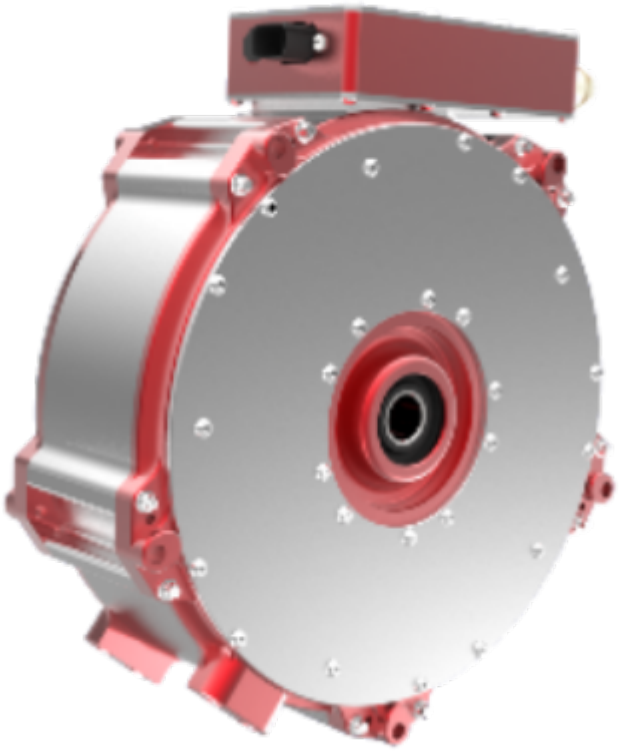
MOTORPRINTER



SYNCHRO-SYM Technologies

– MOTORPRINTER: Only Practical Electric Motor and Generator 3D Printer Method –

Our Mission:

Innovate For Our Clean, Efficient, and Sustainable Energy Future!

MOTORPRINTER

MOTORPRINTER → BOTTOM LINE UP FRONT:

MOTORPRINTER is a patented *3D Printer for the low cost, rapid, just-in-time additive manufacture of the highest performance electromagnetic axial-flux cores with integral frame and winding assemblies for low or high frequency, high power electric motors, generators, and transformers* (**i.e., electric machines**).

MOTORPRINTER *uniquely* layers readily available materials that are optimally pre-manufactured to be ultra performance/price enhanced: 1) for the electric machine magnetic core component, such as ultrathin, high performance amorphous metal or nanocrystalline metal ribbon that *provides 10x the permeability and 80% lower core loss than electrical steels but with similar flux saturation*, 2) for the integral structural frame component, such as high performance structural building materials, and 3) for the multiphase winding component, such as high performance shaped magnetic wire. In contrast, layering material of all other 3D Printers is optimally pre-manufactured to be performance/price compatible with the 3D Printer and not for the electric

machine product being manufactured. As a result, a practical electric motor 3D Printer has never materialized until MOTORPRINTER.

MOTORPRINTER *is essential for manufacturing high power, high frequency magnetics* (e.g., transformers) with the highest performance magnetic materials: a) for leveraging the switching speed, high temperature performance of wide bandgap semiconductors, b) for facilitating high efficiency and compact power conditioning, c) for automatic frequency and phase translation, such as only provided by a position dependent flux high frequency transformer of Brushless Real Time Emulation Control (BRTEC), and d) for implementing the only symmetric synchronous electric machine system, called SYNCHRO-SYM.

MOTORPRINTER is essential for solving the manufacturing production and thermal management challenges and the structural, permeability, and flux saturation limits of soft magnetic material, such as found in RE-PM YASA style electric motors, with the unique ability of forming perfectly aligned slots and channels of any programmable shape for windings, permanent magnets, reluctance saliencies, or thermal management in high permeable and structural solid nanocrystalline or amorphous ribbon materials.

MOTORPRINTER *eliminates the high capital equipment, offshored oppressed labor, and large facility costs of traditional century old, industrial powered, highly capitalized assembly line electric machine manufacture* with a portable, scalable, household power, low waste, non-smokestack, compact, remotely controlled, additive manufacturing footprint (e.g., shipping container).

MOTORPRINTER revolutionizes and democratizes the manufacture of axial-flux high frequency and low frequency electric motors, generators, and transformers with a rapid, just-in-time, compact, scalable, low waste, non-smokestack, remotely

controlled, self-contained 3D Printing method, which provides a competitive advantage over all other electric machine manufacturers.

