

(51) International Patent Classification:
G01J 1/42 (2006.01) *H01S 3/00* (2006.01)(21) International Application Number:
PCT/US2018/051842(22) International Filing Date:
20 September 2018 (20.09.2018)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15/807,967 09 November 2017 (09.11.2017) US(71) Applicant: **GENERAL ELECTRIC COMPANY**
[US/US]; General Electric Company, 1 River Road, Schenectady, New York 12345 (US).(72) Inventors: **ROYCHOWDHURY, Subhrajit**; General Electric Company, One Research Circle, Niskayuna, New York 12309 (US). **SPEARS, Thomas**; General Electric Company, One Research Circle, Niskayuna, New York 12309 (US). **GAMBONE, Justin**; General Electric Company, One Research Circle, Niskayuna, New York 12309 (US).(74) Agent: **OVERBECK, Brian P.** et al.; General Electric Company, GE Aviation Patent Operation, 1 Neumann Way, Mail Drop F16, Cincinnati, Ohio 45215 (US).(81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME,

(54) Title: OPTIC TRAIN MONITORING FOR ADDITIVE MANUFACTURING

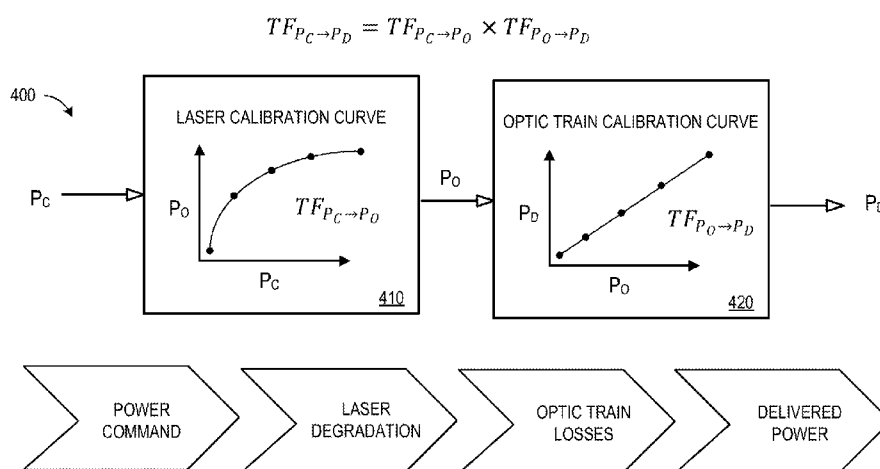


FIG. 4

(57) **Abstract:** Some embodiments facilitate creation of an industrial asset item via an additive manufacturing process. A laser source may receive a laser power command signal P_C and generate a laser beam output in accordance with P_C . A first sensor may measure a power P_D of a laser beam delivered for the additive manufacturing process. A second sensor may measure a power P_O associated with the laser beam output from the laser source, wherein at least a portion of an optic train is located between the first and second sensors. A monitoring apparatus, coupled to the first and second sensors, may monitor P_C , P_O and P_D to facilitate creation of the industrial asset item. Responsive to the monitoring, the system may control at least one aspect of the additive manufacturing process, automatically generate an advisory indication, automatically localize a detected problem in the system, automatically predict a future performance of the system, etc.



MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ,
OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA,
SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN,
TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

- (84) Designated States** (*unless otherwise indicated, for every kind of regional protection available*): ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Declarations under Rule 4.17:

- *as to applicant's entitlement to apply for and be granted a patent (Rule 4.17(ii))*
- *as to the applicant's entitlement to claim the priority of the earlier application (Rule 4.17(iii))*

Published:

- *with international search report (Art. 21(3))*

OPTIC TRAIN MONITORING FOR ADDITIVE MANUFACTURING

BACKGROUND

[0001] Some embodiments disclosed herein relate to industrial assets and, more particularly, to systems and methods associated with optic train monitoring for an additive manufacturing machine.

[0002] In some additive manufacturing processes, a laser system is used to generate an item. For example, power from the laser system might be directed to a powder in a build chamber to print the item as a series of horizontal slices. The exact placement and amount of the power may be strictly controlled to facilitate an accurate generation of the item. In some cases, however, various components of a laser system might inadvertently reduce the actual amount of power being delivered. For example, laser degradation and optical train losses can reduce the amount power that is delivered. Continuously testing a laser system to ensure that it is functioning properly can be a costly approach that leads to printers being unavailable as they are brought off-line for testing. Moreover, locating the cause of a power loss (so that it can be corrected) may be a time consuming and error prone process. It would therefore be desirable to efficiently and accurately facilitate creation of an industrial asset item via an additive manufacturing process.

