CENTER FOR COMPACT AND EFFICIENT FLUID POWER
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Seamless Electric to Hydraulic Conversion

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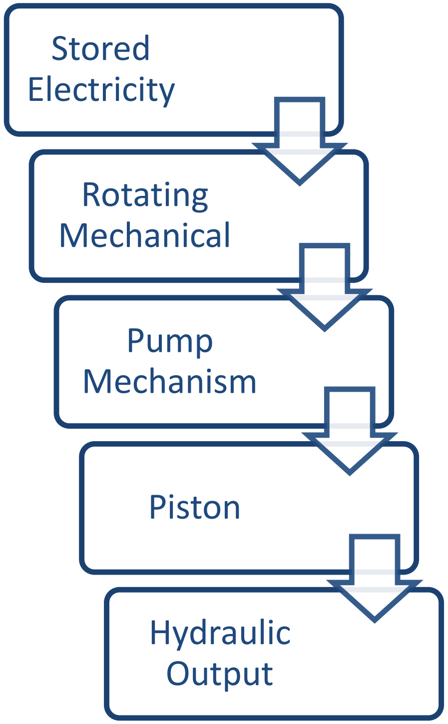
Funded by the CCEFP

Motivation

- Electric → Hydraulic Conversion
  - – Push for electrification
    - Mobile and Industrial Systems

Concentric hydraulic power unit

Conventional Approach:



Stored Electricity

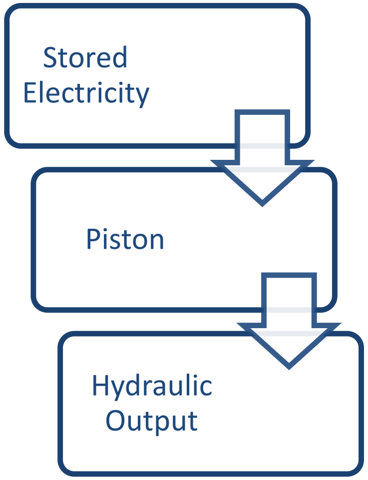
Rotating Mechanical

Pump Mechanism

Piston

Hydraulic Output

Proposed Approach:



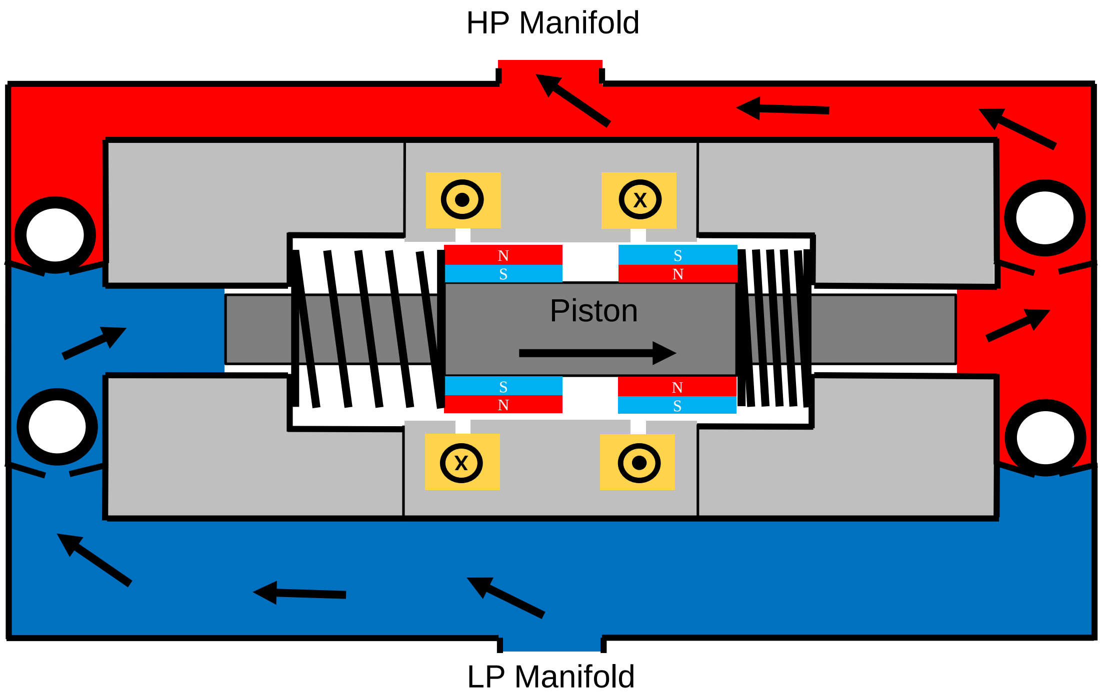
Stored Electricity

Piston

Hydraulic Output

Prior Work

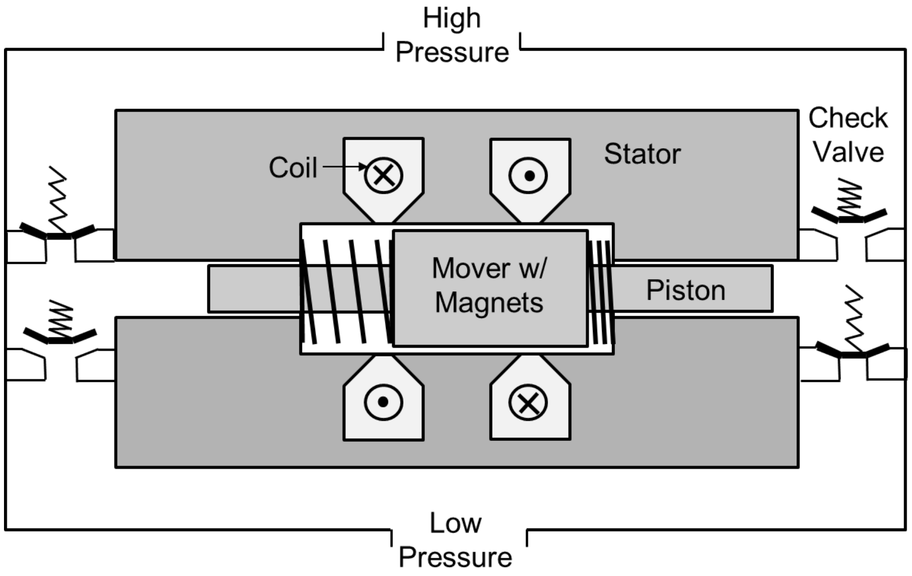
- Human Power Scale
- Electro-Hydraulic Actuation (EHA)



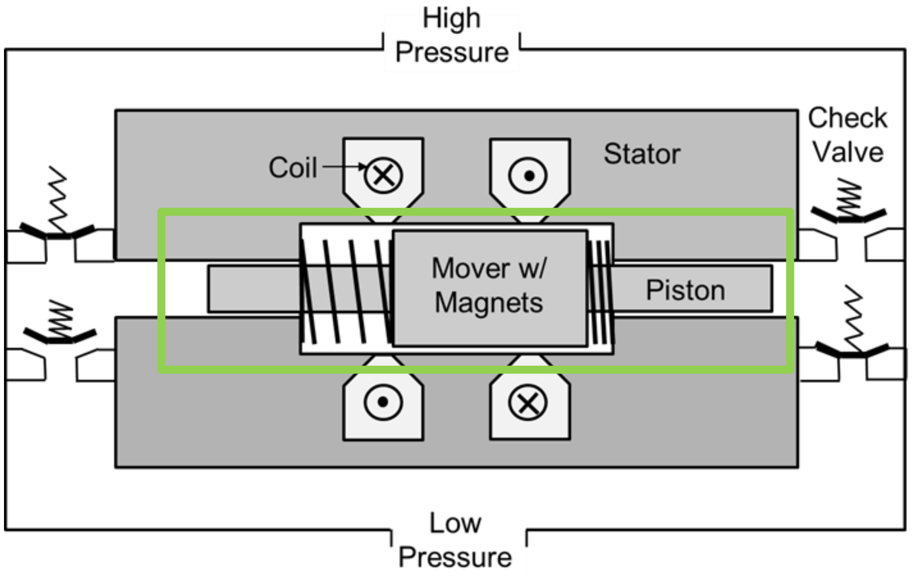
Hogan, Paul. (2017). A Linear Electromagnetic Piston Pump. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/190593.

Proposed Concept

- Charge Pump in hydrostatic transmission (HST)
  - Direct electric control good for lower pressure, high frequency application
  - Variable displacement