MOTORPRINTER (with BEM-CAD) innovates a novel thermal management system, which allows for higher power density, lower winding resistance and sustained core electromagnetic properties, which are directly related to operating temperatures, and avoids component damage, which are directly related operating temperatures, such as winding resistance, curie points, semiconductors, etc.

MOTORPRINTER → DETAILS:

MOTORPRINTER is a patented “method” for the low cost, rapid, just-in time *additive* manufacture of ultrahigh performance, low or high frequency, high power *axial-flux* electric motor, generator, and transformer cores (i.e., axial-flux “electric machine” cores) of any programmable size or power rating: 1) with readily available, environmentally friendly, and optimally pre-manufactured layering materials (*i.e., feedstock*) with electromagnetic, structural, and thermal properties that are exclusively made for the highest performance of the electric machine product, such as ultrathin nanocrystalline, amorphous, or electrical steel ribbon, magnet wire, and structural materials, instead of traditional layering materials that are specifically manufactured for compatibility with the 3D Printer, 2) cores with highest performing, ultrathin electrical steel, amorphous metal, or nanocrystalline metal ribbon that has been impractical with conventional electric machine manufacturing due to high tool wear, material property damage, or ultrathin material machine

dexterity, 3) with perfectly aligned slots and internal channels of any programmable shape (for containing windings, permanent magnets, reluctance saliencies, cooling channels, etc.), 4) without damaging the delicate attributes of the pre-processed high performance materials, such as amorphous metal ribbon, that has been impractical with conventional electric machine manufacturing due to high tool wear, material damage, or ultrathin material machine dexterity, 5) without the extraneous time, material damage, tool wear, and cost of secondary or post-process operations, such as Blanchard grinding for a perfectly flat air-gap surface, 6) without tool wear, 7) with the magnetic flux ideally confined to the solid, low loss, high permeable, non-crystalline core material, 8) with winding and integral frame assemblies from inexpensive, readily available, optimally pre-manufactured, high performance magnet wire and structural steel, aluminum, or composite building materials, instead of the traditional inventory of pre-designed and pre-ordered casted components, and 9) with production scaling by vertically (stacking) or horizontally (grouping) adding another small, household power, self-contained MOTORPRINTER footprint.

The ideal 3D Printer would additively deposit one molecular layer at a time with product centric material properties, but no such 3D Printer exists at this time. Instead, all 3D Printers additively layer pre-manufactured materials one laminate layer at a time, such as powders, filaments, welding, or in the case of MOTORPRINTER, non-crystalline metal ribbon. Also, all 3D Printers implement some degree of subtractive manufacturing for at least finishing the product dimensions.

NOTE: *Electric machines, which include compact and efficient high frequency transformers, are the essential backbone components of the entire electricity infrastructure.*

Furthermore, magnetic core material with high flux saturation limits, high permeability, and low core loss that can be conveniently manufactured into high power, high frequency magnetic cores is essential. Evolving material science is improving nanocrystalline or amorphous metal ribbons for high power, high frequency cores while preserving low loss, high flux saturation, and high permeability but still, manufacturing of moderately complex transformer cores with these materials has not been practical. Also, soft magnetic composite materials, such as ferrite, show low permeability, low flux saturation limits, or are difficult to structurally form in the large size factor for high power applications. As the only empirically proven laminated object manufacturing (LOM) 3D Printer for electric machines with solid amorphous or nanocrystalline metal ribbon, the patented ***MOTORPRINTER*** *is an essential enabler of the smart electricity infrastructure.*

NOTE: *As a patented "method," which protects the manufacturing IP and more importantly, the product manufactured with the IP, MOTORPRINTER will democratize the distributed manufacture of electric machines by mitigating unfair trade practices*, such as offshoring for low cost oppressed labor, and by conveniently localizing and scaling rapid just-in-time electric machine manufacturing at the research facility, at the boutique motor manufacturing facility, or at the traditional OEM manufacturing facility.

NOTE: *Unlike all other 3D Printers, which utilize specially pre-manufactured raw materials that are specifically compatible with the 3D Printer without regard to the product being 3D Printed, MOTORPRINTER rapidly 3D Prints axial flux electric machines just-in-time by directly using readily available pre-manufactured materials that are optimized to the lowest cost and highest performing electromagnetic, thermal, and structural properties for the highest electric machine efficiency and smallest size, such as amorphous metal ribbon. As a result, MOTORPRINTER is the only 3D Printer of electric*

motors, generators, and transformer because the specific electromagnetic, structural, and thermal properties of the premanufactured layering materials are preserved during the additive manufacturing process.

