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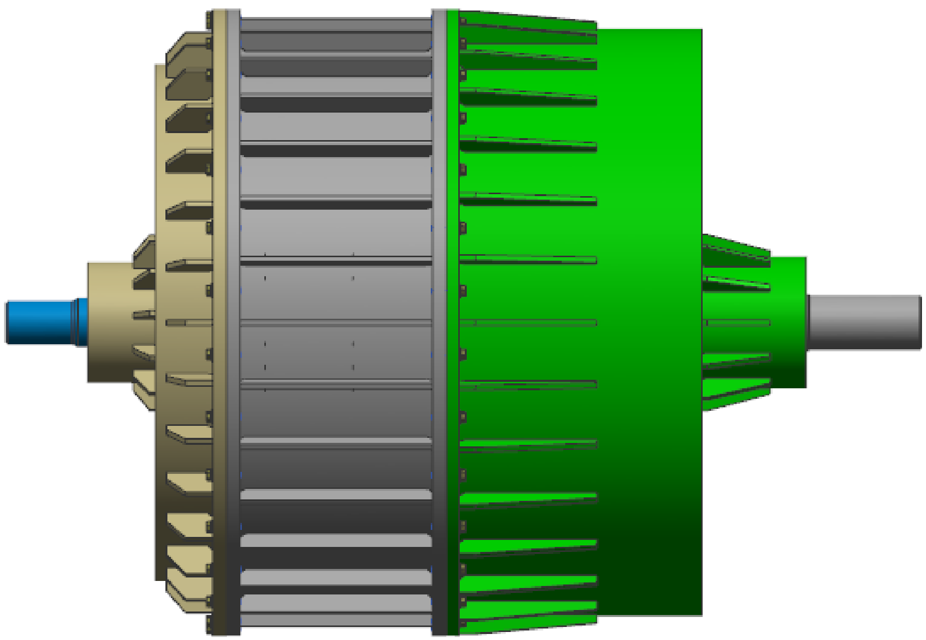

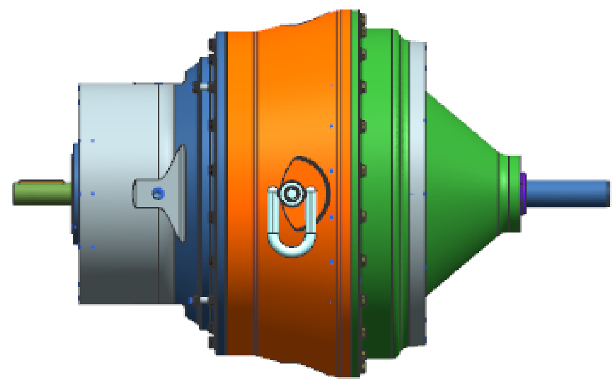

Magnetic Gears: The Key to Robust, Cost-Effective Hydropower Drivetrains

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Project Overview

Magnetic Gears: The Key to Robust, Cost-Effective Hydropower Drivetrains

The Challenge: State-of-the-art gearboxes have maintenance, life, and size compromises. A magnetic gearbox opens possibility of high performance, high reliability, and long life.

Partners:

DRIVE SYSTEM DESIGN — Engineering Design/Analysis Partner

NREL (National Renewable Energy Laboratory) — Testing Partner

Next Generation Hydropower (HydroNEXT)

Optimization

- Optimize technical, environmental, and water-use efficiency of existing fleet
- Collect and disseminate data on new and existing assets
- Facilitate interagency collaboration to increase regulatory process efficiency
- Identify revenue streams for ancillary services

Growth

- Lower costs of hydropower components and civil works
- **Increase power train efficiency for low-head, variable flow applications**
- Facilitate mechanisms for testing and advancing new hydropower systems and components
- Reduce costs and deployment timelines of new PSH plants
- Prepare the incoming hydropower workforce