SUMMARY

[0003] Some embodiments facilitate creation of an industrial asset item via an additive manufacturing process. A laser source may receive a laser power command signal PC and generate a laser beam output in accordance with PC. A first sensor may measure a power PD of a laser beam delivered for the additive manufacturing process. A second sensor may measure a power PO associated with the laser beam output from the laser source, wherein at least a portion of an optic train is located between the first and second sensors. A monitoring apparatus, coupled to the first and second sensors, may monitor PC, PO, and PD to facilitate creation of the industrial asset item. Responsive to the monitoring, the system may control at least one aspect of the additive manufacturing process, automatically generate an advisory indication, automatically localize a detected problem in the system, automatically predict a future performance of the system, *etc.*

[0004] Some embodiments comprise: means for receiving, at a laser source, a laser power command signal PC; means for generating a laser beam output in accordance with PC; means for measuring, at a first sensor, a power PD of a laser beam delivered for the additive manufacturing process; means for measuring, at a second sensor, a power PO associated with the laser beam output from the laser source, wherein at least a portion of an optic train is located between the first and

second sensors; and means for monitoring P_C , P_O , and P_D to facilitate creation of the industrial asset item.

[0005] Some embodiments comprise: means for depositing material in a build chamber; means for receiving, at a laser source, a laser power command signal P_C ; means for generating a laser beam output in accordance with P_C ; means for measuring, at a first sensor, a power P_D of a laser beam delivered for the additive manufacturing process; means for measuring, at a second sensor, a power P_O associated with the laser beam output from the laser source, wherein at least a portion of an optic train is located between the first and second sensors; means for directing a build beam to selectively fuse or cure the material in a pattern corresponding to a cross-sectional layer of the workpiece; means for monitoring P_C , P_O , and P_D ; and means for controlling at least one aspect of making the workpiece in response to said monitoring.

[0006] Technical effects of some embodiments of the invention are improved and computerized ways to efficiently and accurately facilitate creation of an industrial asset item via an additive manufacturing process. With these and other advantages and features that will become hereinafter apparent, a more complete understanding of the nature of the invention can be obtained by referring to the following detailed description and to the drawings appended hereto.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 illustrates a portion of an additive manufacturing system.

[0008] FIG. 2 illustrates power monitoring for an additive manufacturing system.

[0009] FIG. 3 illustrates a portion of an additive manufacturing system in accordance with some embodiments.

[0010] FIG. 4 illustrates power monitoring for an additive manufacturing system according to some embodiments.

[0011] FIG. 5 is a method that may be associated with an additive manufacturing system in accordance with some embodiments.

[0012] FIG. 6 is a high-level overview of a system for laser self-calibration according to some embodiments.

[0013] FIG. 7 is an optic train health monitoring architecture in accordance with some embodiments.

[0014] FIG. 8 is a more detailed cross-section of an additive manufacturing printer according to some embodiments.

[0015] FIG. 9 is an advisory indication method that may be associated with an additive manufacturing system in accordance with some embodiments.

[0016] FIG. 10 illustrates an advisory indication display in accordance with some embodiments.

[0017] FIG. 11 is a performance prediction method that may be associated with an additive manufacturing system in accordance with some embodiments.

[0018] FIG. 12 illustrates a performance prediction display in accordance with some embodiments.

[0019] FIG. 13 illustrates a platform according to some embodiments.

[0020] FIG. 14 is a tabular portion of a laser power monitoring database in accordance with some embodiments.

[0021] FIG. 15 illustrates a tablet computer providing a display according to some embodiments.

DETAILED DESCRIPTION

[0022] In the following detailed description, numerous specific details are set forth in order to provide a thorough understanding of embodiments. However, it will be understood by those of ordinary skill in the art that the embodiments may be practiced without these specific details. In other instances, well-known methods, procedures, components and circuits have not been described in detail so as not to obscure the embodiments.

[0023] One or more specific embodiments of the present invention will be described below. In an effort to provide a concise description of these embodiments, all features of an actual implementation may not be described in the specification. It should be appreciated that in the development of any such actual implementation, as in any engineering or design project, numerous implementation-specific decisions must be made to achieve the developers' specific goals, such as compliance with system-related and business-related constraints, which may vary from one implementation to another. Moreover, it should be appreciated that such a development effort might be complex and time consuming, but would nevertheless be a routine undertaking of design, fabrication, and manufacture for those of ordinary skill having the benefit of this disclosure.

