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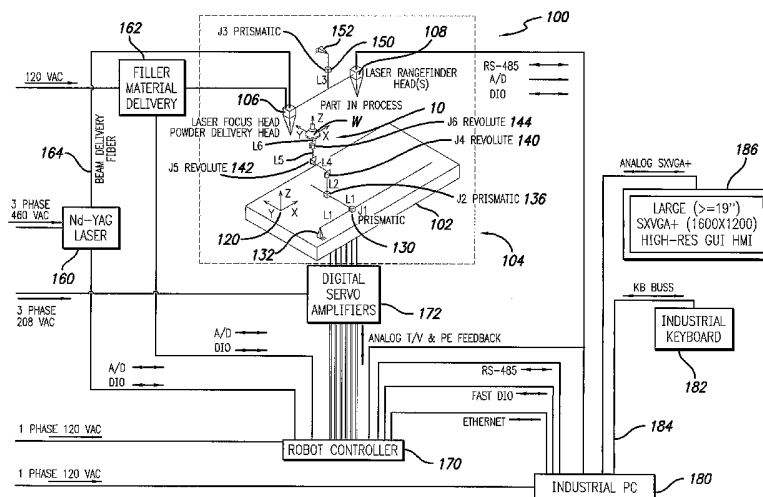
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(54) Title: 3-D ADAPTIVE LASER POWDER FUSION WELDING



(57) Abstract: A 3-D adaptive laser powder fusion welding system (100) provides for both modeling/gauging of a workpiece as well as repair, restoration, and/or manufacture thereof. By providing a work platform and apparatus support system, five degrees of control in the form of two linear axes and three rotational axes are provided. The sixth linear axis is controlled via the displacement of a laser powder fusion (LPF) welding head (106) and a laser rangefinding head (108). The laser rangefinding head (108) system enables the workpiece W to be modeled electronically or otherwise. Additionally, the rangefinding system (100) enables a model part to serve as a template from which repairs or construction are affected. The LPF welding head (106) then affects any repairs or manufacture that are needed on the workpiece W. The LPF welding head is powered by filler material. The entire system is generally controlled by computer which enable the operator to be separated from a generally hot and hostile welding environment.



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3-D ADAPTIVE LASER POWDER FUSION WELDING

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CROSS-REFERENCES TO RELATED APPLICATIONS

[0002] This patent application is related to, but claims no priority from, United States Patent Number 10/071,025 filed 2/08/2002 for Hand Held Laser Powder Fusion Welding Torch and United States Patent Number 10/206,411 filed 7/26/2002 for Powder Feed Splitter for Hand-Held Laser Powder Fusion Welding Torch, which are
15 incorporated by reference.

BACKGROUND OF THE INVENTION

Field of the Invention

20 [0003] This invention relates to Laser Powder Fusion Welding (LPFW) Systems and more particularly to a platform system for a Laser Powder Fusion Welding System enabling the workpiece to be disposed with respect to the laser head according to the six usual axes (roll, pitch, yaw, and x, y, z) as well as a teaching tool in order to affect repair and to provide three-dimensional data entry for the laser welding head.

25

Description of the Related Art

[0004] In the past, developments regarding Laser Powder Fusion Welding (LPFW) have been on a primitive or preliminary basis. Generally, the workpiece is held stationary while a moveable LPFW head is then applied in order to construct,
30 fabricate, or repair the workpiece. In some circumstances, the table or platform upon which the workpiece rests may be rotated and the workpiece constructed or worked upon in the matter of a potter's wheel or similar.

[0005] Such geometrical disposition between the generally stationary workpiece and the moveable LPFW head constrains the types of articles that can be fabricated

and/or repaired by the LPFW head. Certain angles and dispositions between the workpiece and LPFW head more readily accommodate the specific geometries of the workpiece and may enable better LPFW head functioning and performance in order to achieve the goals of the LPFW process. Current means do not allow for significant workpiece manipulation for engagement by the LPFW head or significant LPFW head manipulation for workpiece engagement.

[0006] LPFW Welding is particularly advantageous for certain materials that are not readily welded by other means. Components needing LPFW often exhibit variation from nominal surface contours in excess of what the welding process will tolerate. This causes or may lead to a higher probability of defect rates or the inability to use LPFW at all unless the components are machined prior to welding in a manner that minimizes such variation. Such additional operations increase cost due to the added labor and material. They also increase the time it takes to operate on the workpiece.

[0007] Currently, there are no machines or processes available to adapt to multi-dimensional part variability. It is generally well known that most high temperature super alloys (including those with refractory metals) are defined as "non-weldable" by conventional welding methods. Existing laser welding systems do not have the capability to trace and program a complex geometry for a part in a manner that positions the laser normal to the surface in a constant fixed distance during LPF (Laser Powder Fusion) welding.

[0008] In view of the foregoing, there is a need for providing an LPF system that can engage a dimensionally-variable part for both welding and tracing. Such a system could provide for greater reliability in part repair and enable LPF welding to be applied to super alloys or refractory materials.

