Depositing Charged Metal Particles

Logan Marlow and David Rubrecht
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TA - Sam Sagan

1 - Introduction

1A - Objective

Additive manufacturing, also known as 3D printing, is a method for creating complex structures given any design without the need for elaborate hand crafting or machining. Similar to printing onto paper, a 3D printer takes a digital file and outputs a flat pattern onto some base. Except 3D printing doesn't stop there. True to its name, the Z axis is added to the previously glory hogging X and Y axises. Through various means, layer upon layer of patterns are built up, eventually yielding a three dimensional object. By having an automatic means of making complex shapes, people with ideas that are lacking in either crafting skills or access to a machine shop can easily see their imagination printed before their eyes.

Our goal is to work towards making additive manufacturing scalable with conductive materials, specifically metals. By designing and creating an apparatus that reliably charges and deposits small amounts of metal particles, we would be one step closer to a system that can reliably thermally isolate metal particles. Our idea is to use a conically shaped plastic container that holds a moderate amount of metal powder. Using controlled rotation of a cylinder placed at the tip of the cone, metal particle(s) can be dropped reliably. Charging of the powder will be accomplished through electrical capacitance, placing an electrically insulated lead with a positive voltage applied near the top of the powder and a negative (ground) plate at the bottom. The surface charge on the powder towards the bottom (tip) will be negative, giving the dropped particles a net negative charge. Future continuations of this project can suspend these charged metal particles in air with dynamic electric fields, thermally isolating them while holding them steady for heating (through laser, maser, or electron beam).

1B - Background

Currently, metal 3D printing is restricted to objects of small volumes. Techniques such as direct metal laser sintering (DMLS) are expensive to use and become increasingly difficult to scale to large manufacturing volumes. They operate by having a perfectly level bed of powder that then has a pattern sintered on it via an overhead laser or electron beam. The pattern is then sunk 1 layer of metal powder deep through vibration or a thin layer of powder is spread over the pattern. More layers are added in this fashion. While this technique allows for a high degree of resolution and speed, it has some glaring limitations. Having such a large surface area of powder exposed to air leads to much of the powder becoming oxidized. Also, the larger the volume of manufacturing space that is attempted, the more difficult it is to prevent convection currents from creating turbulence in the air, causing unevenness in the powder bed surface. In addition, the thermal conductivity of the powder forces the sintering means to either be extremely powerful or the entire volume must be kept at high temperatures. Other methods exist for printing 3D metal designs, but they all either too material inefficient or imprecise to be used widely[1].

Our device will enable a new technique of metal 3D printing; one that is precise, efficient in power and materials, and most of all, scalable.

1C - High Level Requirements

- Must drop/deposit particles in consistently less than 10 particles.
- Must drop particles in a consistent location, with less than 10 square mm of spread.
- Deposited particles must be charged, with a consistent magnitude of Coulombs.

2 - Design

The overall device will require 4 main modules; power, control, a charging unit, and a dispensing unit. This power supply must be able to reliably convert 120 VAC into 2 different DC voltages, 5V for controls and 12V for higher power modules. The control unit is composed of a microcontroller and a LED that indicates the current state of the device. The charging unit will take the higher voltage power line to power the charging shell and powder. The dispensing unit will also use the higher voltage line to feed a stepper motor driver.

