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Structural Mass Saving Potential of a 5-MW Direct-Drive Generator Designed for Additive Manufacturing

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Present

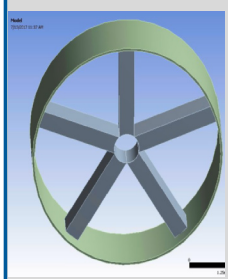


Figure 1. Spoke arm conventional rotor

Future

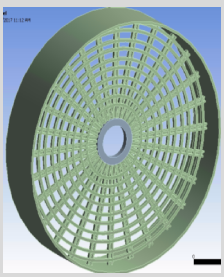


Figure 2. U-Beam spoked web rotor

Introduction

Research Goal: To reduce the mass, deformation, and cost of wind turbine direct-drive generators through additive manufacturing of bio-inspired geometries.

Additive Manufacturing—A Game Changer for Wind

Additive Manufacturing, or three-dimensional printing, refers to a manufacturing process in which a part is built layer by layer. Advantages of additive manufacturing include less material waste, "free complexity," and lower labor costs.

Application to Wind Turbines

- -Generator design
- -Embedded sensors
- -Blades
- -Hub casings
- -Turbine towers
- -Gearbox

Large-Scale Metal Printing

Electron Beam Melting (EBM):

- A high-power electron beam selectively melts electrically conductive metal powder

Pros: Fast, vacuum required, low thermal stress
Cons: Produces x-rays, few materials

Figure 3. EBM Melt Pool[1]

[1]Auto Desk, "Electron Beam Melting." [Online]. Available: https://redshift.autodesk.com/electron-beam-melting/.

Direct Metal Laser Sintering (DMLS):

- Focused laser beam selectively melts metal powder

Pros: Good surface finish, high resolution
Cons: Slow, large amount powder to fill bed

Figure 4. DMLS Machine[2]

[2]John Hewitt, "3D printing with metal: The final frontier of additive manufacturing," [Online]. Available: https://www.extremetech.com/extreme/143552-3d-printing-with-metal-the-final-frontier-of-additive-manufacturing. Accessed: July 20, 2017.

Powder-Binder Jetting:

Selected

- Alternating layers of sand and binder
- Build up a mold in which the desired metal is cast

Pros: Cheap, large scale, bridge to conventional
Cons: Rough surface finish, one use mold

Figure 5. ExOne Sand Cast Printer [3]

[3] "Inside ExOne," English. [Online]. Available: http://www.exone.com/. Accessed: July 10, 2017.

Radial-Flux Permanent-Magnet Direct-Drive Generator (PMDD)

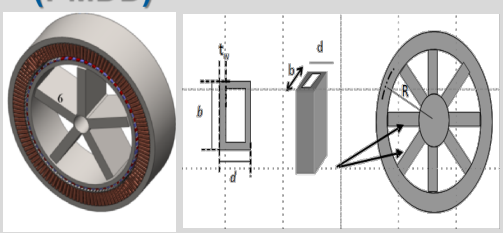
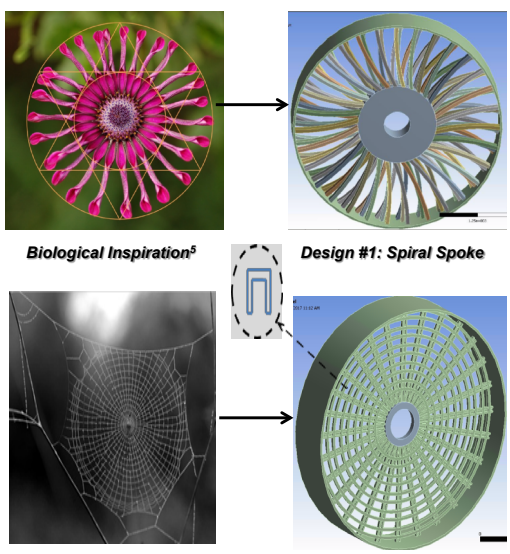


Figure 6. PMDD radial-flux generator structure[4]

[4] L. Sethuraman, K. Dykes. 2017. GeneratorSE-A Sizing Tool for Variable-Speed Wind Turbine Generators. NREL/TP-5000-66462. National Renewable Energy Laboratory (NREL), Golden, CO (US). https://www.nrel.gov/docs/fy17osti/66462.pdf.

