

INTEGRATED COLD SPRAY SYSTEM AND A METHOD THEREOF

Technical Field

[0001] This invention generally relates to cold spray technology. More specifically, the invention relates to an integrated cold spray system and a method thereof.

Background

[0002] Cold spray technology has become a significant tool in the field of material repair and surface coating, particularly for metallic components. The cold spray process involves the acceleration of metal powders through a high-velocity gas stream, typically nitrogen, which propels the particles at supersonic speeds through a specialized nozzle. Upon impact with a substrate, these particles deform plastically, bonding to the surface and each other to form a coating. The cold spray process is unique as it operates below the melting point of the materials, preserving the substrate's integrity and avoiding thermal damage. Such properties makes the cold spray process particularly suitable for repairing heat-sensitive components.

[0003] Existing cold spray systems, such as those described in US Patent No. 11292019B2, features a six-axis robotic arm to control the spray nozzle's position relative to the work surface, offering a level of precision crucial for applications in aerospace, defense, and marine industries. However, such cold spray systems have notable limitations, lacking a fully integrated control mechanism that synchronizes the operation of the robotic arm, spray booth, and dust collection system. The absence necessitates

manual coordination, increasing the potential for operational inefficiencies and human error.

[0004] Moreover, existing systems rely on external heating elements to heat the carrier gas, adding to the system's complexity and physical footprint. The use of such external components complicates maintenance and operation, particularly in environments where space is limited. Additionally, the existing solutions do not ensure that the correct robotic program is executed for specific repair tasks. In high-precision environments like aircraft component repair, the absence of such features can lead to suboptimal repairs, potentially compromising the safety and integrity of the repaired components.

[0005] The present invention is directed to overcome one or more limitations stated above or any other limitations associated with the known arts.

SUMMARY OF INVENTION

[0006] In one embodiment, an integrated cold spray system is disclosed. In one example, the integrating cold spray system may include a spray booth including a cold spray gun coupled to a powder feed system and a gas supply system. The cold spray gun receives powder from the powder feed system and carrier gases from the gas supply system. The cold spray gun includes a nozzle to supply a mixture of the powder and the carrier gases to a work piece to be cold sprayed. Further, the spray booth may include a robotic arm including an end effector to hold the cold spray gun. Further, the spray booth may include a radio frequency identification and detection (RFID) system to collect information associated with the work piece. Further, the spray booth may include a

human-machine interface (HMI) system in communication with the spray booth, and the RFID system.

[0007] In an aspect, the spray booth may include a ventilation system including a dust collector to capture dust, and airborne particles within the spray booth.

[0008] In an aspect, the powder feed system stores and transports the powder from a reservoir or a hopper to the cold spray gun.

[0009] In another aspect, the nozzle is a converging-diverging nozzle. The nozzle has a first inlet for receiving the carrier gases from the gas supply system and a second inlet for receiving the powder from the powder feed system. The nozzle accelerates the carrier gases and mixes the carrier gases with the powder before directing the mixture onto the work piece.

[0010] In another aspect, the gas supply system is a high-pressure gas supply system configured to provide the carrier gases at high velocities to the cold spray gun. The gas supply system includes a gas pressure regulator and a gas temperature control unit.

[0011] In another aspect, the robotic arm is a six-axis robotic arm.

[0012] In one aspect, the cold spray gun is mounted on the end effector of the robotic arm, allowing the robotic arm to move and orient the cold spray gun precisely.

[0013] In another aspect, the dust and airborne particles are generated due to at least one of a cold spray process, a high velocity gas stream, abrasion or mechanical preparation, a coating process and/or overspray.

[0014] In yet another aspect, the dust corresponds to excess powder generated during a coating process. The dust collector removes the excess powder from spray booth environment.

[0015] In another aspect, the dust collector creates a controlled airflow that draws in and filters out the dust and airborne particles.

[0016] In one aspect, the dust collector uses one or more filters to capture the dust and airborne particles.

[0017] In another aspect, the RFID system includes at least one RFID tag and an RFID reader. A target RFID tag of the at least one RFID tag is mounted on a fixture of the work piece to be cold sprayed. The RFID reader collects information associated with the work piece from the target RFID tag when the RFID tag and the RFID reader are in a prespecified proximity and transmits the collected information to the HMI system.

[0018] In another aspect, the HMI system includes error-proofing mechanisms that prevent execution of an operation not matching the target RFID tag mounted on the fixture of the work piece.

[0019] In one aspect, the information associated with the work piece includes a type of the workpiece, and components of the work piece.

[0020] In another aspect, the HMI system adjusts operational parameters of a cold spray process automatically based on the type of work piece.

[0021] In one aspect, the HMI system controls one or more operations of the cold spray gun, the robotic arm, and the ventilation system. The HMI system includes a controller for controlling the one or more operations.

[0022] In another aspect, the HMI system controls the one or more operations of the cold spray gun based on the information received from the RFID system. Further, the HMI system controls the one or more operations of the robotic arm based on real-time data collected through a first set of sensors in proximity to the robotic arm. Further, the HMI system controls the one or more operations of the dust collector based on information collected from a second set of sensors.