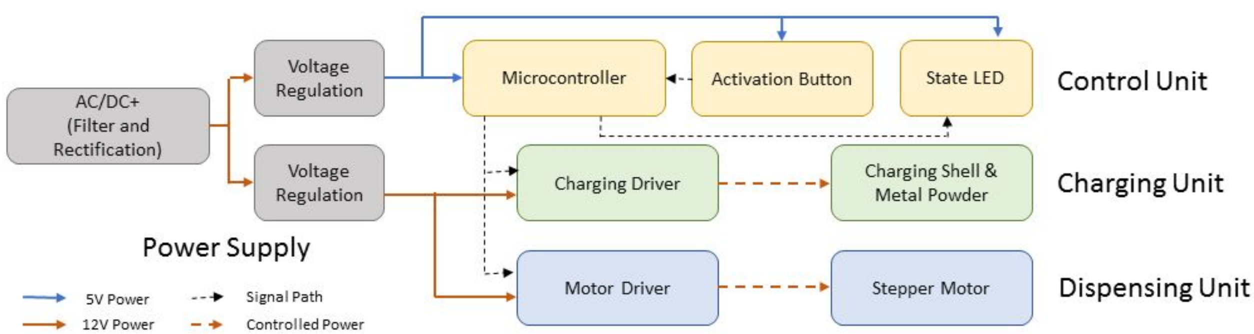

Figure 1 - Block Diagram

2A - Physical Design

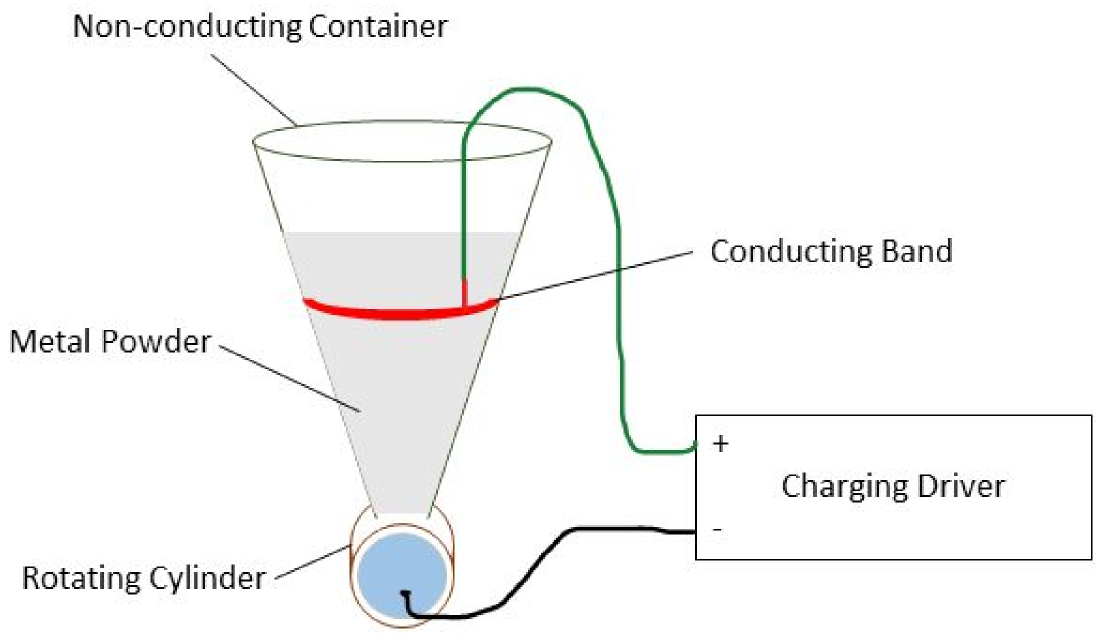

Figure 2 - Physical Layout

Mechanically, there is only 1 component that requires attention. The rotating cylinder involves multiple electrical modules as well as precise fabrication, making it an aspect that requires high tolerances. For an in-depth explanation and analysis of the rotating cylinder, please refer to section 2F - Risk Analysis.

Overall, the unit operates through the conical device shown in Figure 3. A non-conducting container holds the metal powder, which comes to a taper at the junction with the cylinder. The container must have a tight seal with the rotating cylinder, preventing powder from leaking out. Also interior the container, a conducting metal band lines the central latitude of the container. Connected to the positive end of the charging driver, this will be the electrical connection between the driver circuit and the metal powder. To avoid too much amperage from traversing too little volume of metal powder, the surface area of the connection is increased by making the band circumvent the interior of the container.

It should be noted that a stepper motor is connected directly to the rotating cylinder, but was not included in Figure 3 due to a lack of artistic skill. That motor will be powered and controlled via the dedicated motor driver (section 2E).

2B - Power Supply

A twin output voltage power supply is necessary to both adequately energize the stepper motor and charging unit and provide the lower voltage to power some of the control units. AC wall power will be simultaneously transformed, rectified, and regulated into 2 DC voltage rails.

2Ba - AC/DC Filter and Rectification

The AC power from a standard US power outlet must be filtered, transformed, and rectified to produce robust DC power lines for both the low power microcontroller and the power hungry motor/charging unit. Must provide robust DC voltages to be regulated and used throughout the device.

Requirement 1: Must adequately convert 120 VAC at 60Hz to 2 voltage rails.
Requirement 2: The higher rail needs to provide >2.01A. at 12 volts.

