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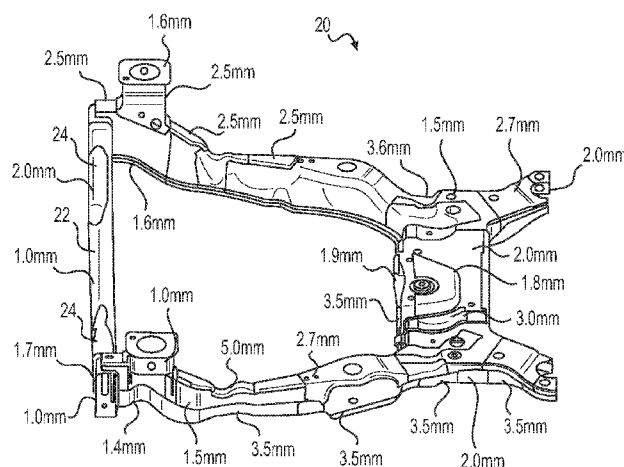


FIG. 1A

(57) Abstract: An electromagnetic particle disposition system that utilizes electromagnetic forces to deposit charged metal particles onto a metal part. The metal part includes a plurality of localized areas that will be subjected to various levels of stress, for example, the metal part may be integrated into an automobile body. Values corresponding to the amount of stress the localized areas will receive are used to determine minimum operational strength and stiffness requirements wherein more metal particles will be needed in areas with greater requirements. During operation, the metal particles are charged and introduced into an electrostatic field and the metal part is grounded. An electrostatic discharge field is then developed between the charged metal particle and the grounded metal part such that the metal particle is attracted to the grounded metal part and accelerates to a sufficient terminal velocity to form a solid state bond upon impact.



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ELECTROMAGNETICALLY ASSISTED METAL SPRAY PROCESS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This PCT International Patent Application claims the benefit of and priority to U.S. Provisional Patent Application Serial No. 62/730,270 filed on September 12, 2018, titled “Electromagnetically Assisted Metal Spray Process,” and also claims the benefit of and priority to U.S. Provisional Patent Application Serial No. 62/823,320 filed on March 25, 2019, titled “Electromagnetically Assisted Metal Spray Process,” the entire disclosures of which is hereby incorporated by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

[0002] The present invention relates to a process for depositing metal particles onto a substrate. More particularly, the present invention relates to a particle depositing tool, a process of depositing metal particles, and a part with thickened localized areas produced by same.

2. Related Art

[0003] This section provides background information related to the present disclosure which is not necessarily prior art.

[0004] Parts stamped from metal oftentimes have localized areas which require greater strength or stiffness properties depending on what the parts ultimate end use will be. For example, localized areas of a part stamped for use in automobiles may be subjected to inconsistent types of stresses via rough driving surfaces, internal vibrations, and exposure to corrosive environments. Because certain localized areas can experience these hardships more than other localized areas of the same part, stamped parts are oftentimes produced over gauged to satisfy specific strength or stiffness requirements of whichever localized

area within the stamped part will be subject to the most stress. This extra and unnecessary material accompanies both an increased weight and cost of production.

[0005] Various attempts have been made to add material specifically to areas subjected to increased stresses such that the entire part does not need to be produced with a uniformly thick gauge. Stated another way, processes have been developed to produce a part out of a thin gauged sheet and apply material to strengthen only those localized areas which are particularly at risk to breaking via high stress exposure during operation. One such process is an arc-spraying procedure that utilizes an electric arc to melt wires. The molten metal is then atomized with compressed air to create a spray stream that applies the coating onto the surface being sprayed. While exhibiting certain benefits, the arc-spraying procedure is limited by low deposition rates as higher deposition rates cause the part to be too porous. Another spraying process is called cold spraying. During cold spraying, particles are accelerated at very high speeds by a carrier gas forced through a converging-diverging de Laval type nozzle. Upon impact, solid particles with sufficient kinetic energy deform plastically and bond mechanically to the substrate to form a coating. Much like the arc-spray process, the cold spray process is also limited by low deposition rates. Depending on the materials used and methods of spraying, sprayed particles must reach a critical velocity before impacting the part in order to form a bond. In addition to the above spraying processes, additional processes have been developed which apply material via a laser. For example, in a laser metal deposition process metal is applied to a surface of a component in sequential layers. The laser generates a semi-controlled molten bath on the surface of the part that one or more metal powders is sprayed onto through a nozzle. The powder then melts and bonds with the molten base material or bath. While the use of a laser exhibits certain benefits over the other spraying processes, the laser metal deposition

process is also limited by both very high expense and negatively impacting the strength and ductility of the substrate on which the molten bath is formed.

[0006] Accordingly, there is a continuing desire to develop and further refine processes that are capable of quickly depositing material onto a localized area of a component without negatively impacting strength or ductility.

SUMMARY OF THE INVENTION

[0007] This section provides a general summary of the inventive concepts associated with this disclosure and is not intended to be interpreted as a complete and comprehensive listing of all of its aspects, objectives, features, and advantages.

[0008] It is an aspect of the subject invention to provide an electromagnetic particle disposition system for bonding particles of metal material onto a grounded part of metal material. The electromagnetic particle disposition system comprises an electrostatic nozzle having a discharge line that extends between an entry port for placement of particles and a discharge port spaced from the entry port. The discharge line includes a charged state wherein particles traveling from the entry port to the discharge port develop a positive charge by electrostatic induction from contact with the discharge line. A capacitor is located adjacent to the discharge port for developing an electrostatic discharge field directed to the grounded part that attracts and accelerates the charged particle towards the grounded part until the particle reaches a terminal velocity upon impact with the grounded part that bonds the particle to the grounded part.

[0009] It is another aspect of the subject invention to provide a method of bonding particles of metal material onto a part of metal material that includes a plurality of localized areas so that at least two of the localized areas have different gauges. The method comprises the steps of: grounding the part; providing an electrostatic nozzle and aiming it at one of the plurality of localized areas; generating an electrostatic discharge field between

the electrostatic nozzle and the grounded part; and charging the metal particle and projecting it through the electrostatic discharge field onto the localized area until the gauge of the localized area becomes larger to withstand greater stress.

[0010] Further areas of applicability will become apparent from the description provided herein. The description and specific examples in this summary are intended for purpose of illustration only and are not intended to limit the scope of the present disclosure.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] The drawings described herein are for illustrative purposes only of selected embodiments and are not intended to limit the scope of the present disclosure. The inventive concepts associated with the present disclosure will be more readily understood by reference to the following description in combination with the accompanying drawings wherein:

[0012] Figure 1A and Figure 1B illustrate an automotive component assembled out several stamped parts wherein certain parts have localized areas with varying thicknesses;

[0013] Figure 2A through Figure 2D schematically illustrate the forces utilized in accordance with various aspects of the present disclosure;

[0014] Figure 3 illustrates a electromagnetic nozzle assembly having electromagnetic coils to accelerate a particle;

[0015] Figure 4A through Figure 4E illustrate an electrostatic nozzle assembly in accordance with another aspect of the disclosure;

[0016] Figure 5A through Figure 5C sequentially illustrate the electrostatic nozzle assembly with a particle guiding attachment depositing particles to form a vertical wall;

[0017] Figure 6A through Figure 6E sequentially illustrate an enlarged view of the electrostatic nozzle assembly depositing charged particles on a part;

[0018] Figure 7 is a flow chart illustrating the steps of forming a part via the electromagnetic nozzle assembly shown in Figure 3;

[0019] Figure 8 is a flow chart illustrating the steps of forming a part via the electrostatic nozzle assembly shown in Figure 4A through Figure 4E;

[0020] Figure 9 is a flow chart illustrating forming a vertical wall via the electrostatic nozzle assembly that includes the particle guiding attachment as shown in Figure 5A through Figure 5C;

[0021] Figure 10 is a schematic illustration of a particle deposition assembly having a conveyer system; and

[0022] Figure 11A through Figure 11C are graphical representations of critical particle velocity relative to various charges and particle sizes.

DESCRIPTION OF THE ENABLING EMBODIMENT

[0023] Example embodiments will now be described more fully with reference to the accompanying drawings. In general, the subject embodiments are directed to an electromagnetically assisted particle deposition system that uses an particle depositing tool for adding material to localized areas of a part to strengthen and stiffen the localized area to meet certain operational requirements. However, the example embodiments are only provided so that this disclosure will be thorough, and will fully convey the scope to those who are skilled in the art. Numerous specific details are set forth such as examples of specific components, devices, and methods, to provide a thorough understanding of embodiments of the present disclosure. It will be apparent to those skilled in the art that specific details need not be employed, that example embodiments may be embodied in many different forms and that neither should be construed to limit the scope of the disclosure. In some example embodiments, well-known processes, well-known device structures, and well-known technologies are not described in detail.

[0024] Referring to the Figures, wherein like numerals indicate corresponding parts throughout the views, the electromagnetically assisted particle deposition system and an associated particle depositing tool is intended for increasing the efficiency of adding material to a localized area of a stamped part. As it will be appreciated with further reading, the electromagnetically assisted particle deposition system and the particle depositing tool allow for high deposition rates and inexpensive operational costs.

[0025] With reference initially to one example embodiment shown in Figure 1A and Figure 1B an automotive component 20, shown as a cradle, is assembled out of various parts 22 formed from stamped steel. Localized areas 24 are indicated by grey-scale markers and with specifying gauge measurements of average optimal thickness in millimeters (mm). The non-uniform distribution of thickness (gauge of the steel) across the localized areas 24 illustrates a component 20 that combines optimum performance with minimum material usage with a focus on enhanced stiffness. The gauge measurements range from 1mm to 5mm. As will be appreciated with further reading, each part 22 can be initially stamped from sheet at a minimum gauge and then additional material is deposited via the electromagnetically assisted particle deposition system. Alternatively, the part 22 can be initially stamped from a sheet at a gauge above minimum but less than maximum. The additional material can then be deposited on a part 22 before assembling into the component 20 or otherwise deposited directly on the component after assembly of the parts 22. Similarly, the additional material can be deposited directly on the blank part ASM. To this extent, the added material can be deposited directly on a joint between parts 22 after assembly and can assist in the joining of two or more parts into a smooth, uninterrupted surface. The connection of parts 22 can include any combination of welding, rivets, deposited particles, or any other methodology. By way of example, looking at the part, shown as a cross-beam 22 in Figure 1A, the optimal thickness includes a central localized

portion that is 1mm thick and outer localized portions that are 1.7mm and 2mm, respectively. As such, the cross-beam 22 can be stamped out of a uniform piece of 1mm steel and then the additional material can be deposited to the localized portions in the amount of .7mm and 1mm, respectively. With reference now to Figure 1B, the component 20 is shown with material added to localized areas 24 indicated by the varying grey-scale. Unlike Figure 1A which illustrates an optimized average thickness over a larger localized portion, the component in Figure 1B represents the exact optimized location (localized area 24) of the added material without relying on average. A table is presented with Figure 1B to specify a thickness in mm associated with each shade in the grey-scale. The components 20 presented in Figures 1A and 1B have been shown to reduce weight of conventionally constructed like-parts by approximately 6.76kg. More particularly, the component 20 constructed in accordance with the electromagnetically assisted particle deposition system weights approximately 19.74kg whereas a component constructed with conventional processes weights approximately 26.50kg. In one example embodiment, the part 22 is formed of steel and the added material is steel, iron, another ferrous material, or another iron-containing material. Likewise, while the component 20 is shown as an automotive cradle and the part 22 is shown as a portion of the cradle, it should be appreciated that the component 20 is not limited to a cradle and that the various parts 22 with localized areas 24 could vary in size and shape. The present disclosure is not limited to the substrate on which the additional material is deposited.

[0026] Figure 2A and Figure 2B schematically illustrate one the forces that the electromagnetically assisted particle deposition system 10 can utilize to project particles onto a part 22. With reference initially to Figure 2A, it schematically illustrates one configuration (via a rail assembly 109 presented in Figure 3) by which the electromagnetically assisted particle deposition system 10 creates a directed force upon the

charged particle via the right hand rule of magnetic force. As shown, there is a first rail 26 and a second rail 28 wherein current is supplied to the first rail 26. A magnetic field 30 is generated in and about the charged first rail 26. As shown by the arrow that extends between rails 26, 28. The particle is a conductive material and must make contact with both rails 26, 28 such that current can enter the first rail 26 and transfer across the particle to the second rail 28 resulting in an electromagnetic force shown with an arrow designated "Force." Alternatively, an armature 29 can be used to transfer the current between rails 26, 28 and drive the particle forward. Conceptually, the electromagnetic force drives the charged particle, pushing it out of the electromagnetic field in an increasing velocity. Figure 2B schematically illustrates the electromagnetic field produced from a coil 32, wherein the magnetic field 30' is linearized within the coil 32 to propel a particle or armature contacting both sides of the coil 32 forward.

[0027] Referring now to Figure 3, the electromagnetically assisted particle deposition system 10 is shown to include an electromagnetic nozzle assembly 100 adapted to deliver material to localized areas 24 of a stamped part 22 or component 20 by utilizing the forces schematically illustrated in Figure 2A and Figure 2B. The assembly 100 includes an acceleration tube 102 used to deliver the material onto the stamped part 22. The acceleration tube 102 extends along an axis A for directing the deposition of the particles there along. A central portion 108 extends between a first end 104 and a second end 106. The central portion 108 is housed within an energy sleeve 110 that includes one of coils 32 or rails 26, 28. As previously stated, it is important that the particle and/or armature 29 contact both rails 26, 28, therefore, it should be appreciated that both rails 26, 28 project at least partially into the acceleration tube 102. When powered, the energy sleeve develops a linearized magnetic field directed along the axis A. The first end 104 of the acceleration tube 102 further includes a nozzle 112 with an opening 114 from which the charged

particles are discharged. The opening can be a rectangular shape 114', 114'', and array of circular openings 114''', or one large central opening 114'''. The various shaped openings thus correspond to the cross-sectional shape of deposited particles on the substrate 22. A powdered metal stock container 116 is attached to the second end 106 of the acceleration tube 102 and holds metal particles before they are deposited on the localized area 24 of the stamped part 22.