[0023] In one aspect, the second set of sensors includes one or more of a temperature sensor, an airflow sensor, a pressure sensor, a collision sensor, a LiDAR system, a flow switch, an air quality sensor, a level sensor, an air velocity sensor, and/or a filter condition sensor.

[0024] In another aspect, the robotic arm is programmed to execute precise movements and orientations based on requirements of a cold spray process, as specified by the HMI system.

[0025] In one aspect, the powder is metal powder.

[0026] In another aspect, the integrated cold spray system comprises a motorized work piece loading system fixed under the robotic arm. The work piece loading system is configured to move forward and backward for loading and unloading the work piece.

[0027] In another embodiment, a method for controlling an integrated cold spray system is disclosed. In one example, the method may include receiving information associated with a work piece to be cold sprayed, from a radio frequency identification and detection (RFID) system by a controller of a human-machine interface (HMI) system. Further, the method may include determining one or more pre-specified operations to be performed using a robotic arm and a cold spray gun for executing a coating process for

the work piece by the controller. Further, the method may include controlling based on the determined one or more operations, the robotic arm and the cold spray gun to coat the work piece by the controller.

[0028] In one aspect, a spray booth includes the cold spray gun, the robotic arm, and a ventilation system. The ventilation system further includes a dust collector.

[0029] In another aspect, the method further comprises receiving data from a set of sensors and controlling operations of the dust collector based on the received data. The dust collector is configured to capture dust and airborne particles.

[0030] In another aspect, the cold spray gun is mounted on an end effector of the robotic arm. The controller controls the robotic arm to move and orient the cold spray gun precisely.

[0031] In one aspect, the controlling includes controlling the cold spray gun to supply a mixture of powder received from a powder feed system and carrier gases received from a gas supply system to the work piece.

[0032] It is to be understood that both the foregoing general description and the following detailed description are exemplary and explanatory only and are not restrictive of the invention, as claimed.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] The accompanying drawings, which are incorporated in and constitute a part of this disclosure, illustrate exemplary embodiments and, together with the description, serve to explain the disclosed principles.

[0034] **FIG. 1** illustrates a block diagram of an integrated cold spray system, in accordance with some embodiments of the present disclosure.

[0035] **FIG. 2** illustrates a front view of the integrated cold spray system, in accordance with some embodiments of the present disclosure.

[0036] **FIG. 3** illustrates a robotic arm of the integrated cold spray system, in accordance with some embodiments of the present disclosure.

[0037] **FIG. 4** illustrates a cold spray gun of the integrated cold spray system, in accordance with some embodiment of the present disclosure.

[0038] **FIG. 5** illustrates a radio frequency identification and detection (RFID) system of the integrated cold spray system, in accordance with some embodiments of the present disclosure.

[0039] **FIGs. 6A and 6B** illustrates an exemplary User interface (UI) of the integrated cold spray system, in accordance with some embodiments of the present disclosure.

[0040] **FIG. 7** illustrates the exemplary UI of the integrated cold spray system, in accordance with some embodiments of the present disclosure.

[0041] **FIG. 8** illustrates the exemplary UI of the integrated cold spray system, in accordance with some embodiments of the present disclosure.

[0042] **FIGs. 9A and 9B** illustrates the exemplary UI of the integrated cold spray system, in accordance with some embodiments of the present disclosure.

[0043] **FIG. 10** illustrates a flowchart of an exemplary operational method of the integrated cold spray system, in accordance with some embodiments of the present disclosure.

DETAILED DESCRIPTION

[0044] Exemplary embodiments are described with reference to the accompanying drawings. Wherever convenient, the same reference numbers are used throughout the drawings to refer to the same or like parts. While examples and features of disclosed principles are described herein, modifications, adaptations, and other implementations are possible without departing from the spirit and scope of the disclosed embodiments. It is intended that the following detailed description be considered as exemplary only, with the true scope and spirit being indicated by the following claims.

[0045] Referring now to **FIG. 1**, a block diagram of an integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present disclosure. The integrated cold spray system 100 uses high-pressure, high-velocity gas to deposit and build-up metal powders into dense material on a work piece. The metal powder undergo substantial plastic deformation to adhere onto the substrate and each other using the significant kinetic energy from the gas. The integrated cold spray system 100 deposits and builds up metal relatively rapidly without causing significant heat input to the work piece, and also bonds different metals together. The integrated cold spray system 100 performs a low-temperature process to minimize heat damage to the work piece, allowing cold spray to be performed near heat-sensitive areas, such as insulated rail-joints.

