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Designing the First Experimental Setup Using X-Ray Diffraction to Analyze the Metallurgic Additive Manufacturing Process *In-situ*

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Abstract
A conceptual design of a metallurgic additive manufacturing (AM) direct energy deposition (DED) 3D printer for an x-ray environment using the Cornell High Energy Synchrotron Source (CHESS) was designed and modeled in Inventor. The design includes the necessary translation and rotation stages required to print a sample part and analysis the part using a large flux of high energy x-rays. In addition, a generic MATLAB code was written that takes various input parameters and outputs the necessary x-rays exit window size on the AM box, so the diffracted x-rays can be projected out of the AM box and onto the x-ray detector.

Background, Application, and Motivation
Conventional metal manufacturing is a subtractive process that involves starting with a large block of metal that is machined (often cut/carved) to form the shape of the desired part. Metallurgic additive manufacturing (AM) is the opposite - starting with a blank canvas, a laser or electron beam fuses the powder metal to a metal substrate to 3D print the desired part. Not only does this technique save on material, it allows for more complex shapes and metal compositions to be made, as well as opening the doors for manufacturing metal parts in remote environments, such as out at sea and in space.

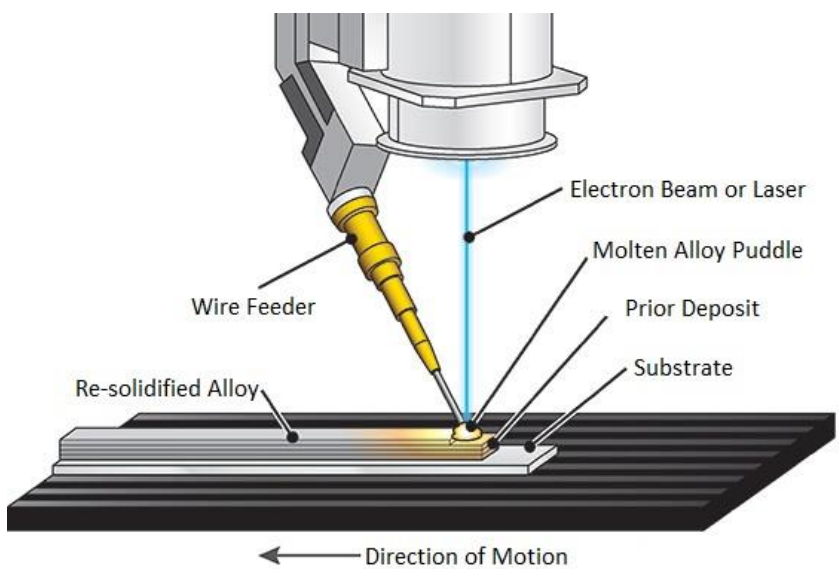

Figure 1. Diagram showing DED metallurgic additive manufacturing [Sciaky, 2018, EBAM].

Currently, AM parts lack structural integrity. The synchrotron at Cornell University provides a large flux of high energy x-rays that can be used to analyze AM parts as they are being built *in-situ* (in real-time) in order to better understand how the different factors affect AM final products. These factors include: solidification rate, microstructures, phase changes, residual stress, porosity, etc.

Determining the X-ray Exit Window Size

Unlike commercial additive manufacturing, this AM setup must accommodate an x-ray environment. There must be an entrance window where the x-ray beamline can pass through to reach the sample part of interest. Additionally, there needs to be a larger exit window where the diffracted x-rays can pass through and project onto the x-ray detector. A MATLAB code was written that takes various input parameters such as, the size of the sample part, and the location of the sample part relative to the detector and the inside of the AM box, and outputs the necessary x-rays exit window size on the AM box