[0028] A particle feed air/gas tube 118 is fed into the powdered metal stock container 116 push particles into the acceleration tube 108 via introduction of gas. A control valve 120 regulates the rate at which the particle feed air/gas tube 118 releases gas into the powdered metal stock container 116. Once the particles enter the acceleration tube 102, it either makes contact with the rails 26, 28 or enters armature 29 in contact with the rails 26, 28 and are subjected to the forces described in reference to Figure 2A and Figure 2B. A build-up of deposited material 122 is shown on the localized area 24 of the stamped part 22. In operation, electromagnetic forces acting upon the charged particles cause the particles to contact the localized area 24, or already deposited material 122, at rates around 600 to 1000 meters per second and at a flow rate of up to 12kg per minute. While these rates may vary, the speed at which the charged particle comes in contact with either the localized area 24 or already deposited material 122 is fast enough to create a solid state bond with little porosity while still maintaining high deposition rates.

[0029] Referring back to Figure 2C and Figure 2D, schematic illustrations of various forces which the electromagnetically assisted particle deposition system 10 utilizes are presented in accordance with another embodiment of the disclosure. More specifically, Figure 2C illustrates the Lorentz force, which is an aggregation of both electric and magnetic force on a charged particle. The schematic image represents the trajectory of the particle with a positive or negative charge q under the influence of a magnetic field B . It

should be appreciated that the Magnetic field B is directed perpendicular to the trajectory. Figure 2D illustrates an electromagnetic field of attraction between a positively charged element and a negatively charged element.

[0030] Referring now to Figure 4A through Figure 6E an electromagnetically assisted particle deposition system 10' is provided in accordance with another embodiment. More specifically, the embodiment presented in Figure 4A through Figure 6E utilizes an electrostatic discharge system 200 that generates the forces presented in Figures 2C and 2D. The electrostatic discharge system 200 generates an electromagnetic field to attract a particle P^+ that has received an electrostatic charge towards a grounded component 20. Both the particle P^+ and the grounded component may be formed of steel or other ferrous metal. The attraction of the particle must generate enough force to accelerate the particle to a critical velocity of approximately between 500 m/s and 900 m/s in order to form a solid state bond to the component 20. As a charge is developed on the particle P^+ and the generated magnetic field attracts the particle P^+ towards the grounded component. Acceleration of the charged particle will depend at least partially the strength of the magnetic field and the charge on the particle P^+ .

[0031] As best shown in Figure 4A through Figure 5C, the electrostatic discharge system 200 includes an electrostatic nozzle assembly 202 having an electrostatic nozzle 204. The electrostatic nozzle 204 includes a power source 206 (Figure 5A), a discharge line 208, a capacitor 212, and a discharge port 210. As will be described in further detail below, the power source 206 provides electricity to charge the discharge line 208 into a charged state such that it becomes an electrostatic charger for particles that come into contact therewith. The discharge line 208 extends between an entry port 203 and a discharge port 210. A pair of insulators 207, 209 are disposed on opposite sides of the discharge line 208, next to the entry port 203 and the discharge port 210. The insulators 207, 209 are

preferably constructed of a non-conductive, rigid material. For example, the insulators 207, 209 may be formed of ceramic, hard plastic, or a metal coated with a non-conductive coating. The capacitor 212 is spaced from the discharge port 210 via one of the insulators 209 and defines a central opening 201 aligned with the discharge port 210. The capacitor 212 may be an integral or a separate piece from the discharge line 208. A capacitor power source 205 charges the capacitor 212 to produce a positive electric field resulting in an electromagnetic discharge field developing between the discharge port 210 and the grounded component 20 or part 22. As will be described in further detail below, charged particles P⁺ pass through and are uninterrupted by the positive field of the charged capacitor 212 during use. Similar to the previous embodiment, particles are initially stored in a metal particle stock 214. Particles are then fed from the metal particle stock 214, past one of the insulators 207, and into the entry port 203. The particles contained in the metal particle stock 214 are typically not charged. The rate at which particles enter the discharge line 208 are regulated by a control valve 216 that also controls the mixture and volume flow of air fed therethrough. The insulator 207 is typically spaced between and separates the control valve 216 and the discharge line 208. A metal feed air/gas tube 218 is fluidically connected to the control valve 216 and can help initially accelerate the particles into the discharge line 208 and push them therethrough. In operation, particles rest upon the control valve 216 and the control valve 216 remains closed. The metal feed air/gas tube 218 is pressurized and connected to the control valve 216 upstream from at least some of the particles resting thereon. Therefore, once the control valve 216 is open, the upstream air pressure forces metal particles into the discharge line 208. The line 208 is generally perpendicularly aligned with respect to the component 20 or part 22 to prevent the particles from bouncing upon contact. Generally perpendicular alignment may be within a range of 20° degrees from perpendicular.

[0032] The electrostatic discharge system 200 utilizes particles P having equal to or less than 0.5mm radius and preferably approximately 0.1mm radius. Initially, an electric charge is developed in the discharge line 208 via electricity from the power source 206. A particle P is deposited into the discharge line 208 in an uncharged or neutral state. The discharge line 208 includes a charged state wherein an uncharged particle P collects free ions through electrostatic induction as it contacts an interior surface of the discharge line 208. The discharge line 208 may be formed of a metal such as steel or steel alloy so that it can transfer the static electricity withstand the abrasive effects of the particles. As the particle P captures free ions, a charge is developed in the particle via the trading of electrons between the charged particle P⁺ and the surrounding medium. The magnitude of the charge can be controlled by changing the particle P size, the electrostatic field strength, and the time that the particle P is in the charge area. One example is presented in Figure 4D wherein the discharge line 208 is helically shaped to allow more contact between the particle P and the discharge line 208. The pitch of the helical shape can vary and the metal feed air/gas tube 218 or an upper portion of the discharge line 208 may further include a fan 211 to help urge the particle therethrough. While the magnitude of the charge may be varied, the electrostatic discharge system 200 may be configured such that the charge particle P⁺ can reach a saturation point of captured ions and develops its own positive electrical field. In one preferred arrangement, the charged particle P⁺ has a charge of 45 μC when it exits the discharge line 208. The capacitor 212 receives current from the capacitor power source 205 and develops a strong positive charge adjacent to the discharge port 210. As best shown in Figure 4C, the component or substrate 20 is then placed in close proximity to the capacitor 212 and grounded. The positive charge of the capacitor 212 is spaced close enough to the grounded component 20 that an electrostatic discharge path is developed over the localized area 24. The electrostatic discharge field acts upon the grounded substrate and

the localized area 24 begins to develop a negative charge as it attracts electrons towards the discharge field. These excess electrons are simultaneously discharged to the ground 27.

The charged particle P⁺ that is positively saturated then passes through and is uninterrupted by the positive charge of the capacitor 212 but is attracted to the grounded component 20 and more particularly the localized area 24 which is the closest portion of the component 20 to the discharge port 210. In one exemplary embodiment, the capacitor 212 is a 300V positive capacitor 212 that includes a coil. The power of attraction between the charged particle P⁺ and the grounded component 20 accelerates the charged particle P⁺ as a function of the distance between the discharge port 210 and the grounded component 20 and the amount of respective charges of the particle P⁺ and the capacitor 212. During acceleration, the charged particle P⁺ reaches a high enough terminal velocity to form a bond, preferably a solid state bond. Similar to the various openings 114 in Figure 3, the discharge port 210 and or central opening 201 of the capacitor 212 may be constructed to have numerous cross-sectional shapes as a pattern guide on which the particles are deposited. By way of example, if the central opening 201 is configured to have a circular cross-sectional shape, then the cross-section of particles P accumulated on the localized area 24 will also be relatively circular. The same rule will apply to cross-sections of rectilinear shapes, star shapes, elliptical shapes, ring shapes, letters, numbers, arrays, origin identifies etc. In addition to altering the central opening 201, the discharge port 210 and/or capacitor 212 may be configured to selectively receive various caps 213 (Figure 4E) having cap ports 215 each defining a different cross-sectional shape for a specific applications. More particularly, the cap 213 includes a cap entry port 217 that matches the cross-sectional shape of the central opening 201 and tapers or expands to the cap exit port 215 so that charged particles P⁺ enter the cap 213 from the central opening 201 uninterrupted via the uniform cross-section and are then guided into the cap exit port 215. The cap 213 can

sleeve or otherwise connect to the capacitor 212 or other portions of the electrostatic nozzle 204 through various quick-release clips, fasteners, etc. (not shown). The cap 213 is typically formed of non-ferrous material that can withstand particles being ejected therethrough. As such, various caps 213 can be quickly replaced to change the outline of deposition as needed.

[0033] In reference to Figure 5A through Figure 5C, the electrostatic discharge system 200 can further be applied to a base component 20 to form a vertical wall 25 on a localized area 24. To form the vertical wall 25, the electrostatic nozzle assembly 202 may be modified to include a particle guiding attachment 220. The particle guiding attachment 220 is connected to the electrostatic nozzle 204 via a connection portion 222 and includes an arm 223 that extends parallel to the discharge line 208 to a guide portion 224. The guide portion 224 defines an aperture 226 such that charged particles P^+ exiting the discharge port 210 are limited to contacting and bonding to the localized area 24' only through the aperture 226. Accordingly, the cross-sectional shape of the aperture 226 outlines a uniform and corresponding cross-sectional shape of the deposited particles on the base component 20. Similar to the cap 213 or discharge port 210, the shape of the aperture may be circular, rectangular, annular, or other desired shapes such as letters, numerals, product and origin identifiers, etc. It is preferable that the guide portion 224 is constructed out of a non-ferrous material that can withstand forming a bond with the accelerated charged particles P^+ upon impact. For example, the guide portion 224 may be formed of ceramic, a metal with a non-conductive coating, or other non-conductive materials that are hard enough to resist bonding to the particles. The arm 223 holds the guide portion 224 at a predetermined distance D from the discharge port 210. The predetermined distance can vary as will be described in more detail below. The base component 20 is grounded via connection to the ground device 27 (such as a GFCI). A lifting mechanism 228 moves the electrostatic nozzle 204 with

respect to the base component 20 and is directed via a controller 230 to maintain a uniform distance between the guide portion 224 and/or discharge port 210 and the accumulated particles on the base component 20. Accordingly, as the charged particles P^+ are deposited on the localized area 25, a vertical wall 31 is formed towards the discharge port 210. In order to form a vertical wall 31 of uniform thickness and porosity, the controller 230 maintains a constant distance D between a top 23 of the vertical wall 31 (i.e., localized area 25) and the discharge port 210 by moving the electrostatic nozzle 204 vertically at the rate in which the vertical wall 31 develops, which is typically constant. The lifting mechanism 228 may further include one or more distance sensors 229 for maintaining a uniform distance. It should be also be appreciated, that the lifting mechanism 228 can also be configured to move in multiple directions with respect to the base component 20 to form elaborately shaped vertical walls 31 that extend with respect to each other and the base component 20 at various angles. Likewise, it should also be appreciated that the base component 20 can alternatively or additionally be moved via the lift mechanism 228 relative to the electrostatic nozzle 204.

[0034] Referring now to Figure 6A through Figure 6E, a series of time captures illustrate charged particles P^+ being deposited on a localized area 24 of a component 20 and/or a vertical wall 25 of a base component 20. In the present example, the charge particle P^+ has a radius of 0.1mm and is charged to 45 μC while the capacitor 212 is a 300V positive capacitor 212. The discharge port 210 is located at approximately 0.9mm from the localized area 24 and the charged particles P^+ contact the component 20 to form an approximately 0.4mm deposit radius. The velocity of the particles are indicated by grey-scale and exit through the discharge port 210 at a velocity of approximately 100 m/s or less and continue to accelerate through the electrostatic discharge field to a terminal velocity of approximately 900 m/s. Figure 6A through Figure 6E are sequential where Figure 6A is

captured at 1.1 milliseconds, Figure 6E is capture at 17.2 millisecond, and Figures 6B through 6D are captured sequentially therebetween as indicated. It should be appreciated that the particle size radius, μC charge, and voltage can vary in relation to each other and in accordance with various specific applications.

[0035] A method 300 of depositing particles on a localized is also provided. As shown in Figure 7, the method 300 begins by determining 302 the lowest value of gauge required for a part or component. In other words, a determination is made on which localized area of a part or component will undergo the least amount of stress and the minimum required gauge to safely withstand that stress. Once determined 302, the part may still be in the shape of a metal sheet or blank that is selected in accordance with the minimum gauge that will ultimately form the shaped part. The sheet may then be stamped 304 into the part before undergoing subsequent steps. Next, localized areas of the part or component that will be subjected to increased stress are determined 306 and provided a value 308 based on the amount of stress the given localized area is determined to receive during use, i.e., during operation of a vehicle that includes the part or component. An acceleration tube is then aimed 210 at the localized area determined to be subjected to additional stresses such that the localized area is the closest portion of the part or component to a discharge port of the acceleration tube. An electromagnetic field is generated 312 in the acceleration tube 102 and metal particles are introduced 314 into the electromagnetic field, such that they make contact with a coil or a pair of rails as described above. Upon introduction 314 of the metal particles (preferably such that the particle contacts both rails), the metal particles form a deposit 316 on the localized area 24 by being accelerated towards the localized area 24 until they reach a critical velocity creating impact forceful enough to create a solid state bond. The particles are typically deposited at a rate of 600 to 1000 meters per second and preferably over 500 meters per second. The method 300

repeats 318 until the deposit 316 formed of the metal particles on the localized area reach at least a minimum thickness capable of withstanding the provided value 308 of stress associated with that localized area 24. If the part 22 has not yet been stamped, it can be stamped 304 or otherwise shaped after deposition of the particles. The component or part can further be welded 320 to another part or larger component before or after deposition of the particles. Alternatively, the metal particles can be formed 316 onto the sheet metal that is later stamped 304 into the part and then welded 320 to a second part. Moreover, the particle deposition can be added to a joint between two parts to strengthen and/or connect the parts.