[0046] The integrated cold spray system 100 may include a cold spray gun 102, a powder feed system 104, a gas supply system 106, and a gas heater 108. In an embodiment, the cold spray gun 102 may be coupled to the powder feed system 104 and the gas supply system 106 via one or more hollow pipes 110. The one or more hollow

pipes 110 may carry the powder and the carrier gases to the cold spray gun 102. The one or more hollow pipes 110 may be, but not limited to, made of steel, iron, metal-alloys, hard plastic, etc. Further, the cold spray gun 102 receives powder from the powder feed system 104 and carrier gases from the gas supply system 106. The powder feed system 104 may store and transport the powder from a reservoir or a hopper to the cold spray gun 102. The power may be a metal power, such as iron, galvanized steel, metal-alloy, etc. Further, the gas supply system 106 may be a high-pressure gas supply system configured to provide the carrier gases at high velocities to the cold spray gun 102. The gas supply system 106 may include a carrier gas pressure regulator to regulate the flow of the carrier gas and a carrier gas temperature control unit to control the temperature of the carrier gas. The carrier gases may be a neutral gas, such as nitrogen, air, helium, neon, etc.

[0047] In an embodiment, the carrier gases may pass through the gas heater 108 to increase the kinetic energy of the carrier gas. The gas heater 108 may be, but not limited to, a gas radiant heater, flued gas heater, gas convector heater, etc. The carrier gases may carry the powder to the cold spray gun 102 at a high velocity due to the increased kinetic energy. The high velocity carrier gases may accelerate the powder to a Mach 1 to Mach 2 speed. Further, the cold spray gun 102 may include a nozzle to supply a mixture of the powder and the carrier gases to a work piece 112 to be cold sprayed. The nozzle may be a de Laval nozzle. The work piece 112 is placed at a pre-defined distance i.e., stand-off distance in front of the cold spray gun 102, such that the nozzle of the cold spray gun 102 is aimed at the work piece 112. The work piece 112 may be a metal piece that needs to be repaired, or powder coated with the powder. The cold

sprayed powder may build a dense coating 114, adhering strongly on the work piece 112. It should be noted that the coating 114 is successful when the powder is able to attain a critical velocity prior to the impact on the work piece 112. The critical velocity is dependent on several parameters, such as carrier gas pressure, carrier gas temperature and predefined distance, as well as material properties such as powder morphology and metallurgy.

[0048] By way of an example, to ensure a desired thickness and dimensions of the coating 114 on the work piece 112, the integrated cold spray system 102 uses nickel alloy particles as powder and nitrogen as the carrier gas. Further, the integrated cold spray system 102 supplies the nickel alloy powder mixed with nitrogen at a pressure of 175psi and temperature 500°C to the work piece 112 placed at the pre-defined distance of 10mm to 20mm. Further, the coating 114 is grinded using a manual hand grinder or rail profile grinder with sandpaper and grinding disc to ensure a smooth surface of the work piece 112.

[0049] Referring now to **FIG. 2**, a front view 200 of the integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present invention. FIG. 2 is explained in conjunction with FIG. 1. The front view 200 depicts an enclosed spray booth 202. The spray booth 202 is configured to house the cold spray gun 102, a robotic arm 204, a ventilation system, a radio frequency identification and detection (RFID) system, a Human Machine Interface (HMI) system, the powder feed system 104, the gas supply system 106, the gas heater 108, the one or more hollow pipes 110, a platform 206, a first set of sensors, a second set of sensors, and the work piece 112.

[0050] The spray booth 202 may be, but not limited to, made of iron, steel, metal-alloys, galvanized steel, aluminum, nickel, bronze, brass, etc. The spray booth 202 may include a pair of doors 208 configured to automatically close before starting the cold spray process. The pair of doors 208 is configured to seal and enclose the spray booth during the cold spray coating process. The pair of doors 208 may be a sliding door, a hinged door, a collapsable door, etc. In some embodiments, the pair of doors 208 may include a collision sensor and Light Detection and Ranging (LiDAR) system to automatically stop the motion of the pair of doors 208 once obstacles are detected from in front of the spray booth 202. The LiDAR system may be attached in front of the pair of doors 208. The LiDAR system is a remote sensing sensor that uses laser light to measure distances. The LiDAR system works by emitting laser pulses and measuring the time takes for the light to bounce back after hitting an object. Based on the time-of-flight data, the LiDAR system calculates the distance to the object.

[0051] Further, the pair of doors 208 may include a transparent portion 210 to monitor the cold spray process from outside the spray booth 202. The transparent portion may be a glass portion, plastic portion, transparent fiber portion, etc. Further, the pair of doors 208 may include handles 212 to hold the pair of doors 208.

[0052] In an embodiment, the work piece 112 is placed on the platform 206 housed in the spray booth 202. The work piece 112 may be a metal piece in need of repair or coating. In some embodiments, the platform 206 may include a clamping assembly to secure the work piece 112 during the cold spray coating process. The clamping assembly may include, but not limited to, a C-clamp, a bar clamp, a deep-throat

bar clam, a one-handed bar clamp, a spring clamp, a ratchet-action band clamp, a mitre clamp, and hand screws.

[0053] In some embodiments, the platform may be attached on top of a motorized work piece loading system. The work piece loading system is configured to move forward and backward for loading and unloading the workpiece. The motorized work piece loading system may comprise a energy chains system to move the platform. In simpler words, during loading the work piece, the work piece loading system may automatically move forward to hold the workpiece, and then retract backward.