SUMMARY OF THE INVENTION

[0009] In view of the foregoing disadvantages, the 3-D adaptive laser powder fusion welding system set forth herein provides means by which multi-dimensional parts can be traced for welding and welded despite significant variability in the part's geometry. Additionally, beyond the tracing function which enables a three-dimensional modeling of a part, laser powder fusion (LPF) welding can then be applied to a part that departs from a model that has either been traced before or is otherwise available as a model.

[0010] By bringing LPF welding to bear upon such variable geometry parts, the use of refractory materials or super alloys may become more readily available as the barriers to use of such materials that arise from their "unweldable" nature by conventional means is overcome by the use of LPF welding.

5 [0011] The 3-D adaptive laser powder fusion welding system set forth herein provides means by which a model parts can be traced and archived for future reference. Such archiving of models occurs in a 3-D representation in an information storage device, such as a computer. Additionally, Laser Powder Fusion Welding (LPFW) is achieved by a laser welding head. A staging apparatus enables articulation
10 of a workpiece in the six classical axes: x, y, and z as well as roll, pitch, and yaw. Consequently, the three spatial and three angular axes are enabled so that the laser powder fusion welding head can perform laser powder fusion welding activities on the workpiece. The stage also provides means by which the laser range finding head can perform its tracing and archiving functions.

15 [0012] By providing such a system, "golden" parts can be imaged, modeled, or otherwise archived to memory. Once modeled electronically or digitally, the electronic model representation can then be transmitted to other laser powder fusion welding systems so that repairs and operations can be performed anywhere according to a model that may also be archived locally or far away, even on another continent.
20 In fact, a high-resolution tracing center for parts could provide the electronic templates for worldwide manufacture and repair.

[0013] By providing such a system, manufacture, alteration, and repair of parts that are subject to laser powder fusion welding are readily and easily achieved. Furthermore, those materials which are generally not subject to regular welding
25 processes are now opened up for commercial and technical exploitation due to the removal of the prior obstacle of not being susceptible to normal welding processes.

[0014] In one embodiment, the 3-D adaptive laser powder fusion welding system subjects a workpiece to laser powder fusion welding via a laser head system and a linear displacement element coupled to the laser head and enabling the laser head to
30 be displaced linearly in a first dimension. A support apparatus holds the workpiece adjacent the laser head in an adjustable and selectable manner and provides five degrees of freedom for the workpiece in second and third linear dimensions and first, second, and third rotational dimensions. In this way; the laser head may engage the

workpiece about its exterior. By so engaging the workpiece, the welding system enables welding to occur at almost any, if not every, surface of the workpiece.

[0015] In another embodiment, the 3-D adaptive laser powder fusion welding system subjects a workpiece to laser powder fusion welding via a laser head system that includes a laser welding head, a powder feed delivery system, and a tracing system that determines the topology of the workpiece. A linear displacement element coupled to the laser head enables the laser head to be displaced linearly in a first dimension and a support apparatus holds the workpiece adjacent the laser head in an adjustable and selectable manner. The support apparatus provides five additional degrees of freedom for the workpiece in second and third linear dimensions and first, second, and third rotational dimensions. The support apparatus including an x-axis prismatic element enabling linear travel along a first linear axis, a y-axis prismatic element enabling linear travel along a second linear axis, a roll revolute element enabling angular travel centered upon a roll axis, a pitch revolute element enabling angular travel centered upon a pitch axis, a yaw revolute element enabling angular travel centered upon a yaw axis. The x-axis, y-axis, roll revolute element, pitch revolute element, and yaw revolute elements are coupled to one another. A filler delivery system providing filler material to the laser head system. A laser supplying laser light to the laser head system is included and may generally rely upon an Nd-YAG laser. Alternative sources of laser energy may also be used, including lasers based on or using carbon dioxide (CO₂) and/or ytterbium fiber diode laser systems. A controller system controls operation of the filler delivery system, the laser, the laser head system, the linear displacement element, and the support apparatus. The controller system includes: a digital servo amplifier system coupled to the support apparatus and controlling operation of the five degrees of freedom; a robot controller coupled to and controlling the laser head system, the linear displacement element, and the digital servo amplifier; and a computer programmably operating the robot controller and enabling recording of data through the controller system. The 3-D LPF system is able to engage the workpiece about an exterior of the workpiece and by so engaging the workpiece, the welding system enables welding to occur at almost any, if not every, surface of the workpiece.

[0016] Other features and advantages of the present invention will become apparent from the following description of the preferred embodiments taken in conjunction with the accompanying drawing which illustrates, by way of example, the principles of the system set forth herein.

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BRIEF DESCRIPTION OF THE DRAWINGS

[0017] Figure 1 shows a schematic diagram of the 3-D adaptive laser powder fusion welding system set forth herein with the central positioning table and related welding equipment being generally circumscribed in schematic form by control and communication elements.

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[0018] Figure 2 is an enlarged portion of Figure 1 as designated by the dashed box in Figure 1.

DESCRIPTION OF A PREFERRED EMBODIMENT

[0019] The detailed description set forth below in connection with the appended drawings is intended as a description of presently-preferred embodiments of the invention and does not represent the only forms in which the present invention may be constructed and/or utilized. The description sets forth the functions and the sequence of steps for constructing and operating the invention in connection with the illustrated embodiments. However, it is to be understood that the same or equivalent functions and sequences may be accomplished by different embodiments that are also intended to be encompassed within the spirit and scope of the invention.