[0036] The present disclosure further provides a method 400 of depositing material on localized areas of a part or component utilizing the electrostatic discharge system 200 of Figures 4A through 6E. The method 400 is similar to method 300 and begins by determining 402 the lowest value of gauge required for a part or component. In other words, a determination is made on which localized area will undergo the least amount of stress and the minimum required gauge to safely withstand that stress. Once determined 402, the part may initially be introduced as a metal sheet or blank that is chosen based on the minimum gauge requirements. The sheet may further be stamped 404 to form the part or component before subsequent steps. Next, localized areas of the part or component that will be subjected to increased stress are determined 406 and provided a value 408 based on the amount of stress the given localized area is expected to receive. Next, an electrostatic nozzle is aimed 410 at the localized area determined to be subjected to additional stresses. The localized area is preferably the portion of the part or component that is closest to the discharge port. An electrostatic field is generated 412 in electrostatic nozzle 204 and the part or component is grounded 414. The electrostatic field includes an electrostatic discharge field at least partially formed by a capacitor that develops a discharge field

between a discharge port to the grounded part or component. Preferably, the grounded part or component is placed within 2mm and more preferably yet within 1mm from the discharge port and/or a central opening of the capacitor. Next, the metal particles are introduced 416 into the electromagnetic field, it is preferable the metal particles are introduced 416 in a non-charged state. Upon introduction 416 of the metal particles, each metal particle contacts and rubs against an interior surface of the charged discharge line and attracts and captures 418 free ions until it receives a positive charge. The step of capturing 418 free ions preferably includes the metal particle reaching a saturation point of ions. As free ions are captured, the charged particle develops a positive electrical field. A force of attraction is generated 420 between the grounded part or component and the positive electrical field of the charged metal particle. The closer the charged particle is to the grounded part or component, the larger the force of attraction as the particle is accelerated 422 towards the localized area. The charged particle preferably has a terminal velocity of at least 500 m/s as it contacts and is deposited 424 on the localized area to form a solid state bond therewith. If the part is not previously stamped 404, it can be after deposition of the particles.

[0037] Figure 9 provides an additional flowchart, which illustrates a method 500 of forming a vertical wall as shown in the embodiment presented in Figure 5A through 5C. The method 500 of forming a vertical wall can include all or some of the steps of method 300 or method 400 and/or some combination thereof as designated by step 508. As one exemplary example, the method 500 includes all of the steps of method 400 beginning at step 410. More specifically, the method 500 may begin by providing 502 a base component or part and determining 504 a location to develop a vertical wall via deposition of metal particles. An electrostatic nozzle and/or acceleration tube, generically referred to as depositing tool, is oriented 506 with a lift mechanism that can move the depositing tool with

respect to the base component or part. The provided depositing tool may further include a guide portion. Next various steps outlined in the method 300 or the method 400 of depositing the metal particle onto the part or component are performed as designated by 508. During a continued deposition of particles, the depositing tool is moved 510 at a rate to maintain a predetermined distance between the deposited particles and the depositing tool as the deposited particles accumulate 512 on the component or part to form a vertical wall. It should be appreciated that the vertical wall can encompass any structure that extends vertically from the component or part but may more specifically include cubic vertical walls that extend perpendicularly from the part, letters, numbers, etc., as previously described. Moreover, it should be appreciated that in addition to moving the depositing tool vertically, the lifting mechanism may further move the depositing tool in other directions to form the vertical wall in non-linear and non-perpendicular directions. Furthermore, it should also be appreciated that the guide portion or cap may be selected based on the desired deposition shape and be connected and replaced between cycles with other guide portions or caps having differently shaped apertures.

[0038] With reference now to Figure 10, the electromagnetically assisted particle deposition system may further be part of a larger particle deposition system 600. The particle deposition system 600 is provided within a manufacturing setting and includes a conveyor system 602. The conveyor system 602 includes a conveyor belt 604 having a loading zone 606, a containment booth 608, and an unloading zone 610. The component 20 or part 22 is initially placed on the loading zone 606 via a loading robot 612, the component 20 or part 22 is then conveyed to the containment booth 608. The containment booth 608 includes a spraying enclosure 614 where the depositing tool is located and where the particle deposition process takes place (the method 300, the method 400, and/or the method 500) and an inspection enclosure 616 wherein the deposited material is examined for

integrity. After examination, the component 20 or part 22 is removed from the unloading zone 610 with a unloading robot 618 for subsequent processing, e.g., stamping, painting, welding to additional components.

[0039] Referring now to Figure 11A through Figure 11C, graphical representations of aspects of the particle deposition process are shown. Figure 11A graphically illustrates particle velocity as a function of various charged particle P^+ charges relative to the capacitor 212 voltage, wherein the particle has a 0.1mm particle radius. Figure 11B graphically illustrates the electrostatic force relative to the drag force acting upon the charge particle P^+ , wherein the particle has a 0.1mm particle radius. Figure 11C graphically illustrates particle velocity as a function of various charged particle P^+ charges and the capacitor 212 charge relative to particle radius.

[0040] It should be appreciated that the foregoing description of the embodiments has been provided for purposes of illustration. In other words, the subject disclosure is not intended to be exhaustive or to limit the disclosure. Individual elements or features of a particular embodiment are generally not limited to that particular embodiment, but, where applicable, are interchangeable and can be used in a selected embodiment, even if not specifically shown or described. For example, unless otherwise indicated the elements “part,” “component,” and “substrate” may all be interchanged without detracting from the subject disclosure. The same may also be varied in many ways. Such variations are not to be regarded as a departure from the disclosure, and all such modifications are intended to be included within the scope of disclosure.

CLAIMS

What is claimed is:

Claim 1. An electromagnetic particle disposition system for bonding particles of metal material onto a grounded part of metal material comprising:

an electrostatic nozzle having a discharge line extending between an entry port for placement of particles and a discharge port spaced from the entry port;

the discharge line including a charged state wherein particles traveling from the entry port to the discharge port develop a positive charge by electrostatic induction from contact with the discharge line; and

a capacitor located adjacent to the discharge port for developing an electrostatic discharge field directed to the grounded part that attracts and accelerates the charged particle towards the grounded part until the particle reaches a terminal velocity upon impact with the grounded part that bonds the particle to the grounded part.

Claim 2. The electromagnetic particle disposition system of Claim 1, wherein the capacitor is annularly shaped and defines a central opening aligned with the discharge port.

Claim 3. The electromagnetic particle disposition system of Claim 2, further including an insulator located between the discharge port and the capacitor.

Claim 4. The electromagnetic particle disposition system of Claim 1, wherein the discharge line defines a helical-shape to allow more contact and electrostatic induction between the particle and the discharge line.

Claim 5. The electromagnetic particle disposition system of Claim 1, including a particle stock for storing a plurality of particles next to the entry port.

Claim 6. The electromagnetic particle disposition system of Claim 5, further including a control valve between the particle stock and the entry port.

Claim 7. The electromagnetic particle disposition system of Claim 6, further including an air gas tube in communication with the control valve to assist in urging particles into the entry port from the particle stock.

Claim 8. The electromagnetic particle disposition system of Claim 6, including an insulator located between the entry port and the particle stock.

Claim 9. The electromagnetic particle disposition system of Claim 1, further including a lifting mechanism that moves the electrostatic nozzle with respect to the grounded part.

Claim 10. The electromagnetic particle disposition system of Claim 9, further including a particle guiding attachment connected to the electrostatic nozzle and having a guide portion spaced from the discharge port that defines an aperture for outlining a cross-section of particles deposited on the grounded part.

Claim 11. A method of bonding particles of metal material onto a part of metal material that includes a plurality of localized areas until at least two of the localized areas have a different gauge comprising the steps of:

grounding the part;

providing an electrostatic nozzle and aiming it at one of the plurality of localized areas;

generating an electrostatic discharge field between the electrostatic nozzle and the grounded part; and

charging the metal particle and projecting it through the electrostatic discharge field onto the localized area so that the metal particle bonds to the localized area and the gauge of the localized area becomes larger.

Claim 12. The method according to Claim 11, wherein the metal particle has a radius that is smaller than .5 mm.

Claim 13. The method according to Claim 11, wherein the part forms a portion of an automotive component and the method further comprises the steps of:

determining the lowest value of gauge required for the part based on selecting at least one of the plurality of localized areas that will undergo the least amount of stress during operation of the automotive component;

selecting a metal blank having the lowest value of gauge to form the part; and

aiming the electrostatic nozzle at one of the plurality of localized areas that will not undergo the least amount of stress.

Claim 14. The method according to Claim 11, further including providing a particle guiding attachment defining an aperture for outlining a cross-section of metal particles deposited on the part and continuing to bond metal particles on the part until a vertical wall comprising deposited metal particles is formed.

Claim 15. The method according to Claim 11, wherein the terminal velocity of the metal particle as it impacts the localized area is at least 500 m/s and forms a solid state bond therebetween.