[0054] In an embodiment, the RFID system is attached to the platform 206 to collect information associated with the work piece 112. The information associated with the work piece 112 may include, but not limited to, a type of the workpiece, and components of the work piece 112. Further, the RFID system may transmit the information such as fixture, material, chemical properties, dimensions and part drawing number associated with the work piece 112 to the HMI system. The HMI system may adjust operational parameters of the cold spray process automatically based on the information associated with the work piece 112. The operational parameters may include, but not limited to, a velocity of carrier gas, temperature of carrier gas, movement of the robotic arm 204, pre-defined distance of the cold spray gun 102 from the work piece 112, etc.

[0055] In an embodiment, the HMI system may be in communication with the spray booth, and the RFID system. The communication may be established via, but not limited to, wires, cables, 5G network, 4G network, Bluetooth (BLE), Wireless-Fidelity (Wi-Fi), etc. The HMI system includes error-proofing mechanisms that prevent execution of

an operation not matching the information associated with the work piece 112. Further, the HMI system controls one or more operations of the cold spray gun 102, the robotic arm 204, and a ventilation system. The HMI system may include a controller, such as a microprocessor, microcontroller, PLC for controlling the one or more operations.

[0056] In some embodiments, the HMI system controls the one or more operations of the cold spray gun 102 based on the information received from the RFID system, the robotic arm 204 based on real-time data collected through a first set of sensors in proximity to the robotic arm 204, and a dust collector based on information collected from a second set of sensors. In an exemplary embodiment, the second set of sensors may include one or more of a temperature sensor, an airflow sensor, a pressure sensor, a collision and LiDAR sensor, a flow switch, an air quality sensor, a level sensor, an air velocity sensor, and/or a filter condition sensor.

[0057] In an embodiment, the robotic arm 204 housed in the spray booth 202 may be a six-axis robotic arm. The robotic arm 204 may be configured to hold the cold spray gun 102 and move in six dimensions to reach each portion of the work piece 112 as explained in detail in FIG. 3., The cold spray gun 102 is mounted on an end effector of the robotic arm 204, allowing the robotic arm 204 to move and orient the cold spray gun 102 precisely. Further, the cold spray gun 102 sprays the powder on the work piece 112 as explained in detail in FIG. 1.

[0058] In some embodiments, some dust and airborne particles may be generated due to at least one of a cold spray process, a high velocity carrier gas stream, abrasion or mechanical preparation, a coating process and/or overspray. The dust corresponds to excess powder generated during the cold spray coating process. The dust

and airborne particles may be cleared from the spray booth 202 using the ventilation system. The ventilation system may include a dust collector to capture dust, and airborne particles within the spray booth 202. The dust collector creates a controlled airflow that draws in and filters out the dust and airborne particles. Further, the dust collector uses one or more filters to capture the dust and airborne particles.

[0059] Referring now to **FIG. 3**, the robotic arm 204 of the integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present invention. FIG. 3 is explained in conjunction with FIGs. 1-2. The robotic arm 204 is a six-axis robotic arm mounted on the platform 206 or a floor of the spray booth 202. The robotic arm 204 may be made up of, but not limited to, steel, iron, metal-alloys, hard plastic, etc. The robotic arm 204 may include a plurality of motors to ensure the rotational movement of different parts of the robotic arm 204. In an embodiment, the robotic arm 204 may be capable of moving in different directions on the different axis, such as a first axis, a second axis, a third axis, a fourth axis, a fifth axis, and a sixth axis.

[0060] In an embodiment, the robotic arm 204 may include the end effector 302 configured to hold the cold spray gun 102. The end effector 302 allows the robotic arm 204 to move and orient the cold spray gun 102 precisely on the work piece 112. Further, the robotic arm 204 may be controlled by the HMI system based on the operational parameters and the RFID system. The robotic arm 204 may be programmed to execute precise movements and orientations based on requirements of the cold spray process, as specified by the HMI system.

[0061] Referring now to **FIG. 4**, a cold spray gun 102 of the integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present invention.

FIG. 4 is explained in conjunction with FIGs. 1-3. The cold spray gun 102 is detachably attached to the end effector 302 of the robotic arm 204 via a one end 402. Further, the nozzle 404 is attached to a second end 406 of the cold spray gun 102.

[0062] In an embodiment, the nozzle 404 may be a converging-diverging nozzle. Further, the nozzle 404 has a first inlet for receiving the carrier gases from the gas supply system 106 and a second inlet for receiving the powder from the powder feed system 104. The nozzle 404 accelerates the carrier gases and mixes the carrier gases with the powder before directing the mixture onto the work piece 112. The nozzle 404 may be made up of, but not limited to, a steel, iron, metal alloys, hard plastic, etc.

[0063] Referring now to **FIG. 5**, a radio frequency identification and detection (RFID) system 502 of the integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present invention. FIG. 5 is explained in conjunction with FIGs. 1-4. The RFID system 502 is attached to the platform 206 of the spray booth 202 to collect information associated with the work piece 112.

