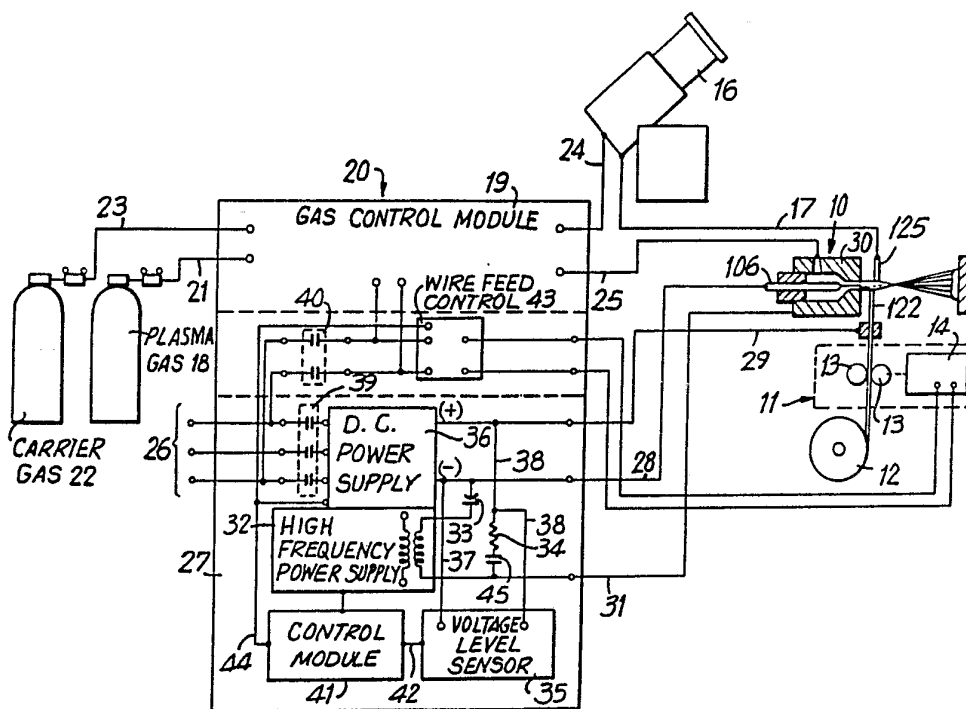


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(54) Title: HIGH VELOCITY ELECTRIC-ARC SPRAY APPARATUS AND METHOD OF FORMING MATERIALS



(57) Abstract

A high velocity arc spray apparatus includes a transferred-arc-plasma torch assembly (10) which forms a transferred-arc column. A metal feedstock (122) is fed into the transferred-arc column at an angle such that no portion of the metal feedstock (122) is closer to the transferred-arc-plasma torch assembly (10) than the leading edge of the metal feedstock (122) in the feeding direction. A power source (27) is coupled to both the metal feedstock and transferred-arc-plasma torch assembly (10) for creating an electrical potential difference between the metal feedstock (122) and the transferred torch assembly (10).

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HIGH VELOCITY ELECTRIC-ARC SPRAY
APPARATUS AND METHOD OF FORMING MATERIALS

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This invention relates generally to an electric-arc-spray apparatus and methods of thermally spraying materials, and in particular, to a single wire fed electric-arc type spray system which utilizes a high velocity transferred plasma arc to produce extremely dense materials such as coatings and freestanding near-net-shapes as well as an apparatus for producing high density materials formed by thermal spraying which have superior metallurgical and physical characteristics.

Thermal spray processes have been employed broadly in numerous industries to apply protective coatings to a variety of substrates including metal, ceramic, plastic and paper. More recently, thermal spray methods have been utilized for the fabrication of high-tech composite materials as coatings and as freestanding near-net-shape structures. By heating and accelerating particles of one or more materials to form a high-energy particle stream, thermal spraying provides a method by which materials starting in wire or powder form may be rapidly deposited on a substrate. While a number of parameters dictate the composition and microstructure of the sprayed coating or article, the velocity and temperature of the particles as they impact the substrate are important factors in determining the density and uniformity of the deposit.

One prior art thermal spray technique is the utilization of a combustion flame to spray metals and other

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materials, in powder, wire or rod form onto a substrate. A
1 mixture of a fuel gas such as acetylene and an oxygen-
containing gas (oxy-fuel) are flowed through a nozzle and then
ignited at the nozzle tip. The material to be sprayed is
metered into the flame where it is heated and propelled to the
5 surface of the substrate. The feedstock may comprise a metal
rod or wire which is passed axially into the center of the
flame front or, alternatively, the rod or wire may be fed
tangentially into the flame. Similarly, a metal powder may be
injected axially into the flame front by means of a carrier
10 gas. Some powder only combustion flame guns utilize a gravity
feed mechanism by which a powdered material is simply dropped
into the flame front. Conventional flame spraying, however,
is typically a low velocity thermal spray process in the
subsonic range and usually produces coatings which have a high
15 degree of porosity.

Another spraying technique is known as plasma
spraying. Plasma spraying utilizes a high-velocity gas plasma
to spray generally powdered or particular material onto a
substrate. To form a plasma, gas is flowed through an
20 electric arc in the nozzle of a plasma spray gun, causing the
gas to ionize into a plasma stream. The plasma stream thus
formed is at an extremely high temperature, often exceeding
10,000 degrees C. The material to be sprayed, typically
particles of about 20 to 100 microns, are entrained in the
25 plasma and may reach a velocity exceeding mach 1. While
plasma spraying can produce high density coatings, it is a
complex procedure which requires expensive equipment and

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1 considerable skill on the part of an operator for proper
application.

In another thermal spray technique known from U.S.
Patent No. 3,546,415, an electric arc is generated in an arc
5 zone between two consumable wire electrodes. As the
electrodes melt, the arc is maintained by continuously feeding
the electrodes into the arc zone. The molten metal at the
electrode tips is atomized by a blast of generally cold
compressed gas. The atomized metal is then propelled by the
10 gas jet to a substrate forming a deposit.

Conventional electric-arc thermal sprayed coatings
are generally dense and reasonably free of oxide, however, the
process requires that two consumable wires (electrodes) be fed
to the spraying apparatus resulting in several disadvantages.
15 Firstly, the spray gun which is often desired to be
lightweight and easily handleable, is bulky and cumbersome
due to the number of heavy electrical power cables and
electrically insulated wire feed conduits which are required.
Also, instabilities in the spraying process occur due to
20 unavoidable irregularities which are inherent in the process
of feeding two wires simultaneously and precisely to the arc
zone in the spray gun. Such wire feed instabilities result in
inconsistent characteristics in the coating characteristics
often detrimental to coating quality. In addition, since
25 molten particles are initially formed from both an anode and a
cathode, two distinctive particle size ranges are produced
from the two electrodes, which is not conducive to forming a
uniform coating structure.

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1 An arc spray system known from U.S. Patent No.
4,668,852, provides variation of the arrangement of flowing
the atomizing gas through and around the arc-zone. However,
this technique only provides improved atomizing, at subsonic
5 velocities and also does not resolve the difficulties incurred
because of dual-wire feed instabilities.

To improve the velocity of the atomizing gas, an
arrangement was devised as known from U.S. Patent No.
4,788,402 whereby a plasma jet is formed in a manner so that
10 the plasma gas is accelerated to sonic or supersonic velocity
as it exits the anode nozzle of the plasma torch. Two wires
are simultaneously fed into the exiting, high velocity ionized
gas stream at acute angles to the axis of flow of this plasma
stream. These two wires are electrically energized with
15 respect to each other and an arc is formed between the two
wires, through the ionized plasma jet stream. Such an
arrangement provides a means of atomizing the metal particles
formed from the melting ends of the two wires at very high
velocities which could be sonic or even supersonic. However,
20 such an apparatus still requires the simultaneous feeding of
two consumable wires, not resolving the instability problems
associated with the simultaneous feeding of two wires.

A method is known from U.S. Patent No. 3,140,380 to
form several plasma streams angularly displaced around a
25 central axis. A single wire is fed along the central axis of
this configured multi-plasma torch and is melted by the heat
of the plasma and the molten particles are atomized and
propelled to a substrate to form a coating by the combined

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1 plasma streams at the converging point of these multiple
plasma streams. In this configuration, the heat available to
melt this single wire is only that which is obtained by
convection from the plasma stream. Also, the velocity of the
5 converging plasma streams is relatively low and therefore the
atomizing and propelling of the metal particles occurs at low
velocity, thereby not producing high density pore-free
coatings.

A single wire arc apparatus and process is known
10 from U.S. Patent No. 3,064,114 in which a single wire is fed
through the central axis of a plasma torch. This wire acts as
a consumable electrode being fed into an arc chamber. An arc
is struck between this wire and a coaxially aligned outlet
nozzle. Gas is fed into the arc chamber, coaxial to the
15 electrode wire, where it is expanded by the electric arc and
causes a highly heated gas stream carrying metal from the
electrode tip to flow through the nozzle. This jet of gas
coaxial to the electrode wire also assists in converting the
electrode wire tip which is being melted by the electric arc,
20 into a stream of fine metal droplets.

It is also known from U.S. Patent No. 3,085,750 to
provide a metal plate in the pathway of the torch to bend and
direct the flow path of the heated gas stream. There are
several deficiencies with this type of metal spray process.
25 Firstly, the velocity of this process is subsonic, yielding
deposits which are quite porous and resulting coatings which
are comprised generally of relatively large particles.
Additionally, a great deal of difficulty can be encountered in

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1 preventing build-up of the metal droplets on the walls of the
outlet nozzle.