[0024] Correct power delivery with minimal variation to a powder bed may be an important factor associated build quality for an additive manufacturing process. As used herein, the phrase “additive manufacturing process” might refer to, for example, Direct Metal Laser Melting (“DMLM”) process or similar three-dimensional printing technique. A fraction of the power may, however, be lost along the different components of a laser system while a laser beam travels from a source to a powder bed. As a result, components, such as those within an optic train, may be calibrated in connection with commanded as compared to delivered power using an involved and

time consuming method. Unfortunately, the loss in an optic train may vary with degradation and/or misalignment or faults in different components (and is therefore highly variable). To prevent this, a time-consuming calibration might be performed at a regular interval (*e.g.*, every six months) during which the machine will remain off-line. Also, in case of a fault, the current method to identify and correct for it is also time consuming and involved. According to some embodiments described herein, systems and methods are provided for online health monitoring of various components in an optic train while builds are ongoing. Moreover, self-calibrate for deviations might be made when and/or service advisories might be automatically generated. This may also facilitate automatic root-cause identification (with a certain degree of confidence) when service is needed, which may also reduce downtimes.

[0025] FIG. 1 is a high-level overview of a portion of an additive manufacturing system 100. In particular, a commanded amount of power (P_C) may be signaled to a laser and optic train 150 and, as a result, a laser having an amount of power may be delivered (P_D) (*e.g.*, delivered to powder in a build chamber of a three-dimensional printer). FIG. 2 illustrates power monitoring 200 for such an additive manufacturing system. Once again, a laser is commanded specific power values (P_C) and a power meter is kept at the powder bed to measure the delivered power (P_D) at that point. A calibration curve ($TF_{P_C \rightarrow P_D}$) 250 is then generated from the input and output data. As the calibration curve is generated for the entire laser system, it might not provide any insight about the root cause of a fault that may have caused the curve 250 to shift. Also, without a melt-pool monitoring system any shift in the curve remains undetected until after the part is built (that is, the shift may only be detectable during post build inspection). Even with a melt-pool monitoring system, the root cause of shift is not always evident (and even if detected, the machine still needs to be taken off-line for re-calibration).

[0026] Some embodiments described herein apply a “divide-and-conquer” approach for automatic root cause identification, self-correction and/or calibration, generation of service advisories, *etc.* FIG. 3 is a high-level overview of a portion of an additive manufacturing system 300. In particular, a commanded amount of power (P_C) may be signaled to a laser 310 than outputs a beam with power P_O . The beam travels through an optic train 120 and, as a result, a laser having an amount of power may be delivered (P_D) (*e.g.*, delivered to powder in a build chamber of a three-dimensional printer). FIG. 3 illustrates power monitoring 300 for such an additive manufacturing system. Note that the combined calibration curve of FIG. 2 is broken up into two calibration curves 410, 420 associated with: (1) the laser and (2) the optic train, respectively. The commanded power to the laser P_C and the laser output P_O are measured online during a build to detect any significant

shift from the respective calibration curve 410 to generate a flag. In some embodiments, a bead on plate scan pattern can be run before starting any build to update the calibration curve automatically (which might, for example, take less than a minute) during which the system measure P_C and P_O . If the laser is degraded to a point where it does not have enough headroom, the system may generate a service advisory to replace the laser.

[0027] According to some embodiments, the elements of the system 400 automatically facilitate creation of an industrial asset item via an additive manufacturing process. For example, FIG. 5 illustrates a method 500 that might be performed according to some embodiments of the present invention. The flow charts described herein do not imply a fixed order to the steps, and embodiments of the present invention may be practiced in any order that is practicable. Note that any of the methods described herein may be performed by hardware, software, or any combination of these approaches. For example, a computer-readable storage medium may store thereon instructions that when executed by a machine result in performance according to any of the embodiments described herein.

[0028] Note that the method of FIG. 5 may facilitate creation of an industrial asset item via an additive manufacturing process (*e.g.*, associated with a DMLM three-dimensional printer). At 510, a laser source may receive a laser power command signal P_C . At 520, the laser source may generate a laser beam output in accordance with P_C . At 530, a first sensor may measure a power P_D of a laser beam delivered for the additive manufacturing process. As used herein, the term “sensor” might refer to any apparatus capable of measuring power, including direct and indirect power measuring devices. By way of examples only, a sensor might be associated with a power meter, a photodiode, a photometer, a solid-state semiconductor detector, a photomultiplier tube, a thermocouple, an in-beam profiler, *etc.*

[0029] At 540, a second sensor may measure a power P_O associated with the laser beam output from the laser source. Note that at least a portion of an optic train is located between the first and second sensors. As used herein, the phrase “optic train” might refer to a portion of a laser system that includes various components, such as an optical fiber, a collimator, a galvanometer, a beam splitter, a dynamic focusing unit, *etc.*

