LINEAR INDUCTION MOTOR

Electrical and Computer Engineering

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Project Advisor: Professor Steven Gutschlag

11/19/2015

Outline of Presentation

- Project Overview
- Tyler
- Mason
- Tim
- Conclusion

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Project Overview

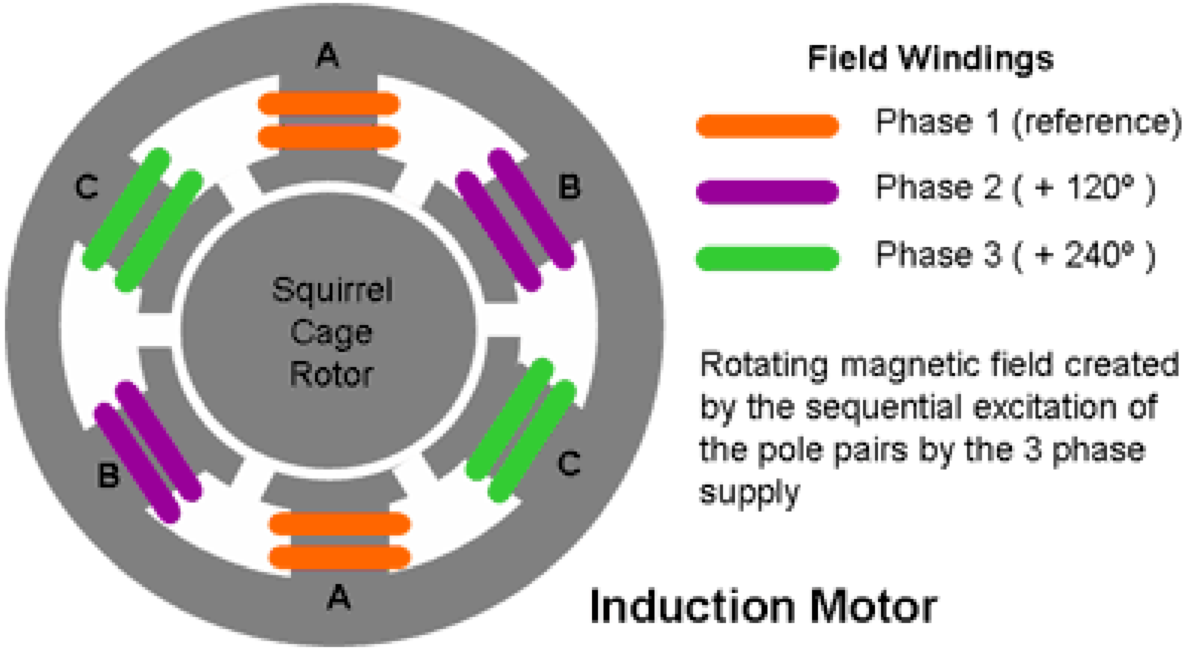
Linear Induction Motor Background

- Alternating Current 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

[1]

Alternating Current Induction Machines

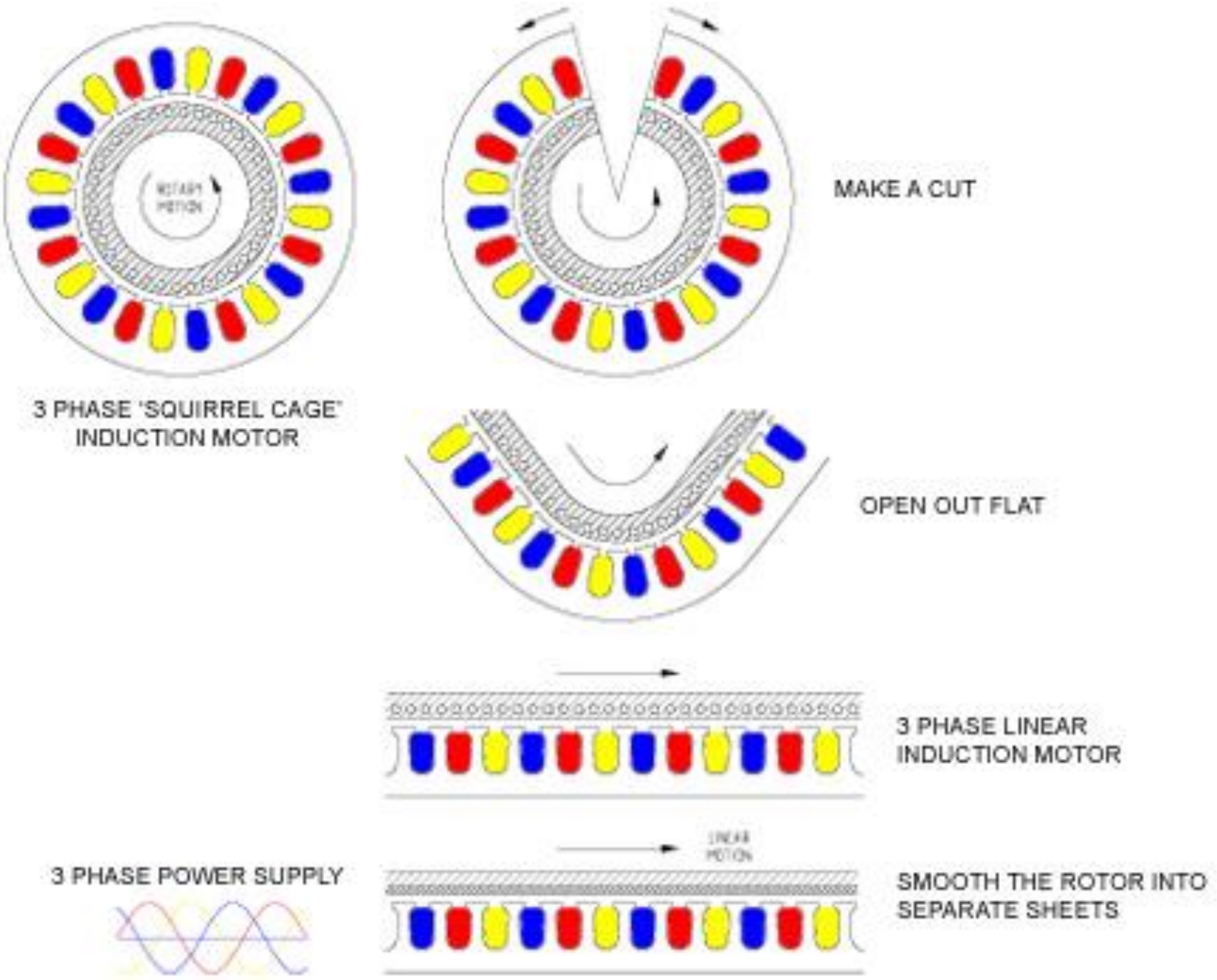
- Most common AC machine in industry
- Produces magnetic fields in an infinite loop of rotary motion
- Stator wrapped around rotor