 An arrangement is known from U.S. Patent No.
4,370,538 in which a single wire is fed at an acute angle into
5 a plasma stream internally within a dual stream torch. A
transferred-arc is established between the cathode of the
plasma torch and the wire anode, thereby melting the tip of
the wire. Sufficient gas flow in the plasma stream is
established to help to initially atomize the molten metal at
10 the wire tip. This gas flow is at a relatively low velocity
but at high temperature and the initially atomized particles
are subsequently moved into a second, cooler, very high
velocity gas stream for further atomization and acceleration.
This second gas stream is derived from combusting an oxy-fuel
15 mixture in a separate combustion chamber which is also an
integral part of the proposed thermal spray torch. The hot
combustion product, gas, is directed to coaxially combine with
the plasma stream containing the partially atomized molten
metal particles. One of the drawbacks of such an apparatus is
20 the high degree of complexity of the equipment of combining
several processes (plasma, combustion and wire arc) in one
assembly along with the extremely fine balance of control of
these three processes to get them to work in harmony with each
other. In addition, the operation of such an apparatus is
25 very expensive, requiring large consumptions of fuel gas and
oxygen. Additionally, when the wire is fed at an acute angle
into the plasma stream and an arc is struck between the wire
tip anode and the cathode electrode of the plasma torch,

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1 secondary arcs (double arcing) can randomly occur between the
wire and the anode nozzle of the internal plasma torch.
Double arcing is a condition in which a shorter electrical
path is found for the transferred-arc current to flow from the
5 cathode electrode through internal arcing within the torch to
a second arc which will form between a point on the outer
surface of the torch and the wire. Such secondary (double)
arcs can be destructive to the internal plasma torch and to
the overall spray torch.

10 Another system is known from U.S. Patent No.
4,604,306 in which two separate torches are employed, namely a
plasma torch and a high velocity combustion torch. The plasma
torch is described as a transferred-arc type torch in which an
arc is struck between the cathode electrode of the torch and
15 the tip end of a wire which is fed into an initially formed
pilot plasma stream at an acute angle relative thereto. The
molten particles which are partially atomized and accelerated
from the transferred-arc zone are injected into a "quiescent
zone" formed at the exit of a high velocity oxy-fuel gun. The
20 same disadvantages apply to this configuration as those
pertaining to U.S. Patent No. 4,370,538 previously mentioned.
Since the wire is fed into the plasma stream at an acute
angle, secondary arcing between the wire and the plasma torch
anode pilot nozzle commonly occur due to this physical
25 configuration resulting in damage and destruction of the
plasma torch. In addition, the apparatus is complex requiring
critical mechanical alignment between the plasma torch and

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1 oxy-fuel combustion torch and the process is very costly to
operate.

5 One solution to the problem of secondary arcing is
known from U.S. Patent No. 4,762,977. A high velocity annular
gaseous sheath is formed concentrically about the transferred-
arc column to form an arc column guide restricting the arc
column to within a region closely spaced radially from the
axial extension of the nozzle, such that the arc column cannot
penetrate this sheath. When the wire motion is stopped or the
10 wire is withdrawn from the arc-zone, the arc to the tip of the
wire is extinguished by the cold, high velocity annular gas
flow. This solution to secondary arcing creates greater
complexity and bulkiness to the spray apparatus as well as
increasing the operating cost of such a system by requiring an
15 additional high volume of high velocity flow of compressed
air. In addition, it is not always useful to have a high
volume of high velocity cold air impinging on the coating
being formed on the substrate and can actually be detrimental
to achieving the highest quality of coating characteristics.

20 Prior art thermal spray methods have been used to
form composite materials by simultaneously spraying two or
more distinct materials. Ceramic-ceramic composites, ceramic-
metal composites known as "cermets", and metal-ceramic
composites, known as "metal-matrix composites" have been
25 formed as coatings and as freestanding near-net-shape
articles. Materials may also be fabricated by forming a first
particle stream using one spray gun and then combining the

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1 first stream with a particle stream from another gun to form a combined spray at the target surface.

A method of manufacturing a composite material by combined melt-spraying is known from U.S. Patent No.
5 4,740,395. The use of a conventional single-wire combustion spray gun to melt and spray the main constituent metal onto a substrate is combined with an injection means which injects discontinuous fibers as a reinforcing material, together with compressed air into the metal spray wherein the discontinuous
10 fibers are mixed into the metal spray. A composite material is thus formed on a substrate. The limitations of this type of technique are that the resulting deposits contain oxide formations surrounding each metal particle as well as a high degree of porosity resulting from the low-velocity nature of
15 the process. Both of these factors result in deposits which do not have superior properties. In addition, the use of two separate spray guns to form composite coatings is difficult and unwieldy. It would therefore be desirable to provide a single spray gun which could be used to form composite
20 materials such as metal matrix composites which are high density essentially oxide free deposits.

Another means of thermal-spray forming composites such as metal-matrix composite materials as a coating or as freestanding near-net-shape articles, is described in
25 currently pending U.S. Patent Application Serial No. 07/247,024 of co-inventor Daniel R. Marantz. This device combines in a single apparatus a high velocity (operating in the trans-sonic range) oxy-fuel type spray gun with a two-wire

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1 electric-arc spray head. In this apparatus, the high velocity
combustion products, are directed at the arc-zone established
between the two wires, where it acts to atomize and propel the
molten metal formed in the arc, from the two wires to a
5 substrate or article to be coated. Simultaneously, a powder
feedstock of the reinforcement particles is fed into the
combustion process within the high velocity oxy-fuel (HVOF)
gun. This reinforcement particle, typically a refractory
oxide or carbide, is heated and accelerated within the HVOF
10 gun and is combined with the metal particles formed from the
two-wire electric-arc. As the metal and reinforcement
particles imbed themselves into the substrate, they are
subsequently covered up by the splatting metal particles.
This process produces a high density composite coating or bulk
15 metal-matrix composite material.

There are several limitations and drawbacks to this
process. First, since an oxy fuel process is employed, large
amounts of oxides are formed, surrounding each of the metal-
matrix particles. This oxide formation weakens the
20 interparticle bonding, thus forming a metal-matrix which is
mechanically inferior to the wrought starting material. In
addition, since the mechanism of reinforcement particle
loading in the metal-matrix is based on the impact of the hot
particle onto the coated surface, the hardness of the metal
25 matrix material employed plays an important role in how much,
if any, reinforcement particle imbeds itself into the metal-
matrix. Loading of reinforcement into the metal-matrix does
not occur at all in harder materials such as steel and nickel

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1 based alloys. Only very low loading (less than 5%) are
obtainable in medium hardness materials such as copper and its
alloys. In softer materials, such as aluminums and aluminum
alloys, reasonable loadings of 10 to 15 percent can be
5 obtained. However, this appears to be the limiting degree of
loading obtainable.

Another method for thermal spray forming composites
is known from U.S. Patent 4,762,977. In this method a single
wire is fed at an acute angle into a plasma stream in which a
10 transferred-arc is established between the plasma stream and
the tip of the wire. Simultaneously, a stream of carrier gas
carrying powder feedstock is directed into the plasma upstream
from the wire (between the plasma anode nozzle and the tip of
the wire). The powder feedstock thus injected combines with
15 the melted metal particle formed on the tip of the wire and
each are propelled to the substrate all together, thus forming
a composite structure in the resulting coating. However,
since the powder particles and carrier gas are injected
upstream from the tip of the melting wire, the cold carrier
20 gas and entrained particles impinging into the transferred-arc
causes the plasma stream to be cooled which, combined with the
kinetics of interaction of the carrier gas stream and the
plasma gas stream causes erratic arc conditions resulting in
large non-uniformity in the resulting composite coating.
25 Also, because of these interacting conditions and the
resulting loading, the percent of secondary material included
within the metal-matrix is limited to a low level.

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1 Accordingly, it is desirable to provide a single
wire electric spray gun which may be used to form composite
materials such as metal-matrix composites and which achieves
the benefits of supersonic plasma arc powder and wire
5 spraying.

One embodiment of the present invention is directed
to a high velocity arc spray apparatus which comprises
transferred-arc-plasma torch assembly means for forming a
transferred-arc-column and metal feedstock feeding means for
10 feeding a metal feedstock into the transferred-arc column at
an angle such that no portion of the metal feedstock is closer
than the leading edge of the fed metal feedstock to the plasma
torch assembly means. The apparatus further includes power
source means coupled to the metal feedstock and the
15 transferred-arc-plasma torch assembly means. The power source
means selectively energizes the transferred-arc-plasma torch
assembly means and the metal feedstock to create an electrical
potential difference between the metal feedstock and the
transferred-arc-plasma torch assembly means with a
20 corresponding electric current flow. The metal feedstock is
comprised of an anode to effect the transfer of an arc formed
by the transferred-arc column.

Generally speaking, in accordance with the
invention, a high-velocity thermal spray apparatus utilized to
25 form composites, including metal-matrix composites, includes a
plasma torch which can produce a supersonic plasma jet stream.
The torch includes a cathode. A metal wire is continuously
fed at an angular position at an angle perpendicular to the

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1 axis of the plasma-jet stream. A transferred-arc is
established between the wire tip which acts as an anode and
the cathode electrode contained within the plasma torch
causing the wire tip to melt as it is continuously fed into
5 the plasma. The molten metal thus formed is accelerated,
atomized and propelled to a substrate by the supersonic plasma
jet stream.

In another embodiment, the apparatus includes a
single wire oriented at least perpendicularly to a plasma jet
10 stream to which it has established a transferred-arc. The end
of the wire is continuously fed into the transferred-arc. A
feed of powdered feedstock is fed by a carrier gas stream from
a direction 180 degrees angularly displaced from the direction
of the wire feed and oriented to intersect with the plasma-jet
15 stream downstream from the axis of the wire feed.