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[0020] The 3-D adaptive laser powder fusion welding system **100** has a central table or platform **102** upon which geometrical control elements (generally indicated as **104**) operate in order to dispose a workpiece **W** in relation to either a laser powder fusion welding head **106** or a laser rangefinder head **108**. The geometrical control elements **104** generally control five of the six available axes as used herein, these axes are the three lateral axes generally known in the art as x, y, and z that define a three-dimensional space as well as the three rotational axes commonly known as roll, pitch, and yaw. The geometrical control elements **104** associated with the table **102** operate to control the three rotational and the two lateral, x and y, directions of linear displacement. The third axis of linear displacement is controlled by the height at

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which either the LPFW head **106** or laser rangefinder **108** are disposed with respect to the workpiece **W**.

[0021] Generally the linear components are those of high precision and are generally known in the art. As indicated in Figure 1, the term “prismatic” generally indicates linear directions of travel. The term “revolute” indicates an angular displacement control. For the prismatic/linear elements to the geometrical controls **104**, high precision servomotors and the like can be used in order to precisely and accurately control the linear travel of the support apparatus **110**. The support apparatus includes the geometrical control elements as well as any intermediating support elements that serve to displace one geometrical control element from another.

[0022] Similarly, high precision and high accuracy servomotors may serve to provide angular displacement for the revolute elements in the system **100**. Similar to the prismatic elements associated with the support apparatus **110**, prismatic element may also be used in conjunction with the laser heads **106**, **108**.

[0023] Turning now to the details of the table **102**, the set of axes **120** are shown both in association with the table **102** and the workpiece **W**. These axes define similar geometries and are assumed to be identical save for the lateral displacement between the origin of the two. Consequently, use of the terms x, y, and z axes as well as roll, pitch, and yaw are generally relative to the axes **120** shown in Figure 1. Roll is generally considered to be movement around the x-axis or a roll axis, pitch is motion rotating generally upon the y-axis or pitch axis, while yaw is angular motion rotating generally upon the z-axis or yaw axis. The definition of these rotational axes may be relative to the workpiece **W** as opposed to the table **102**.

[0024] On the table **102**, a first linear displacement element **130** is shown supported above the surface of the table **102** by a post or other support **132**. The linear displacement element for the x-axis **130** is also indicated in the drawing Figure 1 as “J1 Prismatic”. The x-axis linear displacement element **130** travels along a rod, screw, path, or otherwise in a manner parallel to the x-axis **120** generally along one side of the table **102**. This leaves the rest of the table space available for motion along the y-axis **120**. While not shown in Figure 1 for drawing purposes, the x-axis linear displacement element **130** travels above the surface of the table as held by the rod or otherwise. The same is similarly true for the other elements of the support apparatus **110** with its geometrical control elements **104**.

- [0025] Coupled to the x linear displacement element **130** is a y linear displacement element **136** which is also indicated in Figure 1 as "J2 Prismatic". In a manner similar to that for the x-axis linear displacement element **130**, the y-axis linear displacement element **136** travels parallel to the y-axis **120** in the same way that the x linear displacement element **130** travels parallel to the x-axis **120**. The x and y linear displacement elements **130**, **136** may have a total possible distance of travel along predefined paths of a certain length designated in Figure 1 as L1. This generally defines a square area having sides of equal length and right angles to each other on which the workpiece **W** may travel. L1 may be an arbitrarily chosen distance for the types of workpieces **W** to be handled in the system **100** set forth herein.
- Alternatively, such distances may be different for the x linear displacement element **130** and the y linear displacement element **136**. If the x and y available travel distances are not equal, the resulting area defined by the x and y linear displacement elements **130**, **136** is a rectangle.
- [0026] With the foundational definition of x-axis and y-axis degrees of freedom for the workpiece **W** via the x and y linear displacement elements **130**, **136**, additional rotational elements provide angular control for roll, pitch, and yaw axis for the workpiece **W**.
- [0027] Separated from the y linear displacement element **136** by an appropriately chosen distance L2, a yaw control **140** (J4 Revolute) enables the workpiece **W** to enjoy angular displacement about the z-axis **120**. Similarly, a pitch control **142** (J5 Revolute) provides angular displacement with respect to the y-axis **120**. The pitch control **142** may be separated from the yaw control **140** by a distance L4.
- [0028] A roll control element **144** (J6 Revolute) may control rotational displacement about the x-axis. The workpiece study of itself may be coupled to the roll control **144** by means of a support having a distance L6 or otherwise.
- [0029] Note should be taken, that the distances between the y linear displacement element **136** and the yaw, pitch, and roll elements **140**, **142**, **144** may also be variable in distance such that distances L2, L4, L5, and L6 may be varied according to pre-selected and adjustable distance controls.
- [0030] From the foregoing, it can be seen that the disposition of the workpiece **W** is controlled in generally five dimensions: two linear (x and y) and three angular (roll, pitch, and yaw). In order to provide for control over the sixth axis, namely displacement along the z-axis **120**, z linear displacement element **150** (J3 Prismatic) is

coupled to both the laser powder fusion welding head **106** and the laser rangefinder head **108** as the two laser heads, **106**, **108** are disposed in a generally perpendicular manner to the z-axis linear displacement element **150** and so generally always enjoy the same height above the table **102**.

