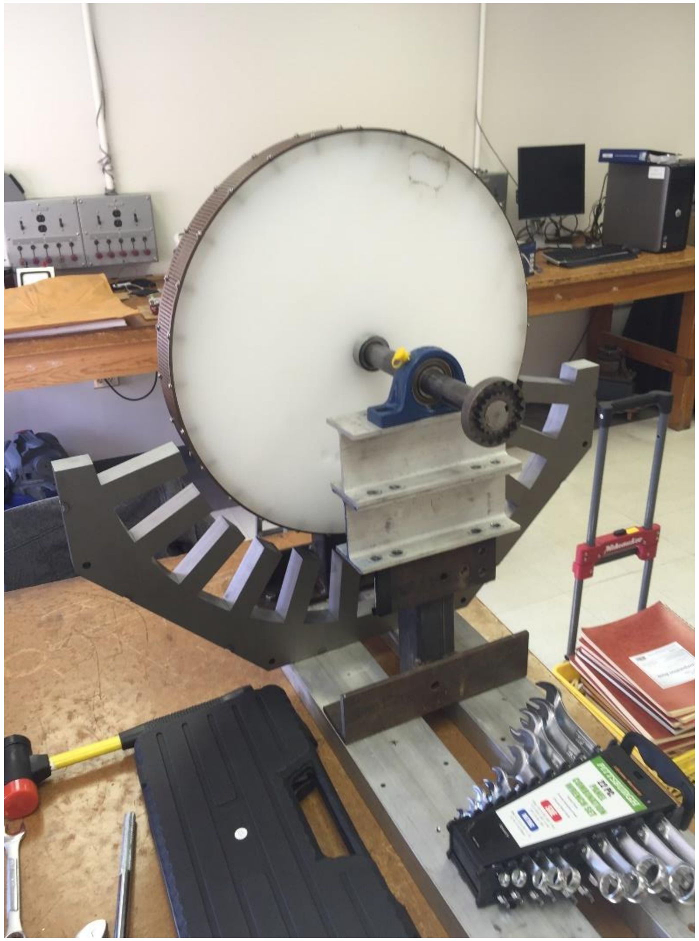
Completed Stator

- Ordered and pressed by Laser Laminations
- Arrived 2/22/16
- Working on mounting solution using angle irons

[10]

Simulated Linear Track Mounting Solution

- Current focus is on raising the mount for the simulated linear track
- Using previous mounting materials to raise the wheel with a new metal base
- Progress made on drilling and cutting mounting solution
- Working on acquiring fine threaded screws to allow for adjustments in wheel height
- Smaller air-gap than anticipated can be achieved



[11]

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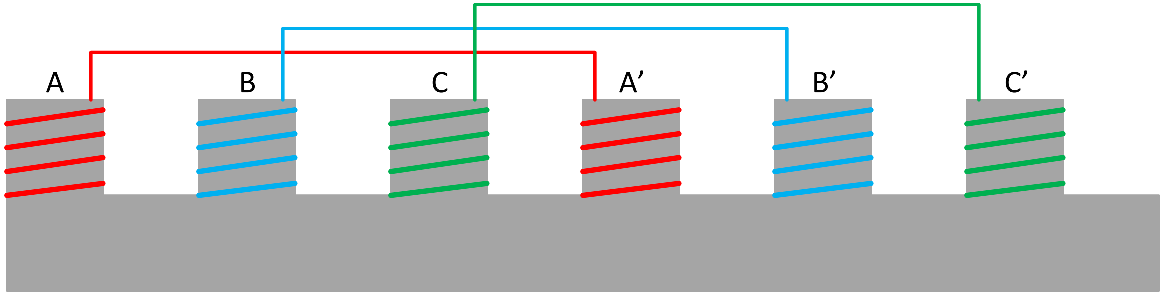
Bobbins

- Plastic material to go in-between the stator teeth and coils
- Necessary to prevent shorting between copper coils and the stator core
- Increases the ease of coil wrapping
- The coils will be wrapped in a salient pole arrangement



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Bobbin Solutions

- CosmoCorp
  - 15 Bobbins
  - 8 weeks turnaround
  - $ 5,000
- Endicottcoil
  - Did not go into specifics
  - $ 1,000 +
- Performance Bodies
  - 10 ft. of Plastic Rolls
  - 22" wide
  - 0.070" thick
  - $19.99
- Awaiting Two Other Quotes