[0030] At 550, a monitoring apparatus may monitor P_C , P_O , and P_D to facilitate creation of the industrial asset item. According to some embodiments, the monitoring is associated with a first laser power lookup table representing power loss within the laser and a second laser power lookup table representing power loss within the optic train. The first laser power lookup table might be associated with, for example, a laser calibration curve $TF_{P_C \rightarrow P_O}$. Similarly, a second laser power

lookup table might be associated with an optic train calibration curve $TF_{P_O \rightarrow P_D}$. In this case, overall system calibration curve might be represented as follows:

$$TF_{P_C \rightarrow P_D} = TF_{P_C \rightarrow P_O} \times TF_{P_O \rightarrow P_D}.$$

[0031] According to some embodiments, the monitoring apparatus may also control at least one aspect of the additive manufacturing process in response to the monitoring in substantially real time. For example, the value of the commanded power P_C might be automatically adjusted to ensure that the amount of delivered power P_D will be appropriate. According to other embodiments, the system may automatically generate an advisory indication (*e.g.*, an alert message might be automatically transmitted to an operator or maintenance technician) in response to the monitoring. According to some embodiments, the system might automatically localize a detected problem in the system in response to the monitoring. For example, the system might indicate that the problem is most likely in the laser, the optic train, *etc.* In some embodiments, a future performance of the system might be automatically predicted in response to the monitoring (*e.g.*, and an offline maintenance procedure might be automatically scheduled to avoid future problems).

[0032] Note that a suitable control loop might be designed around a laser to further extend the life of the laser by extending headroom via feedback when otherwise it would need to be replaced. FIG. 6 is a high-level overview of a system 600 for laser self-calibration according to some embodiments. A controller card may indicate a desired laser power to a laser 620 (*e.g.*, P_C). The laser 620 may then indicate desired amount of power and an actual amount of power to a computer 630, such as a mini field agent (*e.g.*, via an RS 232 port).

[0033] The computer 630 and/or other elements of the system might be, for example, associated with a Personal Computer (“PC”), laptop computer, a tablet computer, a smartphone, an enterprise server, a server farm, and/or a database or similar storage devices. According to some embodiments, an “automated” system 600 may monitor optic train health. As used herein, the term “automated” may refer to, for example, actions that can be performed with little (or no) intervention by a human.

[0034] As used herein, devices, including those associated with the computer 630 and any other device described herein, may exchange information via any communication network which may be one or more of a Local Area Network (“LAN”), a Metropolitan Area Network (“MAN”), a Wide Area Network (“WAN”), a proprietary network, a Public Switched Telephone Network (“PSTN”), a Wireless Application Protocol (“WAP”) network, a Bluetooth network, a wireless LAN network, and/or an Internet Protocol (“IP”) network such as the Internet, an intranet, or an extranet.

Note that any devices described herein may communicate via one or more such communication networks.

[0035] The computer 630 may store information into and/or retrieve information from data stores. The data stores might, for example, store electronic records representing laser power levels, calibration curves, predicted performance, *etc.* The data stores may be locally stored or reside remote from the computer 630. Although a single laser 620 and computer 630 are shown in FIG. 6, any number of such devices may be included. Moreover, various devices described herein might be combined according to embodiments of the present invention. For example, in some embodiments, the controller card 610 and laser 620 (and/or other devices) might be co-located and/or may comprise a single apparatus.

[0036] According to some embodiments, an optic train calibration curve is further broken down by inserting high bandwidth (*e.g.*, several Hz) direct/indirect power measuring devices (*e.g.*, small-footprint power meters, photodiodes/photometers with suitable mirror and filter combination, *etc.*) at appropriate places. For example, FIG. 7 illustrates an optic train health monitoring architecture 700 according to some embodiments. The architecture 700 includes a laser 710 that delivers a beam to an optic train 720. The optic train 720 might include, for example, a collimator 730, beam splitters 740, 760, a dynamic focusing unit 750, a laser power meter 770, a galvanometer 780, *etc.* The optic train 720 may provide a build laser beam to a window of a three-dimensional printer build chamber 790.

[0037] Note that thermocouples can also be inserted along various points in the optic train 720 according to some embodiments to generate service advisory related to optics heating/thermal lensing (*e.g.*, possibly caused by dirty optics). In this way, the divide-and-conquer approach may help identify a root cause automatically and the monitoring engine or application can automatically re-calibrate the system or generate a service advisory depending on the severity and nature of fault.