[0064] In an embodiment, the RFID system 502 includes at least one RFID tag and an RFID reader. A target RFID tag of the at least one RFID tag is mounted on a fixture of the work piece 112 to be cold sprayed. The RFID reader collects information associated with the work piece 112 from the target RFID tag when the RFID tag and the RFID reader are in a prespecified proximity and transmits the collected information to the HMI system. The information associated with the work piece 112 may include a dimension of the work piece 112, a material of the work piece 112, etc.

[0065] In an exemplary embodiment, the RFID system 502 may collect the information associated with the work piece 112, for efficient cold spray process. Further,

the RFID system 502 transmits the information to the HMI system. The HMI system then instructs and controls the gas supply system 106, the powder feed system 104 and the robotic arm 204 to perform the cold spray process on the work piece 112. It should be noted that the RFID system automates the cold spray process with precision without human intervention.

[0066] By way of an example, consider a scenario where a user wants to repair a damaged piece of aluminum sheet containing an RFID tag. In such scenario, the user performs the cold spray process to repair the damage, by clamping the aluminum sheet to the platform of the spray booth. Further, the integrated cold spray system automates the process of the cold spraying. A RFID system scans the RFID tag on the aluminum sheet, extracting the information such as the fixture, material, chemical properties, dimensions, pre-programmed cold spray process, and part drawing number associated with the aluminum sheet. The RFID system extracts metallurgical properties of the aluminum, dimension of the aluminum, size and location of the damage, etc. In some embodiments, the RFID system extracts information that are pre-programmed onto the RFID sensor. Further, the RFID system transmits the information to an HMI system. The HMI system determine a program to cold spray the specific part mounted on the fixture. The HMI system controls the cold spray gun to spray the powder on the damaged part of the aluminum sheet. Further, the HMI system also controls the temperature and pressure of the carrier gas and the powder to be sprayed based on the metallurgical properties of the aluminum sheet. The HMI system also controls the time period of the cold spray process and the distance from which the cold spray gun would spray the powder to ensure optimum binding and strength.

[0067] Referring now to **FIGs. 6A and 6B**, an exemplary User interface (UI) 600 of the integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present invention. FIGs. 6A and 6B is explained in conjunction with FIGs. 1-5. In an embodiment, a user of the integrated cold spray system 102 may monitor the cold spray process from the UI 600 via a user device. The user device may be a tablet, a laptop, a personal computer, a smartphone, etc. The user device may communicate with a plurality of integrated cold spray systems via their HMI systems via a WLAN network, the WI-FI, the cable, HDMI cable, etc.

[0068] FIG. 6A depicts a login page to control the integrated cold spray system 100. The login page may include different HMI systems to choose from, such as HMI#1 602A, HMI#2 602B, an operator selection button 604, a logout button 606, a password button 608, and an admin button 610. In an exemplary embodiment, the user may choose the HMI#1 602A, for cold spray process. The user may then select an operator via the operator button 604. The operator button 604 may include a list of authorized users to operate the integrated cold spray system 100. Further, the user may enter a valid password for accessing the integrated cold spray system 100 as depicted in FIG. 6B. In an embodiment, the password button 606 may be used to change the password for accessing the integrated cold spray system 100. Further, the admin button 610 may be used to access the administrator rights, such as changing the setting of the system 100, modifying the system 100, etc.

[0069] FIG. 6B depicts an enter password page to enter a password associated with the selected operator. The enter password page may include a keypad 612 and a digital screen 614. In an embodiment, the user enter the valid password using the keypad

612, such as 12345678 as shown on the digital screen 614. The user may also enter the password using the user device's keypad.

[0070] Referring now to **FIG. 7**, an exemplary User interface (UI) 700 of the integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present invention. FIG. 7 is explained in conjunction with FIGs. 1-6B. Upon successfully logging in into the HMI system, the user may navigate the status and other operations related to the integrating cold spray system 100.

[0071] FIG. 7 depicts a main page to navigate the settings and operational status of the integrated cold spray system 100. The main page includes a main menu 702 and an operational status screen 704. The main menu 702 may include a manual button 706, a setup button 708, a robot button 710, a status button 712, an alarm button 714, and a help button 716. The manual button 706 may be used to change the manual settings of the system 102. The setup button may be used to change the setup settings, such as changing pre-defined distance and time of cold spray process. Further, the robot button 710 may be used to change the robotic arm settings, such as movement and orientation of cold spray gun 102. The status button 712 may be used to change the status of the system 100. Further, the alarm button 714 may be used to set an alarm during the cold spray process. The help button 716 may be used to reach out the manufacturer or the admin of the system 100.

[0072] Further, the main page may include an auto button 718, a home indicator 720, a robot home button 722, a fixture check indicator 724, and a total usage time screen 726. The auto button 718 may be used to switch different auto mode settings. The home indicator 720 shows a status of the system's 100 home position. Further, the robot home

button 722 may be used to prompt the system 100 to move to its home position. The fixture check indicator 724 may illuminate if there is work piece 112 in the system 100. Further, the total usage time screen 726 shows total time of system 100 in operation.