In another embodiment, the plasma torch includes a
cathode electrode mounted coaxially within an electrically
insulating member at one end of a cylindrical metal body,
closing off the end of the cylindrical body. An axial bore
20 forming a nozzle is provided at the other end of the body.
The cathode electrode is coaxial with the nozzle passage or
bore and within an annular chamber. A plasma forming gas is
introduced into the annular chamber where it flows, preferably
as a vortex flow, through the nozzle. A cup-shaped member
25 concentrically surrounding the outside of the metal body forms
an annular space between the end of the cup-shaped member and
the cylindrical metal body. One end of the cup-shaped member
is closed off forming an end wall while the opposite end is

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1 open. Compressed gas is fed into the annular space for
discharge through the open end of the cup shaped member
forming a converging flow of compressed gas such that the
convergence point is beyond the wire feed point, being
5 downstream from the wire, thereby minimizing any turbulence
which otherwise might effect the stability of the plasma jet
stream. A wire, rod or strip of metal is fed perpendicularly
into a developed plasma arc column emanating from the nozzle
of the plasma torch. An electrical potential difference is
10 developed between the wire which acts as an anode, and the
cathode electrode within the plasma torch, from a DC
electrical source. Molten droplets of metal formed from the
tip of the wire are initially atomized and accelerated by the
supersonic plasma jet developed between the cathode electrode
15 and the anode wire. Additional atomizing and acceleration is
effected by the converging gas discharge from the cup shaped
member.

In another embodiment of the invention, a rotating
disk of feedstock material may be substituted for the wire,
20 rod or strip feedstock. The edge of the rotating disk is
aligned so that the center of the disk is radially disposed
from the axis of the plasma jet by a distance equal to the
radius of the disk and the plane of the face of the disk is
perpendicular to the axis of the plasma jet. As the disk is
25 rotated, a transferred-arc is established between the cathode
electrode of the plasma torch and the edge of the disk which
is electrically charged as an anode. The edge of the disk
will be continuously melted and the melted droplets thus

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1 formed will be atomized and accelerated by the impinging
supersonic velocity, plasma-jet. A rack and pinion is provided
for moving the disk so that the edge of the rotating disk is
melted away as the radial position of the center of the
5 rotating disk is continuously adjusted to maintain the edge of
the disk properly located with respect to the axis of the
plasma-jet. As an alternate embodiment, two rotating discs
can be employed such that the tangential contact point of the
two rotating discs is maintained aligned on the axis of the
10 plasma-jet. Both rotating discs are electrically charged as
anodes and a transferred-arc is established between the two
disk anodes and the cathode electrode within the plasma torch.
The molten droplets thus formed from the simultaneous melting
of the edges of the two discs is then atomized and accelerated
15 by the supersonic plasma-jet.

In another embodiment of this invention, a bar or
plate of feedstock material may be employed in replacement for
the wire, rod or strip form of feedstock. One edge of the
plate is aligned with the axis of the plasma-jet while the
20 plane of the plate is perpendicular to the plasma-jet axis.
The plate is fed in a reciprocating manner with respect to the
plasma-jet axis. A rack and pinion is provided to move the
plate so that a transferred-arc is established with the edge
of the plate, causing the edge to continuously melt the molten
25 droplets thus formed being atomized and accelerated by the
supersonic plasma-jet. As the plate is moved, the position of
the edge of the plate must be continuously adjusted in order

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1 to maintain the proper position of the plate edge with respect
to the axis of the plasma.

In another embodiment of the present invention, a
wire is fed coaxially on the centerline of a bore to be
5 thermally spray coated. A plasma torch of the type previously
described as a part of this invention is radially disposed
with respect to the axis of the wire and supported on a member
capable of rotating this plasma torch around the wire. The
axis of the plasma torch is maintained at all times during
10 rotation at a perpendicular position relative to the axis of
the wire. Rotating fittings are provided to carry the
necessary gases and electrical power to the rotating plasma
torch. A transferred-arc-plasma is established between the
cathode electrode within the plasma torch and the wire which
15 is continuously fed to sustain this transferred-arc. The
transferred-arc is continuously sustained as the plasma torch
is caused to rotate concentrically around the wire axis, thus
causing the continuous melting of the tip of the wire while
the plasma-jet is simultaneously atomizing and accelerating
20 the molten droplets formed on the end of the wire and
propelling them against the wall of the bore. A structure is
provided for axially reciprocating the plasma torch within the
bore while rotating the plasma torch, thereby providing a
continuously uniform coating on the internal surface of a
25 cylindrical bore.

Accordingly, the present invention provides an
improved high velocity electric-arc spray apparatus.

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1 The present invention further provides a single wire
electric-arc spray apparatus and process in which a supersonic
plasma jet is created which is employed as an electric
contacting means to a metal wire as well as acting to atomize
5 and propel molten metal particles to a substrate to form a
high density coating while eliminating the occurrence of
secondary arcing.

 The present invention also provides a single wire
plasma arc spray apparatus and powder feed to produce a metal-
10 matrix composite coating and freestanding near-net-shape
materials of uniformly distributed secondary material within
the metal-matrix while consistently and reliably controlling
the degree of loading over a very broad shape.

 The present invention still further provides a high
15 velocity electric-arc spray apparatus which eliminates
secondary arcing between a wire feed and nozzle.

 The present invention also provides a high velocity
single wire thermal spray apparatus which is simple in
construction and may be operated at relatively low gas
20 consumption and is relatively maintenance-free.

 The present invention further provides a method and
apparatus for producing high performance well bonded coatings
which are substantially uniform in composition and have a very
high density with very low oxides content formed within the
25 coating.

 The invention accordingly comprises the several
steps and the relation of one or more of such steps with
respect to each of the others, and the apparatus embodying

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1 features of construction, combination of elements, and
arrangement of parts which are adapted to effect such steps,
all as exemplified in the following detailed disclosure, and
the scope of the invention will be indicated in the claims.

5 For a fuller understanding of the invention,
reference is had to the following description taken in
connection with the accompanying drawings, in which:

Figure 1 is a schematic diagram of a high velocity
electric arc spray apparatus constructed in accordance with an
10 embodiment of the invention which includes both wire feed and
powder feedstock feed;

Figure 2 is an enlarged cross-sectional view of a
transferred-arc-plasma torch constructed in accordance with an
embodiment of the invention which includes only the wire feed;

15 Figure 3 is an enlarged cross-sectional view of the
transferred-arc-plasma torch of the embodiment of Figure 1;

Figure 4 is a schematic view of a high velocity
thermal spray apparatus constructed in accordance with another
embodiment of the invention in which a rotating disk is used
20 as the feedstock material;

Figure 5 is a cross-sectional view of the
transferred-arc-plasma torch constructed in accordance with
another embodiment of the invention;

25 Figure 6 is a sectional view taken along lines 6-6
of Figure 5; and

Figure 7 is a circuit of a voltage level sensing
circuit constructed in accordance with the invention.

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1 Reference is first made to Figure 1 in which a high
velocity electric-arc spray apparatus constructed in
accordance with the invention includes a transferred-arc-
plasma (TAP) torch assembly 10. A main control and power
5 supply console (main console) 20 controls operation of TAP
torch assembly 10 and includes a gas control module 19, a wire
feed control 43 and a power supply 27,. A plasma gas 18 is
fed to TAP torch assembly 10 by gas control module 19 while
power is supplied to TAP torch assembly 10 as well as a wire
10 122 to form an arc between TAP torch assembly 10 and wire 122.

Wire 122 is fed at a position at least perpendicular
(90°) to the central axis of TAP torch assembly 10. Wire 122
is fed from a wire source 12 by a wire feed assembly 11. Wire
feed assembly 11 includes wire feed rolls 13 disposed on
15 opposed sides of wire 122 and which are driven by a motor 14.
Wire feed assembly 11 is controlled by wire feed control 43.

A plasma gas is supplied from a compressed gas
source 18 to gas control module 19 of main control and power
supply console 20 through gas hose 21. The plasma gas exits
20 gas control module 19 through a gas hose 25, the other end of
which is connected to TAP torch assembly 10.

Electrical power is brought to the system through
the main console 20 at an input 26 where it is transformed and
converted to DC electrical power within the power supply
25 portion 27 of the main console 20. The electrical input is
input through control contactors 39 to a DC power supply 36.

Reference is now also made to Figure 2 in which an
enlarged view of TAP torch assembly 10 is shown. TAP torch

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1 assembly 10 includes a housing 101. A plasma gas inlet block
102 is disposed within housing 101 coaxially with a cathode
support 104. A cathode 106 is disposed within cathode support
104 coaxially therewith. A cup shaped pilot nozzle 107 is
5 disposed about cathode 106. Cathode support block 104 is
coaxially aligned within pilot nozzle support block 110 and
electrically insulated from nozzle support block 110 through
an insulating sleeve 111 disposed therebetween.

Plasma gas inlet block 102 is formed with a gas
10 inlet port 103 which receives the plasma gas and provides its
passage through cathode support 104 exiting through
tangentially oriented ports 105 formed within cathode 106.
Ports 105 communicate at a right angle with a chamber 108
formed between cathode electrode 106 and the inner surface of
15 cup shaped pilot nozzle 107. As the plasma gas exits the
tangential ports 105 into chamber 108 it forms a strong vortex
flow around cathode 106 and exits pilot nozzle bore 109 formed
within pilot nozzle 107.