[0038] Referring to FIG. 8, illustrated schematically is an additive manufacturing machine 10 suitable for carrying out an additive manufacturing method. Basic components of the machine 10 include a table 12, a powder supply 14, a re-coater 16, an overflow container 18, a build platform 20 surrounded by a build chamber 22, a laser source 24, and a beam steering apparatus 26, all surrounded by a housing 28. Each of these components will be described in more detail below.

[0039] The table 12 is a rigid structure defining a planar worksurface 30. The worksurface 30 is coplanar with and defines a virtual workplane. In the illustrated example, it includes a build opening 32 communicating with the build chamber 22 and exposing the build platform 20, a supply opening 34 communicating with the powder supply 14, and an overflow opening 36 communicating with the overflow container 18.

[0040] The re-coater 16 is a rigid, laterally-elongated structure that lies on the worksurface 30. It is connected to an actuator 38 operable to selectively move the re-coater 16 along the worksurface 30. The actuator 38 is depicted schematically in the FIG., with the understanding devices such as pneumatic or hydraulic cylinders, ballscrew or linear electric actuators, and so forth, may be used for this purpose.

[0041] The powder supply 14 comprises a supply container 40 underlying and communicating with the supply opening 34, and an elevator 42. The elevator 42 is a plate-like structure that is vertically slidable within the supply container 40. It is connected to an actuator operable to selectively move the elevator 42 up or down. When the elevator 42 is lowered, a supply of powder “P” of a desired composition (for example, metallic, ceramic, and/or organic powder) may be loaded into the supply container 40. When the elevator 42 is raised, it exposes the powder P above the worksurface 30. Other types of powder supplies may be used; for example, powder, may be dropped into the build chamber 22 by an overhead device (not shown).

[0042] The build platform 20 is a plate-like structure that is vertically slidable below the build opening 32. It is connected to an actuator 46 operable to selectively move the build platform 20 up or down. The actuator 46 is depicted schematically in the figure, with the understanding that devices such as pneumatic or hydraulic cylinders, ballscrew or linear electric actuators, and so forth, may be used for this purpose. When the build platform 20 is lowered into the build chamber 22 during a build process, the build chamber 22 and the build platform 20 collectively surround and support a mass of powder P along with any components being built. This mass of powder is generally referred to as a “powder bed,” and this specific category of additive manufacturing process may be referred to as a “powder bed process.” The overflow container 18 underlies and communicates with the overflow opening 36, and serves as a repository for excess powder P.

[0043] The laser source 24 may comprise any device operable to generate a laser beam “B” of suitable power and other operating characteristics to melt and fuse the powder P during the build process, described in more detail below. The beam steering apparatus 26 may include one or more mirrors, prisms, and/or lenses and provided with suitable actuators, and arranged so that the beam B can be focused to a desired spot size and steered to a desired position in plane coincident with the worksurface 30. For purposes of convenient description, this plane may be referred to as a X-Y plane, and a direction perpendicular to the X-Y plane is denoted as a Z-direction (X, Y, and Z being three mutually perpendicular directions). The beam B may be referred to herein as a “build beam”. The illustrated example, laser energy is transferred to the beam steering apparatus 26 through an optical fiber 27 and a conventional collimator 29.

[0044] The housing 28 serves to isolate and protect the other components of the machine 10. During a build process described below, the housing 28 may be provided with a flow of an appropriate shielding gas which, among other functions, excludes oxygen from the build environment.

[0045] An exemplary basic build process for a workpiece W using the apparatus described above is as follows. The build platform 20 is moved to an initial high position. The build platform 20 is lowered below the worksurface 30 by a selected layer increment. The layer increment affects the speed of the additive manufacturing process and the resolution of the workpiece W. As an example, the layer increment may be about 10 to 50 micrometers (0.0003 to 0.002 in.). Powder “P” is then deposited over the build platform 20 for example, the elevator 42 of the supply container 40 may be raised to push powder through the supply opening 34, exposing it above the worksurface 30. The re-coater 16 is moved across the worksurface to spread the raised powder P horizontally over the build platform 20. Any excess powder P drops through the overflow opening 36 into the overflow container 18 as the re-coater 16 passes from left to right. Subsequently, the re-coater 16 may be moved back to a starting position. The leveled powder P may be referred to as a “build layer” and the exposed upper surface thereof may be referred to as a “build surface.”

[0046] The laser source 24 is used to melt a two-dimensional cross-section or layer of the workpiece W being built. The laser source 24 emits the beam B and the beam steering apparatus 26 is used to steer a focal spot of the beam B over the exposed powder surface in an appropriate pattern. A small portion of exposed layer of the powder P surrounding the focal spot, referred to herein as a “weld pool” 52 is heated by the beam B to a temperature allowing it to sinter or melt, flow, and consolidate. As an example, the weld pool 52 may be on the order of 100 micrometers (0.004 in.) wide. This step may be referred to as fusing the powder P.