2Bb - Voltage Regulation

DC power outputted from the rectifier needs to be effectively regulated and smoothed so as to not disturb the operation of the microcontroller or the driver ICs. 2 separate instances will be used.

Requirement 1: Lower voltage regulator outputs 5V +/- 5% from a input source of 5 volts.
Requirement 2: Higher voltage regulator outputs 12V +/- 5% from a input source of approximately 12 volts.

2C - Control Unit

An ATmega328 will control the state of the dispensing unit and charging circuit, which will be indicated to an external user with a state LED. The state of the device will be dictated through an internal finite state machine and user input through a button. In the future, this unit will also control a levitation unit given input from infrared sensors.

2Ca - Microcontroller

An ATmega328 will keep track of the position the stepper motor rotor (counting steps) as well as the time ‘On’ in the charging circuit. It will use digital output pins to control the two driver circuits[5].

Requirement 1: Must have at least 3 digital output pins and 1 digital input pin.

2Cb - State LED

LED to simply indicate the current state of the device, and for some basic debugging. The LED will be used to indicate whether the device is in the idle, charging, or dispensing state.

Requirement 1: Can be reliably illuminated to be visible from 1 meter away.

2Cc - Activation Button

External button that is pressed by a user to dispense 1 unit of metal powder. Uses the 5V power rail to signal the microcontroller a HIGH or LOW signal

Requirement 1: Outputs 5V as HIGH and 0V as LOW signal.
Requirement 2: Doesn't shock user upon contact (insulated from 12V rail).

2D - Charging Unit

Using a capacitive method of accumulating charge, a driver controlled by the microcontroller will apply a voltage across the metal powder and the insulated metallic 'ground' shell. After a given amount of time, the charging unit will be briefly switched off for the dispensing/dropping of the metal particle.

2Da - Charging Driver

The charging driver will receive a signal from the microcontroller to indicate if it is to be powered or not. It will then connect the higher voltage line to the charging shell and powder. To accomplish this, we will use a transistor because it is easy to turn on or off using a signal from the microcontroller, and because it easily accomplishes the intended task.

Requirement 1: Must be switched on from a signal of 5V (+/- 5%) and off from signal of 0V (+ 5%).
Requirement 2: Must be able to pass through 12V from power supply with max current of 500 mA.

2Db - Charging Shell and Metal Powder

An electrically insulated container holding metal powder, with a rotating cylinder at the bottom used to dispense small quantities of metal powder. The powder must be electrically in contact with the positive lead of the charging driver's 12V. The rotating cylinder must be insulated from the powder (electrically), but must be used as the 'ground' for the capacitive charging.

Requirement 1: Container is electrically insulated.
Requirement 2: Cylinder is not electrically in contact with the powder.
Requirement 3: Cylinder prevents the pouring out of the metal powder when stationary.
Requirement 4: The metal powder must be in contact with the charging driver's 12V positive end.
Requirement 5: Cylinder must behave as the 'ground' of the driver's 12V line.

2E - Dispensing Unit

Using a driver and it's corresponding stepper motor, must be able to reliably and accurately rotate the cylinder in a controlled fashion. Will use motor's rotation to dispense consistent amount of metal powder.

2Ea - Stepper Motor Driver

The stepper motor driver will be controlled by the microcontroller using an enable signal and a signal that will instruct it to step in either a clockwise or counterclockwise direction. The driver will use the 12V power rail to deliver constant current in a timed fashion to the stepper motor, allowing the motor to be controlled by the microcontroller indirectly.

Requirement 1: Takes 2 digital 5V input signals, for stepping and direction.
Requirement 2: Takes 12V power rail to output 2 stepper motor coils each 1.7A.
Requirement 3: Each output of 1.7A must be able to be sent either direction through the motor coils.
Requirement 4: Current through motor coils must follow 2-phase bipolar order and direction for each step.

2Eb - Stepper Motor

Bipolar 2-phase stepper motor for reliably rotating the cylinder. Using discrete step sizes, microcontroller can keep track of relative orientation by counting each step and direction.

Requirement 1: Must be bipolar and 2-phase.
Requirement 2: Must be discrete and precise in amount of degrees rotated per step.

2F - Risk Analysis

The rotating cylinder, which is a mechanical component of both the charging and motor modules, poses the greatest risk of failure. The cylinder must be able to rotate 360 degrees, provide enough of a seal to prevent extraneous particles from leaking, and act as the ground plate in the capacitive charging. While each task is easy to accomplish individually, combining each in a reliable component can add unforeseen obstacles and complicated implementation details.