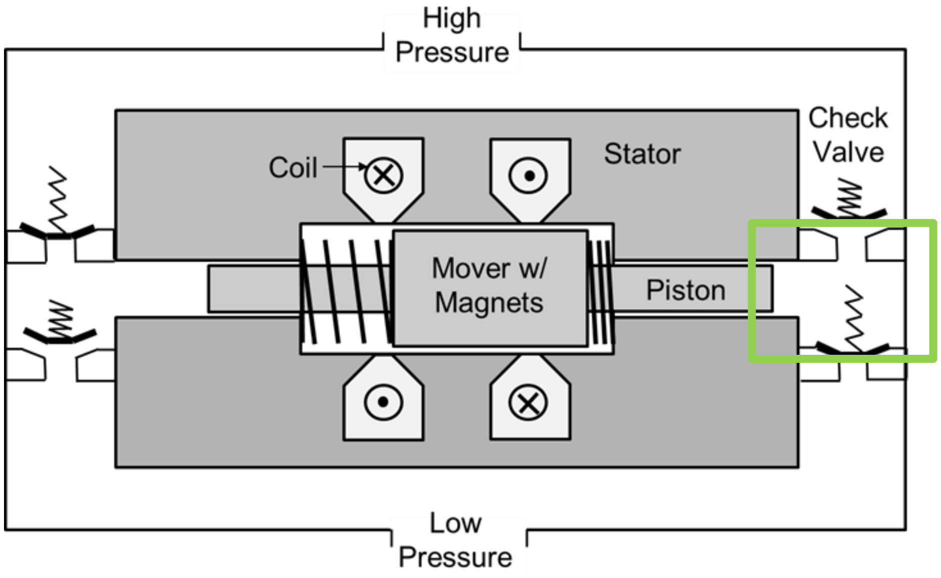


Modeling



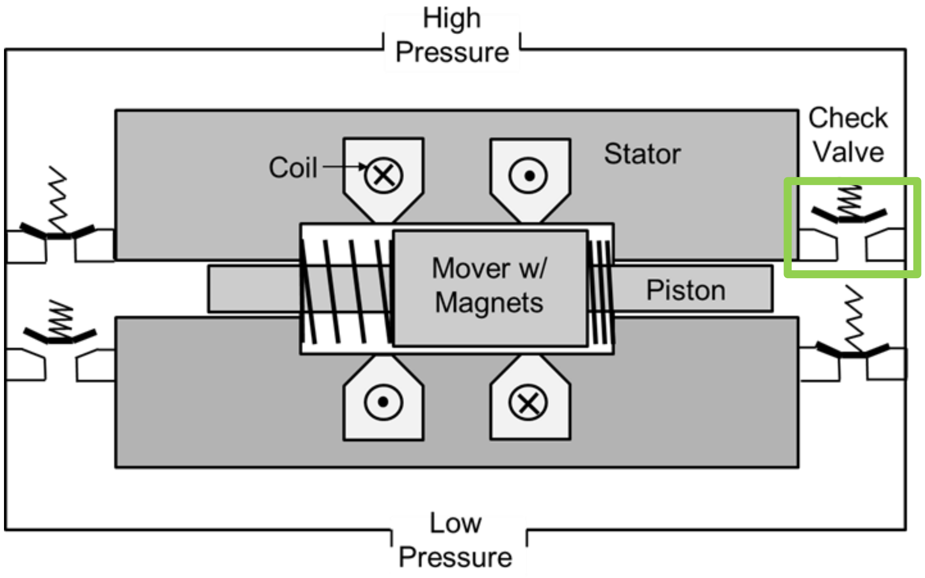
- Piston Dynamics
  - Forces acting:
    - Magnetic Force (input force)
    - Pressure
    - Spring
    - Viscous
  - Leakage Flowrate

Modeling



- Cylinder
  - Pressure Dynamics
  - Bulk Modulus
    - Pressure Dependent

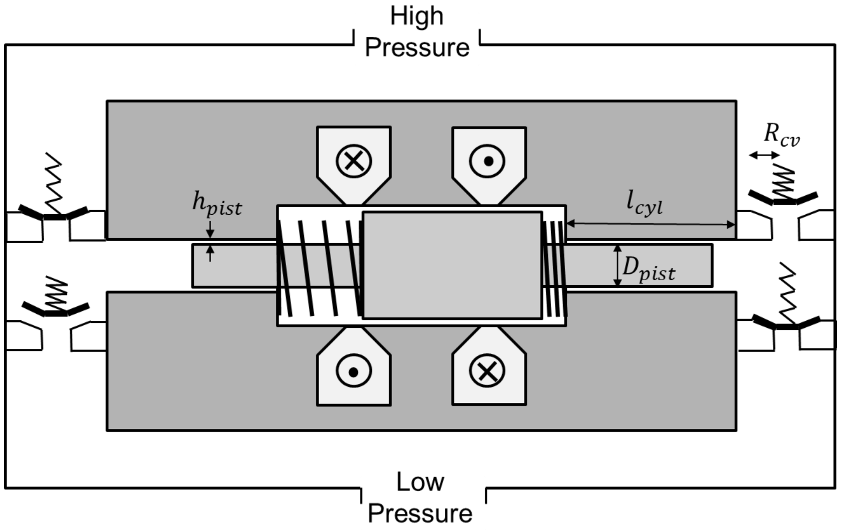
Modeling



- Check Valve Dynamics
  - Forces acting:
    - Pressure
    - Spring
    - Damping
- Flowrate
  - Orifice Equation