Rotating magnetic field created by the sequential excitation of the pole pairs by the 3 phase supply

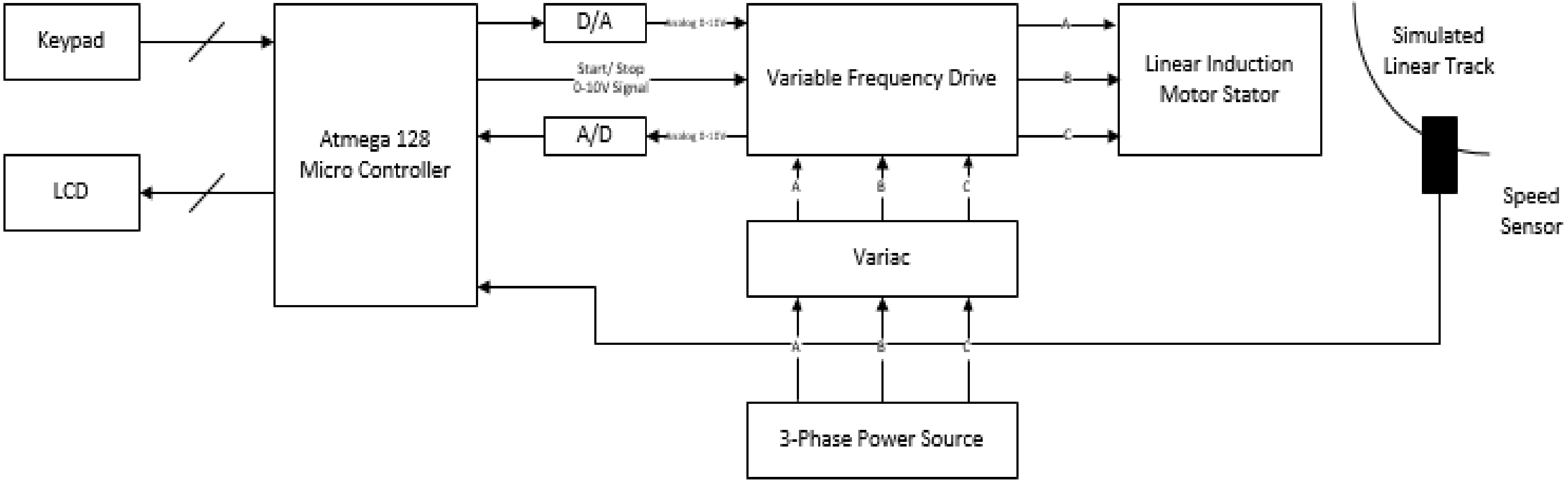
[2]

Rotary to Linear



[3]

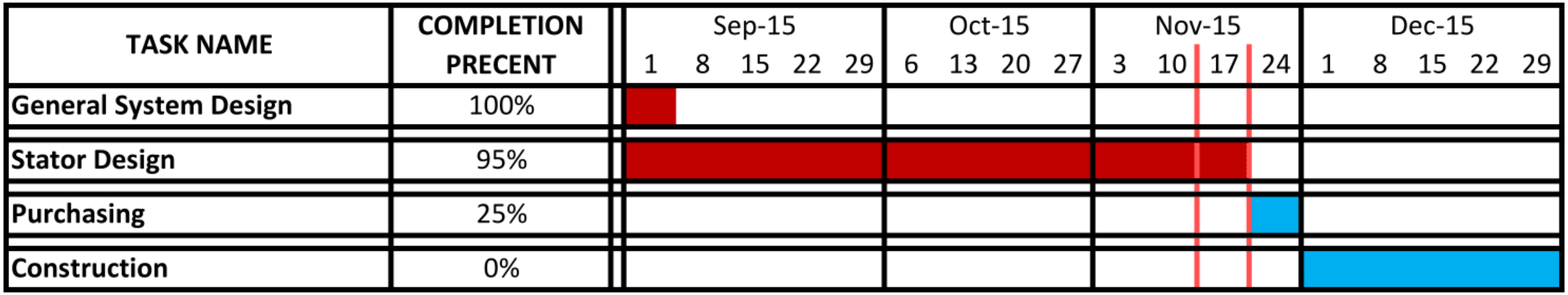
Subsystem Block Diagram



Personal Motivation

- To graduate!

Gantt Chart Current Project



TASK NAME	COMPLETION PRECENT	Sep-15					Oct-15				Nov-15				Dec-15				
		1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29
General System Design	100%	🟥																	
Stator Design	95%	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥						
Purchasing	25%													🟦					
Construction	0%														🟦	🟦	🟦	🟦	🟦

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Tyler

Progress

- Research
  - Rotary to linear conversion models
  - Pole arrangements
- Overall Microcontroller System
  - Tachometer
  - Variable Frequency Drive (VFD)
  - Liquid Crystal Display (LCD)