[0047] The build platform 20 is moved vertically downward by the layer increment, and another layer of powder P is applied in a similar thickness. The laser source 24 again emits the beam B and the beam steering apparatus 26 is used to steer the focal spot of the beam B over the exposed powder surface in an appropriate pattern. The exposed layer of the powder P is heated by the beam B to a temperature allowing it to sinter or melt, flow, and consolidate both within the top layer and with the lower, previously-solidified layer. This cycle of moving the build platform 20, applying powder P, and then directed energy fusing the powder P is repeated until the entire workpiece W is complete.

[0048] The machine 10 and its operation are a representative example of a “powder bed machine.” It will be understood that the principles described herein are applicable to other types of additive manufacturing machines. For example, a known type of additive manufacturing machine

operates by using a laser to selectively cure a layer of liquid resin to form a workpiece. This process may be referred to as Stereo Lithography (“SLA”).

[0049] During the build process, improper or inconsistent beam power is undesirable. If the beam power is too high or low, it can produce inconsistent fusing results. Accordingly, the machine 10 may be provided with a laser power monitoring apparatus 54 and power meter 50 which are operable to measure laser power during operation of the machine 10. Note that the laser source 24 might receive P_C , the power meter 50 might measure P_O , and the laser power monitoring apparatus 54 might measure an estimate of P_D in accordance with any of the embodiments described herein.

[0050] The laser power monitoring apparatus 54 includes a beam splitter 56 which is operable to split off a sample beam “S” from the beam B and direct the sample beam S to a sensor 58. The sample beam S represents a predetermined fixed percentage of the power of the beam B. As used herein, the term “beam splitter” includes any device operable to direct the majority of the beam B along the primary beam path and to divert a controlled portion of the beam. Nonlimiting examples of devices which may be used as beam splitters include dielectric mirrors, prisms, and metallic mirrors. For example, a metallic mirror may be provided which reflects the majority of the light incident thereupon, but which also transmits some incident light therethrough.

[0051] The sensor 58 may be any device which is operable to receive the sample beam S and to generate a signal proportional to the power of the sample beam S. Nonlimiting examples of suitable sensors include semiconductor-based detectors (*e.g.*, photodiodes or photodiodes arrays) and photomultiplier tubes. The sensor 58 is positioned so as to receive the sample beam S from the beam splitter 56. An enclosure may be provided surrounding the beam splitter 56 and the sensor 58 to prevent the escape of laser radiation.

[0052] In the illustrated example, the beam splitter 56 is placed downstream of the collimator 29. The beam splitter 56 turns the majority of the beam B through 90° and directs it to the beam steering apparatus 26. The sample beam S is directed to the sensor 58. Other physical arrangements of the beam splitter 56 and the sensor 58 are possible. For example, the beam splitter 56 could be positioned upstream of the collimator 29.

[0053] The fraction of the build beam B split off to constitute the sample beam S may be determined based on the sensitivity and resolution of the sensor S. It is generally desirable to minimize the energy in the sample beam S as this reduces the power available in the build beam B. For example, if the laser source 24 has a nominal output of 200 W, and a split of 1% is used, this would result in 198 W delivered to the beam steering apparatus 26 and 2 W delivered to the sensor 58.

[0054] The output signal of the sensor 58 may be scaled as required to appropriately represent the power of the build beam B. In the above-noted example where the sample beam S is 1% of laser power, the sensor's output signal would be scaled by a factor of 100 to represent the actual power of the build beam B. If necessary or desirable, further scaling or adjustment to the output signal could be made to compensate for the power lost in the sample beam S and to thereby improve the accuracy of the beam power measurement. In general, the additive manufacturing process is sensitive to a variation in laser power of approximately 1%. It is noted that sensors 58 are commercially available which can detect power levels of small fractions of a Watt with an accuracy of 1% of scale. Accordingly, it is believed that the split or amount of leakage to the sensor 58 could be extremely small, for example 1/100 of 1% of the nominal power of the laser source 24.

[0055] Laser power data obtained from the sensor 58 and power meter 50 may be used for various purposes. For example, it may be used for machine qualification. In this process, the laser power data would be used to characterize the laser power before the machine 10 is used for the first time. This gives a baseline for subsequent measurements, and also gives the user information about the machine 10. For example, a specific machine 10 may be known to have a particular laser power output which may require higher than average laser power settings to achieve acceptable results during the build process.