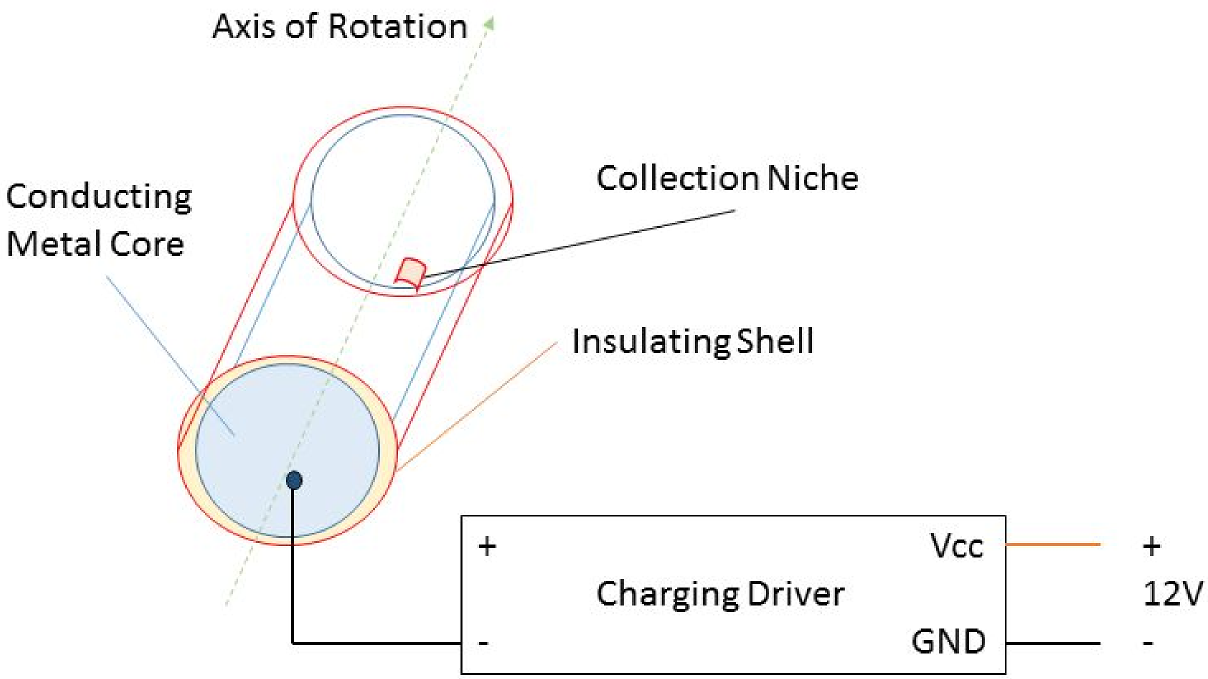

FIgure 3 - Rotating Cylinder

As shown in Figure 3, the rotating cylinder can be broken down into a series of components. Being the 'ground' plate of the charging module and attempting to avoid fringing effects of non-parallel field lines, our current design has the cylinder being composed of mostly metal (aluminum or otherwise). That metal core is then tied to the negative (ground) end of the charging driver, allowing the electric field used for the capacitive charging to always be orthogonal to the surface geometry of the metal powder. This metal core will be non-conducting with the metal powder, separated by an insulating dielectric. This dielectric can be a plastic coating (applied by spraying or dipping in melted vinyl) or a wrapped layer (Teflon).

In terms of dispensing the metal powder, a collection niche(s) can be used. Small negative spaces in the coating (shallow enough to remain insulating from the metal core) can be used to collect small amounts of the metal powder. When rotated to have the niche's normal vector pointing towards the ground, the accumulated powder will fall. It should be noted, based on both the mass of the individual particles and charge accumulated on each particle, they may not fall, even when oriented perfectly downwards due to the electrically attractive force of the capacitor. If this is the case, it is a simple matter of switching off the charging driver and allowing the built up charge on the metal core to dissipate enough for the gravitational force to overcome the electrical attraction.