Bio-Inspired Rotor Designs



Biological Inspiration[5] — *Design #1: Spiral Spoke*

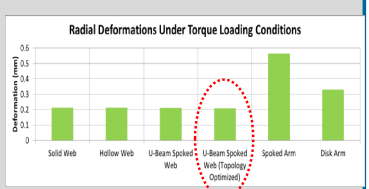
Biological Inspiration[6] — *Design #2: U-Beam Spoked Web*

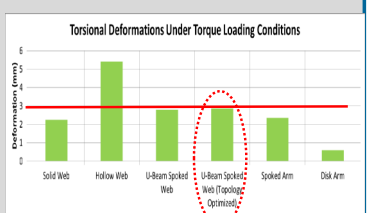
Figure 7. Additive manufacturing rotor designs

[5]"Flower Power Geometry," [Online]. Available: http://joedubs.com/flower-power/ Accessed: February 2017.
[6] A. Grinshpan, "Spider Web Geometry Characterization," Mathematics Umbrella group. [Online]. Available: http://shell.cas.usf.edu/math/mug/0511.htm.

Structural Analysis

- All bio-mimetic designs depict 60% less radial deformation
- Torsional deformations within 3.03 mm limit under torque loading for all except hollow web
- Axial deformation never exceeds critical value (30 mm)





Mass Savings

- U-beam spoked web design 24% less structural mass
- Topology optimization removes unnecessary material

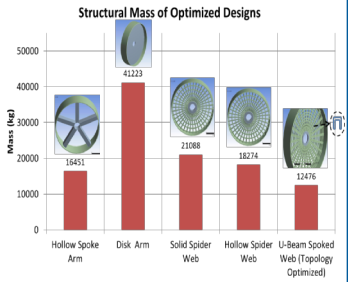


Figure 8. Mass of designs

Mold Analysis and Costing

Is Additive Manufacturing More Expensive?

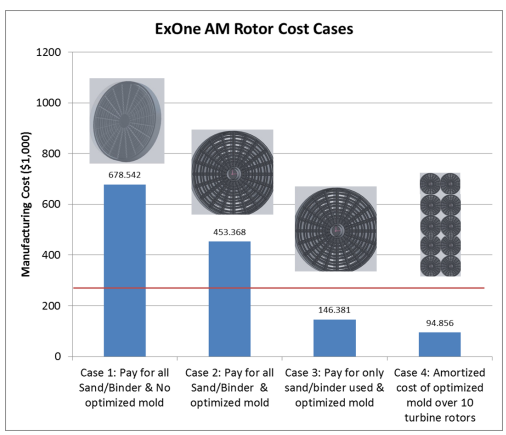
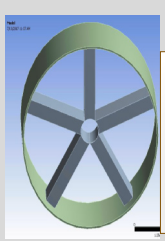


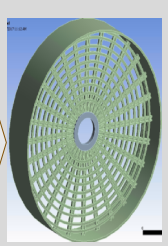
Figure 9. Additive manufacturing costing results

- For single-use sand cast molds, additive manufacturing is more expensive than conventional means.
- Optimizing mold volume reduces costs of additive manufacturing by 38%.
- Additive manufacturing is economical when using indirect tooling (i.e., a mold of a mold).

Conclusions



I. 24% less structural mass
II. 60% less radial deformation
III. Additive manufacturing enables design for functionality
IV. Potential 40% cost savings



Areas of Future Work

I. Stator light weighting using lessons learned from rotor.
II. Advanced bio-mimetic designs with lattice creation
III. Improve conventional and additive manufacturing costing models

Acknowledgments
The lead author would like to thank Lee Jay Fingersh for his mentorship and answering questions as well as giving amazing tours of the NWTC. The lead author would also like to thank Latha Sethuraman for teaching her about electric machines, answering her questions, and helping her continue her work, as well as Katherine Dykes for her costing help. This work was supported in part by the U.S. Department of Energy, Office of Science, Office of Workforce Development for Teachers and Scientists under the Science Undergraduate Laboratory Internships Program.

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International Conference on Future Technologies in Wind Energy
Boulder, CO
October 24–26, 2017
NREL/PO-5000-70322