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Variable Frequency Drive

- 10 Min wait between turning on after turning it off
- This is to allow for capacitors to de-energize.
- VFD
  - 0-10V signal correlates to 0-120 Hz
  - A/D Converter
  - D/A Converter
- A/D Converter
  - Onboard the ATmega128
  - 250 ms interrupt service routine
  - Compares input voltages

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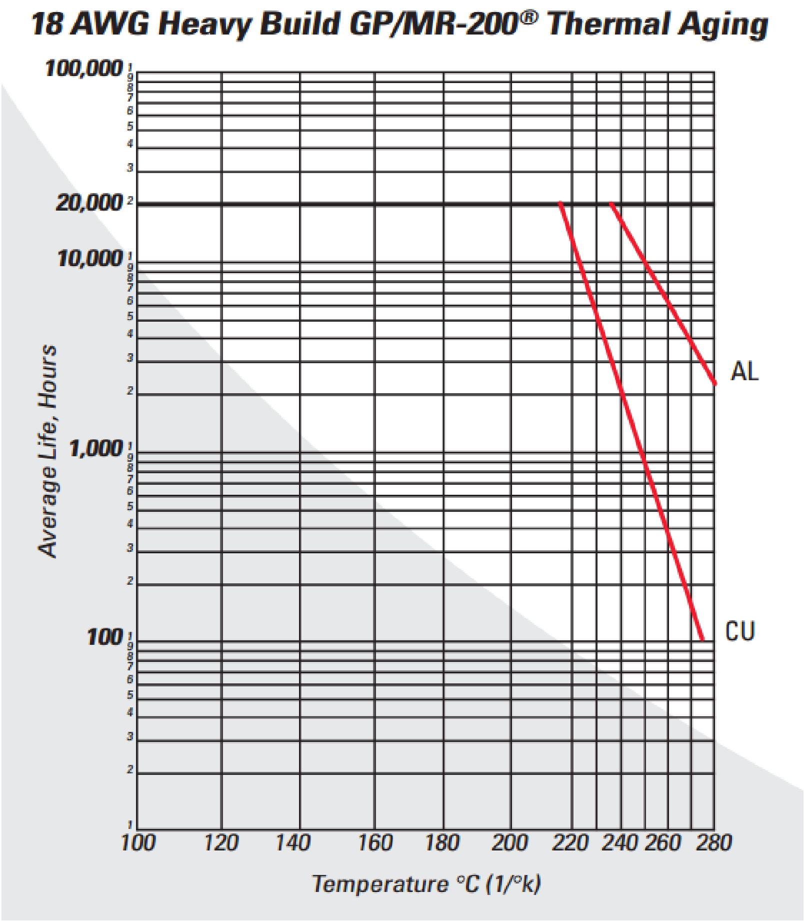
Coil Windings

- 16 AWG Wire
- GP/MR-200 Magnet Wire/ Winding Wire
- Heat is tolerated by coils
- Wire diameter calculated when determining turns per phase and stator tooth width
- 0.418” of tolerance between adjacent wires, not including bobbins



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Component Purchasing

- **Laser Laminations: $375**
  - $225 for metal
  - $100 for pressing
  - $50 shipping
- **Illinois Switchboard: $176**
  - 2,000 ft. of dipped copper wire

Current Project Total: $551

Completed Work

- Stator design
- Stator construction and ordering
- Frequency vs. Speed simulation
- Turns per phase and total wire calculations
- Dipped copper wire ordering
- Mounting solution design for simulated linear track
- Mounting solution design for stator
- Overall system design
- A/D convertor
- Tachometer and LCD interfacing

Work-in-Progress

- D/A convertor
- VFD programming
- Stator mounting completion
- Complete mounting of wheel and stator
- Bobbins
- Coil windings

Project Gantt Chart

TASK NAME	RESPONSIBLE	Date	
General System Design	All	September 4, 2015	
Stator Design		November 17, 2015	
Research Winding Types	Tim	September 22, 2015	
Pole and Slot Pitch	Mason	September 22, 2015	
Pole Depth	All	November 17, 2015	
Slot/Teeth Ratio	All	October 27, 2015	
Number of Coil Windings	All	November 17, 2015	
Purchasing	All	November 30, 2015	
Construction		February 2, 2016	
Coil Windings	Mason and Tim	January 25, 2016	80%
Stator Mount	Mason and Tim	February 8, 2016	75%
Microcontroller Sytem	Tyler	February 8, 2016	80%
VFD Programming	Tyler	February 8, 2016	25%
Sensor Programming	Tyler	January 25, 2016	25%
Implementation	All	February 9, 2016	25%
Testing	All	March 7, 2016	0%