Sustainability

- Design new hydropower systems that minimize or avoid environmental impacts
- Support development of new fish passage technologies and approaches
- Develop technologies, tools, and strategies to evaluate and address environmental impacts
- Increase resilience to climate change

Next Generation Hydropower (HydroNEXT)

Growth

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The Impact

- TARGET:
  - 10X rated power scale of magnetic gearbox
  - 30:1 single-stage ratio
  - >97% efficiency
  - <$0.80/watt capital cost
  - 10 years continuous uptime/non-serviceable
- IMPACT:
  - Improve performance of hydropower drivetrains
  - Lower the levelized cost of energy (LCOE) of low impact hydropower
  - Promote environmental stewardship
- GOAL: to become a supplier of high efficiency, high reliability, low cost drivetrains to hydropower developers

Technical Approach

1. Define Technical Specifications based on Market Opportunity

	Total Potential	Head Range	Head Median	Flow Range	Flow Median	Recommendation
New England	2.14 GW	8-44 ft	18ft	300-5000 cfs	2000 cfs	low head
Mid Atlantic	4.71 GW	0-50 ft	28 ft	200-6000 cfs	1500 cfs	
South Atlantic	2.56 GW	5-40 ft	22 ft	400-6000 cfs	1200 cfs	low head
Great Lakes	1.43 GW	6-19 ft	15 ft	750-4600 cfs	1500 cfs	low head
Ohio	4.76 GW	5-57 ft	27 ft	400-5000 cfs	1500 cfs	
Tennessee	1.36 GW	5-77 ft	27 ft	250-3000 cfs	1000 cfs	
Upper Miss.	2.08 GW	5-28 ft	14 ft	800-8500 cfs	2700 cfs	low head
Lower Miss.	2.07 GW	0-35 ft	19 ft	0-9000 cfs	2000 cfs	low head
Souris Red Rainy	151 MW	7-41 ft	21 ft	1000-10500 cfs	2500 cfs	low head
Missouri	11.69 GW	5-21 ft	12 ft	900-12000 cfs	4000 cfs	low head
Arkansas White Red	6.01 GW	5-29 ft	20 ft	700-12500 cfs	2700 cfs	low head
Texas-Gulf	783 MW	5-54 ft	25 ft	400-7000 cfs	1900 cfs	
Rio Grande	1.64 GW	5-47 ft	22 ft	1100-4700 cfs	3200 cfs	
Upper Colorado	3.03 GW	0-25 ft	14 ft	1000-5500 cfs	2100 cfs	low head
Lower Colo.	2.61 GW	5-41 ft	25 ft	700-1400 cfs	1500 cfs	
Great Basin	564 MW	11-41 ft	21 ft	300-1200 cfs	1000 cfs	low head
Pacific NW	25.23 GW	5-41 ft	14 ft	0-11000 cfs	2500 cfs	low head
California	7.05 GW	7-48 ft	23 ft	300-5000 cfs	1200 cfs	low head

	Technology Type	Torque	Speed	Ratio (if applicable)
Percheron Power	Archimedes Screw	11kNm	25 RPM	30:1 - 50:1
NE Hydropower	Archimedes Screw	proprietary	30-40 RPM	proprietary
Natel Energy	Low Head	20kNm	100-300 RPM	(8:1 at least, multiple stages)
Helios Altas	Low Head	160Nm	30-60RPM	21.26:1
GE-Alstom	Bulb Turbine	500-700kNm	70-125 RPM	varies, multiple stages
ORPC	Hydrokinetic	8kNm	50 RPM	N/A
Verdant Power	Hydrokinetic	7-10kNm	40 RPM	(varies, multiple stages)

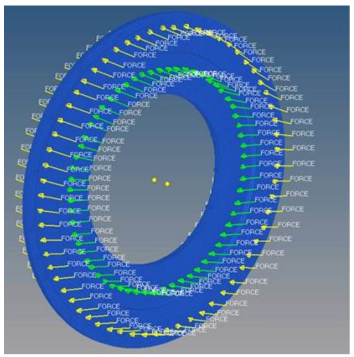
2. Determine Technical Feasibility through Series of Parametric Studies