A cup shaped atomizing nozzle 119 is disposed about
20 plasma nozzle 107. A secondary compressed gas is fed into a
gas input port 112 located on cathode support block 104. The
secondary gas passes through a passage in block 104
distributing itself in manifold chamber 113 before passing
through multiple passages 114 in block 104 before entering and
25 distributing itself in chamber 115. From chamber 115 the
secondary gas passes through multiple sets of passages 116 and
117 and into a manifold 118. The secondary gas, now very
uniformly distributed within manifold 118, exits through the

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1 conical passage 120 formed between the outside surface of the
pilot nozzle 107 and inner surface of atomizing nozzle 119
causing a converging flow of secondary gas, converging at a
point 121 which is located at a distance of approximately 24mm
5 from the face of the pilot nozzle 107.

The negative output of the power supply 27 is
connected through lead 28 to central cathode electrode 106 of
the TAP torch assembly 10. The positive output of power
supply 27 is connected to the wire 122 through electrical
10 power lead 29 so that wire 122 is an anode. An additional
positive connection to power supply 27 supplies pilot power to
the main body 30 of TAP torch assembly 10 through electrical
power lead 31. High frequency generator 32, contained within
the power supply 27, is connected to the negative output
15 connection of power supply 27 through capacitor 33 which acts
to block the DC negative power output of the DC power supply
36 and pass the high frequency power. The other side of high
frequency generator 32 is directly connected to the PILOT
output connection of power supply 27 and is also connected
20 through a pilot dropping resistor 34 and contact switch 45 to
the positive output connection of power supply 27.

A voltage level sensor 35 is located within the
power supply, its input being connected to the output of the
DC power supply 36 by leads and 37 and 38. The output of the
25 voltage level sensor is connected to a control module 41
through central cable 42. The output of the control module 41
is connected to the wire feed control 43 and the DC power
supply 36 by control cable 44 which ultimately controls the

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- 1 "ON" and "OFF" functions of the control contact switches 40
and 39, respectively for turning wire feed 11 and DC power
supply 36 OFF as needed.

5 Wire 122 is fed towards the central axis of TAP
torch assembly 10 at an angle of at least 90° relative
thereto. The central axis of the wire 122 is spaced
approximately 4.5mm from the face of the pilot nozzle 107.
The cathode block 104 is electrically energized with a
negative charge and the wire 122 is electrically charged with
10 a positive charge. Pilot nozzle 107 is electrically energized
from the pilot output from the power supply 27.

To initiate the operation of the system, after
operating an ON control switch, plasma gas 18 is caused to
flow through gas module 19 through hose 25 to TAP torch
15 assembly 10. After an initial period of time, typically two
seconds, DC power supply 36, high frequency supply 32 and the
associated contact switch 45, and wire feed control 43 are
energized simultaneously causing a pilot plasma to be
momentarily activated. During operation, with plasma and
20 secondary gases flowing and the power supply 27 energized, a
non-transferred plasma is initially formed by an arc current
established between the cathode tip 106 and pilot plasma
nozzle 107, through the low pressure region in the center of
the vortex flow of plasma gas, exiting the pilot plasma
25 nozzle. Once this non-transferred plasma is established, a
stream of hot, ionized electrically conductive gas flows out
from the pilot nozzle 107, contacting with the tip of wire 122
to which a transferred-arc 127 is formed establishing a plasma

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1 current to flow from cathode electrode tip 106 through the low
pressure center region of the vortex flow through the pilot
plasma nozzle 107 which acts as a constricting orifice to the
tip of wire 122. Wire 122 is continuously fed by wire feed
5 assembly 11 into the emanating plasma stream thus sustaining
the transferred-arc even as the wire tip is melted off.

Instantly, with establishment of the transferred-
arc, the high frequency supply 32 is de-energized as pilot
contact switch 45 is opened. As wire 122 is continuously fed
10 by wire feed assembly 11, the tip of wire 122 is melted by the
intense heat of the transfer arc and its associated plasma
127. Molten droplets are formed on the tip end of wire 122
which are accelerated and initially atomized into fine molten
particles by the viscous shear force established between the
15 high, supersonic plasma jet velocity and the initial low
velocity of the molten droplets. The molten particles are
further accelerated and atomized by the much larger mass flow
of secondary gas which converges at converging zone 121 beyond
the flow of the plasma stream 127 now containing the finely
20 divided, accelerated particles of molten material. The
particles are further accelerated, atomized and propelled from
converging zone 121 to substrate surface 123 where deposit 124
forms.

During operation of the system, in the event of a
25 hesitation or halting of the wire feed, melt-back of wire 122
will occur. This hesitation in wire feed can randomly occur
due to certain wire-feed inconsistencies caused by such things
as a kink in wire 122 or the like. In addition, if the wire

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1 feed is stopped, such as at the end of the operational cycle,
melt-back will also occur. When melt-back occurs, the
transferred-arc length is extended so as to sustain itself
between cathode 106 and receding wire 122. As this occurs,
5 damage and destruction to the pilot plasma nozzle 107 will
occur in addition to the damage and destruction that will be
inflicted on the wire-guide tip (not shown) which supports and
guides wire 122 to its appropriate position.

This melt-back will occur since the power supply
10 employed in the operation of the apparatus of the present
invention has constant current characteristics. Constant
current characteristics dictate that a preset electrical
current will be maintained over a broad range of conditions by
automatically adjusting the voltage in order to maintain this
15 set current. The wire 122 is fed at a position which is 90°
or greater, to the axis of TAP torch assembly 10. As such, as
melt-back starts to occur, the transferred-arc voltage starts
to increase due to a longer arc length which is forming. A
voltage level sensor 35, which is part of the power supply 27
20 senses the increased voltage and at a predetermined voltage
level, the voltage level sensor de-energizes the DC power
supply 36 as well as the wire feed control 43 preventing
damage to the apparatus.

Reference is made to FIG. 7 in which a voltage level
25 sensor circuit suitable for use in the present invention is
provided. Voltage level sensor circuit 35 receives a positive
and negative input from DC power supply 36. A resistor R_1 is
connected across the positive and negative inputs. A first
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1 diode D_1 is coupled between resistor R_1 and an inducting coil
CR₁. A second diode D_2 is coupled in series with the second
resistor R_2 between a resistor R_3 and the junction between the
cathode of D_1 and inductor CR₁ at its cathode. Resistor R_3 is
5 coupled between the negative output of the DC power supply 36
and resistor R_2 . A transistor Q_1 is coupled to resistor R_3 at
its collector, through resistor R_4 to inductor CR₁ at its
emitter and to the negative output of DC power supply 36 at
its base.

10 By providing a high velocity thermal spray apparatus
which feeds a wire perpendicular to the axis of the plasma jet
thereby maintaining the arcing distance sufficiently great so
that the closest electrical pathway to the wire is at its tip,
it is not possible for secondary arcs to form between any
15 point along the wire extending radially from the axis of the
plasma jet and any point on the face of the pilot plasma
nozzle (anode) of the plasma torch. As the wire is withdrawn
from the axis of the plasma jet, the distance between the tip
of the wire and the face of the pilot plasma nozzle remains
20 either constant or increases with greater degrees of
withdrawal. This is a benefit over the prior art which
utilizes acute angles of wire feed which provide sections
where the wire is closer to the pilot plasma nozzle than at
the tip, leading to double arcing. Additionally, since it is
25 characteristic of plasma arcs that, as the arc length
increases, the arc voltage increases proportionally, by
providing an arc-voltage sensing circuit, as the wire is
withdrawn from the plasma jet and the arc voltage increases,

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- 1 the voltage sensing circuit will cut off the power to the
plasma torch at a predetermined voltage as well as stopping
the wire feeder, thereby preventing the transferred-arc from
extending or secondary arcs forming, either of which
5 conditions are otherwise destructive to the spray apparatus.

The physical configuration of the angular
positioning of wire 122 with respect to the central axis of
the TAP torch assembly 10 in conjunction with voltage level
sensing and control are central feature of the present
10 invention, making practical the use of a TAP torch assembly 10
while preventing damage and/or destruction of components of
TAP torch assembly 10 which are critical to its operation and
performance.

Reference is now made to FIGS. 1 and 3 in which a
15 preferred embodiment of the invention is shown. Like numbers
are utilized to indicate like parts, the difference between
the embodiment of FIG. 2 and that of FIG. 1 being the
inclusion of a powder tube feed for implanting impurities into
the metal to form a metal-matrix composite.

20 A powder injection tube 125 through which a powder
feedstock material is fed in the direction of arrow C is
disposed 180° from wire 122 so as to be on the opposed side of
plasma jet 127. A powder feeder 16 is coupled to powder feed
tube 17. A carrier gas is supplied from a compressed gas
25 source 22 through gas hose 23 to gas control module 19 of main
console 20. The carrier gas exits gas control module 19
through a gas hose 24 to powder feeder 16. Powder feeder 16
is coupled to powder injection tube 125 by powder feed tube

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1 17. By providing a metal wire thermal spray apparatus having
a powder feedstock, injection means in this manner, high
density, metal-matrix composites can be spray formed.

As seen in FIG. 3 powder injection tube 125 is
5 located 180° from the wire 122 and its central axis is also
oriented 90° from the axis of TAP torch assembly 10.
Furthermore, the central axis of powder injector tube 125 is
located at least a distance equal to the radius of wire 122
downstream from the central axis of the wire 122 along the
10 plasma path. In an exemplary embodiment, powder injector tube
125 is at least 1mm downstream of wire 122. Powder particles
suspended in a carrier gas 126 are injected through the plasma
stream 127 directly into the large molten droplets formed on,
and moving away from the melting tip of wire 122. As these
15 powder particles impact the molten droplets, they include
themselves in the molten droplets. These molten droplets with
powder particles included are carried away, first by the
plasma stream 127 and then by the converging secondary gas at
the converging zone 121 and from there to the substrate 123
20 (FIG. 2), forming a coating 124 which in this embodiment would
be a high density metal-matrix composite having the powder
particles uniformly distributed throughout the deposit.

