subject to large variations during manufacture. These variations can result in formation of inconsistent products produced by a metal-based wire-plasma arc additive manufacturing process.

**[0008]** Accordingly, there exists a need in this art for an improved method of controlling the flow of the inert gas to a plasma torch to be ionized into plasma for use in a metal additive manufacturing process.

## SUMMARY

[0008a] In an aspect, the present disclosure refers to a system for controlling flow of a gas to a plasma torch of an additive manufacturing device, comprising:

a source of an inert gas;

a supply manifold in fluid communication with the source of the inert gas;

a plasma torch comprising a gas inlet for receiving the inert gas from an inert gas line connected to the supply manifold, and a gas ionizer electromagnetic field for ionizing the inert gas into plasma;

a sensory kit comprising a temperature measurement unit, a pressure measurement unit, and a mass flow measurement unit, wherein each unit is in communication with one or more sensory connecters connected to a position of the inert gas line between the supply manifold and the gas ionizer electromagnetic field;

a control valve that is in fluid communication with the gas supply manifold and regulates flow of the inert gas from the gas supply manifold to the plasma torch;

a process master controller in communication with the sensory kit;

a part program that provides a mass flow set value and a volumetric flow set value to the process master controller;

a calculation function running on the process master controller calculating actual volumetric flow; and

a) a mass flow control function and a volumetric flow control function running on the process master controller; or

b) a combined mass flow and volumetric flow control function running on the process master controller;

and wherein

the system further comprises a density control element that controls the temperature and/or pressure of the inert gas delivered to the inlet of the plasma torch.

[0008b] In another aspect, the present disclosure refers to a method of delivering a target volumetric flow and a target mass flow of an inert gas to be ionized into plasma to a plasma torch, comprising:

providing an inert gas from a gas supply manifold to an inlet of the plasma torch through a control valve attached to an inert gas supply manifold via an inert gas line;

a) measuring a temperature, a mass flow, and a pressure of the inert gas between the inert gas supply manifold and a gas ionizer electromagnetic field of the plasma torch; or

b) measuring a temperature, a mass flow, and a pressure of the inert gas at or in the vicinity of the plasma torch gas inlet; or

c) measuring a temperature and a pressure of the inert gas inside the plasma torch and a mass flow at or in the vicinity of the plasma torch gas inlet; or

d) any combination of a), b) and c);

calculating an actual volumetric flow rate of the inert gas to the plasma torch:

i) at or in the vicinity of the plasma torch inlet; or

ii) inside the plasma torch; or

iii) at a position of the inert gas supply line between the gas manifold and the plasma torch gas inlet;

comparing the actual volumetric flow rate to a target volumetric flow rate to generate a volumetric flow differential value;

comparing the actual mass flow rate to a target mass flow rate to generate a mass flow differential value;

based on the mass flow differential value and volumetric flow differential value:

x) adjusting the control valve to increase or decrease mass flow of the inert gas through the control valve to the plasma torch gas inlet; or

y) adjusting the density of the inert gas by increasing or decreasing the pressure and/or temperature of the inert gas to yield a modified inert gas volumetric flow, and directing the modified inert gas to the inlet of the plasma torch; or

z) adjusting the control valve and the density of the inert gas by increasing or decreasing the pressure and/or temperature of the inert gas to control the mass flow and volumetric flow of the inert gas to the ionizing electromagnetic field of the plasma torch.

17. The method of claim 16, wherein adjusting the control valve comprises:

generating an adjustment signal based on the mass flow differential value and/or volumetric flow differential value; and

sending the adjustment signal to a driver attached to the control valve, the driver increasing or decreasing an opening of the control valve based on the adjustment signal.

[0008c] In another aspect, the present disclosure refers to a method of delivering a target volumetric flow of an inert gas to a plasma torch to be ionized into plasma, comprising:

attaching a system of the above aspect to an inert gas source; and

activating the system.

**[0009]** Accordingly, embodiments described herein are directed to systems and methods for controlling the flow of the inert gas to a plasma torch that can determine actual volumetric flow and can allow adjustment of the plasma arc pressure and melt pool dynamics for use in metal-based wire-plasma arc additive manufacturing processes. Provided are systems that regulate mass flow and monitor volumetric flow of the gas to the plasma torch. Provided are systems that regulate volumetric flow and monitor mass flow of the gas to the plasma torch. Provided are systems that regulate both mass flow and volumetric flow of the gas to the plasma torch. The systems and methods can include volumetric flow control elements that can be located inside a production chamber at or in the vicinity of the plasma torch gas inlet for receiving the gas to be ionized into plasma by the plasma torch(es) to be able to measure and/or control any gas density variations due to arc radiation disturbance, such as variations in temperature of the gas hoses or pipes. The volumetric flow control elements at or in the vicinity of the plasma torch(es) gas inlet also can allow detection of any mass flow reductions, such as due to leakages, and can act as a second opinion sensor for the mass flow.

**[0010]** An objective of embodiments described herein is to provide a consistent force on the melt-pool during wire plasma arc additive manufacturing processes even if the gas density is subject to variations due to mechanical or environmental disturbances or both. In embodiments, consistent force can be achieved by controlling the volumetric flow of the gas at the plasma torch that forms the ionized gas or plasma. In some embodiments, control of the volumetric flow of the gas at the plasma

torch can be achieved by adjusting the mass flow of the gas to be ionized from the gas supply source, or by adjusting the density of the gas to be ionized at the plasma torch by modifying the temperature or pressure or a combination thereof of the gas, or a combination of adjustments to the mass-flow of the gas to be ionized at the gas supply in combination with volumetric flow of the gas to be ionized by the plasma torch by

adjusting the temperature and/or pressure of the gas to be ionized at or in the vicinity of the plasma torch gas inlet.