Tachometer Subsystem

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

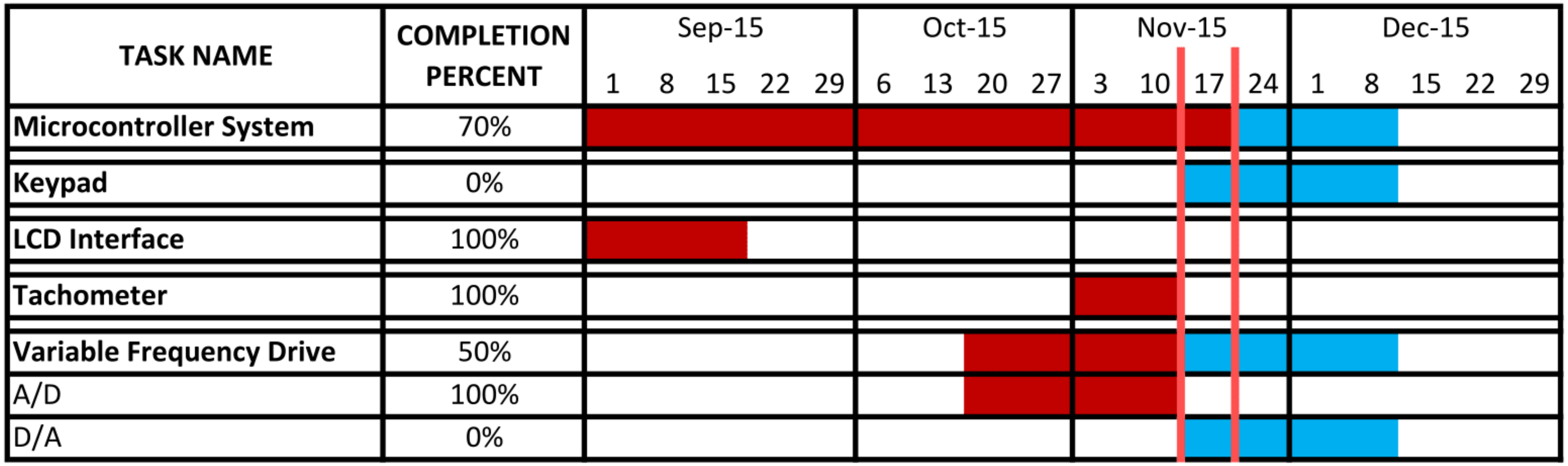
VFD Subsystem

- Main Components
    - 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

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

Gantt Chart



TASK NAME	COMPLETION PERCENT	Sep-15					Oct-15				Nov-15				Dec-15				
		1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29
Microcontroller System	70%	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟦	🟦	🟦			
Keypad	0%												🟦	🟦	🟦	🟦			
LCD Interface	100%	🟥	🟥	🟥															
Tachometer	100%										🟥	🟥							
Variable Frequency Drive	50%								🟥	🟥	🟥	🟥	🟦	🟦	🟦	🟦			
A/D	100%								🟥	🟥	🟥	🟥							
D/A	0%												🟦	🟦	🟦	🟦			

Upcoming Work

- Implementation of Stator
  - Full group effort
- Microcontroller System
  - Keypad
    - Display input keypad value on LCD
    - Input displayed keypad value to D/A converter
  - D/A Converter
    - Input 0-10 V reference signal to VFD
      - Will change output frequency of VFD

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Mason

Progress

- Research
  - Pole Arrangements
  - Rotary to Linear Speed
  - Variable Frequency Drive
  - Turns per Phase
- Calculations
  - Rotary to Linear Speed
  - Ideal Linear Synchronous Speed and Frequency
  - Coil Windings and Turns per Phase
  - Coil Inductance

Work Completed

$$P_{out} = 6.6pn_{ms}B_{ag}A_pT_{ph}k_wI_{ph}\eta(PF) \qquad (1)$$

$P_{out} = Output\ Power$

$p = Number\ of\ Poles$

$n_{ms} = Mechanical\ Cycles\ per\ Second$

$B_{ag} = Average\ Air - Gap\ Flux\ Density\ per\ Pole\ = 1.1\ [T]$

$A_p = Cross - Sectional\ Area\ of\ Pole\ Faces = 0.0346\ [m]$

$T_{ph} = Number\ of\ Turns\ per\ Phase$

$k_w = Coil\ Winding\ Factor\ = 0.86$

$I_{ph} = Input\ Phase\ Current = 3\ [A]$

$\eta = Efficiency = 0.6$

$PF = Power\ Factor = 0.7$

Work Completed

$$L = \frac{31.6\mu_r N^2 r_1^2}{6r_1 + 9l + 10(r_1 - r_2)} \qquad (2)$$

$L =$ *Inductance of Multiple Winding Coil* $[\mu H]$

$\mu_r =$ *Permeability of Material* $[Hm^{-1}]$

$N =$ *Number of Turns*

$r_1 =$ *Inner Diameter of Coil* $[m]$

$l =$ *Length of Stator Teeth* $[m]$

$r_2 =$ *Outer Diameter of Coil* $[m]$

Work Completed

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 1.5867 µH	• Coil Inductance of 15.4940 µH