Optimization

- Parameters being optimized:
  - Piston Diameter
  - Piston/Cylinder Gap Height
  - Check Valve Radius
  - Check Valve Spring Constant
  - Check Valve Cracking Pressure



- Objective function:

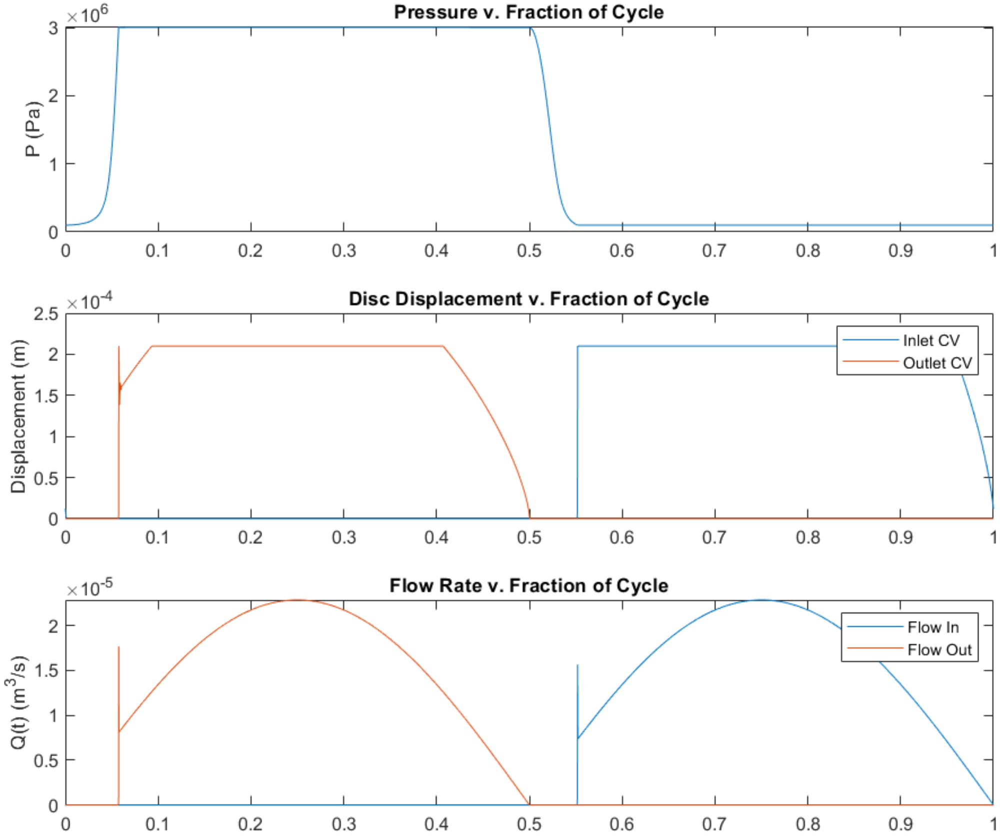
$$\eta = \frac{E_{out}}{E_{in}} = \frac{\int \Delta P Q_{out}}{\int F\, v}$$

- Single Objective Genetic Algorithm

Results- *f* = 50 Hz

$$Efficiency = \ 98.03\%$$

Parameter	Result
Piston Diameter	$5.7\ mm$
Gap Height	$15.7 \mu m$
Disc Radius	$inlet\!:\ 10\ mm$ $outlet\!: 6.4\ mm$
Spring Constant	$inlet\!:\ 53.9\ N/m$ $outlet\!:\ 213.8\ N/m$
Cracking Pressure	$inlet\!:\ 1.00\ kPa$ $outlet\!:\ 1.00\ kPa$