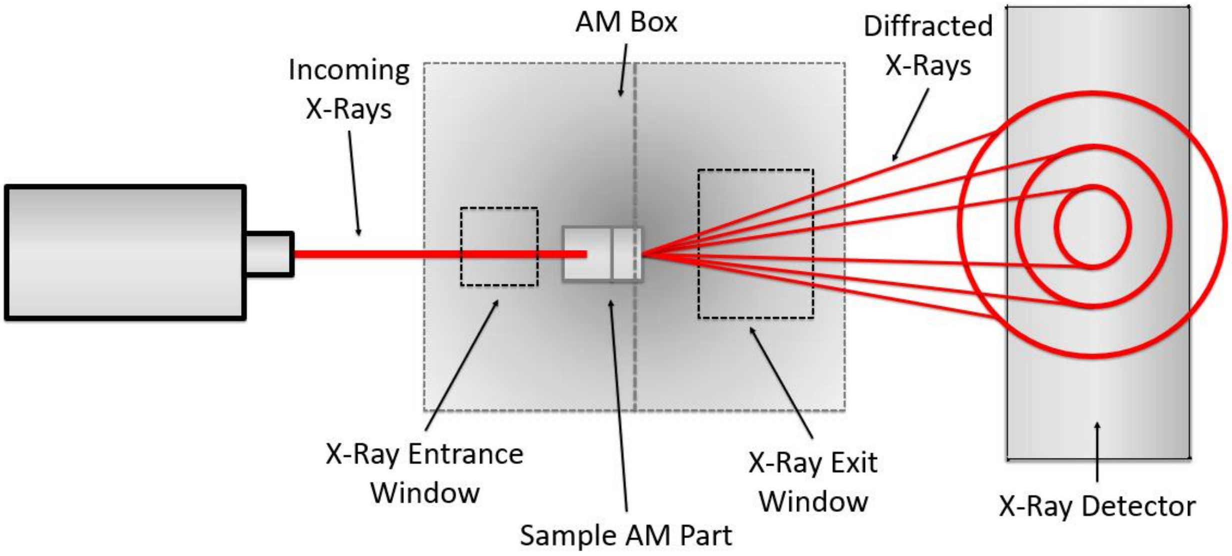

Figure 2. Proposed layout of AM machine in x-ray hutch.

- X-ray entrance & exit windows integrated into containment structure.
- Exit window designed to accommodate diffraction angle.
- X-ray windows made of x-ray transparent material; either silica glass (fused quartz) or beryllium.

Translating and Rotating the Sample Part in the X-Ray Beamline

To further extend real-time x-ray analysis capabilities, multiaxial translation and rotation of the printed sample part is essential to optimize the data collection process.

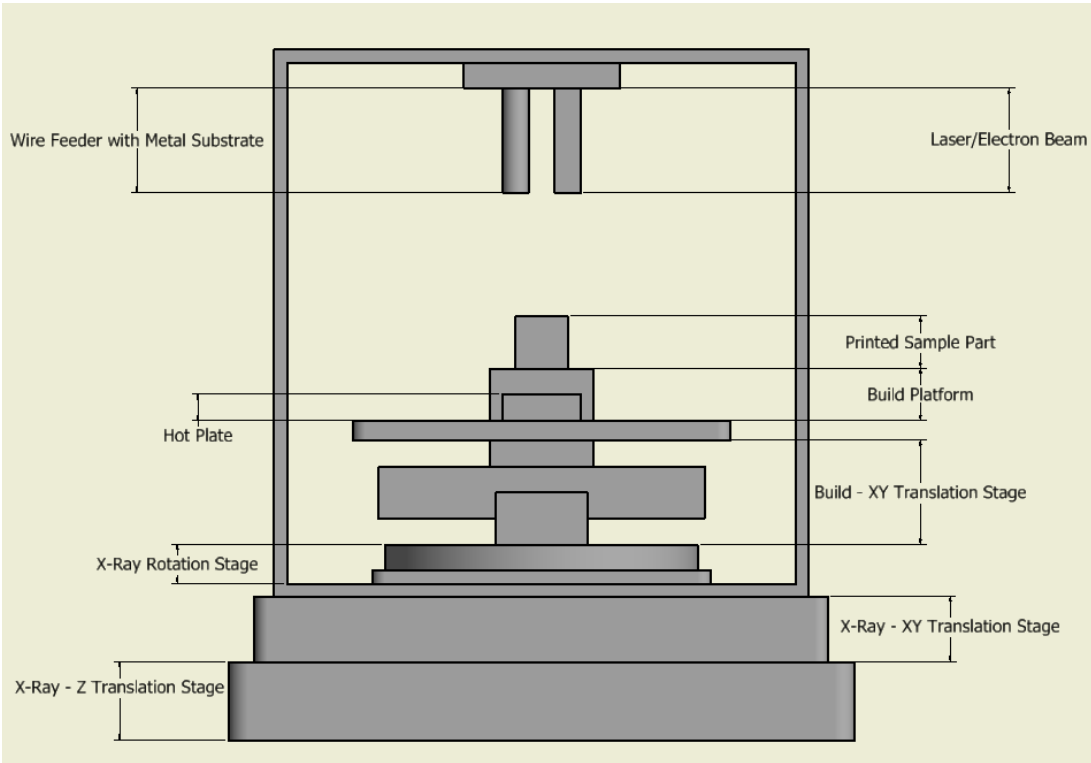

Figure 3. Proposed DED 3D printer setup for x-ray analysis (for diagram purposes walls of 3D printer are transparent).

Printing the sample part (inside AM box)

- Laser/electron beam and wire feeder move in Z-direction.
- Motorized XY translation stage to move sample in additional 2D.
- Motorized rotation stages to move the sample 360 degrees while the print is paused - increasing the number of angles in which x-ray data can be captured.
- Removable build platform – exchangeable to match print material.
- Hot plate to heat build platform in order to control build temperature.
- Powder tray to restrict stray powder from interfering with motorized stages.

Monitoring the printed sample part with x-rays (outside AM box)

- Motorized XY and Z translation stages to move the printed sample part and laser/electron beam relative to x-rays.

The different components used in the conceptual model are for general sizing a layout purposes. Exact stages were not model, however the stages in the model were based from stages that already exist. For stage components, Thorlabs, PI, and Standa were referenced.

Moving Forward

The next step in determining the AM DED 3D printer setup will be selecting specific translation and rotation stages as well as the components necessary for 3D printing (i.e. the laser, wire feeder, etc.)

See external files for MATLAB code and Inventor model.