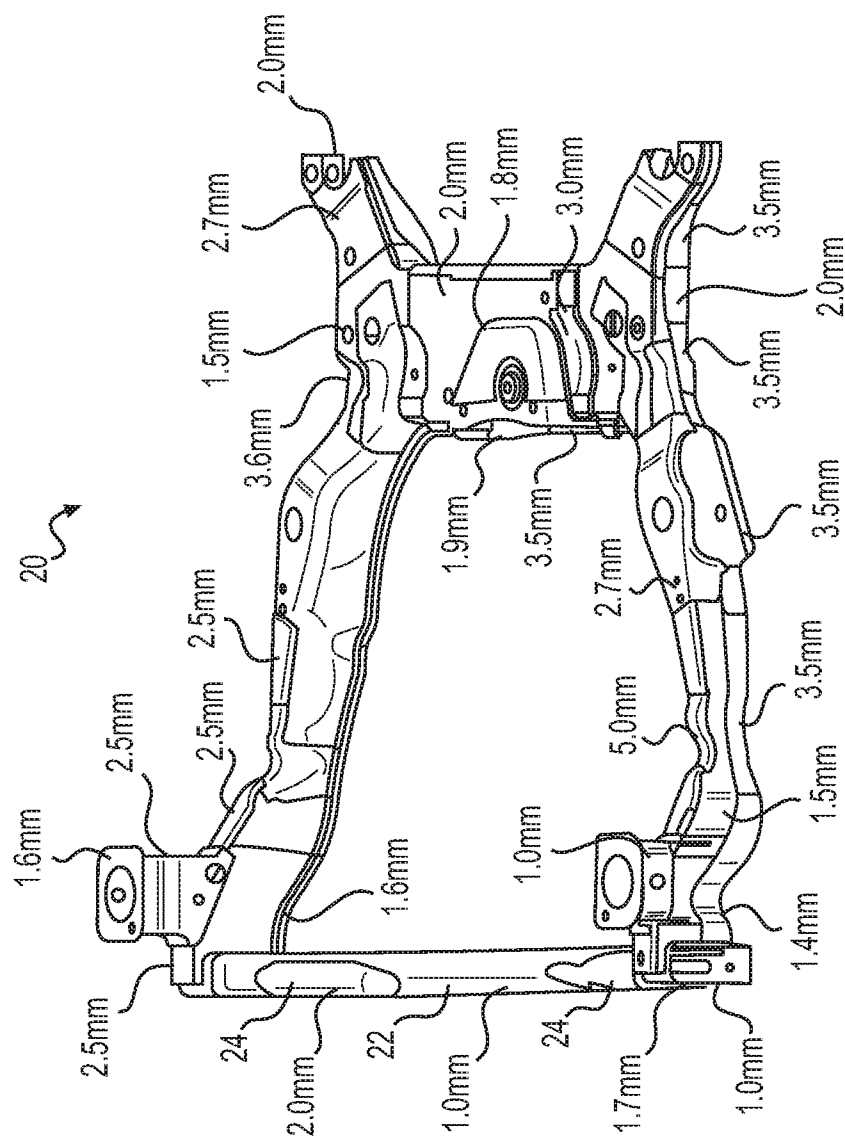


FIG. 1A

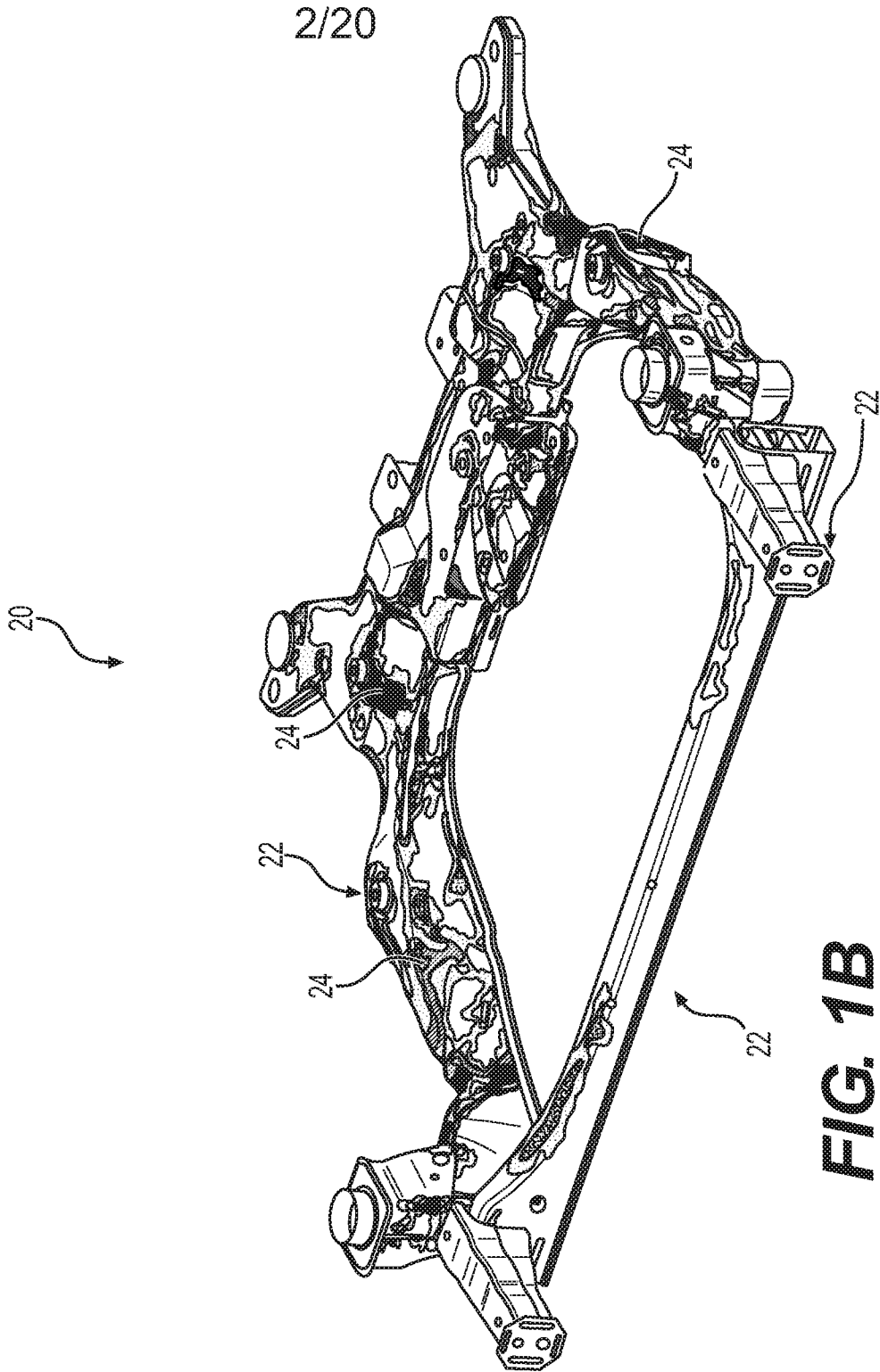
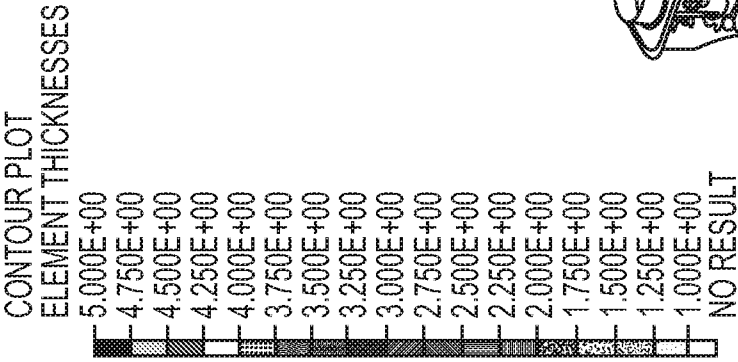


FIG. 1B

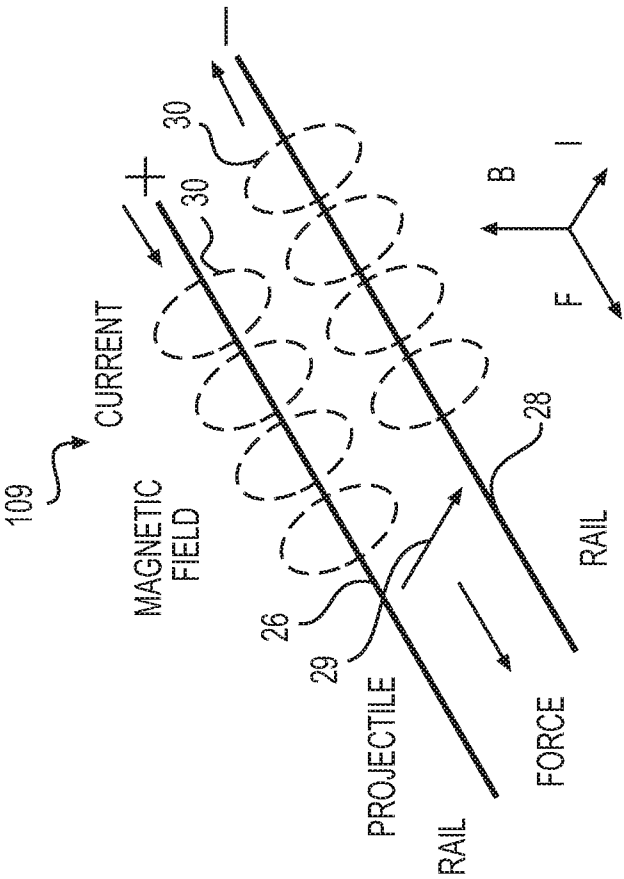


FIG. 2A

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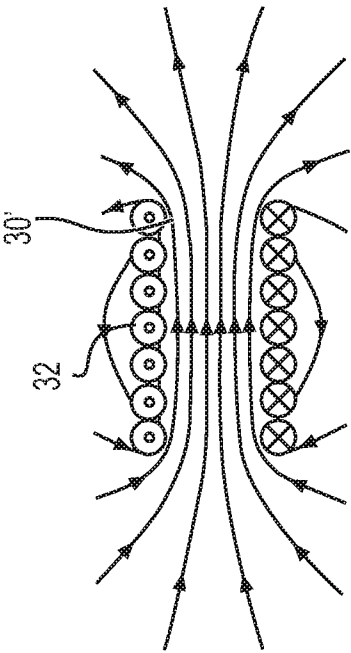