3 - Safety and Ethics

The primary area of concern for our device is in the charging unit. Metal powder can be very volatile and can even explode under certain circumstances. According to Particles.org, “(1) the dust must be suspended in air or gas supporting combustion, (2) must have particle size capable of propagating a flame, (3) dust concentration must be in the explosive range…, (4) must be above minimum ignition temperature…, (5) there must be an ignition source of sufficient energy.”[2].By insuring the charging unit prevents electrical arcing from occurring we can be reasonably sure our device will not have an ignition source to set off a reaction. To ensure this the charging unit will be turned off when not in use, and the metal powder will be insulated from conductors that it could possibly arc to. The flash point of our intended test metal, titanium, is 480 degrees fahrenheit (249 degrees celsius)[3]. The charging unit of our device does not inherently generate any heat, so the metal powder should be kept at room temperature, well below the flash point. We can be sure of this as the metal powder has relatively low resistance according to the experimental findings of Montes, Cuevas, and Cintas[6]. Furthermore, our hopper design, which is intended to keep the charged metal in electrical contact in order to facilitate capacitive charging, will prevent the metal from dispersing in the air. Thus, any threat of fire or explosive hazard has been substantially reduced. Though our device is intended to separate small portions of metal dust and drop them through the air, these miniscule portions are not substantial enough to be in the explosive range or to propagate a flame.

Another area of concern is the power supply. As with any power supply, there is a concern for electrical shock, burns, and fire. Our power supply must adhere to the US safety standard UL60950-1 to reduce the chance of injury occurring while the device is in use[4].

The completed form of this project would allow metal fabricators to manufacture their products at a faster rate, but this has the consequence of possibly reducing the number of jobs available in this industry. It is also true that we cannot be sure what types of items will be manufactured using our device and it is conceivable that someone could use it to produce weapons, or some other means of bringing harm to others. These issues conflict with the IEEE code of ethics #9 because our device can potentially be used to harm others or cause them to lose their jobs[7].

Unfortunately there is no way for us to control how our device will be put to use. We do not believe that the possibility of misuse of our device warrants that we should not develop it, as it is equally likely that it could be used to fabricate devices that will greatly benefit mankind or lower the cost of parts that are difficult to produce using current methods. Given the potential for our device to both do harm and good, we feel that the benefits outweigh the possible harm.

References

[1] i.materialise.com, “How Direct Metal Laser Sintering (DMLS) Really Works”, 2016, July 8. [Online]. Available: https://i.materialise.com/blog/direct-metal-laser-sintering-dmls/. [Accessed: 4 - Feb - 2017].

[2] particles.org.uk, “Powder hazards”, 2012. [Online]. Available: http://www.particles.org.uk/particle_technology_book/chapter_15.pdf. [Accessed: 4 - Feb - 2017].

[3] titanium.com, “Material Safety Data Sheet For Titanium Metal”, 2010, March 3. [Online]. Available: http://titanium.com/wp-content/uploads/2010/10/Material-Safety-Data-Sheet.pdf. [Accessed: 4 - Feb - 2017].

[4] B. Mammano and L. Bahra, ieee.li, “Safety Considerations in Power Supply Design”, 2005. [Online]. Available: https://www.ieee.li/pdf/essay/safety_considerations_in_power_supply_design.pdf. [Accessed: 4 - Feb - 2017].

[5] atmel.com, “Atmel 8-bit Microcontroller with 4/8/16/32kbytes In-System Programmable Flash Datasheet”, 2015. [Online]. Available: http://www.atmel.com/images/Atmel-8271-8-bit-AVR-Microcontroller-ATmega48A-48PA-88A-88PA-168A-168PA-328-328P_datasheet_Complete.pdf. [Accessed: 4 - Feb - 2017].

[6] Montes, J.M., Cuevas, F.G. & Cintas, J. Granular Matter, springer.com, “Electrical Resistivity of a Titanium Powder Mass”, 2011. [Online]. Available: http://link.springer.com/article/10.1007/s10035-010-0246-z. [Accessed: 4 - Feb - 2017].

[7] Ieee.org, "IEEE IEEE Code of Ethics", 2017. [Online]. Available: http://www.ieee.org/about/corporate/governance/p7-8.html. [Accessed: 4 - Feb - 2017].

[8] honeywellprocess.com, “Dielectric Constant Table”, 2011, June 24. [Online]. Available: https://www.honeywellprocess.com/library/marketing/tech-specs/Dielectric%20Constant%20Table.pdf. [Accessed: 4 - Feb - 2017].