[0073] In some embodiments, the main page may render the operational status of program, powder feed system 104, and the integrated cold spray system 100. The operational status of the program may include a bucket number, a drawings number, a fixture number and a robot program. Further, the operational details of the powder feed system 104 may include cold spray gun pressure, cold spray gun temperature, powder feed rate, status of operation. The operational status of the integrated cold spray system 100 may include a robot status, a cold spray gun status, cold spray gun parameters, fixture clamp status, pressure to series parameter, dust collector status, main door status, service door status, and part pressure status.

[0074] Referring now to **FIG. 8**, an exemplary User interface (UI) 800 of the integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present invention. FIG. 8 is explained in conjunction with FIGs. 1-7. Upon selecting the manual button, the user may view and modify the manual settings of the integrated cold spray system 100.

[0075] FIG. 8 depicts a manual page to navigate the manual settings and operational status of the integrated cold spray system 100. The manual page may include a dust collector setting 802, a test strip button 804, an exit button 806, a setup button 808, a robot button 810, a status button 812, an alarm button 814, and a help button 816. The dust collector setting 802 may include an ON button to turn ON the dust collector and an OFF button to turn OFF the dust collector of the integrated cold spray system 100. The

test strip button 804 may prompt the robotic arm to run a test strip program, testing the cold spray process on a test work piece 112. Further, the exit button 806 may be used to go back to the main page. The setup button 808 may be used to render the setup screen. The robot button 810 may be used to view and modify the robotic arm settings. Further, the status button 812 may be used to view and modify the setup settings of the system 100. The alarm button 814 may be used to set or modify the alarm during the cold spray process. Further, the help button 816 may be used to contact the manufacturer or the admin of the integrated cold spray system 100.

[0076] In an embodiment, the manual page may include a powder feed system status screen 818 rendering a cold spray gun pressure, cold spray gun temperature, a powder feed rate, and an enable status of the integrated cold spray system 100. Further, the manual page may include a system status screen 820 rendering the system 100 status to the user. The system status screen 820 may include a robot status, cold spray gun status, cold spray gun parameters, fixture clam status, pressure to series parameters, a dust collector status, a main door status, a service door status, and a part presence in the system 100.

[0077] Referring now to **FIGs. 9A and 9B**, an exemplary human-machine interface (HMI) 900A, 900B of the integrated cold spray system 100 is illustrated, in accordance with some embodiments of the present invention. FIGs. 9A and 9B is explained in conjunction with FIGs. 1-8. In an embodiment, the user may navigate to a setup page by selecting the status button 808 to view or modify the setup settings of the integrated cold spray system 100.

[0078] FIG. 9A depicts a setup page to view and modify the setup settings of the integrated cols spray system 100. The setup page may include a Recipe number button 902, a load button 904, a save button 906, a call button 908, and an exit button 910. The recipe number button 902 may be used to change the recipe number or to select a pre-programmed recipe for executing cols spray process. Further, the load button 904 may be used to load the selected recipe into the integrated cold spray system 100. The save button 906 may be used to save the programmed recipe into the HMI system. The call button 908 may be used to call a selected program and return to main screen. Further, the exit button 910 may be used to return to the previous screen or exit the UI 900.

[0079] In an embodiment, the setup page may include program details screen 912 to render the details of the selected program or the recipe of the cold spray process. The program details screen 912 may include a fixture setting number, a bucket number, a drawings number, a temperature, a pressure, a powder feed rate, a feeder select, a robot program.

[0080] FIG. 9B depicts fixture data screen including recipes and pre-programmed programs for the cold spray process. The fixture data screen may include a next button 914 and an exit button 916. The next button 914 may be used to navigate to a next page upon selecting a desired recipe. Further, the exit button 916 may be used to navigate to the main screen of the UI 900. In an embodiment, the fixture data screen may include a recipe list 918 containing a plurality pre-programmed recipes and the corresponding information for the user to choose from.

[0081] Referring now to **FIG. 10**, an operational method 1000 of the integrated cold spray system 100 is depicted via a flow chart, in accordance with some embodiments

of the present disclosure. FIG. 10 is explained in conjunction with FIGs.1-9B. The method 1000 may be implemented by the controller of the HMI system.

[0082] At step 1002, information associated with a work piece to be cold sprayed is received from the RFID system. The RFID system may extract the information from the RFID tag attached to the work piece, when the workpiece is clamped to the platform of the spray booth. The information associated with the work piece may include metallurgical properties, dimension, size and location of the damage, etc. Further, the RFID system may transmit the information associated with the work piece to the HMI system.

[0083] At step 1004, one or more pre-specified operations to be performed using the robotic arm and the cold spray gun for executing a coating process for the work piece is determined. The one or more pre-specified operations are determined based on the information associated with the work piece. Further, the one or more pre-specified operations may include adjusting the cold spray gun for efficient and optimal coating process, moving the robotic arm to adjust the cold spray gun, material specific settings, such as temperature and velocity of the powder, temperature and pressure of the carrier gas, etc.