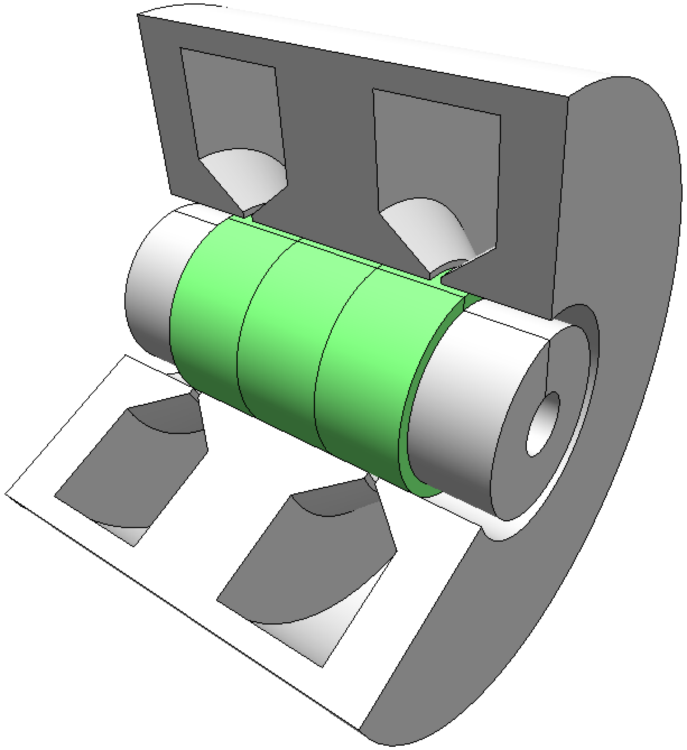
Pressure v. Fraction of Cycle

Disc Displacement v. Fraction of Cycle

Flow Rate v. Fraction of Cycle

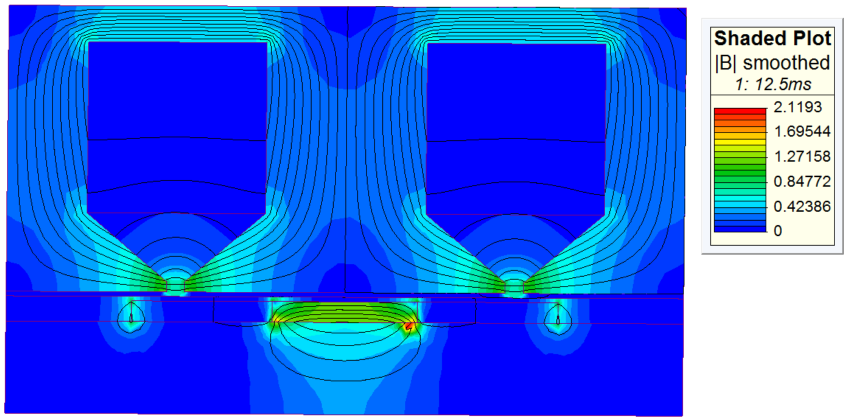
Linear Electric Machine Topology

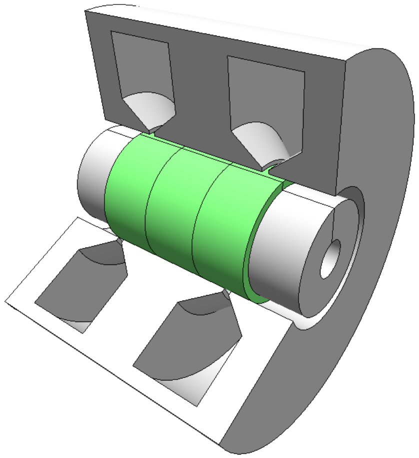
- Selected topology – tubular permanent magnet motor:
  - Effective use of the volume
  - Radial forces are cancelled



Linear Electric Machine Topology

- FEA model of the motor is developed:



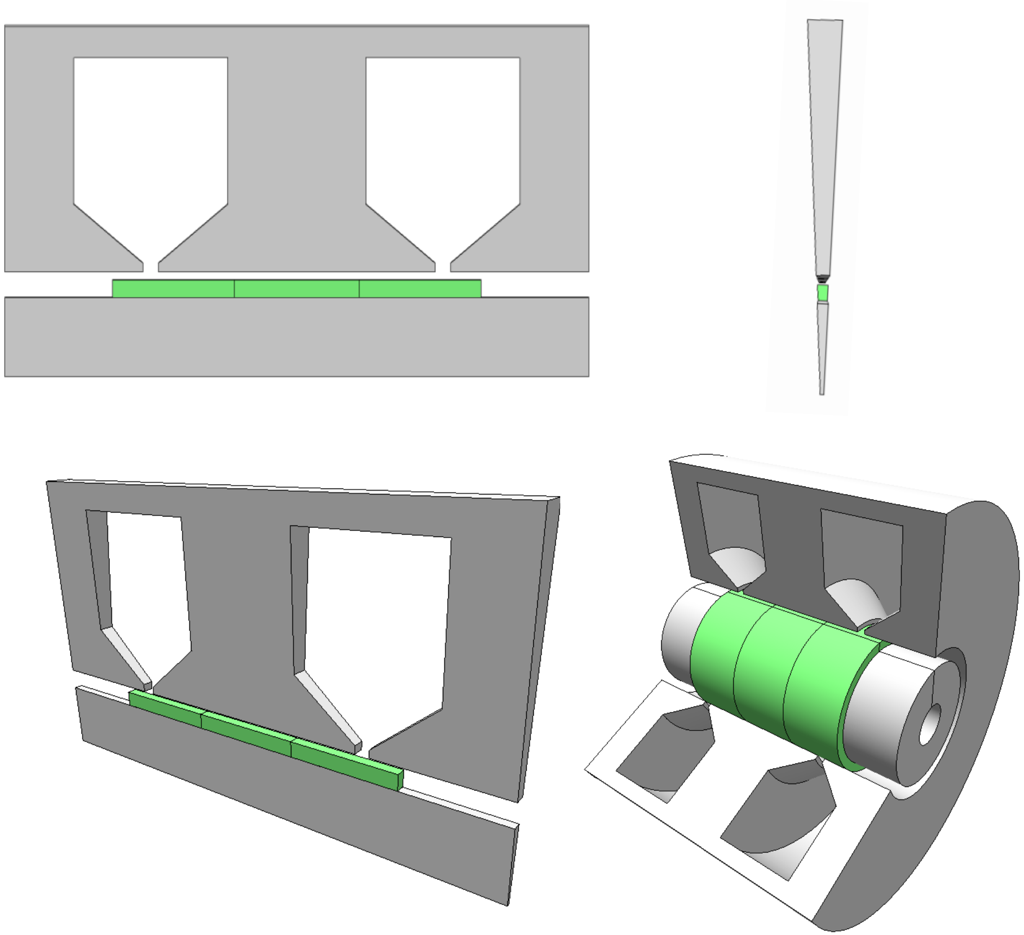


- Using solid iron core generates eddy current losses.
- Alternative: laminations or soft magnetic composite.

Manufacturing Technique 1

1. Laminations – thin iron sheets:

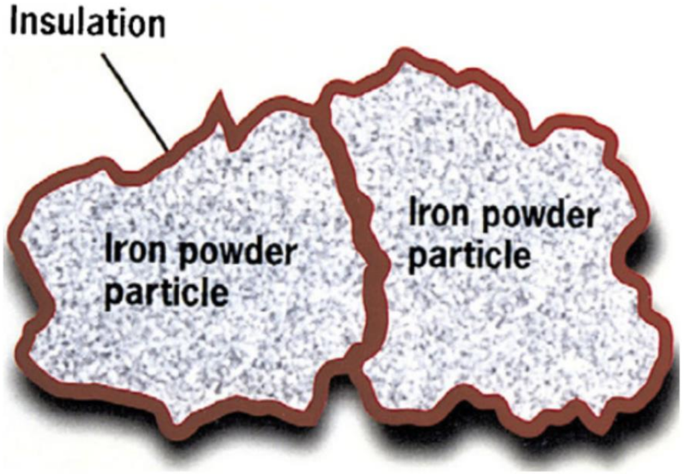
- Iron sheets parallel to the magnetic field flow.



Manufacturing Technique 2

2. Soft magnetic composite (SMC):

- Ferromagnetic powder particles coated with a uniform layer of electrical insulating film.
- Performance comparable to the iron laminations.



L. Pennander, A. Jack, Soft magnetic iron powder material AC properties and their application in electrical machines, Magn. Mater., Euro PM (2003)

Electric Machine Optimization

Design specifications:

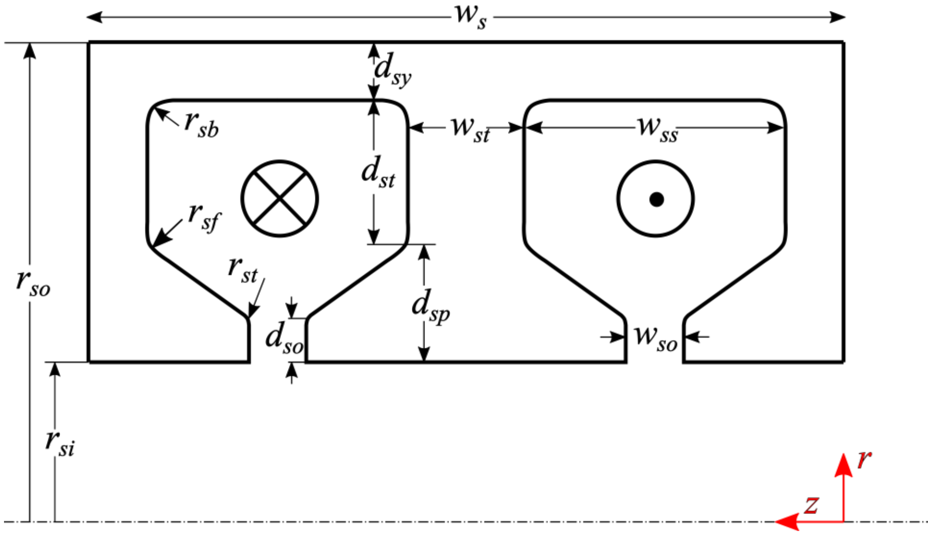
- Output power = 1.1 kW
- Output pressure = 2.7 MPa