5 **[0031]** The z-axis linear displacement element may be coupled to a structure or support that is coupled to the table **102**. For purposes of visual depiction, a post **152** is shown connected to a background substrate which gives ultimate support to the laser heads **106**, **108**.

10 **[0032]** The laser heads **106**, **108** are significantly different in nature. The laser powder fusion welding head **106** is significantly energetic in order to melt a number of materials including plastics and metals. Consequently, the LPF welding head **106** is much more industrial in nature as it needs to resiliently withstand the dynamic and generally hostile environment that arises from laser powder fusion welding. As indicated in Figure 1, the LPF Welding head **106** may be powered by an Nd-YAG
15 (neodymium-yttrium-aluminum garnet) laser **160** which provides sufficient power to the LPF head **106** in order to meld, melt and/or weld the materials used thereby. Alternative sources of laser energy may also be used, including lasers based on or using carbon dioxide (CO₂) and/or yttrium fiber diode laser systems. Such material is delivered by a filler material delivery system **162** which may be operated in
20 accordance with the needs and demands of the workpiece **W** and the welding thereof by the LPF Welding head **106**. The same is similarly true for the laser **160** where the energy arising from the laser **160** is selectably controllable in order to provide better and more adjustable welding for the workpiece **W**.

25 **[0033]** Laser **160** and filler material delivery systems **162** are known in the art but may also be derived from previously filed patent applications assigned to the same assignee as the present technology. U.S. patent application serial number 10/071,025 filed on February 8, 2002 entitled Hand-Held Laser Powder Fusion Welding Torch by Baker et al. is incorporated by reference. United States Patent Application Serial
30 Number 10/206,411 filed July 26, 2002 for a Powder Feed Splitter for Hand-Held Laser Powder Fusion Welding Torch by Renteria et al. is incorporated by reference.

30 **[0034]** The laser light from the laser **160** may be delivered to the LPF Welding head **106** by a beam delivery fiber system **164** that optically transmits laser energy

from the laser to the LPF Welding head **106**. Other means by which the laser energy may be delivered to the LPF Welding head **106** may also substitute for fiber optics.

[0035] The laser rangefinder head system **108** may include one or more laser range finding heads (possibly powered in a diminished-energy mode by the laser **160**) that enable the geometrical contours of the workpiece **W** to be modeled and then coded electronically into a computer or otherwise. Alternatively, a helium-neon (HeNe) laser system may be used, as may a contact type of scanning system, along the lines of RENISHAW or other part-measuring probes to obtain the geometry of a workpiece or template part. By having a model (particularly an exact, precise, and accurate model) of the workpiece **W**, the laser powder fusion welding head **106** can then operate with exact and reliable data of the contours of the workpiece **W** that either are present or that need to be achieved via the welding process.

[0036] As can be seen in Figure 1, the laser heads **106**, **108** generally do not enjoy any horizontal or lateral degree of freedom, but are only adjustable in the vertical, z-axis direction by the z-axis linear displacement element **150** (J3 prismatic). Consequently, it becomes an operation of the support apparatus **110** with its geometrical control elements **104** to dispose the workpiece **W** in proximity to the laser rangefinding head system **108**. The laser rangefinder head system **108** can or completely determine the exterior geometry of the workpiece **W** for modeling purposes or otherwise. This is particularly advantageous when a model part is used for modeling and archiving. Such modeling is known in the art and, in summary, occurs when the rangefinding head system **108** determines the contours towards workpiece **W** as it is disposed along all three linear axes and all three rotational axes beneath the rangefinding system **108**.

[0037] All of the geometrical control elements **104** of the support apparatus **110** as well as the z linear displacement element **150** are coupled to a robot controller **170** (such as one using Adept Windows by Adept Technologies, Inc.) via digital servo amplifiers **172** or the like. This enables machine control for the linear and rotational displacement systems **104**, **150**. The robot controller **170** may also receive information signals from the laser rangefinder head system **108**, the LPF Welding head **106**, the filler material delivery system **162**, and the laser **160** via a variety of signal lines including analog/digital (A/D) signal lines and/or digital input output (DIO) signal lines. Signals are transferred and exchanged between the digital servo

amplifiers 172 and the robot controller 170 subject to traffic across the connection between the two.

[0038] The degrees of freedom present in the support apparatus 110 may require the travel along two or more axes simultaneously to position the workpiece **W** properly. For example, if the workpiece **W** is rolled forward such that its top most portion now faces forward in the positive x direction, it may be necessary to decrease the displacement of the x linear displacement element 130 so that one of the laser heads 106, 108 is directly above the former top most portion of the workpiece (prior to rotation). Such adjustments are generally easily calculated once the equations of motion are known for the support apparatus 110 and such equations may take into account displacement of the workpiece **W** itself, not just the motion of the support apparatus 110.

[0039] The robot controller 170 may communicate with an industrial PC (personal computer) 180 or otherwise. A number of calls, signal schemes, and/or protocols may be used in order to conduct such communication (generally two way) between the controller 170 and the PC 180. These include: Ethernet, fast I/O, RS-485, analog T/V and PE feedback, or otherwise. Other protocols developed in the future may also be advantageously implemented in the present system 100 in order to foster, establish, maintain, provide in a robust and reliable manner the signals necessary to monitor and control the processes going on and about the workpiece **W**.