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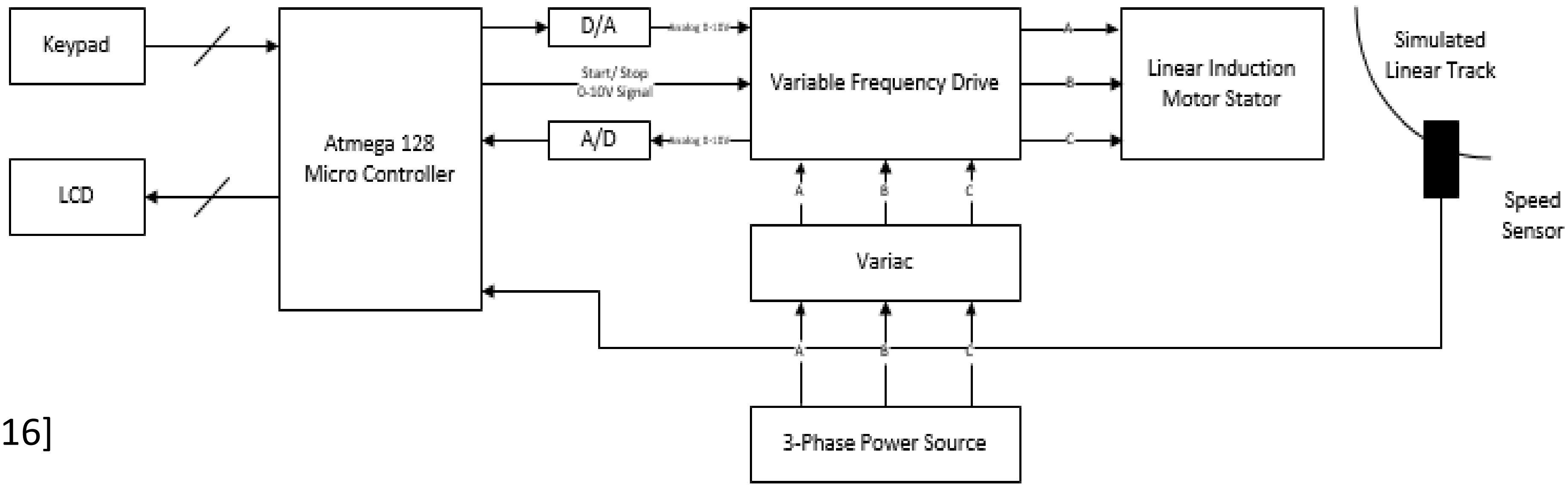
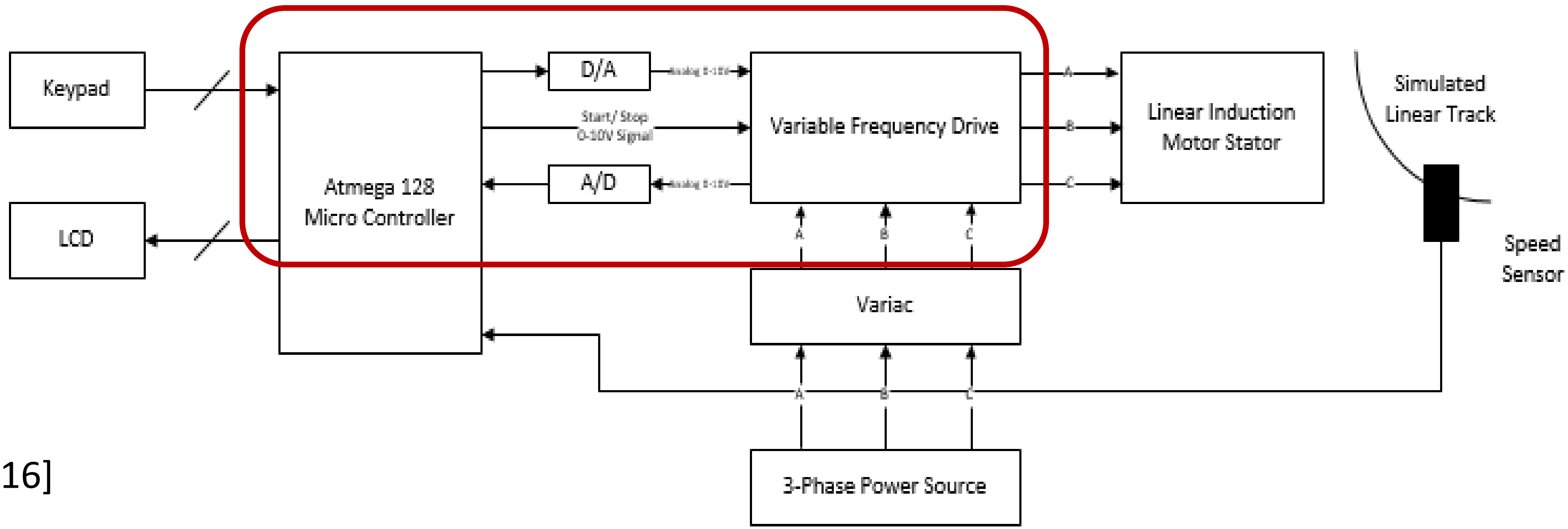
Appendix