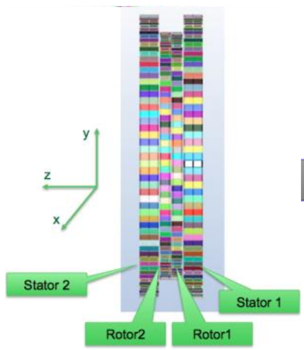
Torque from rotor/stator airgap	Magnetic array arrangement
Rotor eccentricity	Eccentricity ratio
Rotor Axial Offset	Pole Counts
Rotor Diameter	Ratio

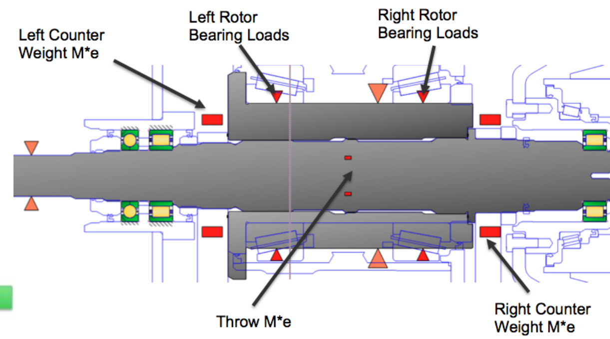
TARGET: 100kW, 30:1 ratio, 40RPM low speed / 1,200 RPM high speed

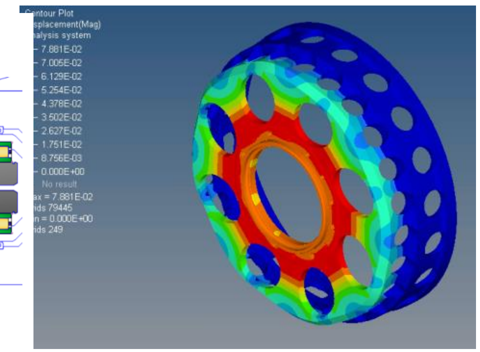
Technical Approach

3-7. Scaled concept design; magnetic, structural, modal, and sealing analyses, detailed design for prototype build









Bearing Summary:

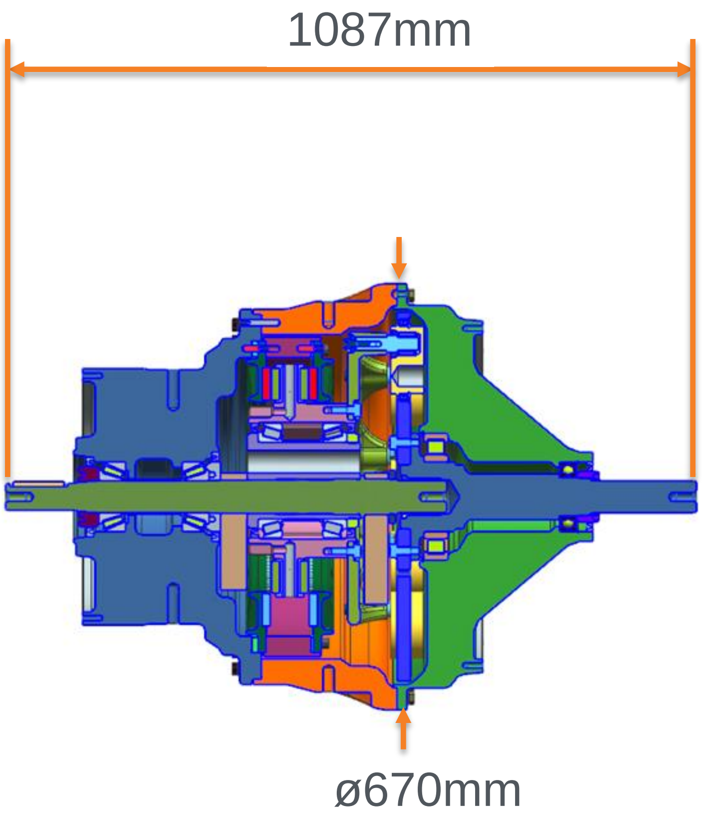
	Description	Safety Factor	% Damage (10 yrs)
1)	4-Point Contact Ball Bearing (4PC)	2.83	4.40
2)	Cylindrical Roller Bearing (CRB)	2.56	4.34
3)	Cylindrical Roller Bearing (CRB)	2.93	2.77
4)	Taper Roller Bearing (TRB)	6.87	0.16
5)	Taper Roller Bearing (TRB)	2.75	3.41
6)	Taper Roller Bearing (TRB)	4.30	0.77
7)	Taper Roller Bearing (TRB)	4.73	0.56
8)	Needle Roller Bearing (NRB)	1.79	14.32
9)	Needle Roller Bearing (NRB)	1.82	13.54
10)	Needle Roller Bearing (NRB)	1.82	13.54
11)	Needle Roller Bearing (NRB)	1.78	14.59