Referring further to FIG. 3, the flow of the
transferred-arc current 128 is more clearly seen established
25 between cathode electrode 106 and the tip of wire 122 which
sustains the plasma stream 127. Mach diamonds 129 can be
observed when proper energy input and plasma gas flows are

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1 established indicating that the plasma stream 127 has gas
velocities which are supersonic.

One of the many advantages provided by the present
invention is the ability to inject the powder feedstock
5 directly into the forming molten metal droplets which permits
the joining of the powder feedstock and metal-matrix while the
matrix material is in a molten or liquid state thereby
eliminating any interdependence on the hardness of the metal-
matrix and the degree of loading for such metals as steel or
10 the like. Also, by varying the relative feed rates of the
powder feedstock, a very broad range of loading of the powder
feedstock in the metal-matrix is obtainable employing a wide
range of selection of metal-matrix materials. In addition, by
injecting the powder feedstock downstream from the central
15 axis of the wire 122, turbulence of the plasma, and thereby
erratic transferred-arc conditions, caused by the injection of
powder and a cold carrier gas, is avoided. Additionally, by
increasing the degree of loading, the strength of the
resulting metal-matrix composite is increased.

20 A number of plasma and secondary gases may be used
in the present invention. The choice of the plasma and
secondary gas is dictated by a number of factors including
availability, economy, and, most importantly, by the effect
which a particular gas has on the spraying operation in terms
25 of the metallurgical and physical characteristics of the spray
deposit as well as the rate of deposit. For the plasma gas,
compressed air is preferred for use as well as for the
secondary gas, particularly for the reason of economy. Such

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1 other gases as nitrogen, argon or mixtures of either of these
two gases with, as an example, hydrogen or helium can also be
very useful especially when it is desired to produce coatings
containing little or no oxide formations.

5 In forming composites, including metal-matrix
composites, the high velocity thermal spray apparatus includes
in one embodiment a fluid feed means for feeding a feedstock,
preferably a powdered (particulate or short fiber) feedstock
directed into the plasma stream and positioned so that the
10 central axis of the powder feed stream is downstream from the
axis of the wire feed, into the molten metal droplets being
accelerated and atomized from the tip of the wire. Many of
the powder particles will include themselves into the larger
droplets of molten metal at this stage. The resulting
15 composite coating or bulk material thus formed is
substantially fully dense as thermally sprayed and the
composite is substantially uniform in composition.

Where the high velocity thermal spray apparatus is
used to form a metal-matrix composite, the powdered or
20 particulate feedstock may be, for example, a refractory
material, including refractory oxides, refractory carbides,
refractory borides, refractory silicides, refractory nitrides
and combinations thereof and carbon whiskers. The wire
feedstock in the disclosed embodiment may be any metal or
25 electrically conductive material in wire, rod, strip, fluid or
liquid form. Thus the high velocity thermal spray apparatus
and methods of this invention may be utilized to form various
substantially fully dense and substantially uniform metal-

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1 matrix composites, many of which cannot be formed by other
known methods of thermal spraying.

It should be noted that the present invention is particularly adapted to permit control of plasma gas
5 temperature and plasma gas enthalpy by proper selection of plasma gas as well as by controlling gas pressures. By controlling the composition of the plasma gas and the gas pressure, a wide range of particle velocities can be attained, thereby tailoring the characteristics of the resulting
10 deposit. The preferred plasma gas pressure range is from about 20 to about 150 psig and more preferably from about 40 to about 100 psig. When operated within these ranges, velocities of the emerging plasma gas stream from the pilot plasma nozzle bore 109 will be supersonic when a corresponding
15 pilot plasma nozzle bore diameter is selected in conjunction with a particular gas pressure and energy input setting. Pilot plasma bore diameters in the range of 1 to 3mm have been found to be the preferred range, corresponding to transferred-arc currents ranging from 20 amperes up to 200 amperes. It
20 will be appreciated that the nature of the plasma gas, its mass flow and the energy input, closely dictate velocity.

With reference to the embodiment of the present invention which is a method and apparatus for forming metal-
25 matrix composite deposits, illustrated in FIG. 3, the TAP torch assembly 10 operates similarly to that described previously herein and in FIG. 2. A powder injection tube 125 is now added in this embodiment and as a central feature to this invention, its location and orientation must be

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1 critically defined in an exemplary embodiment. The location
of the central axis of the powder injector 125 is located 180°
opposite from the central axis of wire 122 and at least 1mm
downstream from the axis of wire 122 and should also be
5 oriented at 90° or greater to the central axis of the TAP
torch assembly 10.

In operation, after the transferred-arc 128 is
established, wire 122 is continuously fed by wire feed
assembly 11 in the direction of arrow D. Simultaneously,
10 carrier gas 126 is caused to flow from powder feeder 16
through powder hose 17 into powder injection tube 125, from
which it is directed into plasma stream 127 in the direction
of arrow C. Because powder injection tube 125 is located
directly opposite the end of wire 122 and slightly downstream,
15 as the powder particles and carrier gas 126 are injected into
plasma stream 127, the powder particles attach to and are
included into the larger molten droplets of metal-matrix which
is flowing from the tip end of wire 122. This condition is
the central feature of this embodiment of the present
20 invention.

In the prior art technology, the powder particles
are generally added up stream from the source of molten metal
particles and are generally directed so that there is a
mixture of individual particles of metal and powder which are
25 propelled to the substrate to form a metal-matrix composite
deposit. Also, the powder particles have a significantly
different velocity in transit to the substrate compared to the
velocity of the molten metal particles. In the embodiment of

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1 the present invention, the velocity of the molten metal
droplets on the tip end of wire 122 is essentially initially
zero and are accelerated from this point toward the substrate
by the plasma stream. The injected powder particles are
5 injected 90° to the axis of the plasma stream and therefore
have initially a zero velocity in the direction toward the
substrate.

Establishing initially equal velocities of the metal
and powder particles in addition to having many of the powder
10 particles included within the molten metal droplets provides
much greater versatility and greatly improved characteristics
of the resulting metal-matrix composite deposit formed by the
method and apparatus of the present invention over the prior
art.

15 Wire 122 is formed of a metal which may be an alloy.
Suitable metals used in fabricating metal-matrix composites
include, titanium, aluminum, steel, and nickel and copper
based alloys. Any metal can be used if it can be drawn into
wire form. Powder cored wires may also be suitable. The flow
20 rates of the materials are controlled by regulating the
injection rate of the powder feedstock or the rate at which
the wire is fed. Numerous powdered materials may be employed
in the operation of the present invention which include
metals, metal alloys, metal oxide such as titania, alumina,
25 zirconia, chromia, and the like and combinations thereof;
refractory compounds such as carbides of tungsten chromium,
titanium, tantalum, silicon, molybdenum, and combinations
thereof; silicides and nitrides may also be used in some

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1 applications. Various combinations of these materials may
also be suitable. These combinations may take the form of
powdered blends, sintered compounds or fused materials. The
preferable particle size range of the feedstock powder ranges
5 from about 5 microns to about 100 microns, although diameters
outside this range may be suitable in some applications, the
preferred average particle size is 15 to about 70 microns.

The present invention further comprises coatings and
near-net-shapes formed in accordance with the method of the
10 present invention. As will be known to those skilled in the
art, freestanding near-net-shapes may be formed by applying a
spray deposit to a mandrel or the like or by spray-filling a
mold cavity. Suitable release agents and techniques will also
be known.

15 Reference is now made to FIG. 4 in which another
embodiment of the invention is provided. Like numerals are
utilized to define like structures. The basic structure of
TAP torch assembly 10 is identical to that fully described in
connection with FIG. 2 the difference being that the wire 122
20 is omitted and is replaced by a rotating disk 139 composed of
the feedstock material.

Two rack and pinion assemblies 131 are driven by a
common motor 132 and coupled by a common drive shaft 133. A
motor 130 is supported by a member 140 coupled with the two
25 rack and pinion drives 131. Rotating disk 139 is supported on
motor 130 and rotated thereby.

Disk 139 is aligned so that the plane of the face of
disk 139 is perpendicular to the central axis of TAP torch

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1 assembly 10 and that the center line of the disk 139 is
parallel to the central axis of TAP torch assembly 10. Disk
139 is rotated by motor drive 130 and the edge of the disk 139
is melted and propelled by the transferred-arc plasma 127.
5 Simultaneously with the continuous melting-off of the outer
edge of disk 139, the disk is continuously adjusted in its
position relative to the axis of TAP torch assembly 10 by rack
and pinion assemblies 131. As the disk edge is melted, the
molten droplets thus formed are atomized and propelled by
10 means of the plasma stream 127 to the substrate 123 to form a
deposit 124.

Similarly, as can readily be understood, a
reciprocating rectangular bar or plate may be substituted for
the rotating disk 139, melting one edge of the bar as it is
15 traversed in front of TAP torch assembly 10 and, similarly to
the rotating disk embodiment, the position of the edge of bar
is continuously adjusted to compensate for the melt-off.
Accordingly, a greater quantity of metal feedstock may be
placed in the plasma jet at a single time for a given
20 thickness of feedstock. It is also contemplated to utilize
two adjacent rotating disks disposed on opposed sides of the
plasma jet. The disks are positioned so that the plasma jet
melts away a portion of both disks at the tangent of the
respective disk edges with each other.

25 Reference is now made to FIGS. 5 and 6 in which a
cross-section and end view diagram of a TAP torch assembly 10
to be employed in a manner suitable for depositing a uniform
coating 134 on the surface of concave surface such as a bore

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1 135 is shown. This embodiment includes a TAP torch assembly
10 similar to TAP torch assembly 10 described in FIG. 2, the
difference being that TAP torch assembly 10 is mounted on a
rotating member 136 to allow rotation concentrically with
5 respect to bore 135 by means of a motor drive, not shown.