[0056] As another example, the laser power data may be used for machine calibration. In this process, the sensor 58 described above would be used to characterize the laser power at regular intervals, for example every three to six months. The series of laser power data collections could be compared to the baseline laser power data and/or to each other. The laser power data can also be compared to a rated power of the laser source 24. These comparisons could help identify a change in the machine characteristics. Corrective action could take the form of machine maintenance or repairs.

[0057] A monitoring method may include establishing one or more predetermined limits for the laser power (relative to the selected, desired, or commanded power level), referred to herein as "laser power limits," for example a minimum power, or a maximum power. A monitoring method may include taking a discrete action in response to one or more laser power limits being exceeded, such as providing a visual or audible alarm to a local or remote operator. A monitoring method may include pausing or stopping the build process in response to one or more laser power limits being exceeded. This is another example of a discrete action. A monitoring method may include real-time control of laser power using methods such as: statistical process control, feedforward control, feedback control using proportional, proportional-integral, or proportional-integral-derivative control logic, neural network control algorithms, or fuzzy logic control algorithms.

[0058] The operation of the apparatus described above may be controlled, for example, by software running on one or more processors embodied in one or more devices such as a Programmable Logic Controller (“PLC”) or a microcomputer (not shown). Such processors may be coupled to the sensors and operating components, for example, through wired or wireless connections. The same processor or processors may be used to retrieve and analyze sensor data, for statistical analysis, and for feedback control.

[0030] The methods described herein have several advantages over the prior art. For example, they may allow for consistent beam power while minimizing interruption of the build process. This has the potential to reduce workpiece variation and scrap rate, improve part quality, and monitor the condition of the machine 10.

[0059] The method 900 of FIG. 9 may facilitate the automatic creation of advisory indications, alert messages, *etc.* for an additive manufacturing process (*e.g.*, associated with a DMLM three-dimensional printer). At 910, a laser source may receive a laser power command signal P_C . At 920, the laser source may generate a laser beam output in accordance with P_C . At 930, a first sensor may measure a power P_D of a laser beam delivered for the additive manufacturing process. At 940, a second sensor may measure a power P_O associated with the laser beam output from the laser source. Note that at least a portion of an optic train is located between the first and second sensors.

[0060] At 950, a monitoring apparatus may monitor P_C , P_O , and P_D to facilitate creation of the industrial asset item. At 960, the system may automatically generate an advisory indication responsive to the monitoring of 950. For example, when power raises above a pre-determined limit (or falls below a lower threshold) and advisory might be automatically transmitted to an operator. According to some embodiments, the advisory might automatically indicate which portion of a laser system is malfunctioning (*e.g.*, the laser source, the optic train, a specific component in the optic train, *etc.*).

[0061] FIG. 10 illustrates an advisory indication display 1000 in accordance with some embodiments. The display 1000 may include an interactive user interface 1010 that graphically displays the status of various elements laser system. According to some embodiments, selection of one or more elements in the display 1000 may result in the appearance of more detailed information about the system, allow an operator to make parameter adjustments, *etc.* Note that the display 1000 include an advisory indication 1020 that indicates which portion of the system might be malfunctioning. According to some embodiments, selection of an icon 1030 (*e.g.* via a computer mouse) may transmit an alert to another operator, device, maintenance scheduling application, *etc.*

[0062] The method 1100 of FIG. 11 may facilitate the automatic prediction of future laser system performance for an additive manufacturing process (*e.g.*, associated with a DMLM three-dimensional printer). At 1112, a laser source may receive a laser power command signal P_C . At 1120, the laser source may generate a laser beam output in accordance with P_C . At 1130, a first sensor may measure a power P_D of a laser beam delivered for the additive manufacturing process. At 1140, a second sensor may measure a power P_O associated with the laser beam output from the laser source. Note that at least a portion of an optic train is located between the first and second sensors.

[0063] At 1150, a monitoring apparatus may monitor P_C , P_O , and P_D to facilitate creation of the industrial asset item. At 1160, the system may automatically generate prediction of future performance responsive to the monitoring of 1150. For example, the system might notice that power losses in the optic train are slowly increasing and recommend a particular maintenance procedure be performed before a particular date to avoid malfunctions. According to some embodiments, the prediction might include recommendations, a list of parts to be inspected, one or more replacement requests, *etc.*

[0064] FIG. 12 illustrates a predicted future performance display 1200 in accordance with some embodiments. The display 1200 may include an interactive user interface 1210 that graphically displays the status of various elements laser system. According to some embodiments, selection of one or more elements in the display 1200 may result in the appearance of more detailed information about the system, allow an operator to make parameter adjustments, *etc.* The display 1200 may include a timeline 1220 indicating measured performance (illustrated by a solid line on the timeline 1220) and predicted future performance (illustrated by a dashed line on the timeline 1220). According to some embodiments, selection of an icon 1230 (*e.g.* via a computer mouse) may schedule a maintenance procedure for an additive manufacturing laser system, predict when tolerances will become unacceptable, *etc.*