System Block Diagram



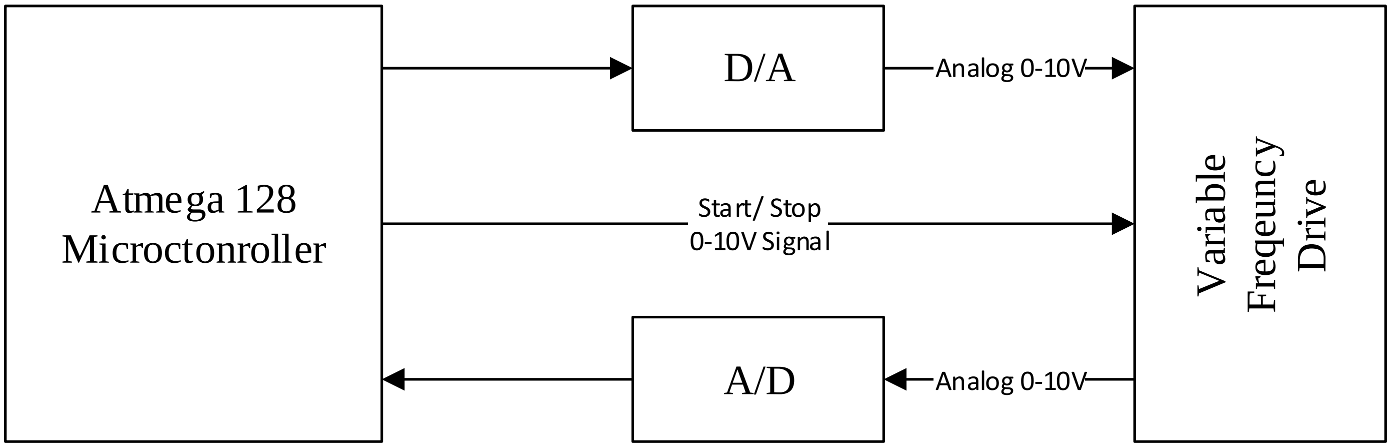
[16]

System Block Diagram



[16]

System Block Diagram



[17]

4-Pole to 2-Pole Comparison

4-Pole Machine Using 16 AWG:	2-Pole Machine Using 16 AWG:
• 45 Wraps fit on a 0.0762 m Tooth	• 45 Wraps fit on a 0.0762 m Tooth
• 851 Turns per Phase	• 1703 Turns per Phase
• 213 Wraps per Stator Tooth	• 852 Wraps per Stator Tooth
• 5 Coil Wrapping Layers per Stator Tooth	• 19 Coil Wrapping Layers per Stator Tooth
• Outer Diameter of 0.0362 m	• Outer Diameter of 0.0601 m
• Coil Inductance of 0.3701 µH	• Coil Inductance of 3.6249 µH

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Turns Per Phase

$$P_{out} = 6.6 p n_{ms} B_{ag} A_p T_{ph} k_w I_{ph} \eta (PF) \qquad (1.1)$$

$$
\begin{aligned}
P_{out} &= Output\ Power \\
p &= Number\ of\ Poles \\
n_{ms} &= Mechanical\ Cycles\ per\ Second \\
B_{ag} &= Average\ Air - Gap\ Flux\ Density\ per\ Pole\ = 1.1\ [T] \\
A_p &= Cross - Sectional\ Area\ of\ Pole\ Faces = 0.0346\ [m] \\
T_{ph} &= Number\ of\ Turns\ per\ Phase \\
k_w &= Coil\ Winding\ Factor\ = 0.86 \\
I_{ph} &= Input\ Phase\ Current = 3\ [A] \\
\eta &= Efficiency = 0.6 \\
PF &= Power\ Factor = 0.7
\end{aligned}
$$