Work Completed

$$\omega = \frac{120f}{p} \tag{3}$$

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

$$v = r\omega\left(\frac{2\pi}{60}\right) \tag{4}$$

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

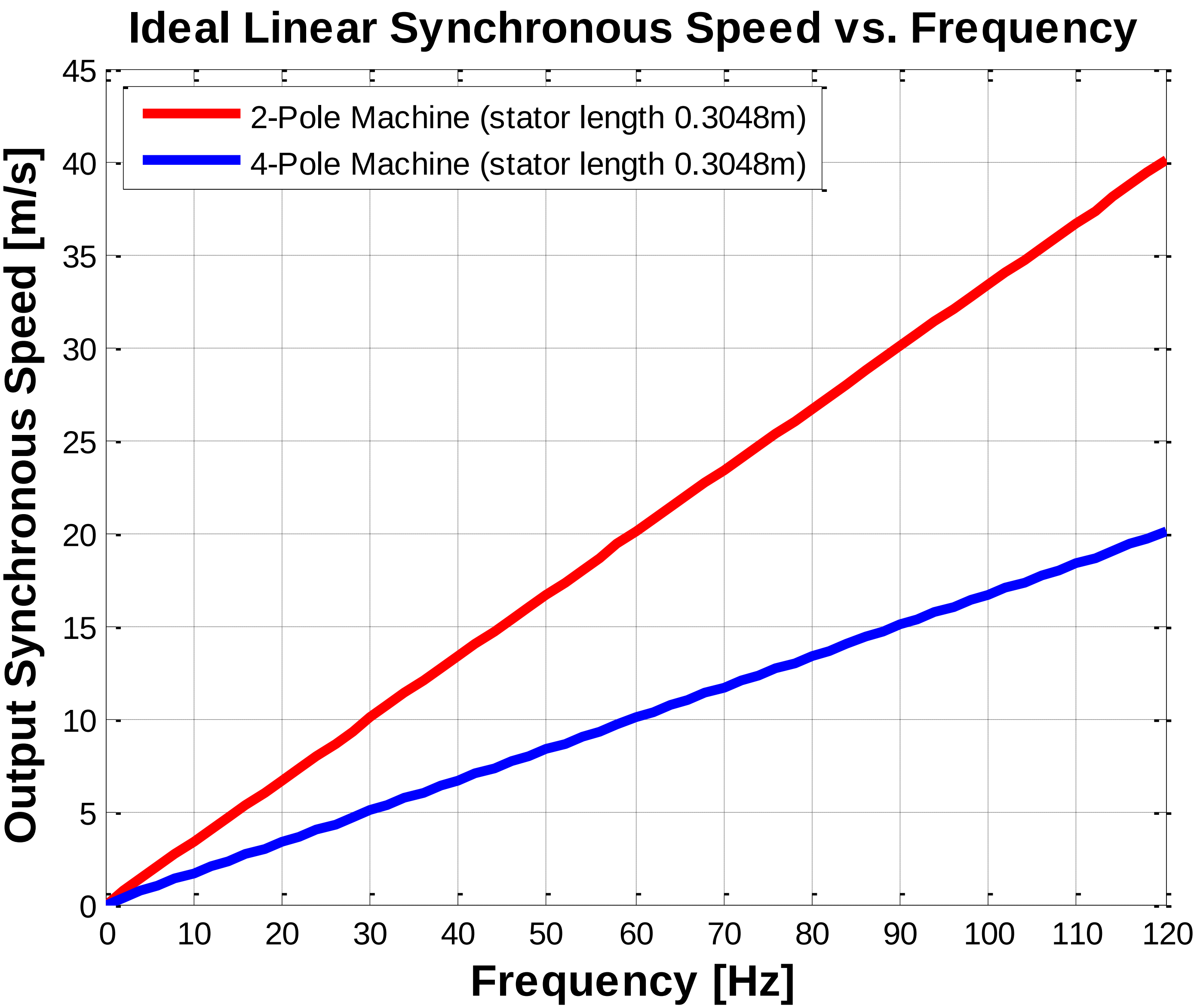
$r =$ Radius of Rotor [m]

$$U_s = 2\tau f \tag{5}$$

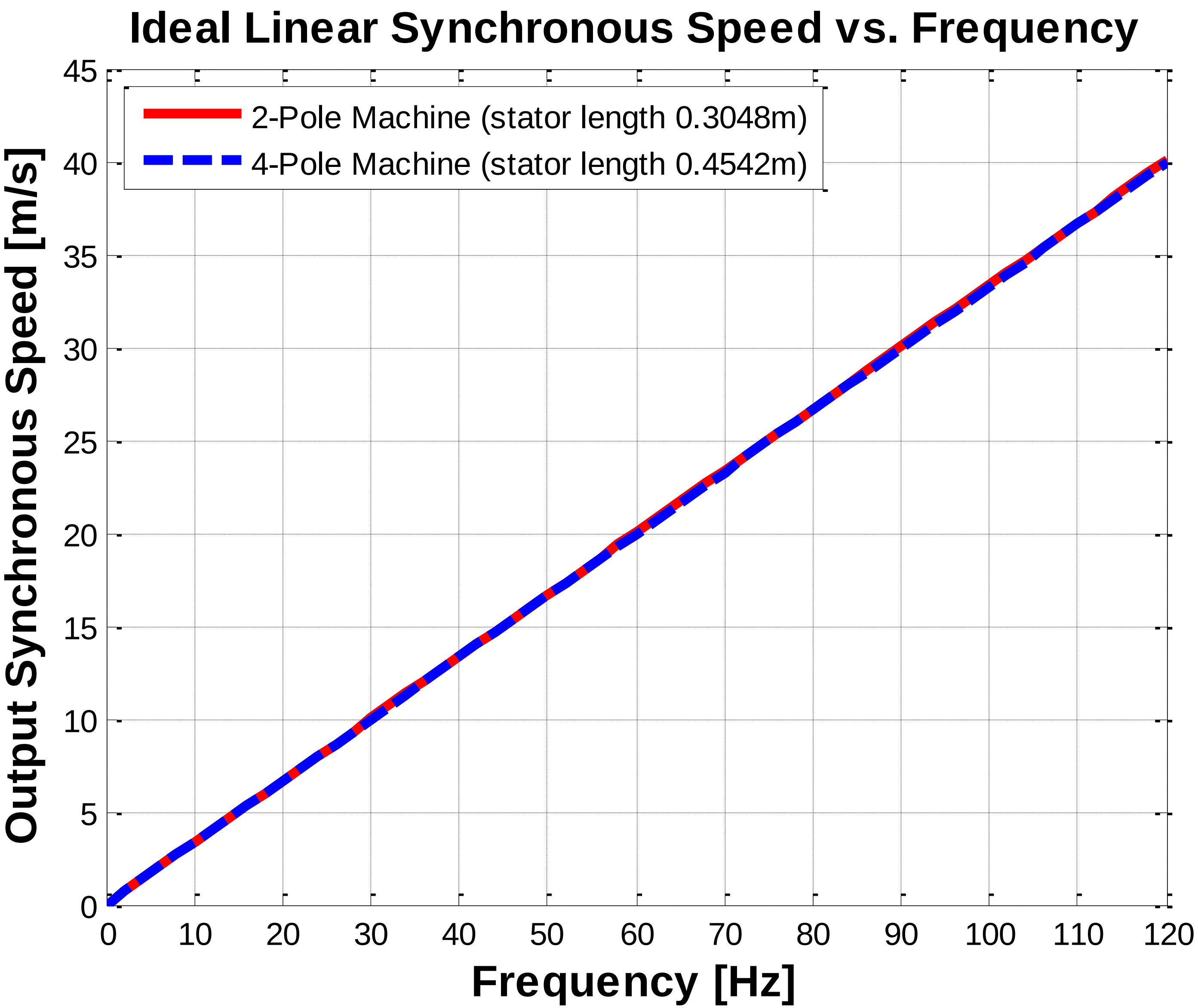
$U_s =$ Linear Synchronous Speed $[\frac{m}{s}]$