[0040] In its turn, the industrial PC may be connected to an industrial keyboard 182 which may be connected to the PC 180 via a keyboard bus 184.

[0041] Visual monitoring of the process by transmission of video, digitized, or other sensor information can be achieved through a high-resolution or other graphics interface such as a super extended visual graphics array (SXVGA) monitor having a high-resolution display and, preferably a graphics user interface for the human machine interface (GUI HMI).

[0042] Generally, electronic control of machine elements is known in the art. However, the achievement of the present system 100 in providing a 3-D adaptive laser powder fusion welding system that both enables modeling and reconstruction/repair/manufacture of workpieces **W** provides significant advantages for LPFW Systems. The system 100 may be powered by a variety of sources with generally the following power requirements being contemplated. 120 volt AC (VAC) power generally supplies the filler material delivery system 162. One phase 120-volt

AC power generally supplies the controller 170 and the PC 180 and related systems. Three phase 208 VAC may power the digital servo amplifiers 172. Three phase 460 VAC may power the laser 160.

- [0043] Set forth below is a possible parts list that indicates devices that may be used to achieve one embodiment of this system

Segment	Sector Name	Subsector Name	Component Name	Manufacturer
Controls				
	Computer Products	Industrial Computers	Motion Controller	Motion Engineering, Inc.
	Control Devices	Relay	Control Relay (Positive guided) General Purpose Relay Small Relay Solid State Relay	Siemens Song Chuan Phoenix Contact Omron
	Electronic Devices	Electronic Filters	AC Line Filter	Corcom
	Operator Interface	Annunciators	Audible Alarm Mast Component	Mallory Telemecanique
		Pilot Devices	22mm Switch	Siemens
	PLC			Allen-Brady Co.
	Safety Components	Safety Components	Cable Pull Switch Guard Switch Light Curtain Safety Relay Touchswitch	Schmersal Schmersal Banner Schmersal Banner
	Sensors	Digital Sensors	Limit Switches-Mechanical Optical Sensor Proximity, Inductive	Baumer Efector, Inc. Efector, Inc.
		Sensor Accessories	Sensor Accessories	Efector, Inc.
		Sensor Cables	Sensor Cables	Efector, Inc.
Electrical				
	Cable & Wire	Cables	Custom Cables Data Highway Cable Ethernet Cable Flat Ribbon Cable Molded Cable Multi Conductor >20 awg Multi Conductor High Flex Multi-Conductor <20 awg	Cameron&Barkley Belden Anicom, Inc. Alpha L-Com Olflex Olflex Olflex
		Wire	Panel Wire	Carol
	Control Devices	Relays	Triac Relay	Omron
	Electronic Devices	Diodes	General Purpose Diode TB Diode	Newark Electronics Phoenix Contact
	Enclosures & Wiring	Conduit	Aluminum Conduit Conduit Fitting Flexible Conduit Galvanized Conduit Plastic Coat Conduit PVC Conduit Steel Conduit	Shealy Electric Wholesale Crouse-Hinds Anaconda Shealy Electric Wholesale Ocal Carlson Shealy Electric Wholesale
		Connectors	BNC Connector Circular Connector D-Sub Connector	L-COM Amp Amp

-12-

Segment	Sector Name	Subsector Name	Component Name	Manufacturer
			Heavy Duty Connector	Harting
			Interface Module	Phoenix Contact
			Power Plug	Hubbell
			Power Receptacle	Hubbell
			Ribbon Connector	Amp
		Enclosures	Climate Control	Rittal Corporation
			Console	Rittal Corporation
			Free-Standing Enclosure	Rittal Corporation
			Junction Box	Rittal Corporation
			Modular Enclosure	Rittal Corporation
			Operator Enclosure	Rittal Corporation
			PC Enclosure	Rittal Corporation
			Push Button Enclosure	Hoffman
			Wallmount Enclosure	Rittal Corporation
		Graphics	Engraved Legend Plate	Panel Graphics, Inc.
		Strain Reliefs	Strain Relief	Olflex
		Terminal Blocks	Terminal Block	Phoenix Contact
		Wire Accessories	Cable End	Telemecanique
			Cable End Marker	Telemecanique
			Cable Tie	Thomas & Betts
			Shrinkable Tubing	Alpha
			Wire Marker	Brady
			Wire Terminal	3M
		Wireduct	Wireduct (Enclosure)	Iboco
			Fiberglass Wireway	Hoffman
			Stainless Wireway	Hoffman
			Steel Wireway	Hoffman
	Motor Controls	Contactors	Contactors	Siemens
		Motor Overloads	Motor Overload	Siemens
		Motor Starters	Motor Starter	Siemens
	Power Distribution	Busbars	Busbar	Siemens
		Busducts	CE Busduct	Mempower
			UL Busduct	Siemens
		Circuit Breakers	High Trip Breaker	Siemens
			Standard Trip Breaker	Siemens
		Disconnects	Breaker Disconnect	Siemens
			Fused Disconnect	Siemens
			Knife Disconnect	Siemens
			Rotary Disconnect	Siemens
		Fuse Holders	DIN Rail Fuse Holder	Gould
			Panel Mount Fuse Holder	Gould
		Fuses	Blade-Type Fuse	Bussman
			Cartridge Fuse	Bussman
			Glass Fuse	Bussman
		Distribution Blocks	Power Dist. Block	Gould
		Power Supplies	DC Power Supply	Siemens
		Surge Suppressors	Device Mount	Siemens
			TB Surge Suppressor	Phoenix Contact
		Transformers	UL Control Transformer	Hevi-Duty
			UL Power Transformer	Acme
		UPS	UPS	Best Power Technology