Rotational to Linear Speed

$$\omega = \frac{120f}{p} \tag{1.3}$$

$\omega =$ *Rotational Speed of Rotor* [*rpm*]
$p =$ *Number of Poles*
$f =$ *Input Frequency* [*Hz*]

$$v = r\omega\left(\frac{2\pi}{60}\right) \tag{1.4}$$

$v =$ *Linear Velocity* $\left[\frac{m}{s}\right]$

$r =$ *Radius of Rotor* [*m*]

$$U_s = 2\tau f \tag{1.5}$$

$U_s =$ *Linear Synchronous Speed* $[\frac{m}{s}]$

$\tau =$ *Pole Pitch* [*m*]

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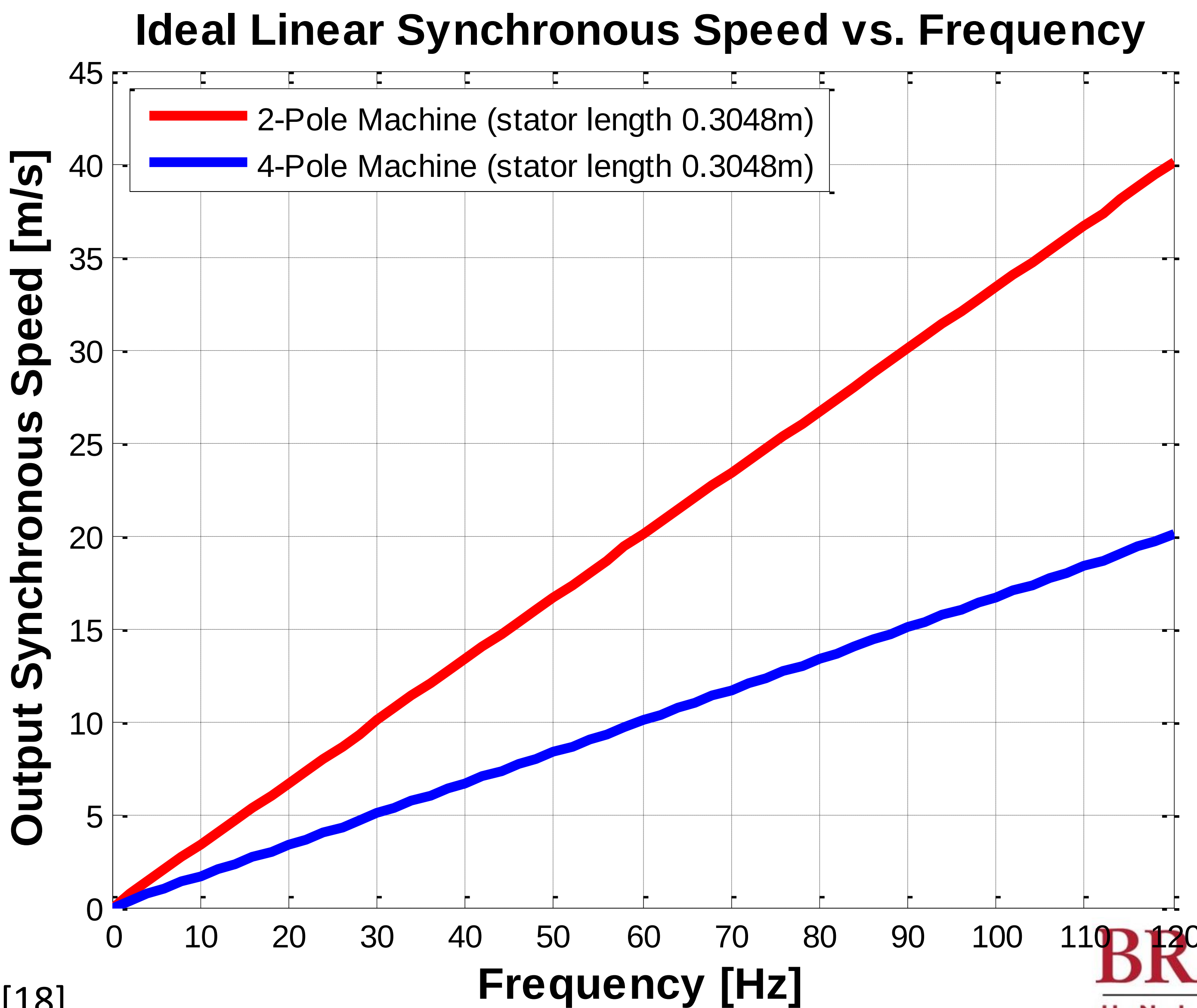
Initial Design



