Process Engineer – Metal 3D Printing

Project & Job Description:

Project History and Description: Dr. Fallah's research, during the past 2 years, has developed and built a versatile 3D printer of metals that is now fully operational. Being the only metal 3D printer with semi-industrial capacity (currently within the Kingston community) and capable of printing a wide range of metals, this machine is planned to serve many academic research groups and industrial R&D units inside Kingston as well as across Ontario and Canada.

The 3D printer is designed based on the Laser Powder Bed Fusion (LPBF) process, a rapidly-growing Additive Manufacturing (AM) technique for near-net-shape manufacturing of metallic parts with exceptionally complex geometries. This technique has attracted increased interest in the production of high value, low production volume parts where it has strong advantages in creating complex geometries. The LPBF technique, however, comes with complex and unique technical challenges that are mainly rooted in metallurgical issues that are inherent to the LPBF processing. These issues become significantly more complex in the processing of reactive/sensitive metals, such as aluminum, titanium and zirconium alloys.

Focusing on such challenges, Dr. Fallah's research group (consisting of graduate and undergraduate students) has designed the 3D printer with exceptional controls for printing reactive metals, i.e., regarding the process atmosphere and laser optics. The 3D printer has now been fully commissioned for continuous operation and detailed operation and maintenance manuals have also been developed.

The ultimate purpose of this assignment is to properly design printing processes, and safely utilize and maintain the 3D printer for a variety of projects dealing with various metals as well as a range of component geometries.

Student's Role: Working alongside Dr. Fallah's research team, the student will be required to fully understand the developed 3D printer system and then:

- Receive training for the safe operation and maintenance of the 3D printer through strictly following the standard operating procedures which includes the initial set-up, as well as the operation of the laser processing and gas circulation/filteration units;
- Receive training for design of control paradigms for safe, continuous operation of the 3D printer through strictly following the control manuals: this task requires establishing interfaces/communications between computer programs/software (such as LabView) with various electrical/control components in the system; This training is necessary since, depending the printing project, the operator may have to modify the process control paradigms;
- Devise processing paradigms (including parameter selection) in order to utilize the metal 3D printer for various projects and research purposes (as well as for potential services provided for external academic and industrial clients); for any given project, the students will design a processing paradigm (depending upon the metal/alloy chosen as well as the geometrical requirements) and then select the process parameters (guided through the existing literature);
- Run the 3D printer strictly following the user manuals and the devised processing paradigms/parameters;
- Visually and metallographically assess the printed components for potential defects, then trouble-shoot and revisit the processing paradigms.

Required Qualifications: To fulfill the above responsibility, other than the general computer skills (such as Microsoft Office, etc.), the student must demonstrate the following capabilities:

- The ability to work with a Mechanical Design software such as SolidWorks, as it will be needed for potential design modifications for various mechanical parts throughout testing/trouble-shooting procedure.
- A basic knowledge of commonly used programming languages/software such as C++ and Matlab, as the student may be required to work with various control units (such as a PLC) to program or modify the existing codes.

- A basic knowledge of electrical circuits, as the student need to understand the circuit diagrams (including power and communication wirings) in the system and potentially modify them in order to fulfill a change to the control algorithms.
- A basic knowledge of materials science, as the student will need to incorporate the material behavior under laser irradiation (such as melting and solidification) throughout testing/trouble-shooting procedure.

It must be mentioned that all skills listed above already exist among the team members and the student will receive supervision/help for advanced procedures/practices.

Relevance to Queen's University Strategic goals: The proposed project is closely aligned with the University's Strategic Research Plan, particularly Theme 6 - Interdisciplinary research in materials, computational analytics and human-machine interactions. Theme 6 includes a specific research cluster related to materials, with *Materials Discovery and Molecular Design* outlined as targeted research areas. Priorities under this theme include designing and creating novel materials, with improved physical structure and behavior over conventional alternatives, and developing advanced technologies which can facilitate the development of novel materials.

Relevance to Greater Kingston Community: The proposed project paves the way for an effective utilization of an infrastructure that will help establish Queen's University as a leader in metal 3D printing technology in Canada as well as world-wide. Particularly, the proposed project can potentially lead to development of next-generation LPBF systems with exceptional controls over metallurgical qualities of 3D printed parts made out of aluminum-, titanium- and zirconium-based powders. The anticipated research outcomes will expand the currently limited use of AM for reactive/sensitive metals such as Al-, Ti-, Zr-, Ni- and Cr-based alloys which are considered as "hard-to-process" given the current state of AM technology, and promote the use of light-weight alloys such as aluminum in AM applications for transportation industry. This will have a great impact on the development of electric vehicles (both in automotive and aerospace sectors), reducing the fossil fuel consumption and CO_2 emissions. The research program will likely create high-paying, high-tech jobs and high-value added services and products that will help with Kingston Community's economy as a whole. Moreover, the multidisciplinary skills in system control design that the student develops throughout this project will be of high demand for many emerging fields across the advanced manufacturing sector. Such fields include several engineering graduate programs at Queen's University as well as engineering/manufacturing companies within the greater Kingston Community.