[0084] At step 1006, the robotic arm and the cold spray gun is controlled to coat the work piece based on the determined one or more operations. Further, the controlling of the robotic arm and the cold spray gun includes controlling the cold spray gun to supply a mixture of powder received from a powder feed system and carrier gases received from a gas supply system to the work piece. The controller of the HMI system controls the robotic arm to move and orient the cold spray gun precisely. Further, a data from a set of sensors and controlling operations of the dust collector is received based on the received

data. The dust collector may capture dust, and airborne particles from the spray booth after completing the cold spray process.

[0085] Thus, the present disclosure may overcome drawbacks of traditional systems discussed before. The present disclosure offers an integration of a six-axis robotic arm, a customized spray booth, a Human-Machine Interface (HMI), and an RFID-based error-proofing system. The integration collectively enhance the precision, efficiency, and reliability of the cold spray process, for repairing metallic components in various high-demand industries, including aerospace, defense, and marine engineering. The integration streamlines the operation, reduces setup time, and minimizes the risk of errors, resulting in a more reliable and efficient repair process.

[0086] The present disclosure offers an HMI system, serving as the central control hub for the entire cold spray system, enabling operators to manage all aspects of the process from a single interface. The disclosure reduces the requirement of operators to manually coordinate different components, increasing the potential for mistakes and inefficiencies. The HMI system is designed with user-friendly features, featuring pre-programmed cold spray processes tailored to specific components or part numbers. The pre-programming capability allows for rapid setup and consistent execution of repairs, ensuring that each repair meets the required specifications. The HMI also includes safety mechanisms and a recovery process in case of power disruption, enhancing the overall reliability of the system.

[0087] Further, to automate the cold spray process, the present disclosure include an RFID system to read RFID tags on fixtures for the products to be cold spray coated, ensuring that only the correct robotic program is executed for each specific

product. The RFID system significantly reduces the risk of human error, particularly critical in high-precision applications such as aircraft component repair or missile launcher maintenance. The RFID system ensures that the cold spray process is conducted according to the exact parameters required for each repair task, improving the quality and consistency of the repairs.

[0088] The present disclosure eliminates external heating elements. Traditional cold spray systems often rely on external heaters to increase the temperature of the carrier gas, introducing several operational challenges. The need to manage external components adds complexity to the system and increases its physical footprint, making it less suitable for use in environments where space is at a premium. By integrating the heating mechanism within the system itself, the present disclosure simplifies the operation and reduces the overall footprint, making the integrated cold spray system easier to maintain, enhancing safety by eliminating the risks associated with external heating elements, such as overheating or equipment failure.

[0089] Further, the present disclosure offers a combination of the six-axis robotic arm and the HMI system for highly precise control of the cold spray process. The robotic arm is programmed to follow complex paths with great accuracy, ensuring that the metal powder is deposited evenly across the work piece. Further, the combination enhances ability to execute repairs rapidly, reducing downtime for critical components.

[0090] The integrated cold spray system minimizes thermal impact on the work piece by operating below the melting point of the materials being deposited. The low-temperature nature of the process also allows for in-situ repairs, which can be conducted without disassembling the component from its operational environment. The integrated

cold spray system's ability to precisely control the temperature and pressure of the carrier gas further enhances its capability to perform repairs with minimal thermal distortion, making it ideal for applications where maintaining the integrity of the substrate is critical, such as in the repair of aircraft components or sensitive electronic devices.

[0091] It will be appreciated that, for clarity purposes, the above description has described embodiments of the invention with reference to different functional units and processors. However, it will be apparent that any suitable distribution of functionality between different functional units, processors or domains may be used without detracting from the invention. For example, functionality illustrated to be performed by separate processors or controllers may be performed by the same processor or controller. Hence, references to specific functional units are only to be seen as references to suitable means for providing the described functionality, rather than indicative of a strict logical or physical structure or organization.

[0092] Although the present invention has been described in connection with some embodiments, it is not intended to be limited to the specific form set forth herein. Rather, the scope of the present invention is limited only by the claims. Additionally, although a feature may appear to be described in connection with particular embodiments, one skilled in the art would recognize that various features of the described embodiments may be combined in accordance with the invention.

[0093] Furthermore, although individually listed, a plurality of means, elements or process steps may be implemented by, for example, a single unit or processor. Additionally, although individual features may be included in different claims, these may possibly be advantageously combined, and the inclusion in different claims does not imply

that a combination of features is not feasible and/or advantageous. Also, the inclusion of a feature in one category of claims does not imply a limitation to this category, but rather the feature may be equally applicable to other claim categories, as appropriate.

CLAIMS

1. An integrated cold spray system comprising:

a spray booth comprising:

a cold spray gun coupled to a powder feed system and a gas supply system, wherein the cold spray gun receives powder from the powder feed system and carrier gases from the gas supply system, and wherein the cold spray gun comprises a nozzle to supply a mixture of the powder and the carrier gases to a work piece to be cold sprayed;

a robotic arm comprising an end effector to hold the cold spray gun;

a radio frequency identification and detection (RFID) system to collect information associated with the work piece; and

a human-machine interface (HMI) system in communication with the spray booth, and the RFID system.