$\tau =$ Pole Pitch [m]

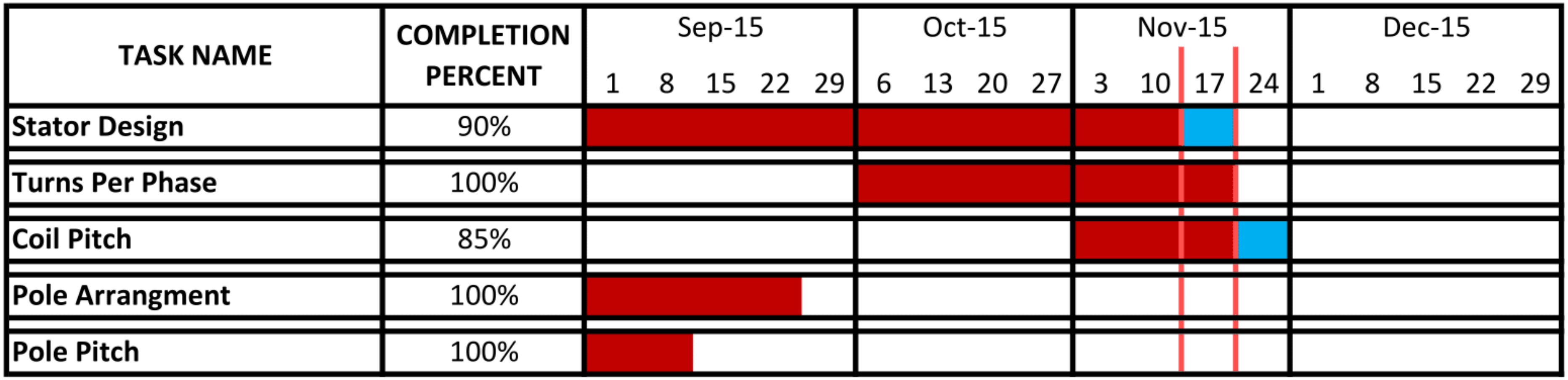
Work Completed



Work Completed



Gantt Chart



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		1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29
Stator Design	90%	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟦						
Turns Per Phase	100%						🟥	🟥	🟥	🟥	🟥	🟥	🟥						
Coil Pitch	85%										🟥	🟥	🟥	🟦					
Pole Arrangment	100%	🟥	🟥	🟥	🟥														
Pole Pitch	100%	🟥	🟥																

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Tim

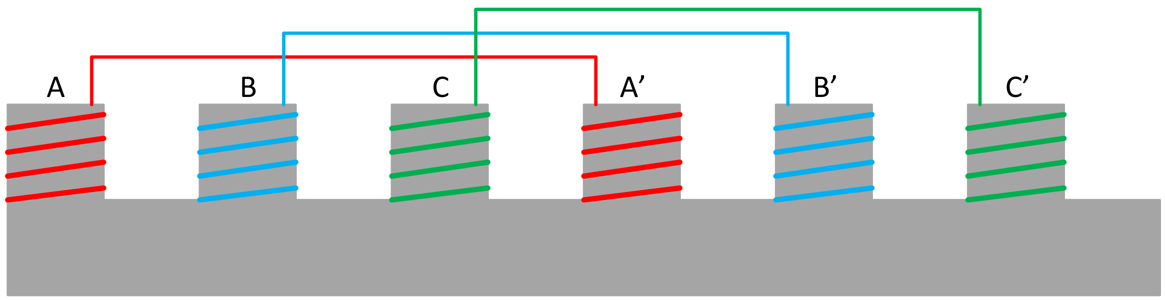
Progress

- Pole Arrangement
  - Salient
  - Non Salient
- Design Stator
- Manufacturing
  - Cost
  - Time

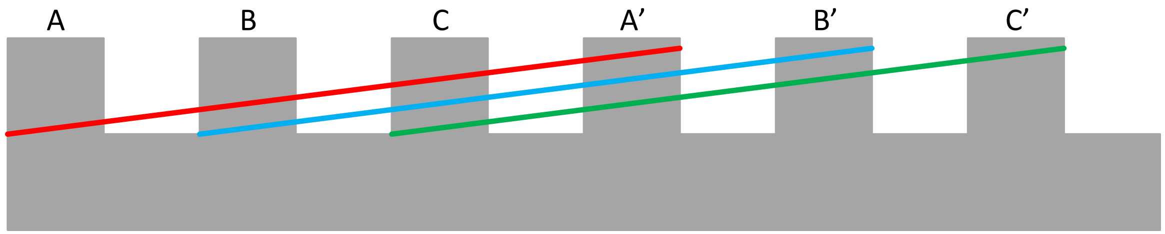
Pole Arrangements

- Understanding poles effect on the system
  - Number
    - Will vary overall speed
    - Will vary output force
  - Salient
    - Single coil per tooth
  - Non-salient or Distributed
    - Coils distributed around multiple teeth

Salient and Non-Salient



Salient



Non-Salient

Design of Stator

Design of Stator

- Material of LIM
  - Laminated Steel
- Length of teeth
  - Allow for coil windings to fit

Design of Stator

- Slot and Teeth Ratio
- Narrow Teeth
  - Generates more force
  - Better Efficiency
  - Better Power Factor
- Tooth Saturation