FIG. 2B

4/20

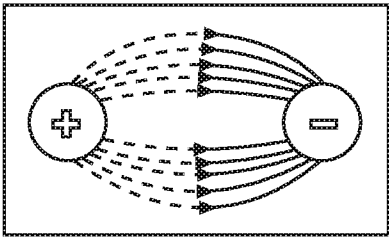


FIG. 2D

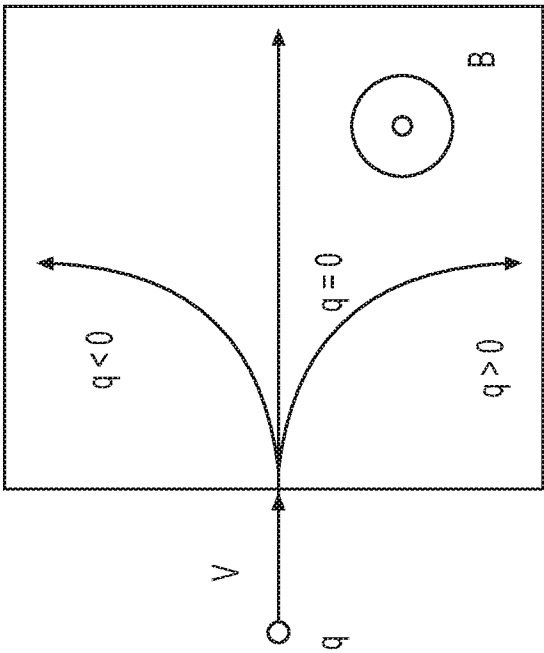


FIG. 2C

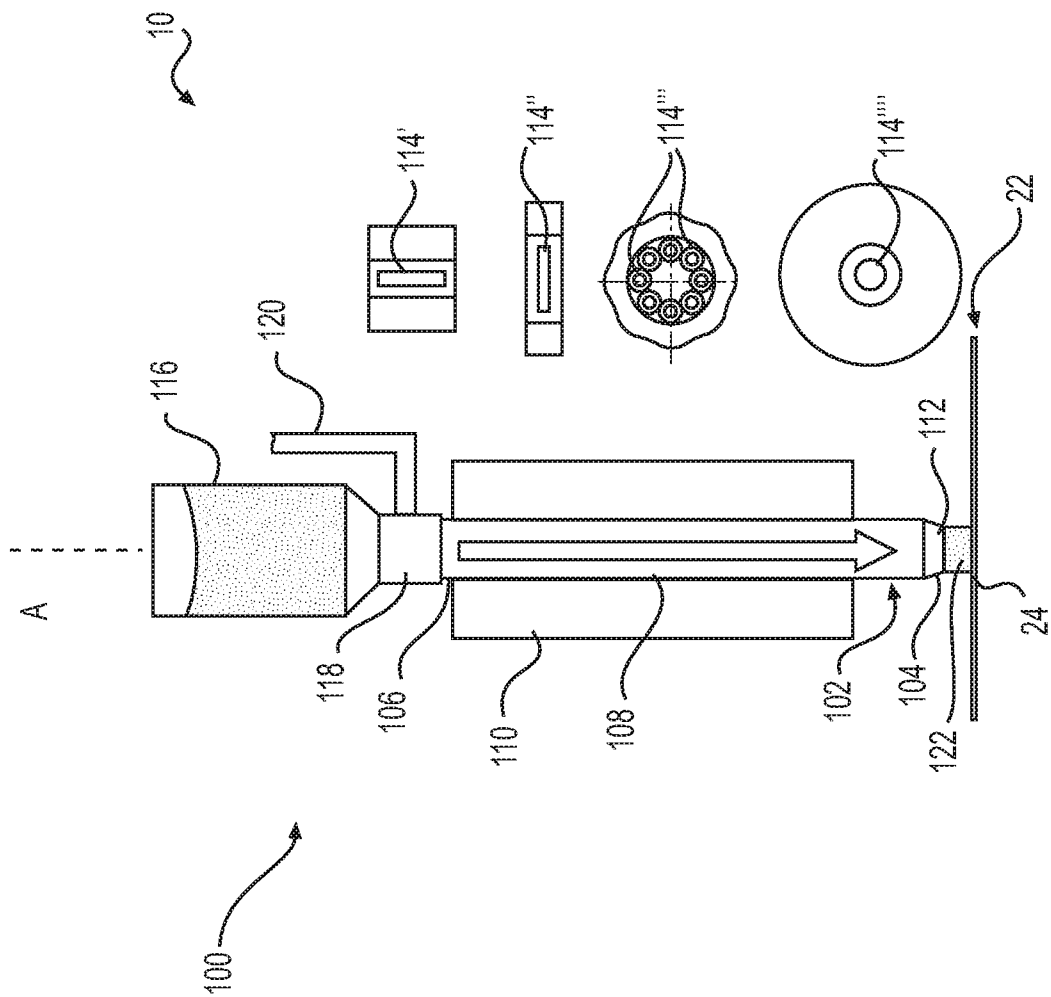


FIG. 3

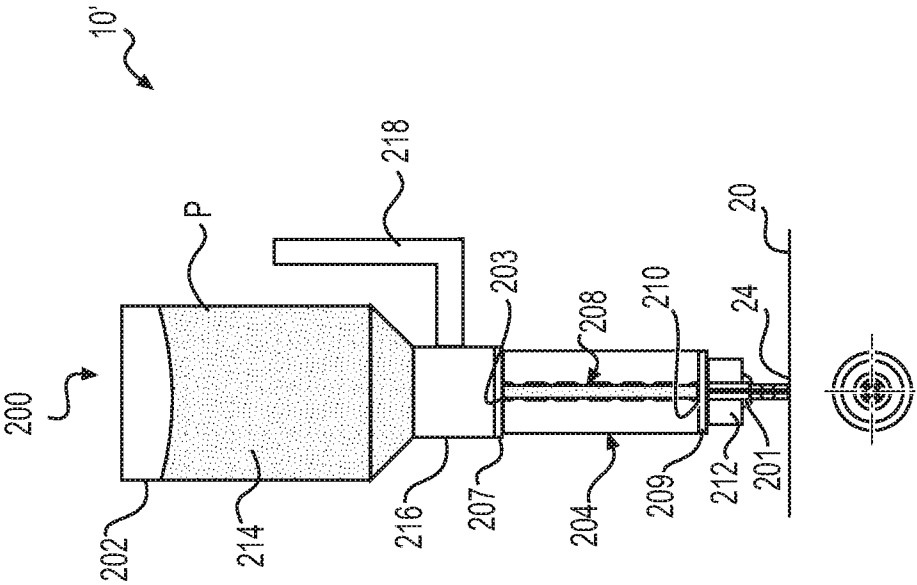


FIG. 4A

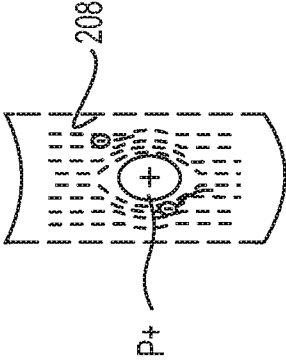


FIG. 4B

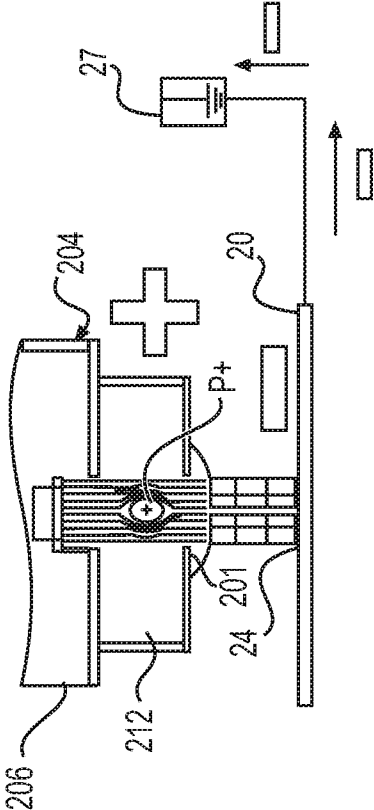


FIG. 4C

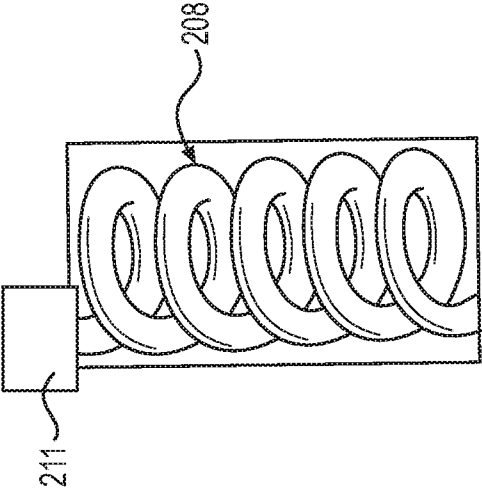


FIG. 4D

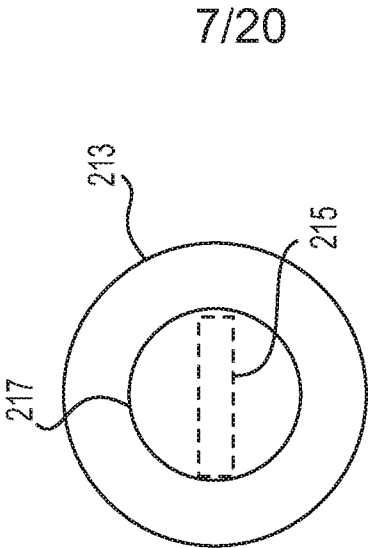


FIG. 4E

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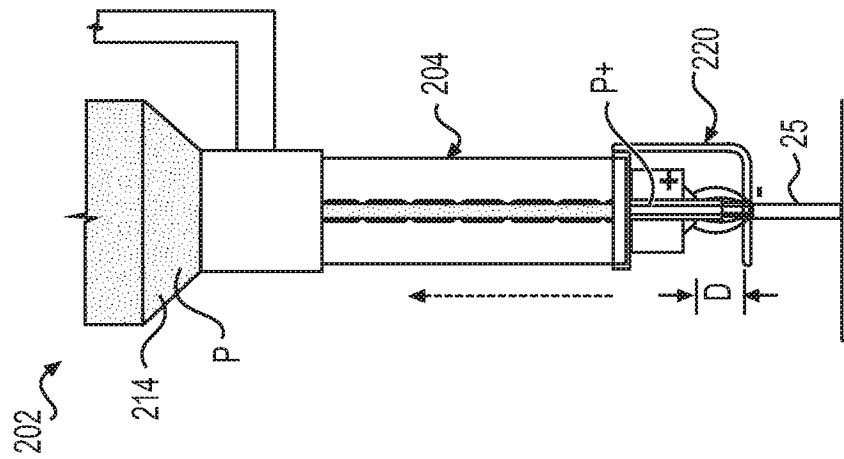