A rotating member 136 is mounted on a stationary end
plate 138. Rotating member 136 is formed with an insulating
wire feed conduit 137 extending through its rotation axis.
TAP torch assembly 10 is mounted at an end of rotating member
10 136 opposite that of stationary end plate 138 on the radius of
rotating member 136 so that plasma jet 127 extends towards
insulating wire feed conduit 137.

Wire 122 is fed on the central axis of the bore
through wire feed conduit 137 which is kept electrically
15 isolated from the rotating member 136 by means of the rigid,
electrically insulating wire feed conduit 137. The gas and
electrical connections to the TAP torch assembly 10 are
brought through the stationary end plate 138 to and through
the rotating member 136 to TAP torch assembly 10. Stationary
20 end plate 138 is maintained in pressure contact with the end
of rotating member 136 by pressure means, not shown. TAP
torch assembly 10 is positioned in relationship to the wire
122 exactly as is described and shown in FIG. 2.

A transferred-arc plasma 127 is established as
25 previously described, melting off the tip of the wire 122 as
it is continuously fed into plasma jet 127. As it is melted
off from the wire tip, the molten droplets are atomized and
propelled by the plasma stream towards the inner wall of the

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1 bore 135. As the rotating member 136 and the TAP torch
assembly 10 are rotated in the direction of arrow B (FIG. 6),
a coating 134 is deposited uniformly on the wall of the bore.
While the deposit is being formed by the rotational movement,
5 the assembly consisting of the wire feed conduit 137, wire
122, stationary end plate 138, rotating member 136 and TAP
torch assembly 10 is reciprocated axially in the direction of
arrow A, up and back within the bore 135, thereby causing the
deposit to form all along the circumference of the bore 135 as
10 well as covering the length of the bore 135. By these
combined motions and actions, bore 135 is completely covered
with a uniform deposit 134.

In the prior art, it has been commonly known that if
it is desired to apply a thermal spray coating to an internal
15 cylindrical surface, a thermal spray apparatus equipped with a
deflector head, deflecting the spray pattern nearing 90° is
employed and the part to be coated is independently rotated
while the thermal spray apparatus is reciprocated up and back
along the axis of the concave surface to provide a uniform
20 coating to the internal surface of the concave surface.
However, it is not always practical or possible to rotate the
part to be coated, such as an automobile engine block, when it
is desired to apply a coating to the cylinder bores contained
with the engine block. By providing a TAP torch assembly
25 which is rotatably mounted about a wire, the wire being fed at
an angle of at least 90° relative to the plasma jet a practical
process for applying coatings to the inner surface of a
concave structure such as a bore is provided.

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1 It will thus be seen that the objects set forth
above, among those made apparent from the preceding
description, are efficiently attained and, since certain
changes may be made in carrying out the above method and in
5 the constructions set forth without departing from the spirit
and the scope of the invention, it is intended that all matter
contained in the above description and shown in the
accompanying drawings shall be interpreted as illustrative and
not in a limiting sense.

10 It is also to be understood that the following
claims are intended to cover all the generic and specific
features of the invention herein described and all statements
of the scope of the invention which, as a matter of language,
might be said to fall therebetween.

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WHAT IS CLAIMED IS:

- 1 1. A high velocity arc spray apparatus comprising
transferred-arc-plasma torch assembly means for forming a
transferred-arc column, metal feedstock feeding means for
5 feeding a metal feedstock into said transferred-arc column at
an angle such that no portion of said metal feedstock is
closer than the leading edge of said fed metal feedstock to
said plasma torch assembly means, power source means coupled
to said metal feedstock and said transferred-arc-plasma torch
10 assembly means for selectively energizing said transferred-
arc-plasma torch assembly means and said metal feedstock to
create an electrical potential difference between said metal
feedstock and said transferred-arc-plasma torch assembly means
with a corresponding electric current flow, said metal
15 feedstock being an anode to effect the transfer of an arc
formed by said transferred-arc column.
2. The high velocity arc spray apparatus of Claim
1, wherein said transferred-arc-plasma torch assembly means
includes a cathode, said transferred-arc extending from said
20 cathode to said anode.
3. The high velocity arc spray apparatus of Claim
1 or 2, wherein said transferred-arc-plasma torch assembly
25 produces a plasma jet and further comprising powder feedstock
feeding means for feeding a powder, said powder being fed
downstream of said metal feedstock in the plasma jet path.
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1 4. The high velocity arc spray apparatus of Claim
3, wherein said plasma jet has a central axis and said powder
feedstock feeding means is disposed at an angle of
substantially 90° with respect to said central axis of said
5 plasma jet.

 5. The high velocity arc spray apparatus of Claim
3 or 4, wherein said powder feedstock feeding means is
disposed at an angle of substantially 180° with respect to
10 said metal feedstock feeding means.

 6. The high velocity arc spray apparatus according
to any of Claims 3 to 5, wherein said metal feedstock is a
wire, said powder feedstock feeding means being disposed at a
15 distance from a central axis of said wire at least as great as
the radius of said wire.

 7. The high velocity arc spray apparatus according
to any of Claims 3 to 6, wherein said power source means is a
constant current device, said power source means varying a
20 voltage to maintain said electric current flow and further
including control means for determining the voltage of said
power source means and de-energizing said transferred-arc-
plasma torch assembly means when said voltage exceeds a
predetermined voltage value, and said control means further
25 turns off said powder feedstock feeding means when said
voltage exceeds said predetermined voltage value.

 8. The high velocity arc spray apparatus of Claim
2, wherein said transferred-arc-plasma torch assembly means
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1 includes a cathode support member, said cathode being
supported thereon, a cup shaped pilot nozzle having an inner
surface disposed about said cathode forming a chamber between
said cathode and said inner surface of said cup shaped pilot
5 nozzle, plasma forming gas source means and transfer means
communicating with said chamber and said plasma forming gas
source means for introducing a plasma forming gas into said
chamber for passage through said cup shaped pilot nozzle, said
plasma gas forming a strong vortex flow around said cathode
10 and as said plasma gas exits said cup shaped pilot nozzle.

9. The high velocity arc spray apparatus of Claim
8, wherein said transfer means communicates with said chamber
at a substantially right angle.

15 10. The high velocity arc spray apparatus of Claim
8 or 9, further comprising a cup shaped atomizing nozzle
disposed about said cup shaped pilot nozzle forming a second
chamber therebetween, compressed gas source means and second
transfer means communicating with said second chamber and said
20 compressed gas source means for introducing a compressed gas
into said second chamber for passage through said cup shaped
atomizing nozzle, said compressed gas forming a strong
converging flow to a converging point beyond said plasma gas.

25 11. The high velocity arc spray apparatus of any of
Claims 1 to 5, wherein said metal feedstock is a metal disk.

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1 12. The high velocity arc spray apparatus of Claim
2 11, wherein said disk is disposed so that the plane of the
3 face of said disk is essentially perpendicular to the central
4 axis of said transferred-arc-plasma torch assembly means and
5 the center line of said disk is essentially parallel to the
6 central axis of said transferred-arc-assembly torch assembly,
7 the centerline of said disk being disposed a distance from the
8 central axis of said transferred-arc-plasma torch assembly
9 means essentially equal to the radius of said disk.

10 13. The high velocity arc spray apparatus of Claim
11 11 or 12, further comprising rotation means for rotating said
12 disk.

13 14. The high velocity arc spray apparatus of Claim
14 11, 12 or 13, wherein said metal feedstock feeding means
15 includes a rack and pinion.

16 15. The high velocity arc spray apparatus of any of
17 Claims 1 to 14, further comprising a rotating member having a
18 wire conduit formed therein, said rotating member rotating
19 about said wire conduit, said transferred-arc-plasma torch
20 assembly means being mounted on said rotating member and said
21 metal feedstock feeding means feeding said metal feedstock
22 through said wire conduit.

23 16. The high velocity arc spray apparatus of Claim
24 15, wherein said transferred-arc-plasma torch assembly means
25 is formed with an axial bore therein forming a nozzle, and
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1 further comprising plasma forming gas source means and
transfer means for introducing said plasma forming gas into
said transferred-arc-plasma torch assembly means for passage
through said nozzle.

5 17. The high velocity arc spray apparatus of any of
Claims 1 to 16, wherein the angle at which the metal feedstock
is fed into the transferred-arc column is at least a 90° angle
with respect to said transferred-arc column.

10 18. A method for forming a matrix metal composite
utilizing a transferred-arc-plasma torch assembly which forms
a transferred-arc column and plasma jet comprising the steps
of

15 feeding a metal wire into said transferred-arc
column at an angle such that no portion of said metal wire is
closer to said transferred-arc-plasma torch assembly than the
tip of said metal wire;

20 creating an electrical potential difference between
said metal wire and said transferred-arc-plasma torch
assembly; and

feeding a powder downstream of said metal wire in
the plasma jet path.

25 19. The method of Claim 18, wherein said plasma jet
has a central axis and further comprising the step of feeding
said powder at an angle of substantially 90° with respect to
said central axis of said plasma jet.

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1 20. The method of Claim 18 or 19, further
comprising the step of feeding said powder at an angle of
substantially 180° with respect to said metal wire.

5 21. The method of any of Claims 18 to 20, wherein
said powder is fed downstream of a central axis of said metal
wire a distance at least as great as the radius of said wire.

10 22. The method of any of Claims 18 to 21, further
comprising the step of forming molten droplets of metal at the
tip of said metal wire, conveying said molten droplets in said
plasma jet, and embedding said powder into said molten
droplets.