-13-

Segment	Sector Name	Subsector Name	Component Name	Manufacturer
Mechanical				
	Conn. & Fastening	Air Service	AirLine Fittings AirLine, Plastic Fittings, SS Miniature Fittings Tubing, SS, Rigid	SMC Frelin Wade Weatherhead SMC H.M. Craig
	Mechanical Devices	Linear motion	Ball Screw Slides Belt Slides	Parker Autom Parker Autom
	Pneumatic Items	Air Preparation	Filter\Regulator\Lubricator	SMC
		Pneumatic Actuators	Cylinder & Accessories-Large Cylinder & Accessories-Small Grippers Pick & Place Units,>400mm Pick & Place Units,<400mm Rodless Cylinders Rotary Actuators Slides & Thrusters	SMC SMC Phd Parker Autom Precision Pneumatics SMC SMC SMC
		Vacuum products	Vacuum Cups Vacuum Generators	SMC SMC
		Valves	Ball Valves Flow Control Valves	SMC SMC
	Power Transmission	Bearings/Bushings	Bearings, Ball Bearings, CamFollower Bearings, Linear, Round Shaft Bearings, Linear, Square Rail Bearings, Mtd, Ball Bearings, Mtd, Spherical Roller Bearings, Mtd, Takeup Bearings, Mtd, Tapered Roller Bearings, Needle Bearings, RodEnd Bushing, Composite Bushing, Spherical Bushing, Plain	Various Brands Various Brands INA INA Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands
		Hardware	Collars Clamps	Various Brands Various Brands
		Motors	AC Motor up to 3 HP	US Motor
		Power Transmission	Belts, timing Belts, Vee Chain Clutches Couplings Joints Gear drives Gear Motors Sheaves, Pulleys & Hubs, Belt Sprockets & Hubs, Chain Gaskets O-Rings	Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands Various Brands
		Sealing	Seals	Various Brands
	Structural Products	Extrusion Accessories	Strut Accessories	Parker ParFrame
		Extrusions	Strut & Extrusions	Parker ParFrame
		Plastics	Plastic	Sheffield

Systems

Segment	Sector Name	Subsector Name	Component Name	Manufacturer
	Air Systems		Vacuum Generators, Large	SMC
	Conveyors	Belt/Roller Conveyors	Conveyors, Other Conveyors, Custom Conveyors, Industrial	EASI Conveyors A&E A&E
		Power&Free Conveyors	Conveyors, Flexible Chain Conveyors, Power & Free	AMC AMC
	Feeding Systems	Feeding Systems	Centrifugal Feeders Feeders, Other InFeed Tables/Conveyors Vibratory Feeders	VIBROMATIC VIBROMATIC VIBROMATIC VIBROMATIC
	Robotics	Robotics	Robots, Cartesian Robots, Gantry, Light & Med Servo Driven Pick & Place	Parker Autom Parker Daedal Parker Autom

[0044] While the present invention has been described with reference to a preferred embodiment or to particular embodiments, it will be understood that various changes and additional variations may be made and equivalents may be substituted for elements thereof without departing from the scope of the invention or the inventive concept thereof. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the invention without departing from the essential scope thereof. Therefore, it is intended that the invention not be limited to particular embodiments disclosed herein for carrying it out, but that the invention includes all embodiments falling within the scope of the appended claims.

CLAIMS

WE CLAIM:

- 5 1. A 3-D adaptive laser powder fusion welding system for subjecting a
workpiece to laser powder fusion welding, the system comprising:
 a laser head system;
 a linear displacement element coupled to the laser head and enabling the laser
head to be displaced linearly in a first dimension; and
10 a support apparatus capable of holding the workpiece adjacent the laser head
in an adjustable and selectable manner, the support apparatus providing five degrees
of freedom in second and third linear dimensions and first, second, and third
rotational dimensions; whereby
 the laser head may engage the workpiece about an exterior of the workpiece.
15
2. A 3-D adaptive laser powder fusion welding system for subjecting a
workpiece to laser powder fusion welding as set forth in Claim 1, wherein the laser
head system further comprises:
 a laser welding head.
20
3. A 3-D adaptive laser powder fusion welding system for subjecting a
workpiece to laser powder fusion welding as set forth in Claim 1, wherein the laser
head system further comprises:
 a powder feed delivery system.
25
4. A 3-D adaptive laser powder fusion welding system for subjecting a
workpiece to laser powder fusion welding as set forth in Claim 1, wherein the laser
head system further comprises:
 a tracing system determining topology of a workpiece.
30
5. A 3-D adaptive laser powder fusion welding system for subjecting a
workpiece to laser powder fusion welding as set forth in Claim 1, wherein the tracing
system further comprises:
 a laser rangefinder.