2. The integrated cold spray system of claim 1, further comprising a ventilation system comprising a dust collector to capture dust, and airborne particles within the spray booth.

3. The integrated cold spray system of claim 1, wherein the powder feed system stores and transports the powder from a reservoir or a hopper to the cold spray gun.

4. The integrated cold spray system of claim 1, wherein the nozzle is a converging-diverging nozzle, wherein the nozzle has a first inlet for receiving the carrier gases from the gas supply system and a second inlet for receiving the powder from the powder feed

system, and wherein the nozzle accelerates the carrier gases and mixes the carrier gases with the powder before directing the mixture onto the work piece.

5. The integrated cold spray system of claim 1, wherein the gas supply system is a high-pressure gas supply system configured to provide the carrier gases at high velocities to the cold spray gun, and wherein the gas supply system comprises a gas pressure regulator and a gas temperature control unit.

6. The integrated cold spray system of claim 1, wherein the robotic arm is a six-axis robotic arm.

7. The integrated cold spray system of claim 1, wherein the cold spray gun is mounted on the end effector of the robotic arm, allowing the robotic arm to move and orient the cold spray gun precisely.

8. The integrated cold spray system of claim 2, wherein the dust and airborne particles are generated due to at least one of a cold spray process, a high velocity gas stream, abrasion or mechanical preparation, a coating process and/or overspray.

9. The integrated cold spray system of claim 2, wherein the dust corresponds to excess powder generated during a coating process, and wherein the dust collector removes the excess powder from spray booth environment.

10. The integrated cold spray system of claim 2, wherein the dust collector creates a controlled airflow that draws in and filters out the dust and airborne particles.

11. The integrated cold spray system of claim 2, wherein the dust collector uses one or more filters to capture the dust and airborne particles.

12. The integrated cold spray system of claim 1, wherein the RFID system comprises at least one RFID tag and an RFID reader, wherein a target RFID tag of the at least one RFID tag is mounted on a fixture of the work piece to be cold sprayed, and wherein the RFID reader collects information associated with the work piece from the target RFID tag when the RFID tag and the RFID reader are in a prespecified proximity and transmits the collected information to the HMI system.

13. The integrated cold spray system of claim 11, wherein the HMI system comprises error-proofing mechanisms that prevent execution of an operation not matching the target RFID tag mounted on the fixture of the work piece.

14. The integrated cold spray system of claim 1, wherein the information associated with the work piece comprises a type of the workpiece, and components of the work piece.

15. The integrated cold spray system of claim 13, wherein the HMI system adjusts operational parameters of a cold spray process automatically based on the type of work piece.

16. The integrated cold spray system of claim 1, wherein the HMI system controls one or more operations of the cold spray gun, the robotic arm, and the ventilation system, and wherein the HMI system comprises a controller for controlling the one or more operations.

17. The integrated cold spray system of claim 15, wherein the HMI system controls the one or more operations of:

the cold spray gun based on the information received from the RFID system;

the robotic arm based on real-time data collected through a first set of sensors in proximity to the robotic arm;

the dust collector based on information collected from a second set of sensors.

18. The integrated cold spray system of claim 16, wherein the second set of sensors comprises one or more of a temperature sensor, an airflow sensor, a pressure sensor, a vibration sensor, a flow switch, an air quality sensor, a level sensor, an air velocity sensor, and/or a filter condition sensor.

19. The integrated cold spray system of claim 1, wherein the robotic arm is programmed to execute precise movements and orientations based on requirements of a cold spray process, as specified by the HMI system.

20. The integrated cold spray system of claim 1, wherein the powder is metal powder.

21. The integrated cold spray system of claim 1, further comprising a motorized work piece loading system fixed under the robotic arm, wherein the work piece loading system is configured to move forward and backward for loading and unloading the workpiece.

22. A method of controlling an integrated cold spray system, the method comprising:

receiving, by a controller of a human-machine interface (HMI) system, information associated with a work piece to be cold sprayed from a radio frequency identification and detection (RFID) system;

determining, by the controller, based on the information, one or more pre-specified operations to be performed using a robotic arm and a cold spray gun for executing a coating process for the work piece; and

controlling, by the controller, based on the determined one or more operations, the robotic arm and the cold spray gun to coat the work piece.

23. The method of claim 21, wherein a spray booth comprises the cold spray gun, the robotic arm, and a ventilation system, and wherein the ventilation system further comprises a dust collector.

24. The method of claim 22, further comprising receiving, by the controller, data from a set of sensors and controlling operations of the dust collector based on the received data, and wherein the dust collector is configured to capture dust, and airborne particles.

25. The method of claim 21, wherein the cold spray gun is mounted on an end effector of the robotic arm, and wherein the controller controls the robotic arm to move and orient the cold spray gun precisely.

26. The method of claim 21, wherein the controlling comprises controlling the cold spray gun to supply a mixture of powder received from a powder feed system and carrier gases received from a gas supply system to the work piece.