15 23. The method of any of Claims 18 to 22, further
comprising the step of forming a supersonic plasma jet.

20 24. The method of any of Claims 18 to 23, wherein
said powder feedstock is a refractory material, metal oxides
or carbon whiskers.

 25. The method of any of Claims 18 to 24, further
comprising the step of forming the metal wire from titanium,
aluminum, steel and nickel or copper based alloys.

25 26. A method for coating a concave surface
utilizing a rotating member having a wire conduit formed
therein, said rotating member rotating about said wire
conduit, transferred-arc-plasma torch assembly means for

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1 forming a transferred-arc column mounted on said rotating
member, wire feeding means for feeding a metal wire through
said wire conduit and into said transferred-arc column at an
angle such that no portion of said metal wire is closer to the
transferred-arc-plasma torch assembly means than the tip of
5 said metal wire, power source means coupled to said metal wire
and said transferred-arc-plasma torch assembly means for
energizing said transferred-arc-plasma torch assembly means
and said metal wire to create an electrical potential
difference therebetween comprising the steps of:
10 positioning said rotating member within said concave
surface;
feeding said metal wire into said transferred-arc;
rotating said rotating member about said wire
conduit; and
15 reciprocally moving said rotating member between a
first direction along the axis of said concave surface and a
second opposite direction along the axis of said concave
surface.

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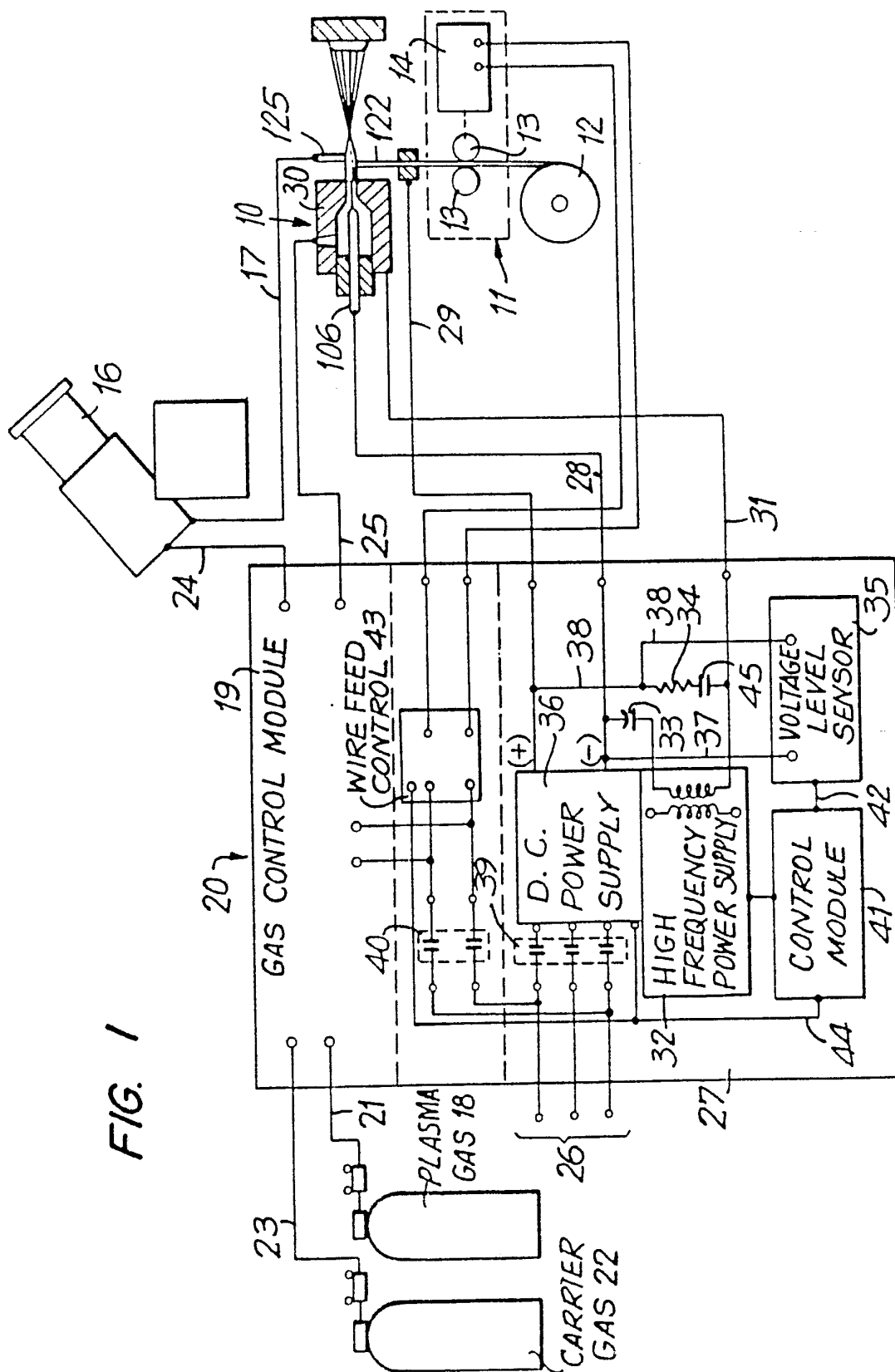
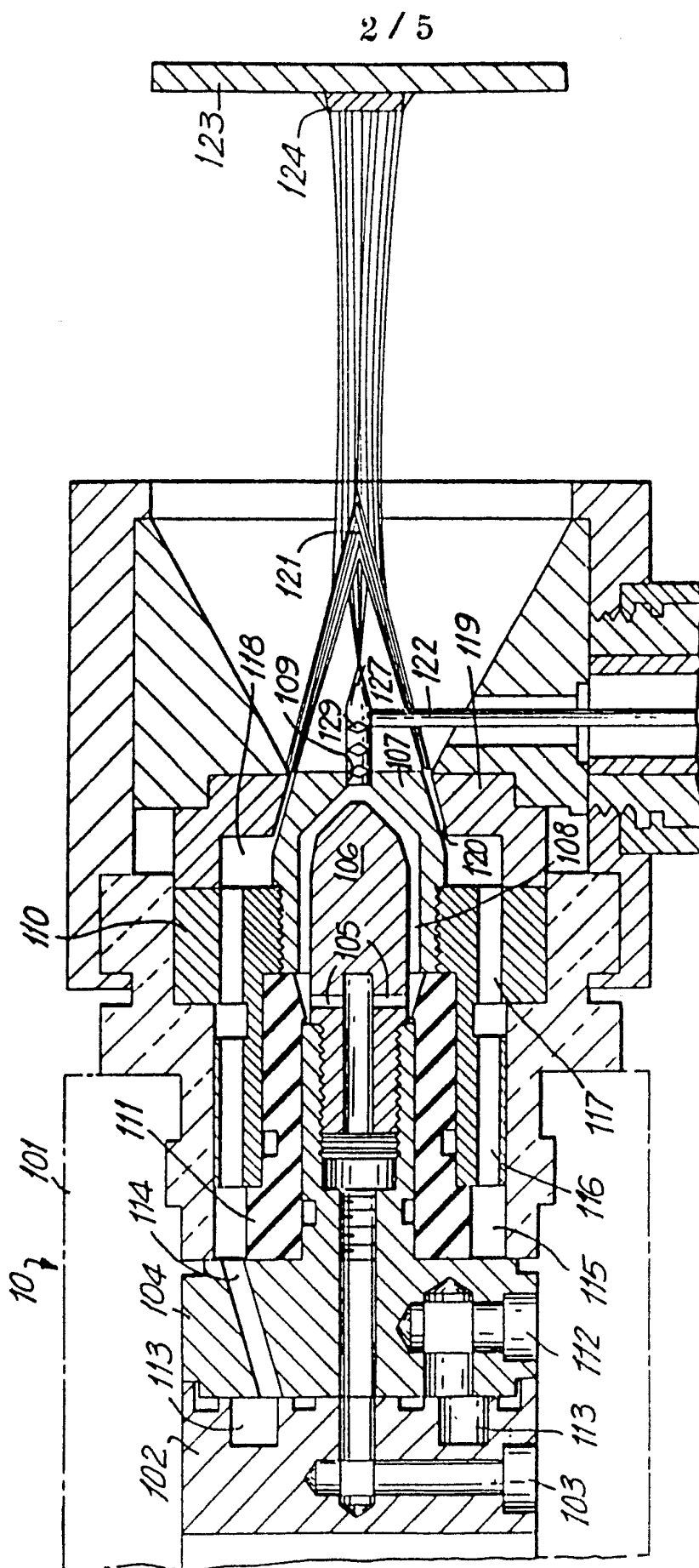