NOTE: *Although virtually the entire base of rotating electric machine manufacturing is devoted to the radial-flux form (or rotor cylinder inside a stator cylinder form) because of traditional manufacturing technology limitation, the axial-flux form of electric machine (or adjacent stator and rotor disks) has been shown to reduce copper utilization by 13-14% and iron utilization by 21.5-32.5%, while providing higher torque density and finer air-gap depth control without rotor and stator surface contention during over speed but requires a more robust frame and bearing assembly.*

NOTE: *Unlike a radial-flux form (i.e., cylinder inside cylinder) that fills in empty space with extra core and structure, the symmetrical structural and electromagnetic form (i.e., adjacent disks) of the axial-flux form optimally utilizes the rotor and stator real-estate and as a result, are similar active (stator or rotor) or passive (rotor) disks.*

NOTE: *Axial-Flux electric motors have flexible control over diameter and length by the convenience of stacking multiple motors lengthwise, which also provides fault resilient redundancy. For example, smaller diameter, lower power motors can be stacked for a longer but larger power motor with a smaller diameter, instead of designing a single, larger power rated, larger diameter motor.*

NOTE: *The axial-flux formfactor provides a non-obstruction outside-to-inside winding approach for automation of any winding style with the potential for orthocyclic winding fill factor (e.g., 90%). In contrast, the radial-flux inside-to-outside winding approach is not friendly to automated winding, except for the hairpin winding style, which may provide a high fill factor (e.g., 90%) and efficiency at low speeds.*

MOTORPRINTER's axial-flux formfactor at least neutralizes any perceived advantages of hairpin windings, while providing rapid, just-in-time additive electric machine manufacture.

***NOTE:** Under design control of BEM's computer aided design tool (**BEM-CAD**), MOTORPRINTER simultaneously 3d-Prints the high frequency power magnetic core of the electronic power conditioner conveniently integrated into the annulus of the low frequency axial-flux electric machine core for another level of electric machine system power density. In contrast, all others electric motor manufacturers place the entire power electronic real-estate, which includes the high frequency magnetics, of the so-called smart motor system in a separate box chassis mounted on the outside of the electric motor frame.*

***NOTE:** Where other electric machine manufacturers traditionally repackage and manufacture their me-too asymmetric electric machine system from the same off-the-shelf core stamped laminations, castings, etc., BEM is just-in-time, additively manufacturing the only symmetric synchronous doubly-fed electric machine system, called SYNCHRO-SYM, with its patented 3D Printer of amorphous metal axial-flux electric machine cores with integral frame and winding assemblies, called MOTORPRINTER.*

***NOTE:** With the unique ability of forming perfectly aligned slots and channels of any programmable shape for installing windings, permanent magnets, reluctance saliencies, or thermal management in high permeable and structural solid nanocrystalline or amorphous ribbon materials, the manufacturing production and thermal management challenges and the structural, permeability, and flux saturation limits of soft magnetic material, such as found in RE-PM YASA style electric motors, are solved*

***NOTE:** In theory, the windings and magnets of axial flux electric machines are robustly held by the core against*

centripetal force, instead of held against the air-gap (e.g., radial flux electric machines. Many consider axial-flux electric motors and generators as the future, particularly for electric vehicles.

The patented **MOTORPRINTER** performance with amorphous metal ribbon has been empirically studied, tested, and successfully proven by the formulation, orchestration, and coordination of BEM with the original inventor, with the foundry of amorphous metal ribbon (i.e., Metglas), and with several fiber laser companies (e.g., IPG Photonics). More information can be found in the MOTORPRINTER whitepaper and a study by Metglas. Also, BEM developed a Computer Aided Design tool (**BEM-CAD**) for the design and programming of MOTORPRINTER manufacture of axial flux electric machine cores with integral frame, bearing bezel, and winding assembly.

Only MOTORPRINTER under the programmable control of BEM-CAD will revolutionize and democratize the manufacture of superior performing low and high frequency, axial-flux electric motors, generators, and transformers and neutralize the advantage of offshoring manufacturing with exploited labor by providing distributed, field programmable, just-in-time, additive manufacture in a small, deployable footprint.

It follows that being compatible with available, highly optimized, premanufactured layering material, MOTORPRINTER fabrication, integration, and manufacturing operation has no risk without the customary engineering solution.

MOTORPRINTER → WHITE PAPERS:

THE NEED FOR 3D PRINTING OF AIRPLANE ELECTRIC MACHINES