25/75

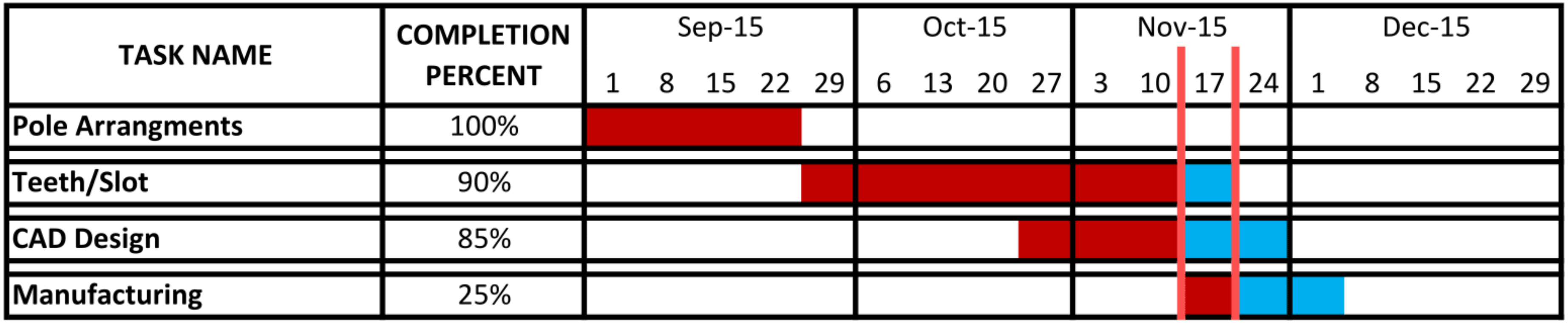
50/50

75/25

Manufacturing

- Laser Laminations
- 1 Week Constructing
- Shipping
- First Lamination most expensive part of manufacturing
- Original 2 Pole Machine cost estimate $250
- New 4 Pole Machine cost raised to $450

Gantt Chart



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		1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29
Pole Arrangments	100%	🟥	🟥	🟥	🟥														
Teeth/Slot	90%					🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟦						
CAD Design	85%									🟥	🟥	🟥	🟦	🟦					
Manufacturing	25%												🟥	🟦	🟦				

Upcoming Work

- Purchasing Stator
- Winding the coils

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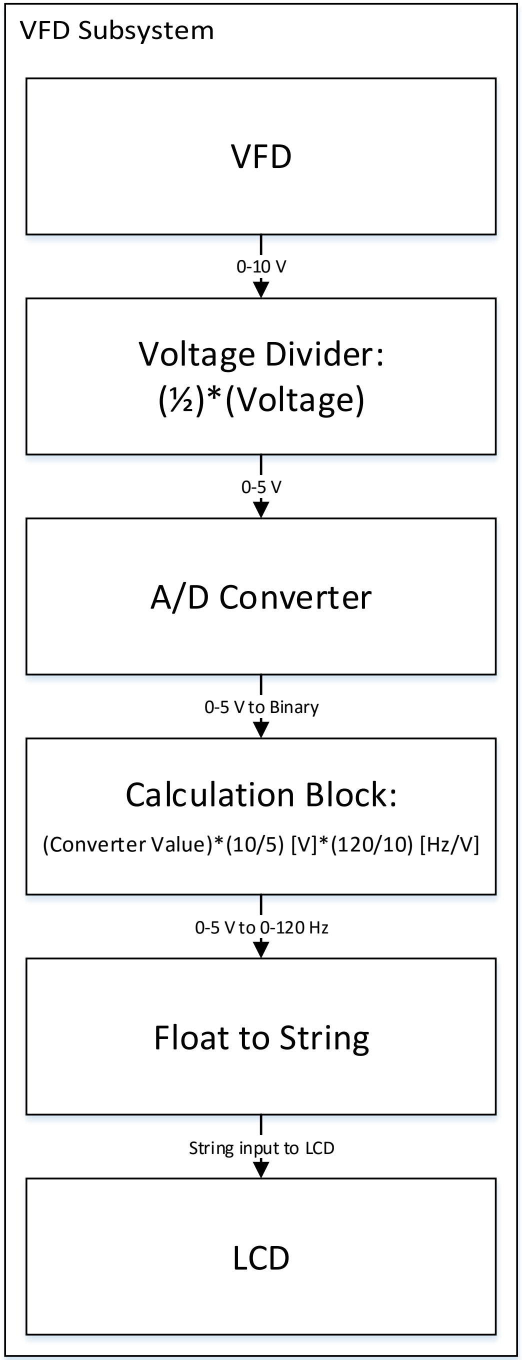
Conclusion

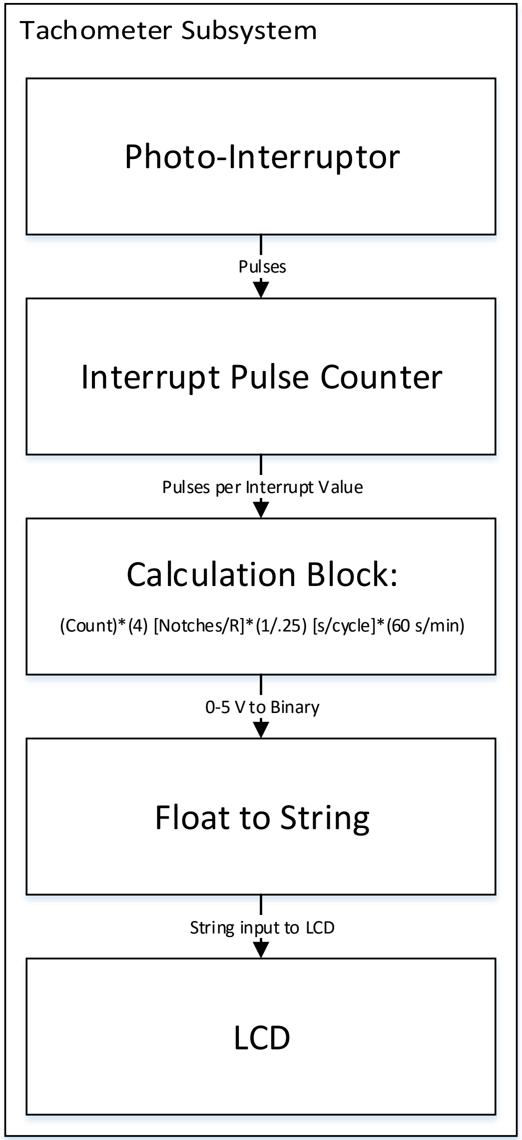
Conclusion

- Work Done
  - Pole Arrangement
  - Coil Windings
  - Teeth/ Slot
  - Design
- Future Work
  - Purchasing
  - Construction
  - Implementation
  - Testing