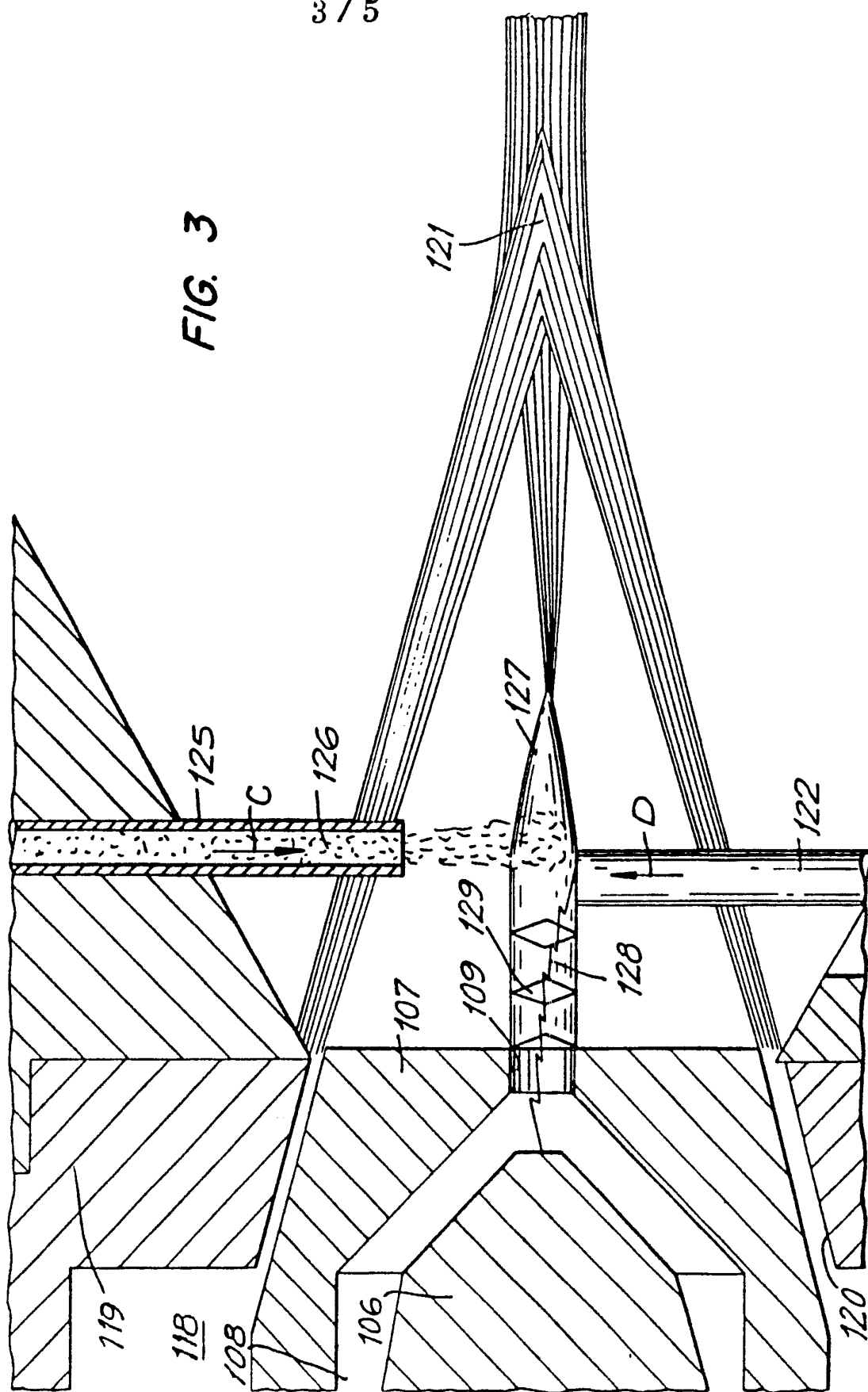
FIG. 1

FIG. 2



3 / 5

FIG. 3



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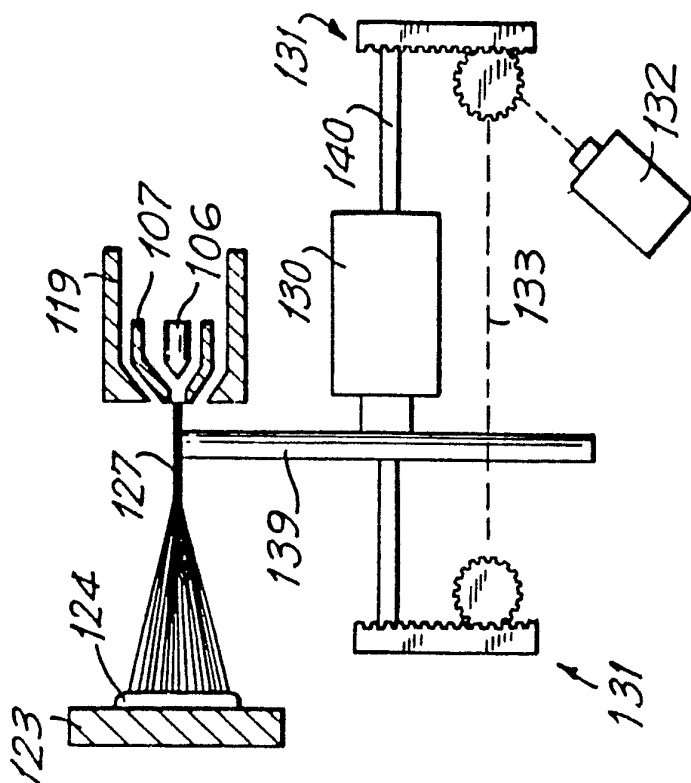


FIG. 4

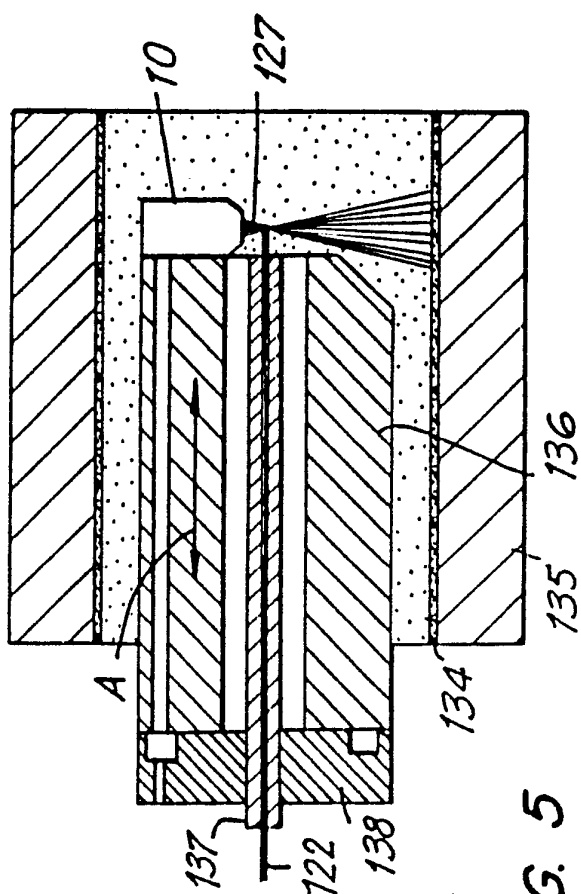


FIG. 5

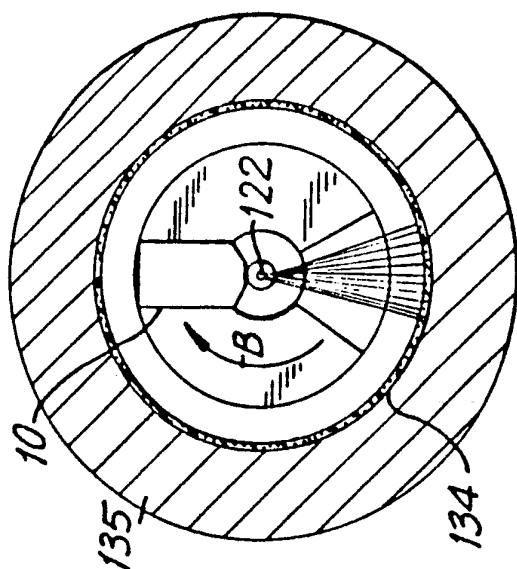


FIG. 6

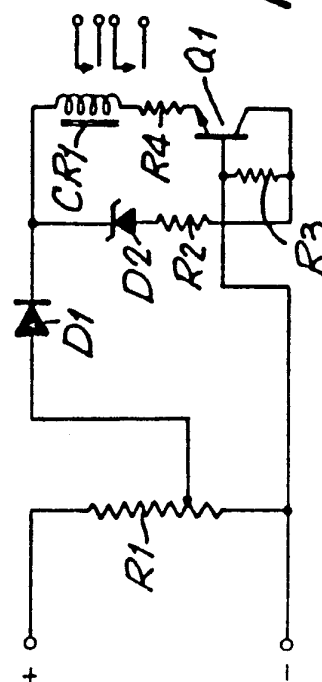


FIG. 7

INTERNATIONAL SEARCH REPORT

International Application No. PCT/US91/06270

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁴

According to International Patent Classification (IPC) or to both National Classification and IPC
 IPC(5): B05D 1/00, 1/02, 1/28, 1/34, 3/06, 3/12, 1/08, 7/16, 7/22; C23C 16/00 B23K 9/00, 9/28;
 US Cl.: 118/302, 326, 620, 715; 427/34, 37, 38, 57, 233, 236, 237, 250, 423, 426, 427; 219/121.36, 121.47,
 121.53, 137.2

II. FIELDS SEARCHED

Minimum Documentation Searched ⁷

Classification System

Classification Symbols

US 118/302, 326, 715; 427/34, 37, 38, 57, 233, 236, 237, 250, 423, 426, 427;
 219/121.36, 121.47, 121.53, 137.2

Documentation Searched other than Minimum Documentation
 to the Extent that such Documents are included in the Fields Searched ⁸

III. DOCUMENTS CONSIDERED TO BE RELEVANT ⁹

Category ¹ Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹² Relevant to Claim No. ¹³

A US, A, 4,762,977 (BROWNING) 09 AUGUST 1988
 See entire document.

1-26

* Special categories of cited documents: ¹⁰

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
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- "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

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

IV. CERTIFICATION

Date of the Actual Completion of the International Search

08 OCTOBER 1991

Date of Mailing of this International Search Report

25 NOV 1991

International Searching Authority

ISA/US

Signature of Authorized Officer

BERNARD D. PIANALTO