Learning Plan::

The high-quality training the student will receive throughout this project will help him/her develop a unique set of skills in system control, mechanical design, process design and operation/maintenance of a state-of-the-art metal 3D printer, as well as professional skills that one can develop during a well-organized, hierarchical team work. Such skills are categorized as follows:

Technical Skills:

Expertise in metal 3D printing: The project opens an exceptional learning opportunity for the student through direct experience in a research environment where a variety of scientific/technical challenges regarding metal 3D printing are being investigated. These include process design and characterization of metal powders and 3D printed parts. Such an enriched learning opportunity is made possible in the research team led by Dr. Fallah who has an extensive experience and expertise in laser Additive Manufacturing of metals as well as in process and machine design for production of specialty powders for AM applications.

System Control and Process Design: The student will be involved in the modification of already-developed control paradigms dealing with powered components such as valves, pressure and oxygen sensors, recirculation pump and vacuum pump. The student will be mentored to undertake the steps necessary for a successful programming and testing of powered components in order to fulfil the overall process requirements.
Dr. Fallah's design team currently includes five PhD students, two MASc and four undergraduate students. Dr. Fallah's experience in machine and process design will ensure sufficient technical expertise so as to effectively guide the commissioning phase of the project. Dr. Fallah has extensive expertise in utilization, modification and control of Laser/CNC systems applied in Laser Powder-fed Deposition AM technique. During industrial R&D activities prior to joining Queen's University, he has led the technical team developing an atomization technology, which involved the design, manufacture, installation and commissioning of a reaction vessel.

Multidisciplinary Research and Development (**R&D):** The proposed project is part of a research infrastructure development which is essentially a multidisciplinary R&D project that involves utilization of state-of-the-art techniques and machinery. These range from mechanical/electrical design of an advanced process vessel to LabVIEW programming for process control as well as in-depth process design and optimization. Such a research program provides a unique opportunity to the student to gain an invaluable vision as to how effectively match their own expertise to the needs of a multidisciplinary program. More specifically, in this project, the student will learn through first-hand experience how to handle the installation, programming and commissioning of a metal 3D printer enclosure that satisfies the system's constraints for process environment and safety.

General Skills:

Professional Development: Throughout this project, the student will professionally develop through a collaborative and hierarchical team work in a laboratory research environment. The collaborative nature of the design project, under Dr. Fallah's supervision, ensures active involvement of the student and their productive interaction with other team members. A professional environment is thus created where student can be effectively trained and flourish as a future expert in a variety of industrially-relevant fields. The student will write monthly progress reports summarizing the progress made, future plans and anticipated technical challenges. These reports will be carefully read by Dr. Fallah and the team members and detailed feedback will be provided to the student as related to the overall project needs as well as standard writing practices for technical reports. Other than a regular weekly group meeting, the student will meet up with any of the team members as often as necessary to ensure all questions/concerns are addressed properly.

Application of Theories in Practice: The student will be closely mentored by the research team in order to effectively apply their theoretical knowledge in implementing a control system that performs according to manufacturing standards and industrial practices. More specifically, the student will learn to apply their theoretical knowledge in control systems (e.g. installation of controllers for various powered components in the system) and electronics (e.g. to wire, program and digitally interface various controllers with a computer software) to a real-life, industrially-relevant machine building project.

Computer-Aided Design: This project will provide a real challenge for the student to develop skills necessary to conduct an industrially-relevant control system using their prior experience with a control software (e.g. LabVIEW). Dr. Fallah's design team with extensive background in LabVIEW and PLC programming will provide the necessary guidance and feedback to the student.

Innovation: The unique features of the 3D printer built enable a research program to deeply address scientific issues with the current state of metal AM technology which are strictly rooted in the shortcomings of current industrial practices. Here, the student will experience conducting a comprehensive procedure to address scientific/technical issues with an advanced manufacturing process through an innovative mechanical design project. Particularly, such innovations are meant to lead to advancing the current state-of-the-art in the field of metal 3D printing. Through fully-engaged mentorship and collaborative team work, Dr. Fallah and his team will carefully walk the student through such innovative design procedure with clearly-defined and monitored mile-stones.