Objectives:

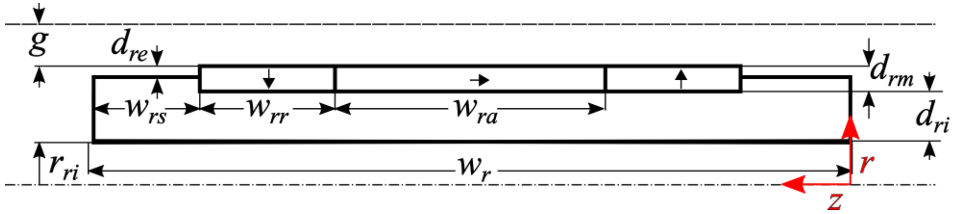
- Maximize efficiency (η)
- Minimize total cost
- Minimize force ripple (FR)

Number of variables: 13

Stator:

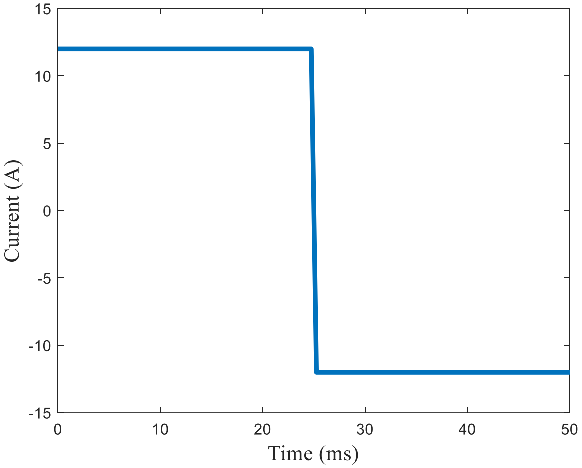


Mover:

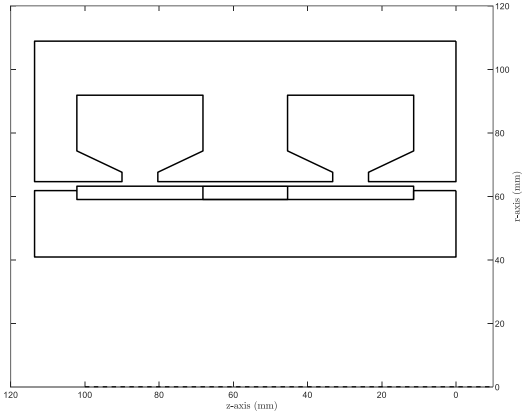


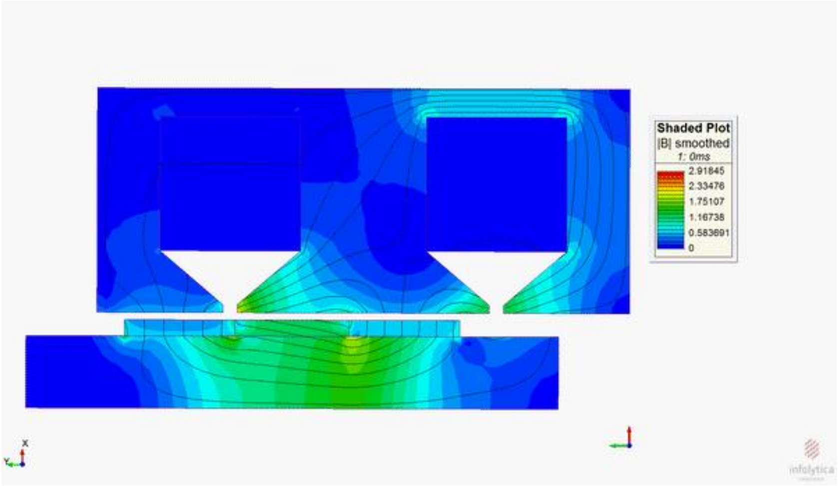
Sample Optimal Design

Square wave current:

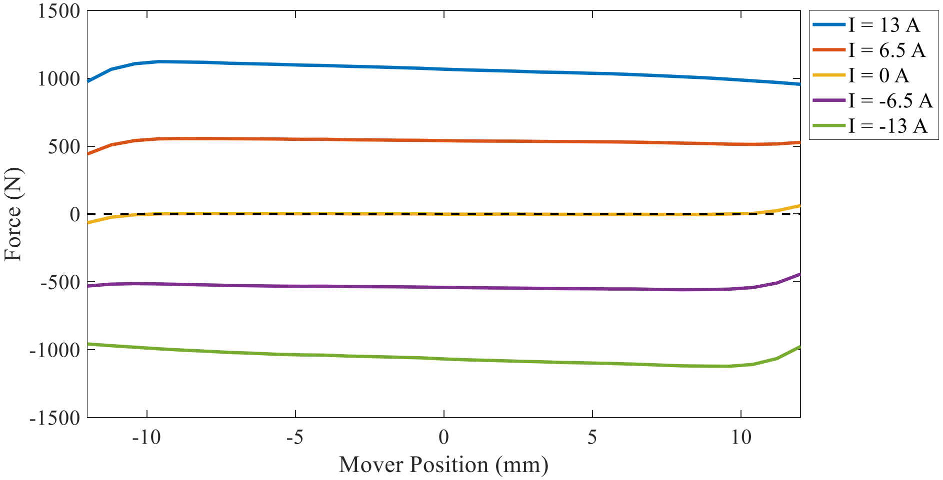


f = 20 Hz
stroke = 23.7 mm
η = 89.9%





Force vs. mover position for different currents:

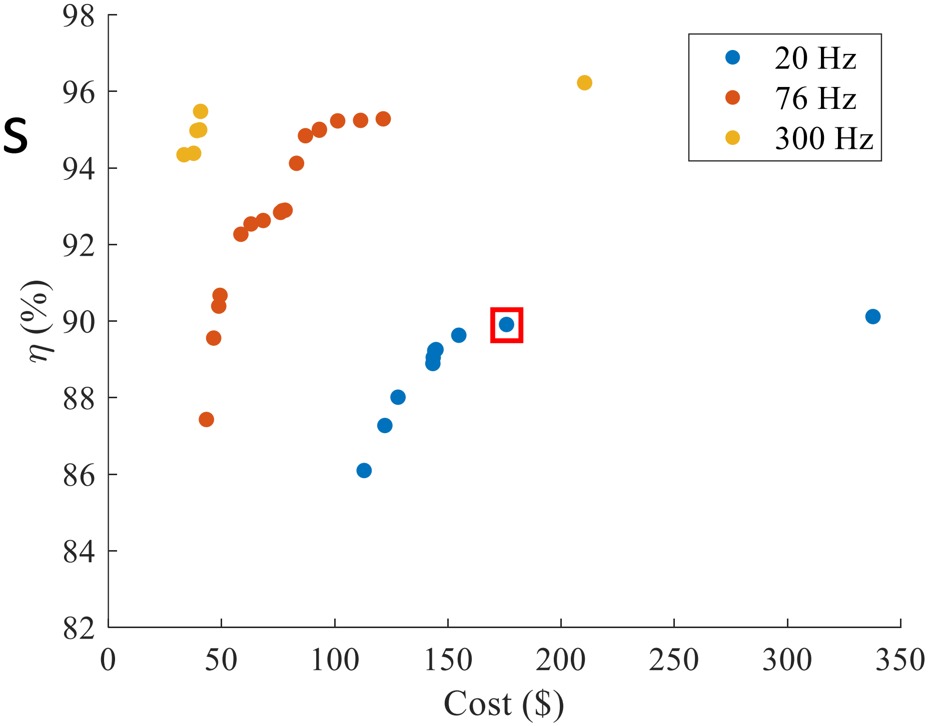


Electric Machine Optimization

Higher frequency:

- Higher efficiency.
- Lower machine materials cost.

Pareto fronts:



bore-to-stroke ratio = 1

Conclusion

- Candidate designs with efficiencies around 90% can be obtained.
- There is a trade-off between the efficiency of the motor and the pump when frequency increases.
- There are separate models developed for electrical and mechanical parts – getting ready to integrate these models.

Future Works

- Select appropriate oscillation frequency.
- Develop combined electrical and mechanical model.
- Construct a physical prototype system.
- Experimentally validate the models.

Thank you

Support for this project was provided by the CCEFP