**[0011]** An objective of embodiments described herein is to improve melt pool dynamics, and thus the geometric shape and mechanical properties of the preform produced by a metal-based wire-plasma arc additive manufacturing process, thereby improving consistency and quality.

**[0012]** Another objective of embodiments provided herein is to create a consistent plasma arc pressure on the melt-pool (i.e. arc force per unit area of melt-pool), by maintaining the gas discharge velocity of the plasma arc from the nozzle of the plasma torch at a target discharge velocity, across various density levels of the inert gas supplied to the plasma torch(es).

**[0013]** Provided in an example are systems and methods for controlling flow of an inert gas to a plasma torch of an additive manufacturing device to be ionized into plasma. The systems and can allow adjustment of the plasma arc pressure exerted on the melt pool, and thus can allow modification of the melt pool dynamics during object fabrication using metal-based wire-plasma arc additive manufacturing processes.

**[0014]** Provided in an example is a system for controlling flow of a gas to a plasma torch of an additive manufacturing device, where the system can include a source of an inert gas; a supply manifold in fluid communication with the source of the inert gas; a plasma torch that includes a gas inlet for receiving the inert gas from an inert gas line connected to the supply manifold, and a gas ionizer electromagnetic field for ionizing the inert gas into plasma. The system can include a sensory kit that can include a temperature measurement unit, a pressure measurement unit, and a mass flow measurement unit. Each unit can be in communication with one or more sensory connecters connected to a position of the inert gas line between the supply manifold and the gas ionizer electromagnetic field. The system also can include a control valve in fluid communication with the gas supply manifold and that regulates flow of the inert gas from the gas supply manifold.

**[0015]** The system can include a process master controller in communication with the sensory kit. The system can include a part program that provides a mass flow set value or a volumetric flow set value or both a mass flow set value and a volumetric flow set value to the process master controller. The system can include a calculation function running on the process master controller calculating actual volumetric flow. The system

processor calculating actual volumetric flow; and a) a mass flow controller in communication with the process master controller; or b) a volumetric flow controller in communication with the process master controller; or c) a mass flow controller and a volumetric flow controller in communication with the process master controller; and a part program that provides a mass flow set value or a volumetric flow set value or both a mass flow set value and a volumetric flow set value to the process master controller, wherein: the mass flow controller compares the mass flow set value from the part program to the actual mass flow value from the sensory kit and modulates the control valve to increase or decrease flow of inert gas to decrease the difference between the mass flow set value and the actual mass flow value; or the volumetric flow controller compares the volumetric flow set value from the part program to the calculated volumetric flow value from the calculation processor and modulates the control valve to increase or decrease flow of inert gas to decrease the difference between the volumetric flow set value and the calculated volumetric flow value. The sensory connecter can be connected to, or connected in the vicinity of, the plasma torch gas inlet.

**[0026]** The sensory kit components can be separated, and the elements can be embedded into different parts of the inert gas line. For example, the mass flow measurement unit of the sensory kit can be located along any part of the inert gas line. In addition, the temperature measurement unit and pressure measurement unit can be located along the gas line or inside the plasma torch. A plurality of sensory connecters can be positioned along the inert gas line.

**[0027]** In the systems, the processor group can include the mass flow controller, and the mass flow controller can be in further in communication with the control valve and can modulate the control valve to increase or decrease flow of inert gas to decrease the difference between the mass flow set value and the actual mass flow value. In the systems, the processor group can include the volumetric flow controller, and the volumetric flow controller can be in further in communication with the control valve and modulates the control valve to increase or decrease flow of inert gas to decrease the difference between the volumetric flow set value and the calculated volumetric flow value. The processor group can be a set of processors doing different tasks in parallel or can be one master processor, such as a process master controller, doing a set of tasks in parallel, to support various functions.

**[0028]** Also provided in an example are methods of delivering a target volumetric flow of an inert gas to be ionized into plasma to a plasma torch. The methods include providing an

The pressure regulator can include a movable plenum chamber that can increase the volume of the pressure regulator and thereby decrease the pressure of the inert gas exiting the pressure regulator, or decrease the volume of the pressure regulator and thereby increase the pressure of the inert gas exiting the pressure regulator. In the methods, the inert gas can be argon.

**[0032]** Also provided in an example are methods of delivering a target volumetric flow of an inert gas to a plasma torch to be ionized into plasma, the methods including attaching a system provided herein to an inert gas source; and activating the system.

**[0033]** Additional features and advantages of the embodiments described herein will be set forth in the description which follows, and in part will be apparent from the description, or may be learned by practice of the invention. The objectives and other advantages of the exemplary embodiments will be realized and attained by the structure particularly pointed out in the written description and claims hereof as well as the appended drawings.

**[0034]** It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory and are intended to provide further explanation of the invention as claimed.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0035]** The accompanying drawings, which are included to provide a further understanding of the invention and are incorporated in and constitute a part of this specification, illustrate embodiments of the invention and together with the description serve to explain the principles of the invention.

**[0036]** In the drawings:

**[0037] FIG. 1** is a simplified diagram showing an exemplary embodiment of a flow of inert gas to be ionized by a plasma torch, the inert gas flowing from a gas supply manifold, through a flow control system provided herein, and through a plasma torch to produce a plasma arc, the pressure of which can be controlled.

**[0038] FIG. 2** is a simplified diagram showing an exemplary embodiment of a flow of inert gas to be ionized from a gas supply manifold, through a flow control system provided herein, and through a plasma torch that include a temperature sensor and a pressure sensor within the plasma torch, the gas passing through a region of an ionizing EM field to produce a plasma arc, the pressure of which can be controlled.