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Original Research Article

3D printed wind turbines part 1: Design considerations and rapid manufacture potential

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ABSTRACT

Recent advances in additive manufacturing (AM) and Fused Material Deposition (FMD) techniques have resulted in the commercialization and popularization of what is commonly known as 3D printing. Small wind turbine technology stands to benefit greatly from this technology when considering turbines intended for disaster relief and rural electrification. With the appropriate design, wind turbines could be rapidly manufactured (printed) and assembled on-site at an as needed basis without additional tooling beyond a 3D printing machine and printing filament. This paper examines the design considerations of such a wind turbine including material properties, reinforcement techniques, integration of non-printed components, printed component design and print optimization. A rapid manufacture-able design is presented of vertical axis configuration. Conclusions are drawn as to the viability and practicality of 3D printed wind turbines and opportunities for future work are identified.

Introduction

Additive manufacturing

Recent advances in additive manufacturing (AM), a construction technique where a three dimensional object is created through the build-up of thin layers of a base material, have resulted in the commercialization and popularization of what is commonly known as 3D printing (3DP). Objects for 3D printing are stored in digital files for modification using 3D modeling software, and are easily copied, and transferred via the internet.

Development of additive manufacturing technology began in the late 1970s with the grant of a patent to Wyn Kelly Swainson for a process where a three dimensional object is created through the build-up of photopolymer material [1]. A computer controlled laser is used to solidify a liquid puddle of plastic monomer [2]. This method is in continued use today and has become known as the Laser Sintering process. One of the main disadvantages of this process, which slowed the technologies main-stream acceptance and popularity, is cost, as very expensive laser equipment is required in each printer.

Following the initial patent grant for the Swainson invention the international scientific and industrial community sought to patent all straight-forward means of additive manufacturing through the build-up of object layers [3]. One such technology which had been developed and patented is known as Fused Material Deposition (FMD) [4] which builds up a 3D model through layers of a thermoplastic material which is heated and extruded through a computer controlled nozzle. This technology has the advantage of utilizing a simple and inexpensive extrusion process as depicted in Fig. 1.

This process did not gain considerable popularity until the expiration of the original patent when in 2007 Adrian Bower described a FMD based printer which would be self-replicating – i.e. able to print the majority of parts from which it is constructed [5]. This began the online-collaboration project known as RepRap which sought to develop a self replicating 3D printer to be released under open-source license around the world. This project was a success with several designs being released and available in kit form at a very low cost. Original RepRap designs have been thoroughly optimized and refined by several companies which have adopted this technology for commercial use such as Makerbot, Ultimaker, and Airwolf 3D. As a result of the RepRap project prices for 3D printers fell by a factor of ten from the period of 2008 through 2011 [6]. Many assembled 3D printers are now commercially available for

Abbreviations: ABS, Acrylonitrile Butadiene Styrene; AM, additive manufacturing; CNC, Computer Numerical Control; FMD, Fused Material Deposition; HMA, hot melt adhesive; PLA, Polylactic Acid; RPM, Revolutions Per Minute; VAWT, Vertical Axis Wind Turbine; 3DP, Three Dimensional Printing.

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less than $1500 USD and complete printer kits for less than $600 USD.

Additive manufacturing stands in contrast to traditional subtractive manufacturing process where material is removed from a stock piece of base substrate to create a component. Computer controlled subtractive processes include single and multi axis CNC machines, lathes, laser and water jet cutting tables. While a variety of three dimensional shapes can be created through subtractive process the technology suffers from the drawback as material is removed at all locations where the tool patch insects the component. Certain hollow and shell components cannot be made through subtractive means. For an additive process a deposition path can be generated such that the extruder does not pass through the same point in space more than once and thus hollows and shells are easily created.

Alternate approaches to hollow creation widely used in industry include casting, forming and extrusion processes. These dies and moulds are made from a tool material and are used to shape a molten or semi-molten material. Although these methods increase the shapes possible for mass manufacture, they are still unable to make many double hollow shapes and ones with intersecting internal passageways. One example is a fuel injector swirler component which would be impossible to cast but produced easily on a 3D printer [7].