FIG. 5C

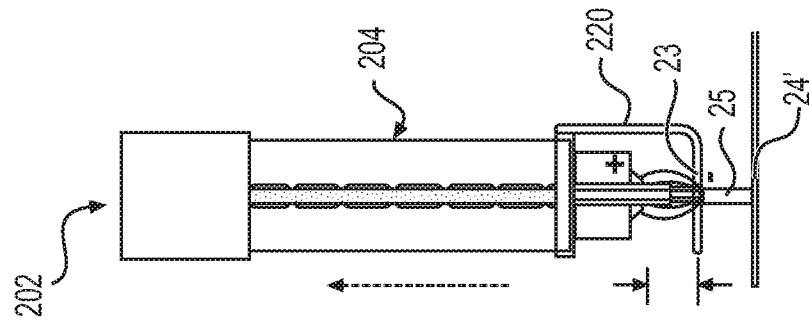


FIG. 5B

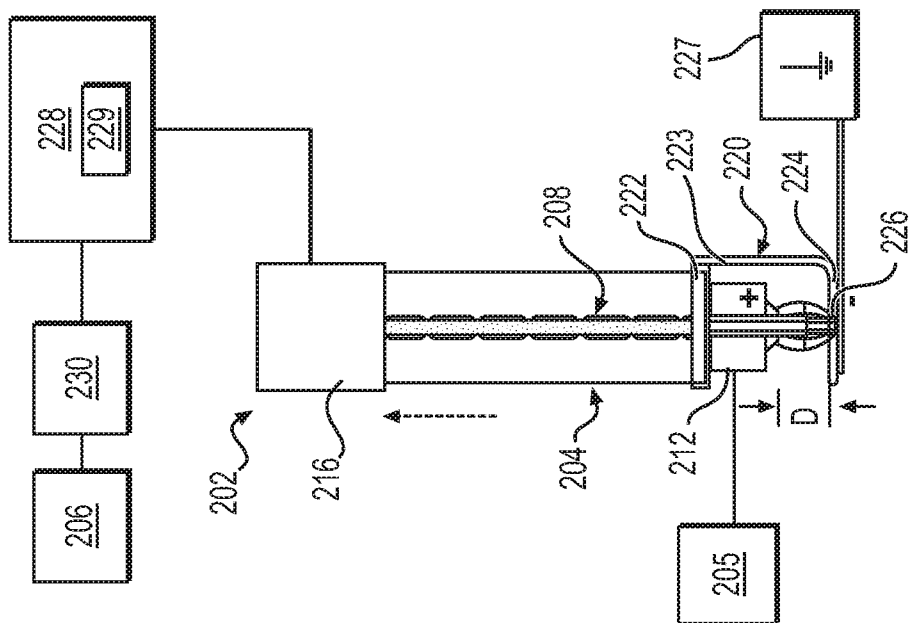


FIG. 5A

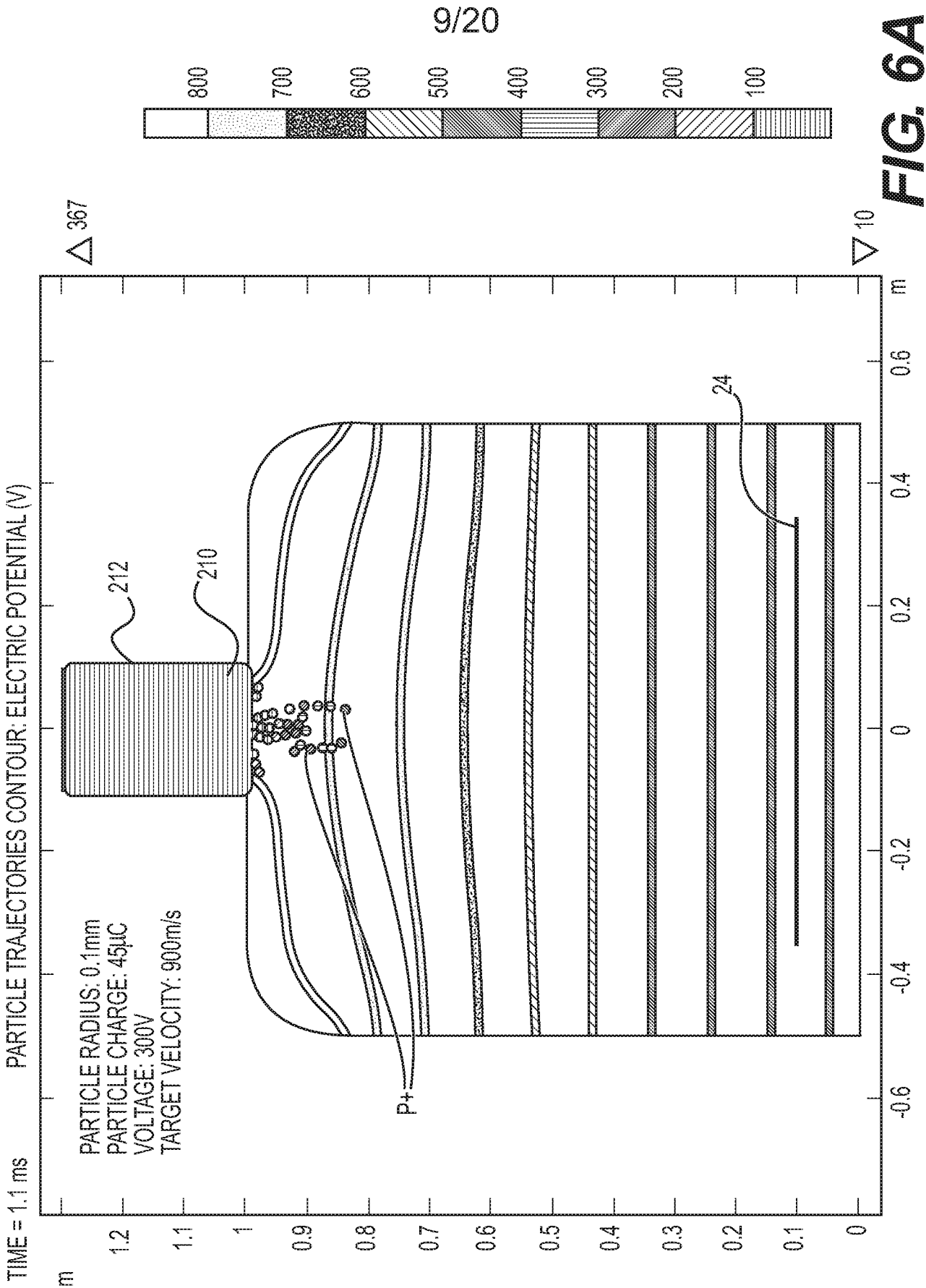
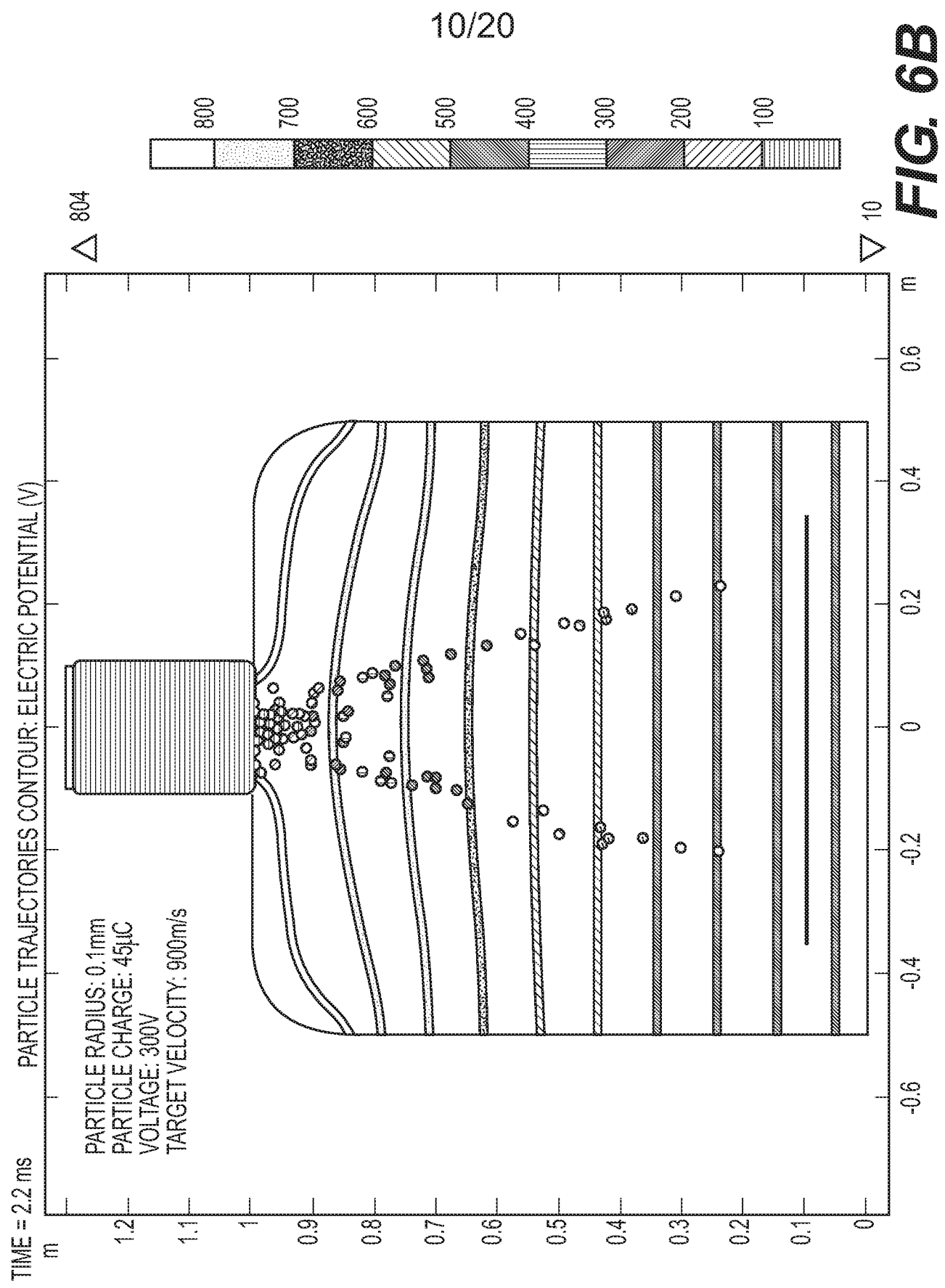
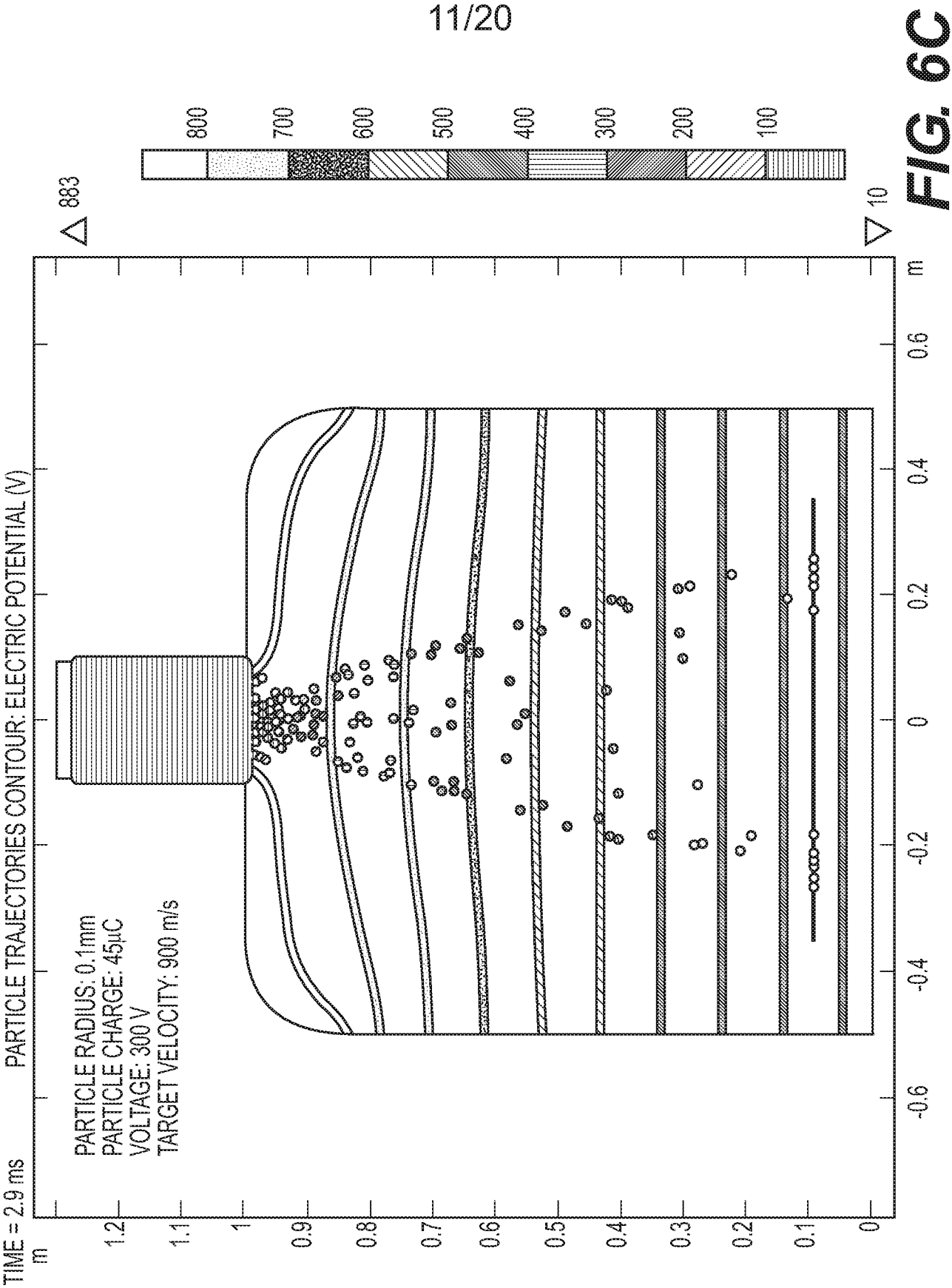
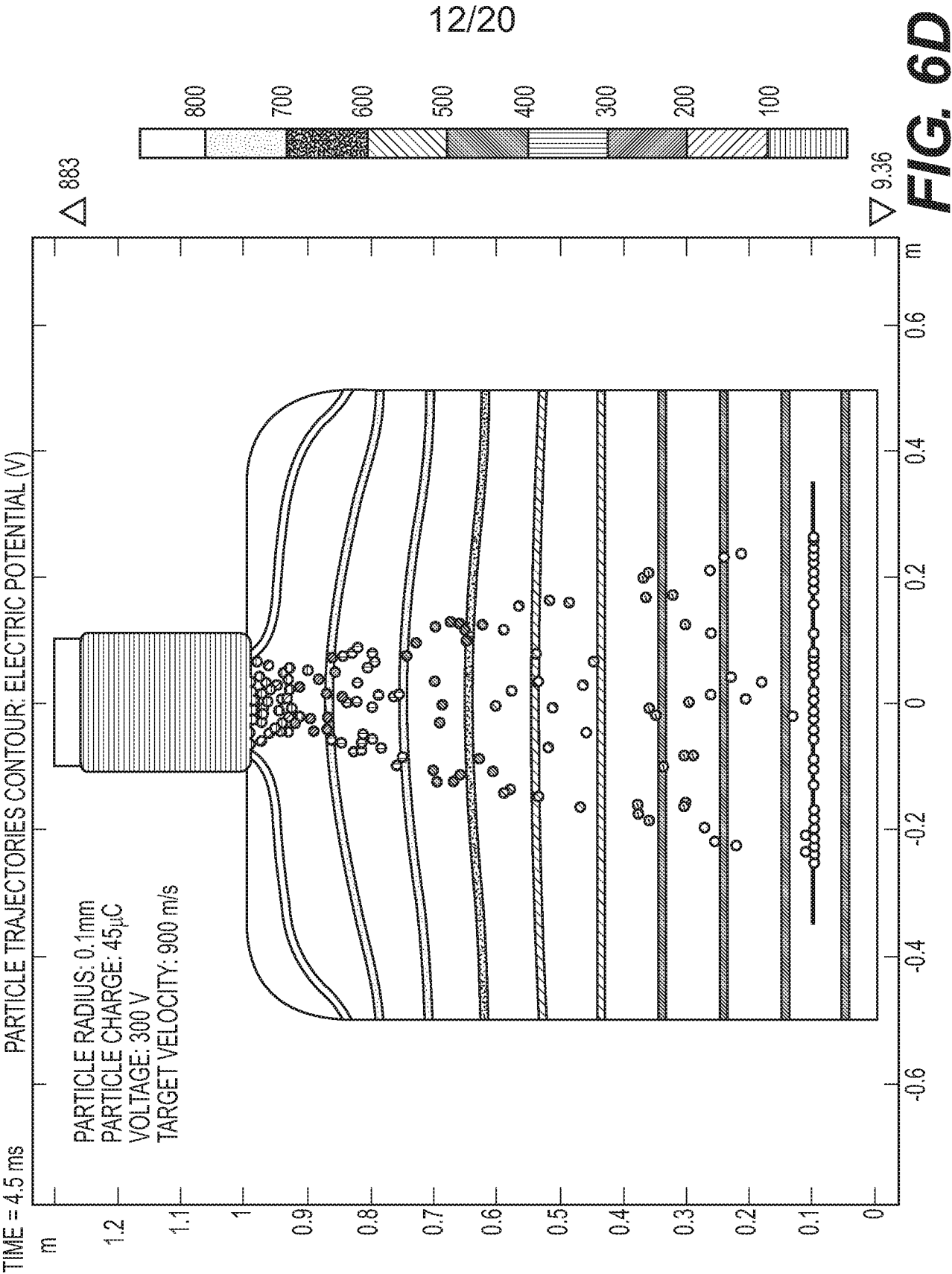
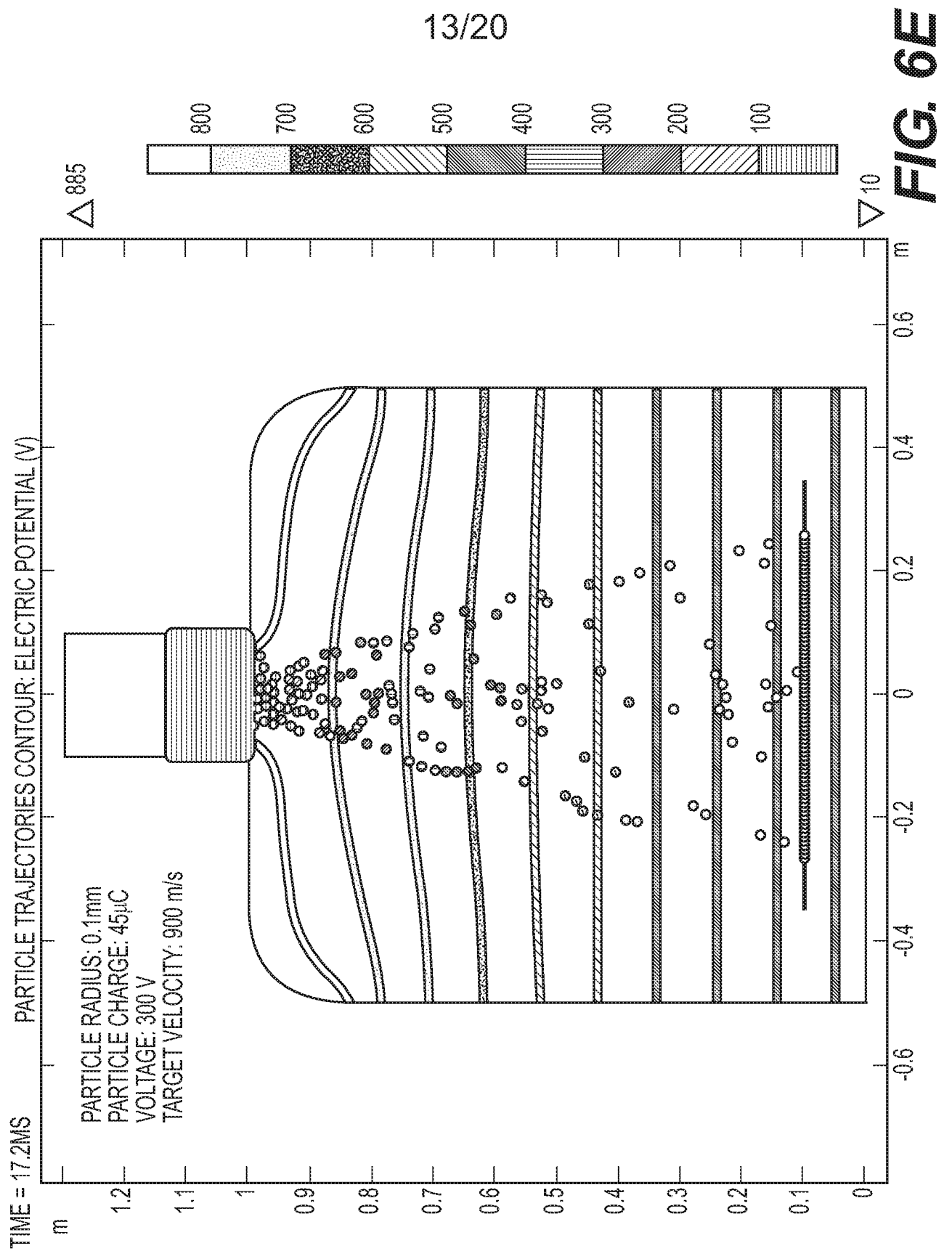