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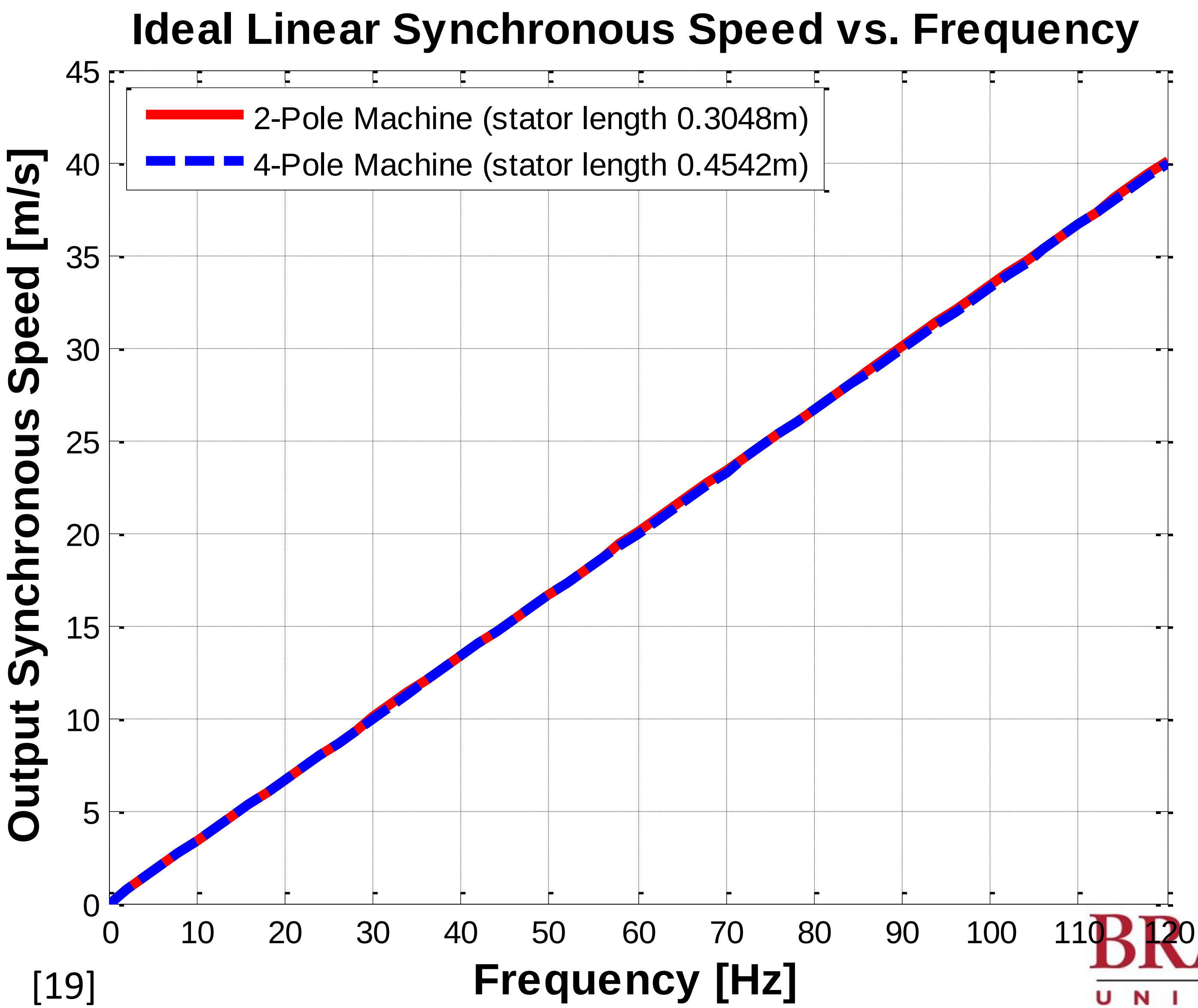
Rotational to Linear Speed