Applications for wind energy technology

The primary and historic application of 3D printing technology for wind turbines has been through rapid prototyping – where a model of a part for industrial manufacture is produced through the 3D printing process such that engineers and designers can test certain component properties within a controlled environment before releasing a design into full production. Typically scale models of larger components are printed. 3DP rapid prototyping has been utilized in the sustainability technology sector to produce aerodynamic research models [8] hydro turbine prototypes [9] and recently micro-scale wind turbines [10]. In each of these cases the printed parts were prototypes simulating the construction and shape of the manufacture-able part in different materials and construction means.

With the emergence of affordable and accessible 3DP technology there is the opportunity for wind energy to realize a second, and potentially equally impactful benefit. By considering the approach of designing small wind turbines as a modular assembly of components for direct manufacture by a consumer level 3D printer, new opportunities are presented for decreasing cost, reducing waste and increasing accessibility for wind turbines around the world. This approach extends beyond rapid prototyping and into rapid manufacturing, defined as the direct production of finished goods from a rapid prototyping device [11].

Rural electrification, disaster relief and humanitarian projects stand to benefit from this approach applied to small wind turbine technology. Rural electrification projects where wind energy can be employed to provide basic electricity as previously studied and developed by authors Bassett et al. [12,13] have potentially profound benefits as wind turbines can be manufactured essentially on-site at an as needed basis to meet energy needs with minimal tools, material and knowledge beyond a 3D printer and filament. Due to the low cost of filament material, capable printers available for as little as $1000, and the minimal labor required, small wind turbines can potentially be produced at a drastically reduced cost.

This can be viewed as the next logical progression in the RepRap project goal of a self-replicating machine. When combining a RepRap 3D printer with an appropriately designed wind turbine the self-replicating principal is extended as the printer can not only physically create its own components but also create a device (the wind turbine) to power its operation. This approach should be applied for other renewable energy technologies as well, particularly small hydro turbines, where the power to size ratio is much greater than for wind turbines.

It is the authors' opinion that wind turbine technology can experience the drastic cost reduction similar to the 3D printer when rapid manufacture is applied via the self-replicating design.

To realize such benefits several design aspects must be considered including material properties, sizing of turbine components based on print size limitations, reinforcement techniques, integration of non-printed parts, and print optimization. The design of the turbine must also be considered in the context of a new set of operations where builders acquire knowledge of 3D modeling software, and print operation and optimization [11].

To investigate the potential design challenges associated with a rapid manufacture-able wind turbine solution, the authors proceeded with the development of one such design adapted from the Venecia-style turbine as presented in [12]. This design was selected as the basis for the initial prototypes due to the author's familiarity with its general performance and construction. The following sections relating to rapid manufacture of a small wind turbine are presented in the context of the Venecia VAWT but the

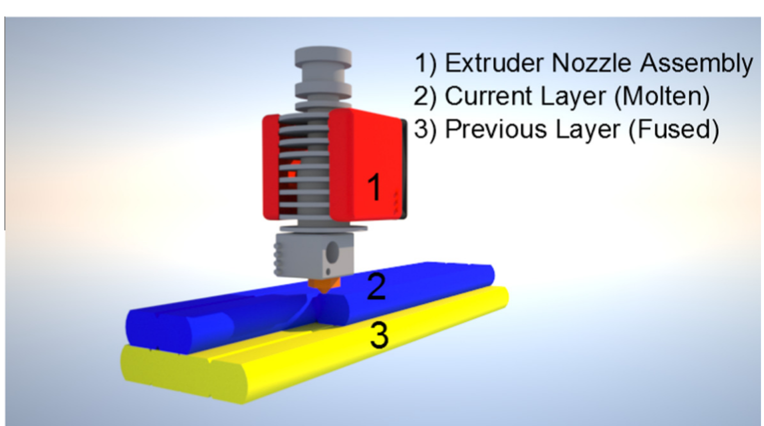

Fig. 1. Fused Material Deposition process through extruded thermoplastic. Other printer components not shown for clarity.