Questions

References

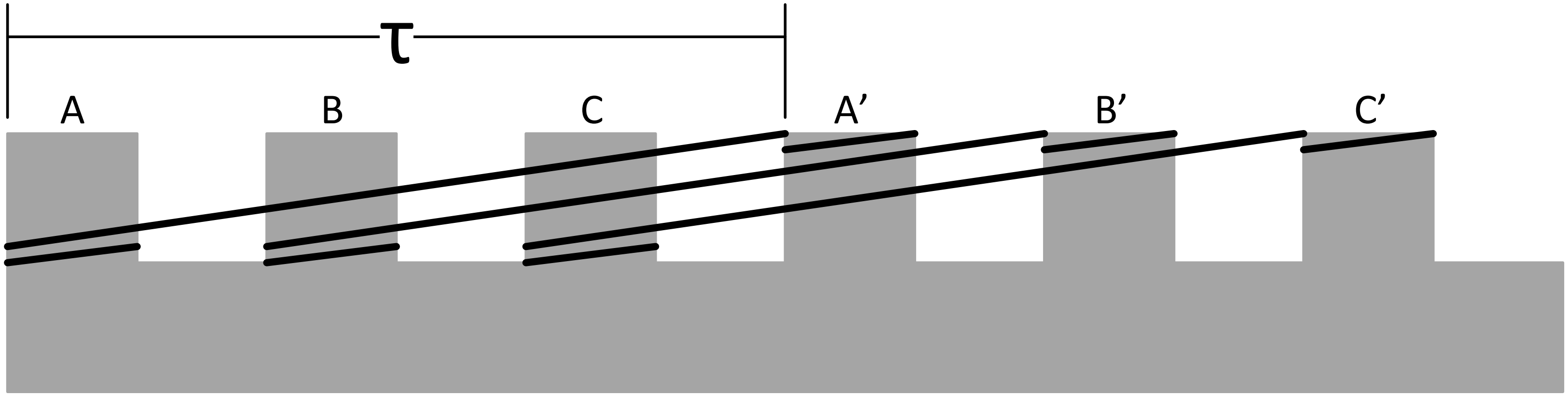

VFD Subsystem
VFD
0-10 V
Voltage Divider:
(½)*(Voltage)
0-5 V
A/D Converter
0-5 V to Binary
Calculation Block:
(Converter Value)*(10/5) [V]*(120/10) [Hz/V]
0-5 V to 0-120 Hz
Float to String
String input to LCD
LCD


Tachometer Subsystem
Photo-Interruptor
Pulses
Interrupt Pulse Counter
Pulses per Interrupt Value
Calculation Block:
(Count)*(4) [Notches/R]*(1/.25) [s/cycle]*(60 s/min)
0-5 V to Binary
Float to String
String input to LCD
LCD