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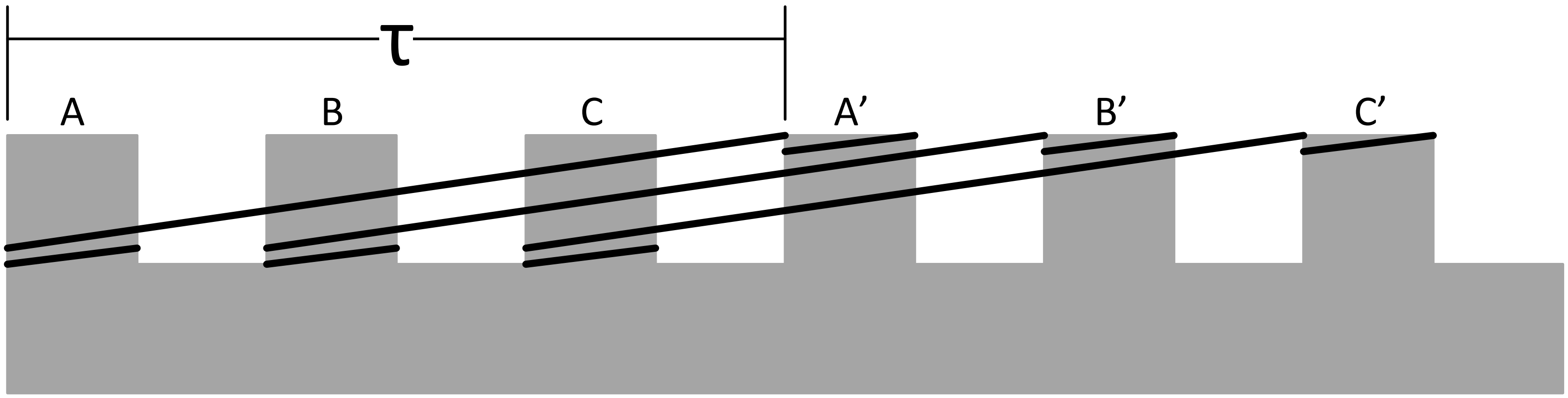
Pole Pitch

$$U_s = 2\tau f \tag{1.6}$$



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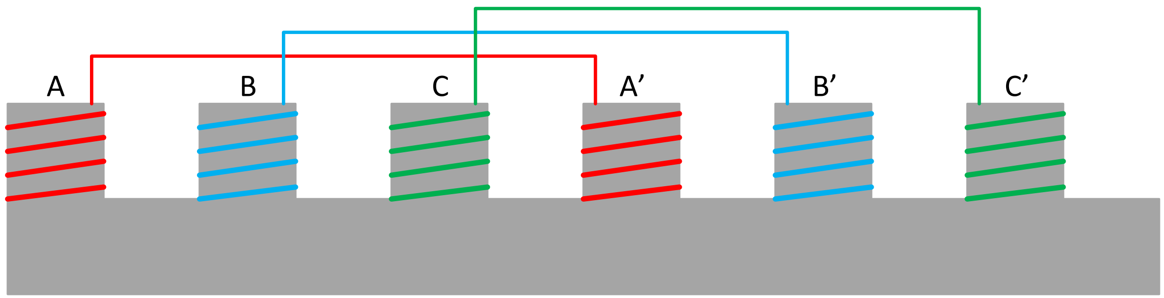
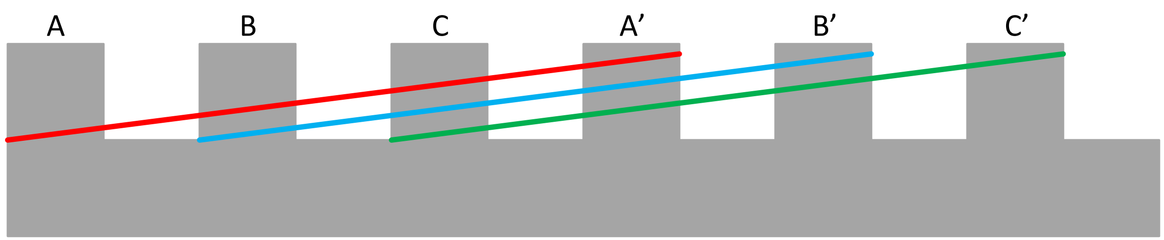
Pole Pitch = 0.1668m