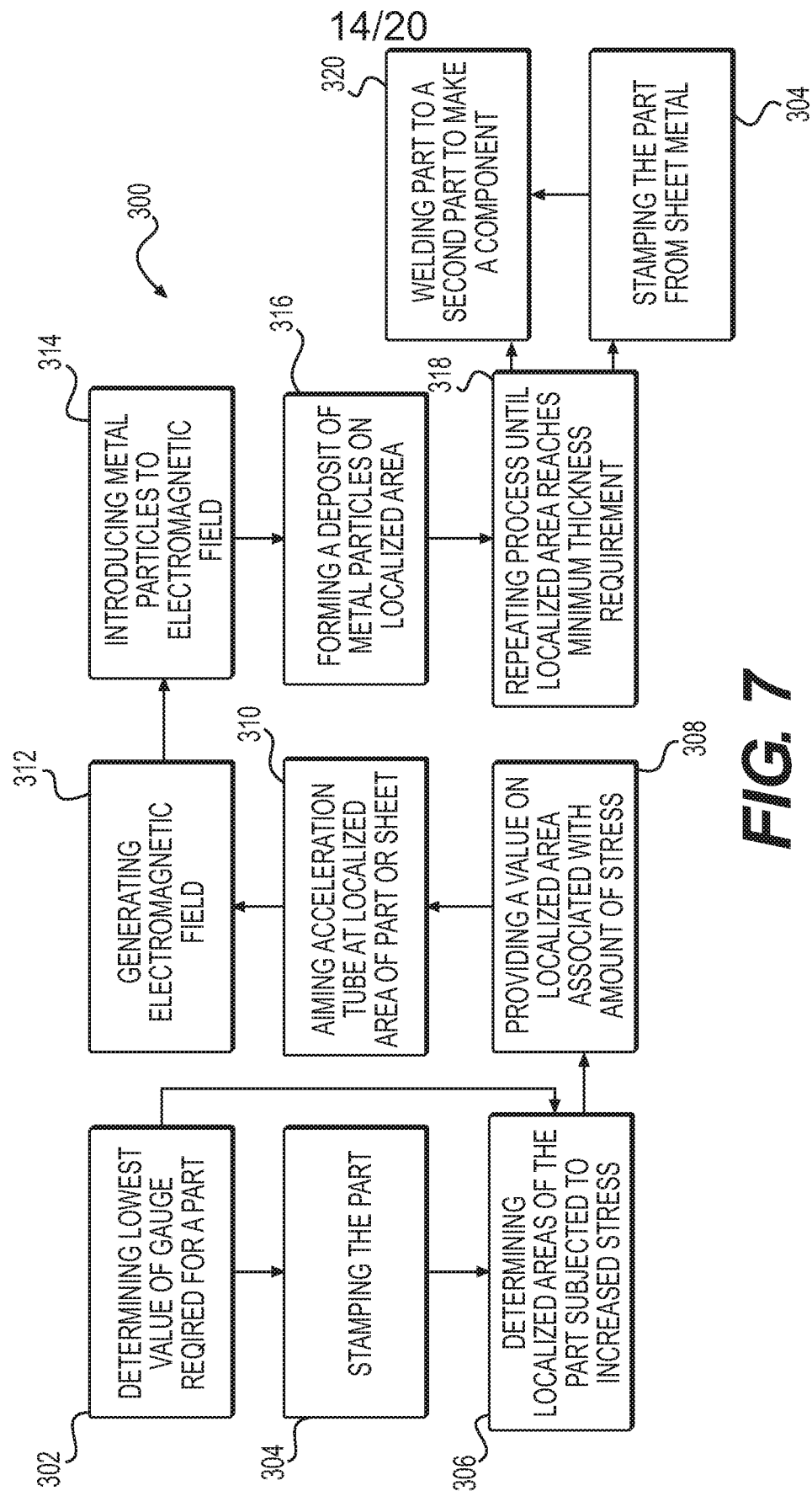
FIG. 6A

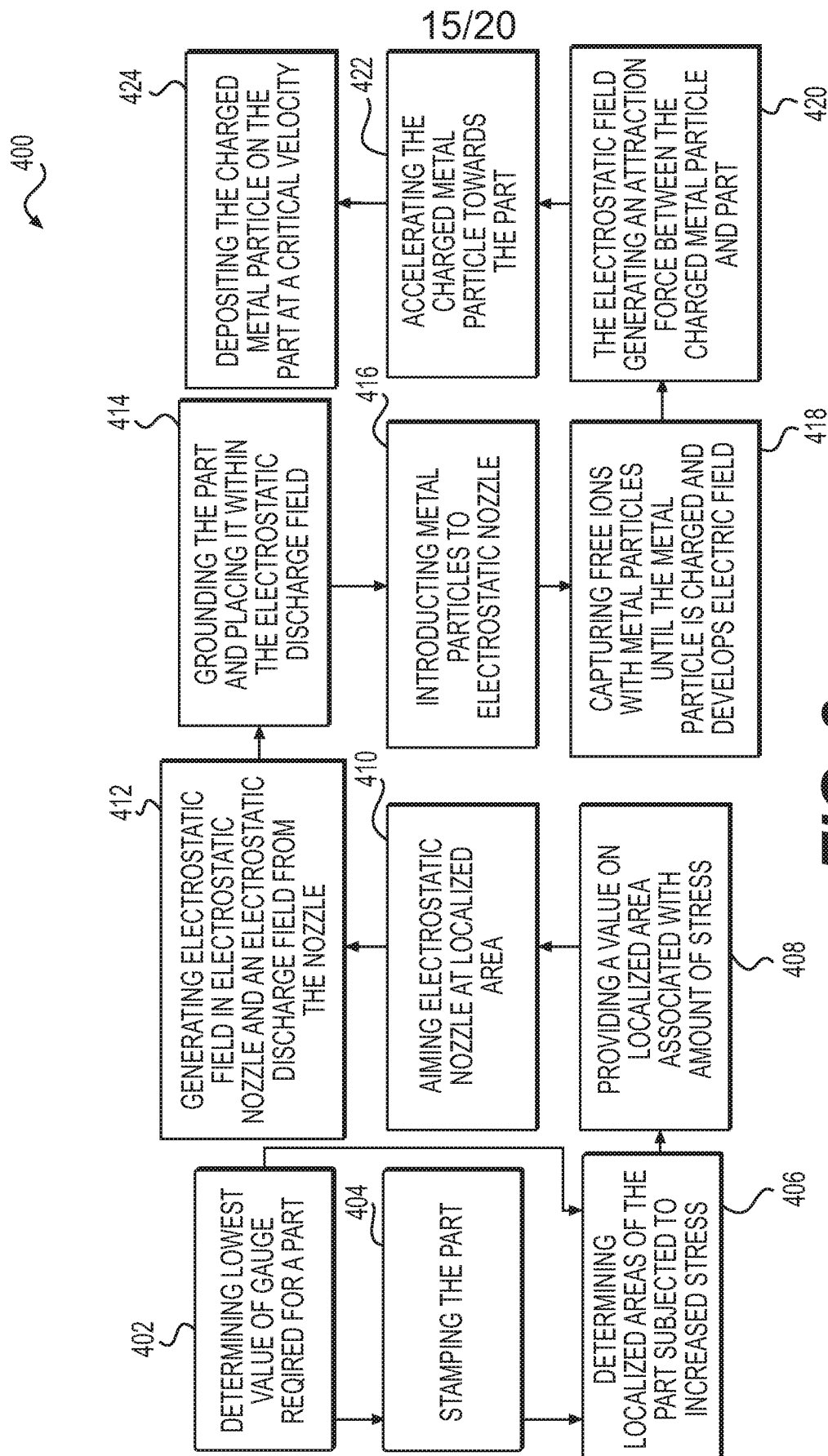




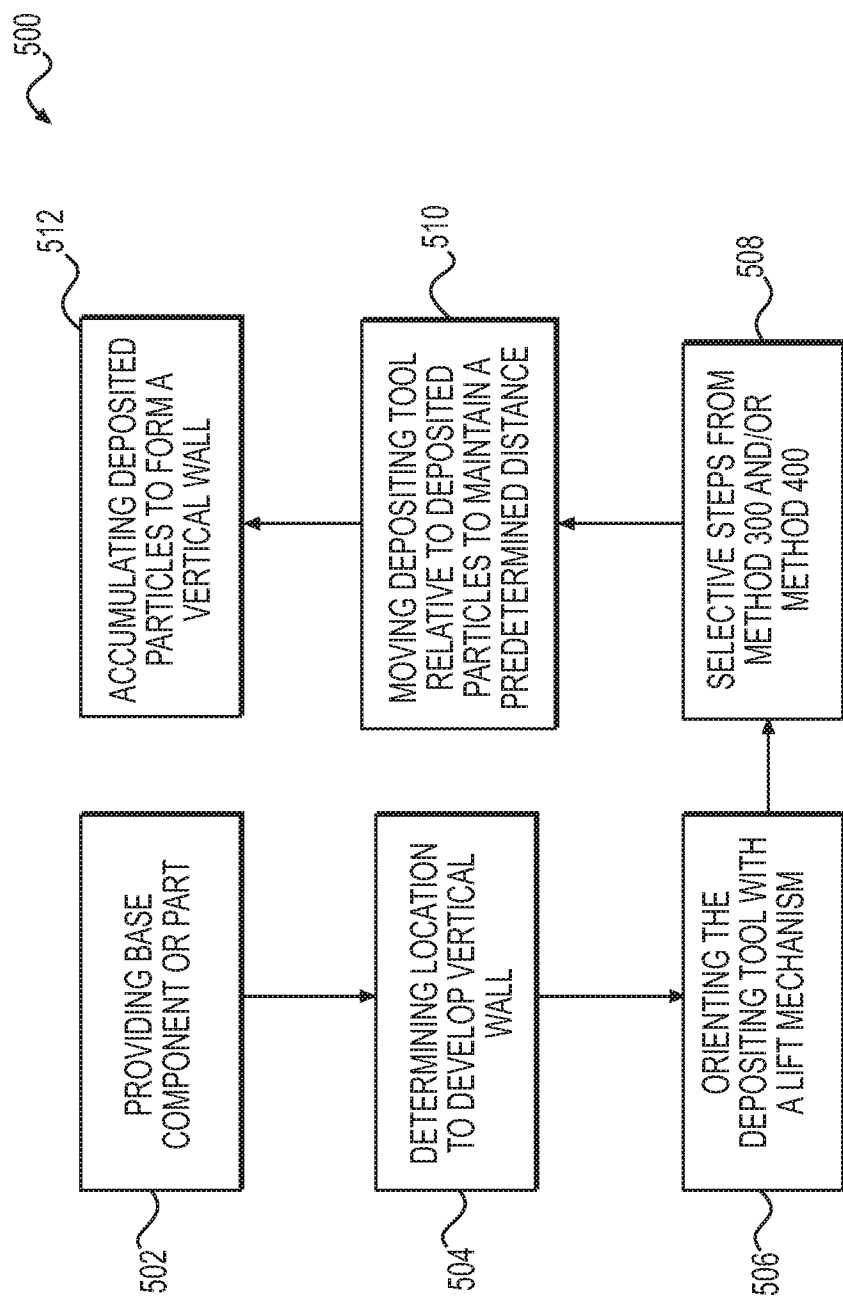






**FIG. 8**

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**FIG. 9**

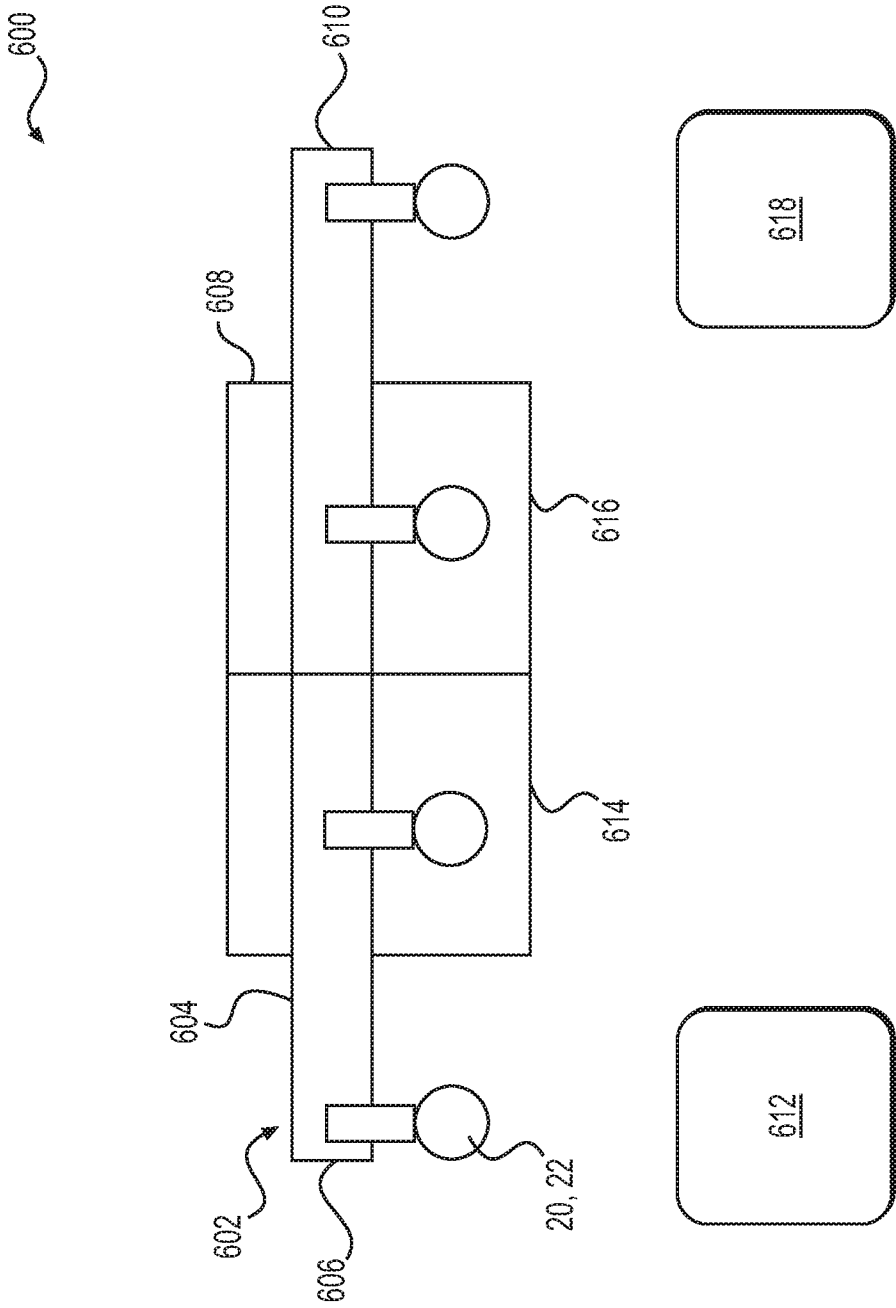


FIG. 10

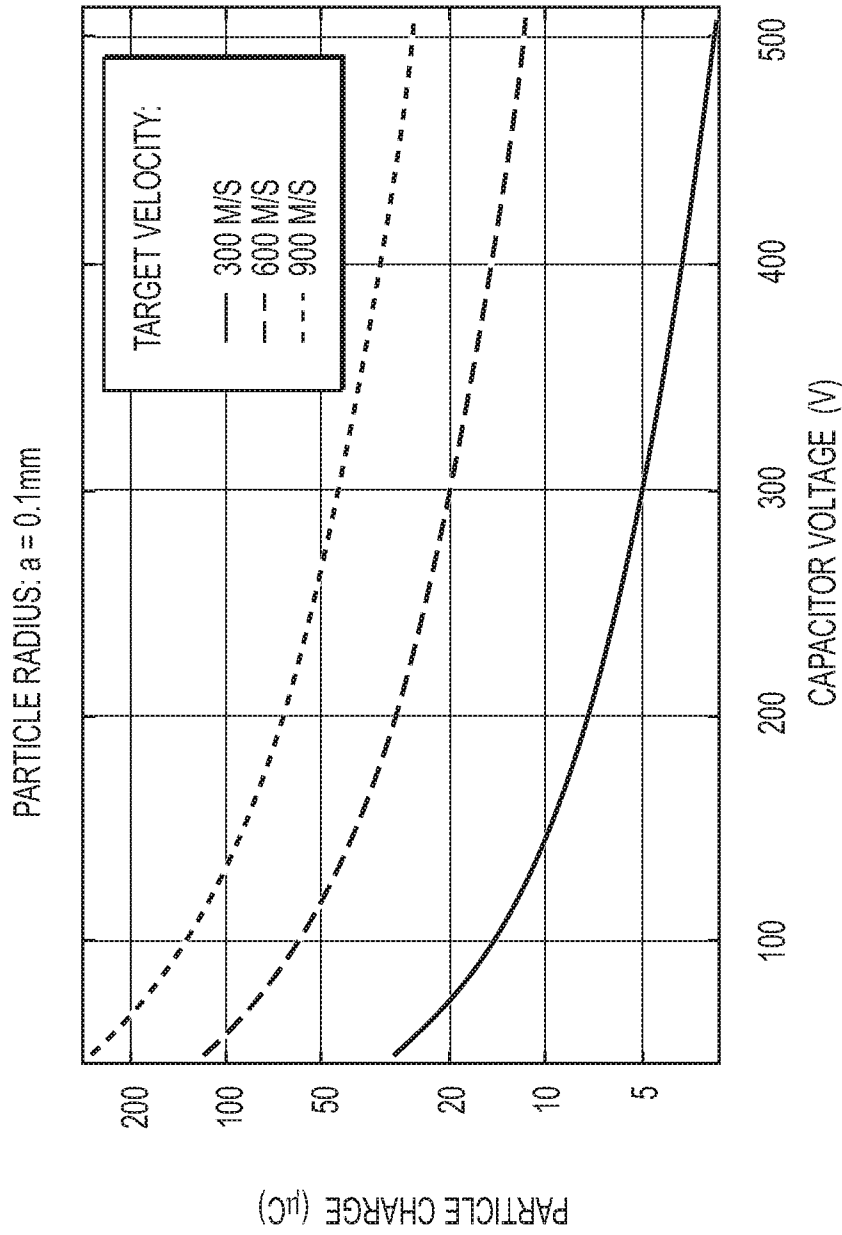


FIG. 11A

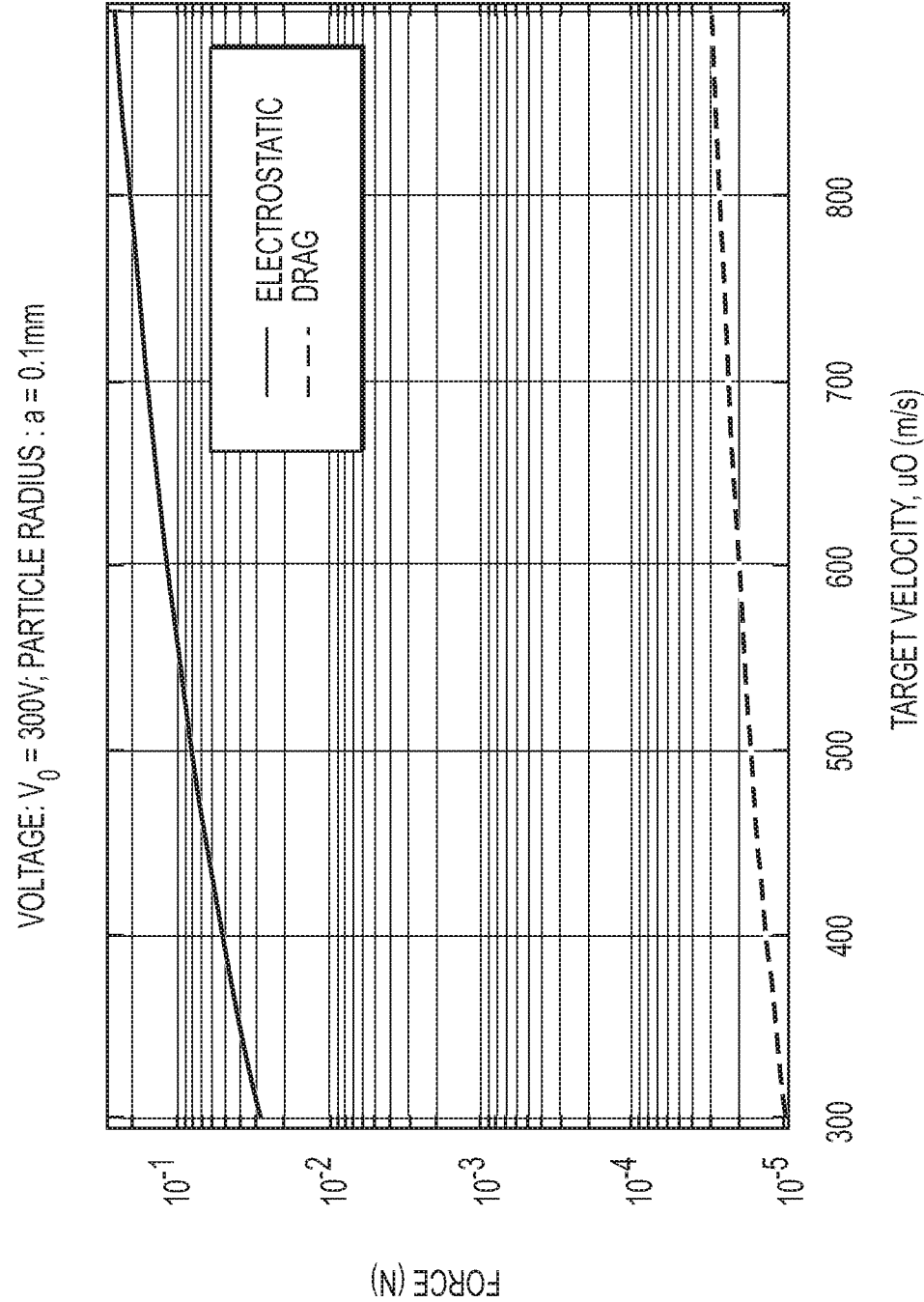


FIG. 11B

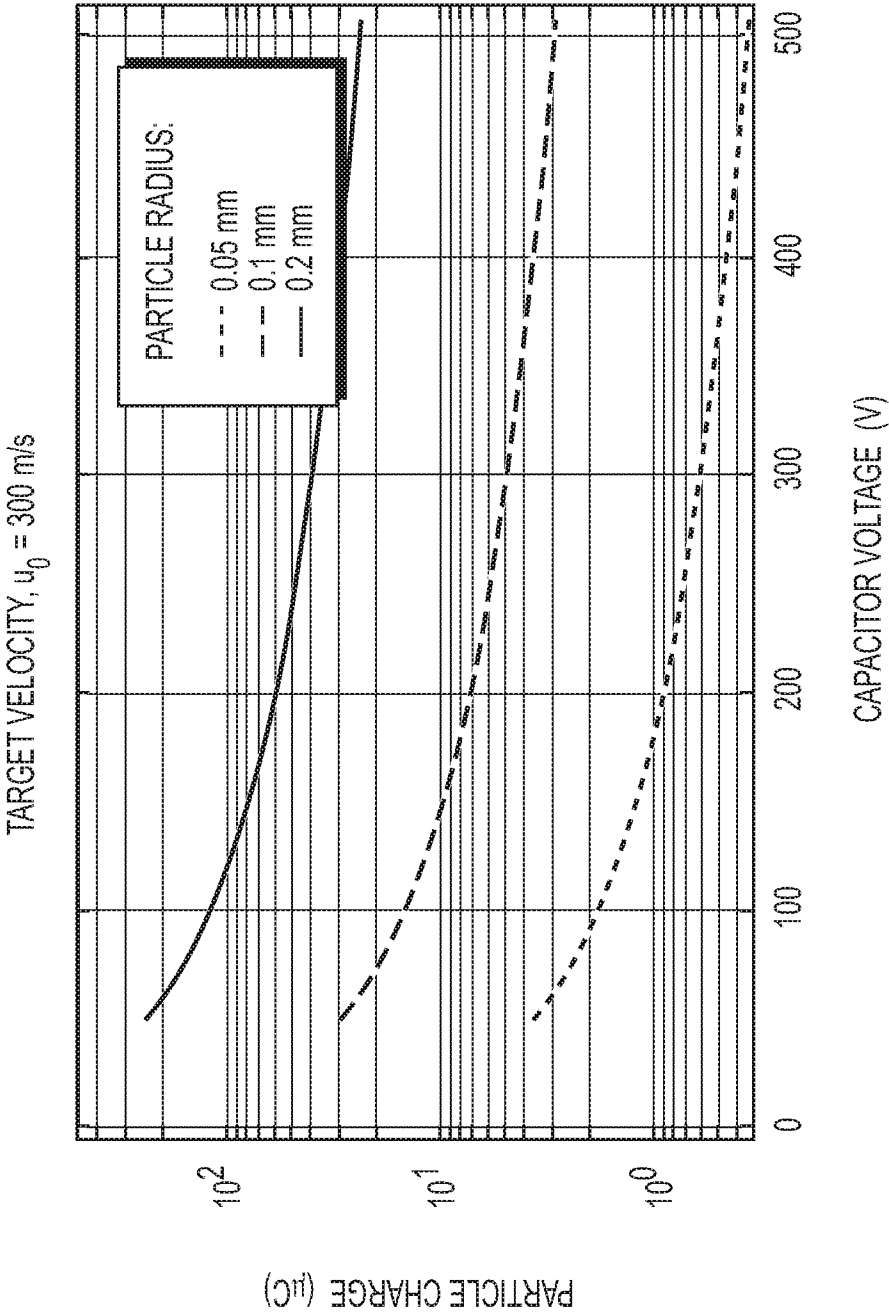


FIG. 11C

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/50753

A. CLASSIFICATION OF SUBJECT MATTER

IPC - B01D 3/06; B01D 53/48; B01D 53/62 (2019.01)

CPC - B01D 3/06; B01D 53/48; B01D 53/62

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

See Search History document

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y --- A	US 3,503,775 A (Austin) 31 March 1970 (31.03.1970) Abstract, col 1 ln 63-67; col 2 ln 44-50; col 3 ln 9-12; col 4 ln 14-26; col 4 ln 48-62; col 5 ln 27-33; col 5 ln 48-51; col 5 ln 72-75; col 8 ln 1-35.	11-12, 15 ----- 1-10, 13-14
Y --- A	An, et al. "High-resolution printing of 3D structures using an electrohydrodynamic inkjet with multiple functional inks." Advanced materials 27.29 (19 June 2015): 4322-4328. Abstract, pg 4322 col 2 para 2; pg 4434 col 1 para 1 - col 2 para 2; pg 4325 col 2 para 2; Figure 1; Figure 2; and Figure 5.	11-12, 15 ----- 1-10, 13-14