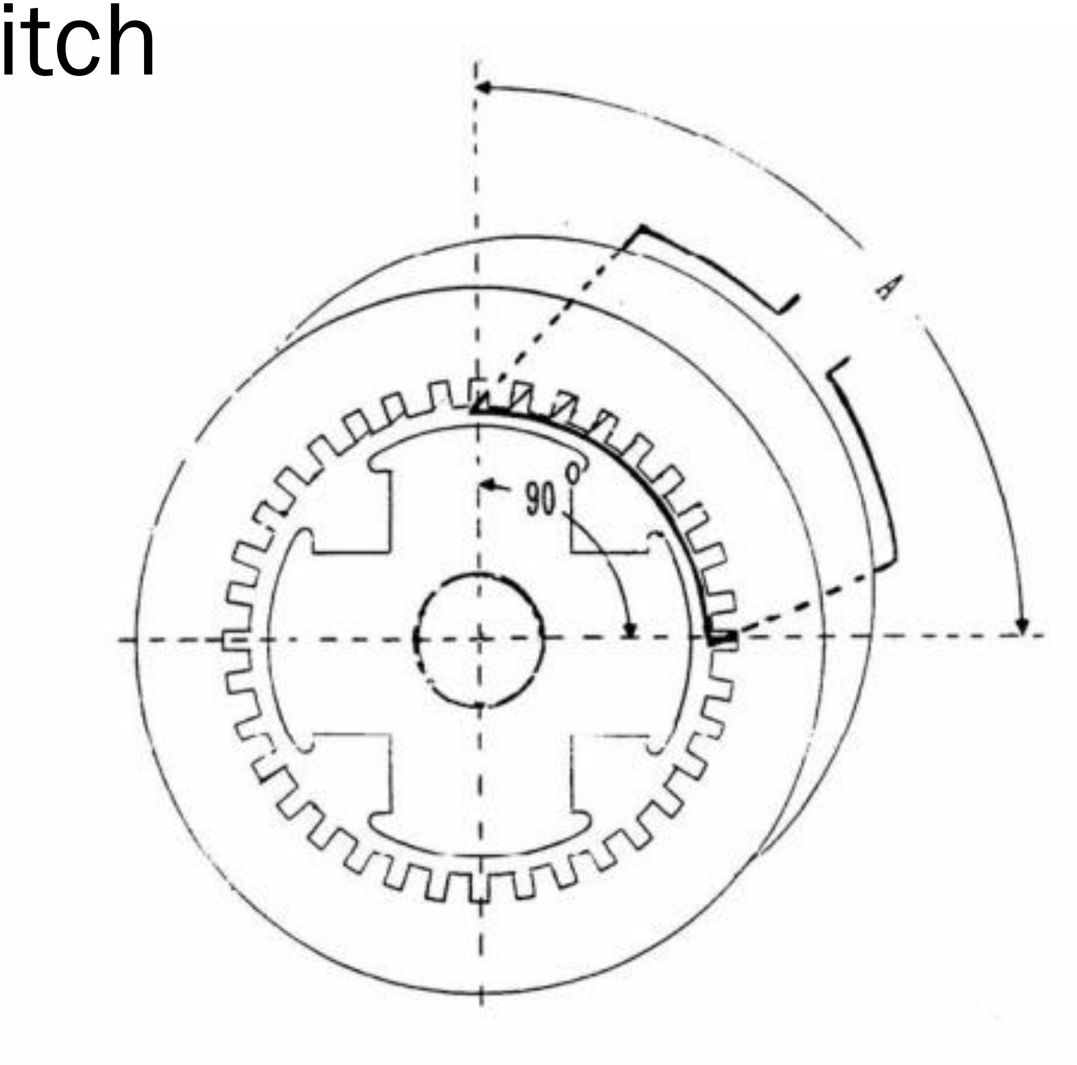
Pole Pitch

$$U_s = 2\tau f$$

Pole Pitch = 0.1668m

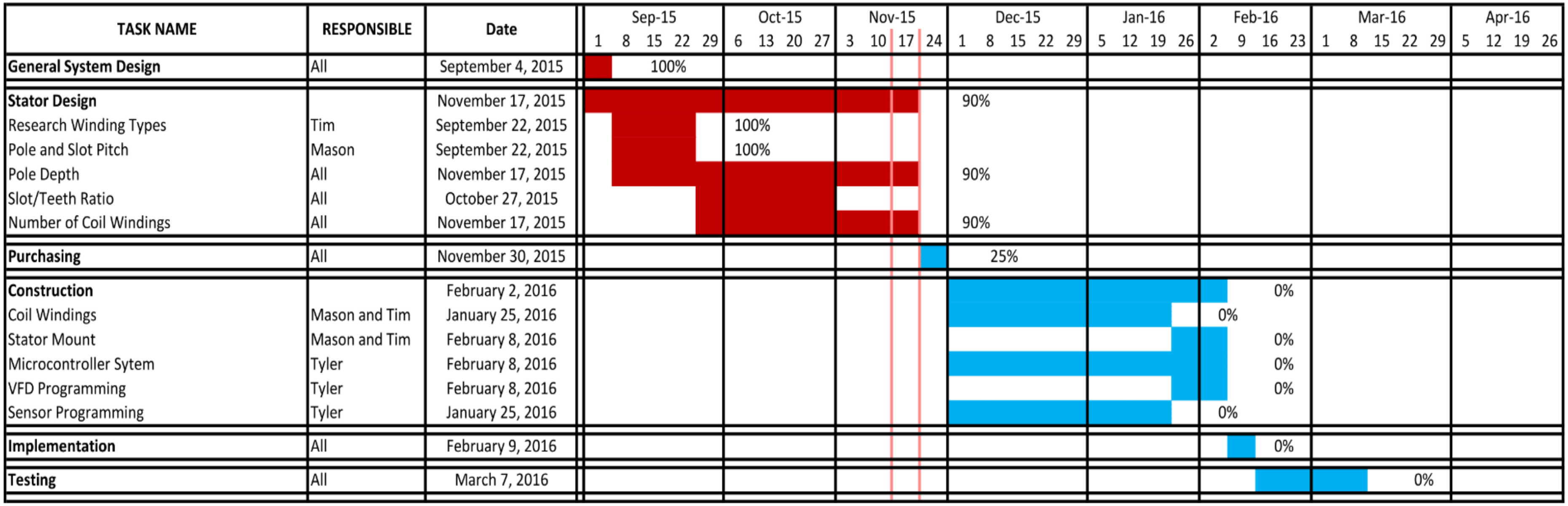


Coil Pitch



http://www.davidsonsales.com/docs_pdf/Coil Pitch.pdf

Master Gantt Chart



TASK NAME	RESPONSIBLE	Date	Sep-15					Oct-15				Nov-15				Dec-15					Jan-16				Feb-16				Mar-16					Apr-16			
			1	8	15	22	29	6	13	20	27	3	10	17	24	1	8	15	22	29	5	12	19	26	2	9	16	23	1	8	15	22	29	5	12	19	26
General System Design	All	September 4, 2015	🟥		100%																																
Stator Design		November 17, 2015	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		90%																					
Research Winding Types	Tim	September 22, 2015		🟥	🟥	🟥		100%																													
Pole and Slot Pitch	Mason	September 22, 2015		🟥	🟥	🟥		100%																													
Pole Depth	All	November 17, 2015		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		90%																					
Slot/Teeth Ratio	All	October 27, 2015					🟥	🟥	🟥	🟥	🟥																										
Number of Coil Windings	All	November 17, 2015					🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥		90%																					
Purchasing	All	November 30, 2015													🟦		25%																				
Construction		February 2, 2016														🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			0%									
Coil Windings	Mason and Tim	January 25, 2016														🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		0%												
Stator Mount	Mason and Tim	February 8, 2016																						🟦	🟦			0%									
Microcontroller Sytem	Tyler	February 8, 2016														🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦			0%									
VFD Programming	Tyler	February 8, 2016																						🟦	🟦			0%									
Sensor Programming	Tyler	January 25, 2016														🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		0%												
Implementation	All	February 9, 2016																								🟦		0%									
Testing	All	March 7, 2016																									🟦	🟦	🟦	🟦		0%					

References

[1] A. Needham. *A maglev train coming out of the Pudong International Airport.* [Photograph]. Retrieved from https://en.wikipedia.org/wiki/Maglev#/media/File:A_maglev_train_coming_out,_Pudong_International_Airport,_Shanghai.jpg

[2] *Linear Induction Motor.* [Photograph]. Retrieved from http://www.mpoweruk.com/motorsac.htm

[3] Force Engineering. *How Linear Induction Motors Work.* [Photograph]. Retrieved from http://www.force.co.uk/linear-motors/how-linear.php