Salient and Non-Salient



[10] Salient Pole Arrangement



[11] Non-Salient Pole Arrangement

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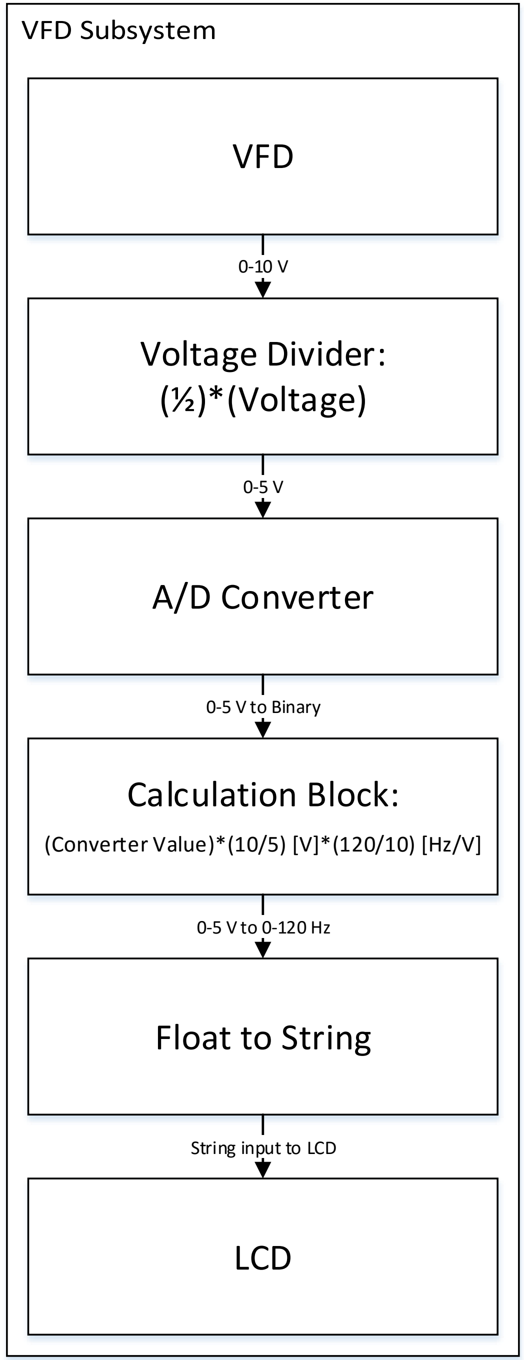

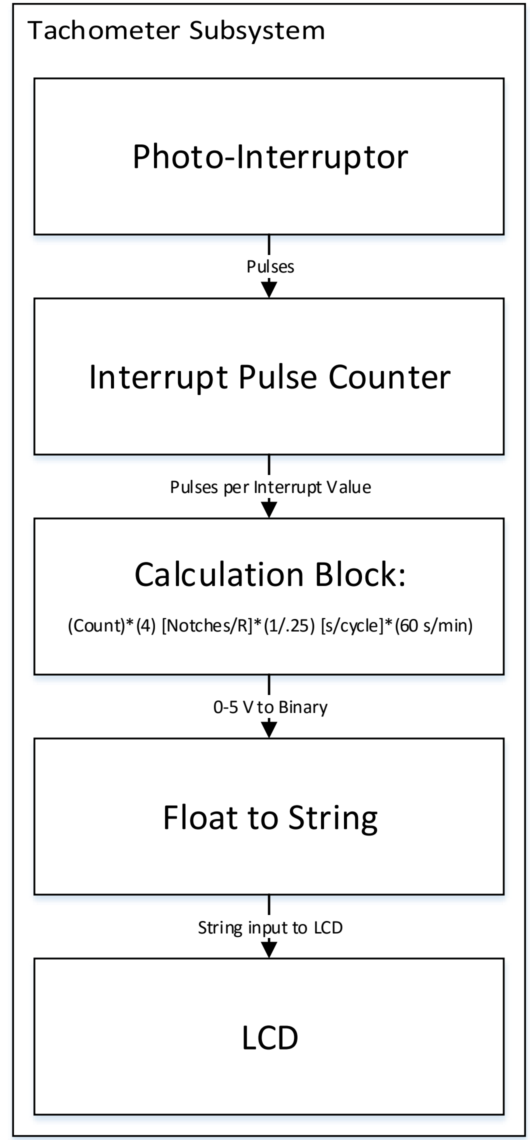

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Tachometer Subsystem

- Main Components
  - Photo-interruptor
  - Transparent Disk with Notches
- External Interrupt
  - Counts pulses
  - 4 pulses per rotation
  - 250 ms interrupt service routine

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LCD Subsystem

- LCD Displayed Values
  - RPM
    - Calculation to obtain RPM
    - Convert to string
    - Input string to LCD
  - Output frequency
    - Calculation to obtain VFD output frequency
    - Convert to string
    - Input string to LCD

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