Shafts Summary:

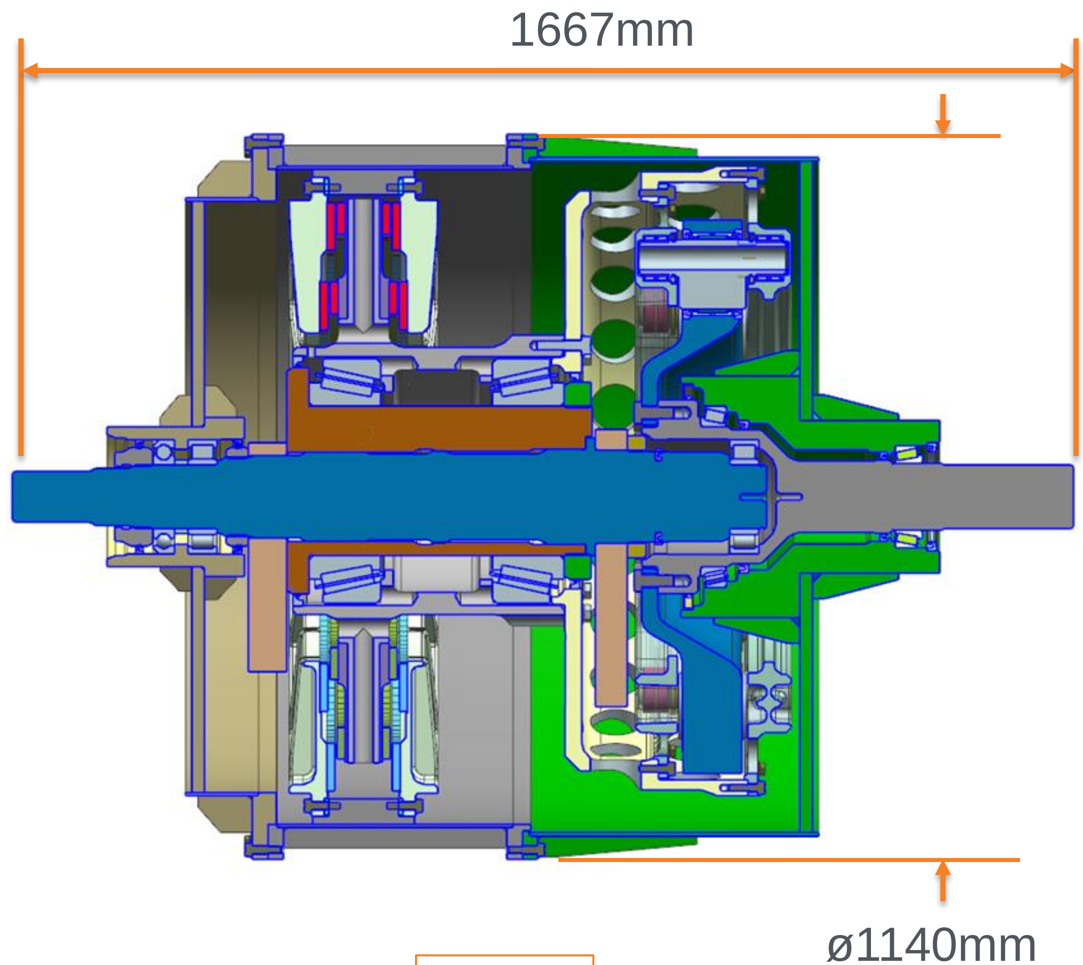
	Description	Safety Factor
1)	Output Shaft	2.89
2)	Eccentric Throw	44.87
3)	Rotor	10.91
4)	Rotor Flange	5.81
5)	Bearing Ring – Top	2.63est
6)	Bearing Ring – Bottom	2.63
7)	Orbital Pucks	4.55
8)	Input Flange	50.00
9)	Input Shaft	3.80
10)	Stator – Top	4.20
11)	Stator – Bottom	4.20