6. A 3-D adaptive laser powder fusion welding system for subjecting a workpiece to laser powder fusion welding as set forth in Claim 1, wherein the support apparatus further comprises:

- an x-axis prismatic element enabling linear travel along a first linear axis;
- 5 a y-axis prismatic element enabling linear travel along a second linear axis;
- a roll revolute element enabling angular travel centered upon a roll axis;
- a pitch revolute element enabling angular travel centered upon a pitch axis;
- and
- a yaw revolute element enabling angular travel centered upon a yaw axis;
- 10 the x-axis, y-axis, roll revolute element, pitch revolute element, and yaw revolute elements coupled to one another.

7. A 3-D adaptive laser powder fusion welding system for subjecting a workpiece to laser powder fusion welding as set forth in Claim 1, further comprising:

- 15 a filler delivery system providing filler material to the laser head system;
- a laser supplying laser light to the laser head system; and
- a controller system controlling operation of the filler delivery system, the laser, the laser head system, the linear displacement element, and the support apparatus.

20

8. A 3-D adaptive laser powder fusion welding system for subjecting a workpiece to laser powder fusion welding as set forth in Claim 7, wherein the laser further comprises an Nd-YAG laser.

25 9. A 3-D adaptive laser powder fusion welding system for subjecting a workpiece to laser powder fusion welding as set forth in Claim 7, wherein the controller system further comprises:

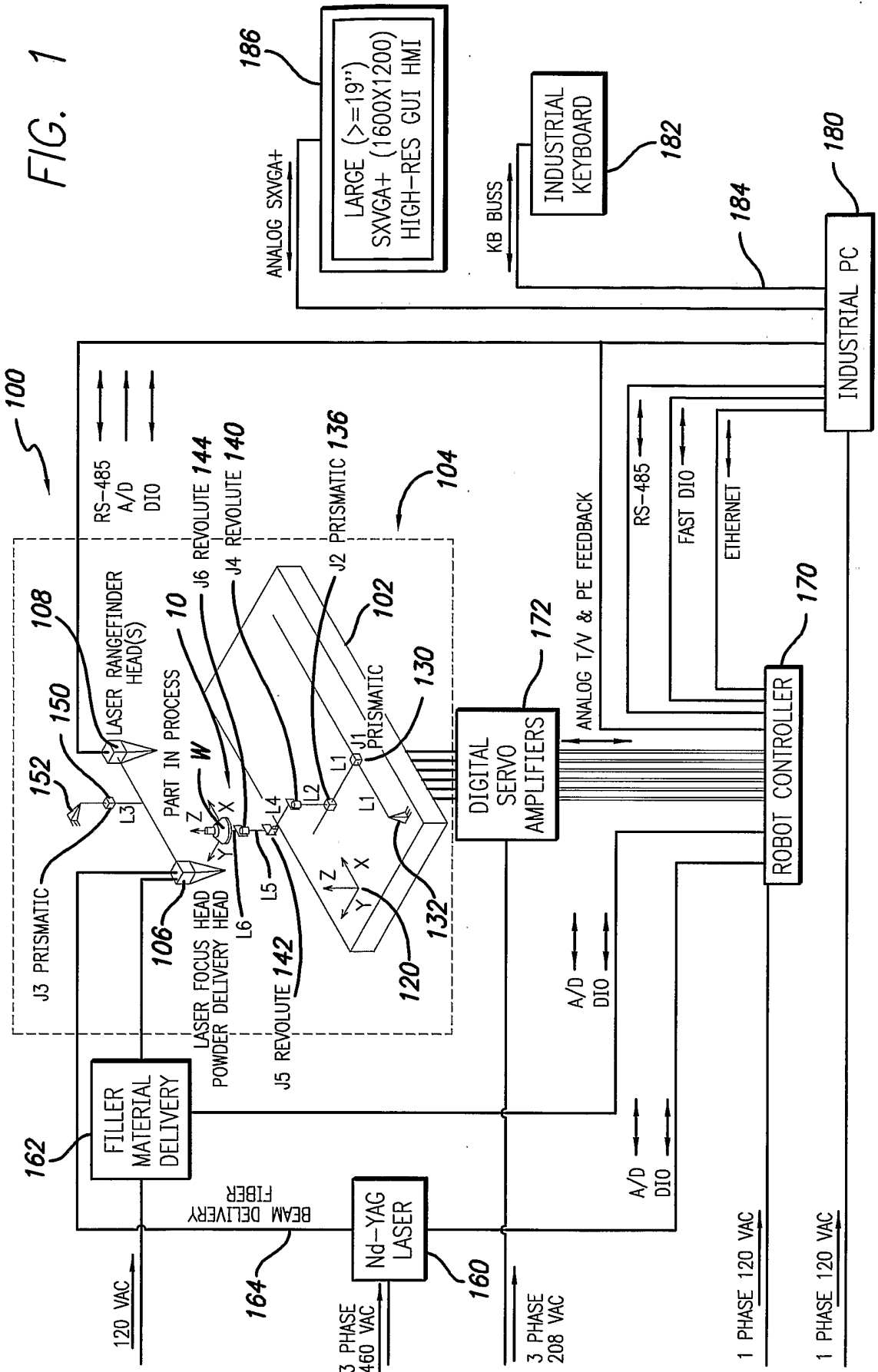
- a digital servo amplifier system coupled to the support apparatus and controlling operation of the five degrees of freedom.