A	US 4,890,784 A (Bampton) 2 January 1990 (02.01.1990) Abstract, col 2 ln 45-54.	15
A	US 2002/0146508 A1 (Bacon et al.) 10 October 2002 (10.10.2002) Abstract, para [0046]-[0047], [0054], [0067], [0082], [0087], [0102]-[0103], Figure 2; Figure 3; Figure 5; and Figure 10.	1-10
A	US 6,855,429 B2 (Stay) 15 February 2005 (15.02.2005) Abstract, col 1 ln 20-44; col 7 ln 30-32.	13
A	US 6,724,854 B1 (Kim et al.) 20 April 2004 (20.04.2004) Abstract, col 2 ln 54-56; col 3 ln 19-21.	13

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

11 November 2019

Date of mailing of the international search report

29 NOV 2019

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Lee Young

Telephone No. PCT Helpdesk: 571-272-4300

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US 19/50753

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4,284,496 A (Newton) 18 August 1981 (18.08.1981) Abstract, col 2 ln 19-30; col 5 ln 17-26; and Figure 1.	14
A	US 2011/0238161 A1 (Fulton et al.) 29 September 2011 (29.09.2011) Entire Document.	1-15
A	US 2016/0279650 A1 (Toyota Jidosha Kabushiki Kaisha) 29 September 2016 (29.09.2016) Entire Document.	1-15
P, X	Reiser, et al. "Multi-metal electrohydrodynamic redox 3D printing at the submicron scale." Nature communications 10.1 (23 April 2019): 1853. Entire Document.	1-15