	Rotating components	Order	Excitation Frequency
1	• Input shaft • Input Drive-in Flange	1st Harmonic 2nd Harmonic	2 Hz 4 Hz
2	• Rotor Shaft • Back iron	1st Harmonic 2nd Harmonic	2 Hz 4 Hz
3	• Rotor Drive Flange • Drive-in Ring	1st Harmonic 2nd Harmonic	2 Hz 4 Hz
4	Output shaft	1st Harmonic 2nd Harmonic	120 Hz 240 Hz
5	Throw	1st Harmonic 2nd Harmonic	120 Hz 240 Hz
6	Counterweight -1	1st Harmonic 2nd Harmonic	120 Hz 240 Hz
7	Counterweight -2	1st Harmonic 2nd Harmonic	120 Hz 240 Hz

Technical Accomplishments



10kW



100kW

Technical Accomplishments

GOAL	RESULT
Increase power rating to suit low impact hydropower industry	Scaled maximum power from 10kW to 100kW Scaled maximum torque from 1600Nm to 30,000Nm
Create a flexible machine that integrates with a variety of turbine types and manufacturers	Gear can be mounted horizontally or vertically Sealed for water tightness Magnets enable flexibility/customization up to 100kW
Maximize power density for larger device	Rotor diameter target: 1219mm Rotor diameter actual: 883 mm
Reduce LCOE	Prototype costs higher than anticipated, but signed CRADA with Oak Ridge National Laboratory (ORNL) to reduce cost in low-volume manufacturing

Project Plan & Schedule

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Schedule

- Project Initiation: April 1, 2016
- GO Decision for Budget Period 2 (BP2) in November 2016
- Planned Completion: August 31, 2017
- On schedule for prototype testing beginning in May 2017

Project Budget

Budget History					
FY2014		FY2015		FY2016	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
				$391.684k	$107.657k

- Total Project Budget: $1,156,441
  - $910.716k Federal Share
  - $245.725k Recipient share
- BP1 completed within outlined schedule and budget
- BP2 prototype materials are still in procurement; possibility of higher costs than anticipated for build but not confirmed.

Partners, Subcontractors, and Collaborators

DRIVE SYSTEM DESIGN — Engineering Design/Analysis Partner

NREL NATIONAL RENEWABLE ENERGY LABORATORY — Testing Partner

Communications and Technology Transfer: none yet

Next Steps and Future Research

FY17/Current research:

Currently in procurement for prototype
Assembly will begin in March 2017
Testing scheduled to begin in April/May 2017

Proposed future research:

Possible future research includes:

- Scale to 350kW+
- Ratio to 100:1+
- Dynamic magnetic flux adjustments in field