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-17-

10. A 3-D adaptive laser powder fusion welding system for subjecting a workpiece to laser powder fusion welding as set forth in Claim 7, wherein the controller system further comprises:

5 a robot controller coupled to and controlling the laser head system, the linear displacement element, and the support apparatus.



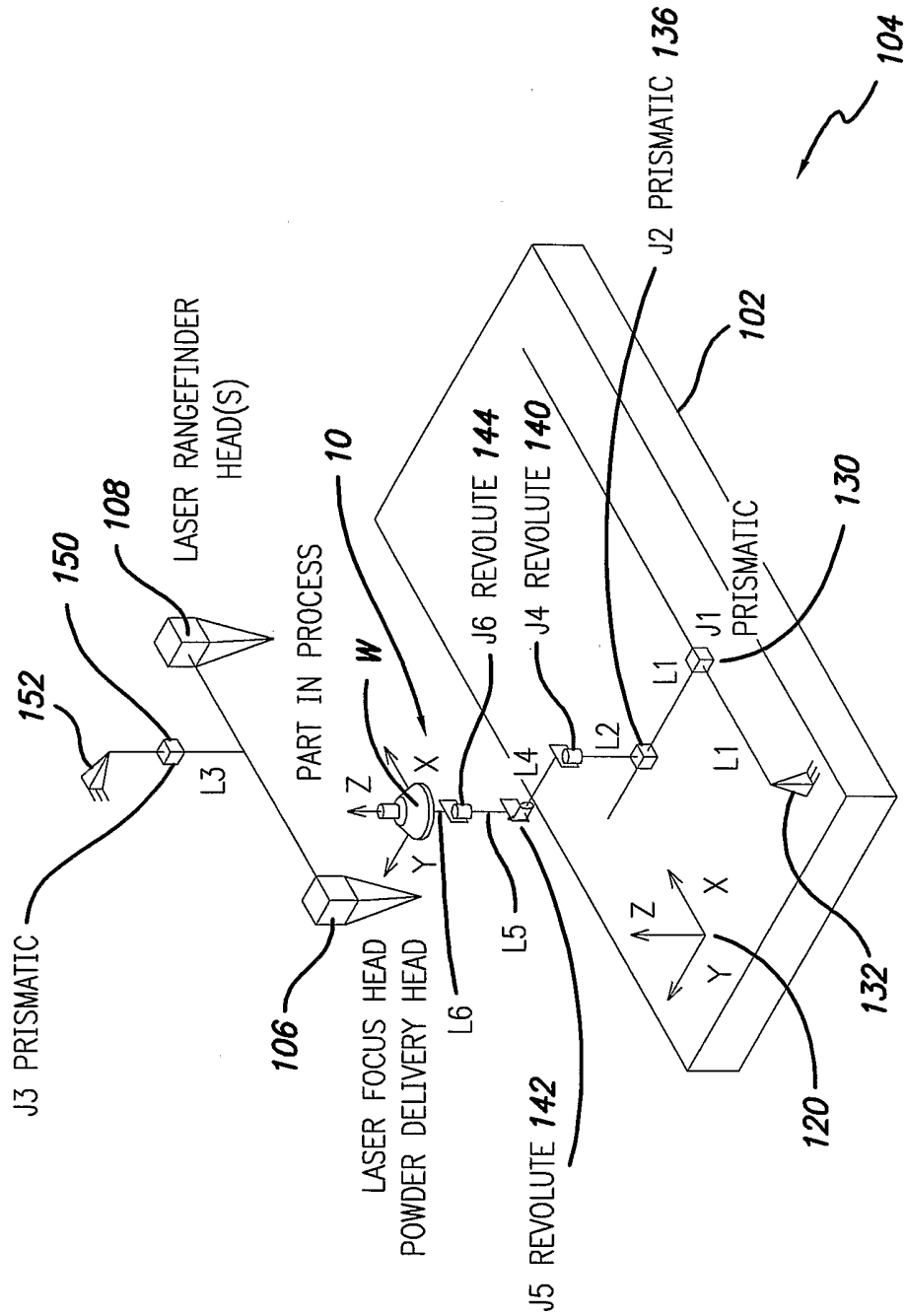


FIG. 2

INTERNATIONAL SEARCH REPORT

Intel.....al Application No
PCT/US2004/023459

A. CLASSIFICATION OF SUBJECT MATTER

IPC 7 B23K26/08 B23K26/34

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)

IPC 7 B23K B23Q B29C

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

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

EPO-Internal, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	JP 11 000783 A (TOYOTA MOTOR CORP) 6 January 1999 (1999-01-06) the whole document -----	1,2

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

° Special categories of cited documents :

- *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)
- *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

14 December 2004

Date of mailing of the international search report

27/12/2004

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Internal Application No
PCT/US2004/023459

PCT/US2004/023459

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
JP 11000783	A	06-01-1999	NONE