[0065] Embodiments described herein may comprise a tool that facilitates creation of an industrial asset item via an additive manufacturing process and may be implemented using any number of different hardware configurations. For example, FIG. 13 illustrates a platform 1300 that may be, for example, associated with the system 600 of FIG. 6 (as well as other systems described herein). The platform 1300 comprises a processor 1310, such as one or more commercially available Central Processing Units (“CPUs”) in the form of one-chip microprocessors, coupled to a communication device 1320 configured to communicate via a communication network (not shown in FIG. 13). The communication device 1320 may be used to communicate, for example, with one or more remote expert devices. Note that communications exchanged via the communication device 1320 may utilize security features, such as those between a public internet user and an internal

network of an insurance enterprise. The security features might be associated with, for example, web servers, firewalls, and/or PCI infrastructure. The platform 1300 further includes an input device 1340 (*e.g.*, a mouse and/or keyboard to enter information about a design file, an industrial asset item, a laser system, *etc.*) and an output device 1350 (*e.g.*, to output maintenance reports, generate production status messages, *etc.*).

[0066] The processor 1310 also communicates with a storage device 1330. The storage device 1330 may comprise any appropriate information storage device, including combinations of magnetic storage devices (*e.g.*, a hard disk drive), optical storage devices, mobile telephones, and/or semiconductor memory devices. The storage device 1330 stores a program 1312 and/or network security service tool or application for controlling the processor 1310. The processor 1310 performs instructions of the program 1312, and thereby operates in accordance with any of the embodiments described herein. For example, the processor 1310 may determine that a laser source has received a laser power command signal P_C and will thus generate a laser beam output in accordance with P_C . A first sensor may measure a power P_D of a laser beam delivered for the additive manufacturing process and that value may be recorded by the processor 1310. A second sensor may measure a power P_O associated with the laser beam output from the laser source (with at least a portion of an optic train being located between the first and second sensors) and that value may also be recorded by the processor 1310. The processor 1310 may then monitor P_C , P_O , and P_D to facilitate creation of the industrial asset item. Responsive to the monitoring, processor 1310 may control at least one aspect of the additive manufacturing process, automatically generate an advisory indication, automatically localize a detected problem in the system, automatically predict a future performance of the system, *etc.*

[0067] The program 1312 may be stored in a compressed, uncompiled and/or encrypted format. The program 1312 may furthermore include other program elements, such as an operating system, a database management system, and/or device drivers used by the processor 1310 to interface with peripheral devices.

[0068] As used herein, information may be “received” by or “transmitted” to, for example: (i) the platform 1300 from another device; or (ii) a software application or module within the platform 1300 from another software application, module, or any other source.

[0069] In some embodiments (such as shown in FIG. 13), the storage device 1330 further stores a laser degradation power lookup table 1360, an optic train power loss lookup table 1370, and a laser power monitoring database 1400. An example of a database that might be used in connection with the platform 1300 will now be described in detail with respect to FIG. 14. Note that the database described herein is only an example, and additional and/or different information may be

stored therein. Moreover, various databases might be split or combined in accordance with any of the embodiments described herein. For example, the optic train power loss lookup table 1370 and/or laser power monitoring database 1400 might be combined and/or linked to each other within the program 1312.

[0070] Referring to FIG. 14, a table is shown that represents the laser power monitoring database 1400 that may be stored at the platform 1300 in accordance with some embodiments. The table may include, for example, entries identifying power measurements associated with a laser system. The table may also define fields 1402, 1404, 1406, 1408, 1410, 1412 for each of the entries. The fields 1402, 1404, 1406, 1408, 1410, 1412 may, according to some embodiments, specify: a laser system identifier 1402, a commanded power P_C 1404, an output power P_O 1406, a delivered power P_D 1408, a date and time 1410, and an advisory action 1412. The laser power monitoring database 1400 may be created and updated, for example, in substantially real time during an additive manufacturing build process.

[0071] The laser system identifier 1402 may be, for example, a unique alphanumeric code identifying a laser system of a three-dimensional DMLM printer. The commanded power P_C 1404, the output power P_O 1406, and the delivered power P_D 1408 may represent measurements made by various sensors located within the laser system. The data and time 1510 might indicate when the measurements were made and the advisory indication 1512 might indicate whether or not the measurements resulted in an advisory indication (*e.g.*, transmission of an alert message or signal).

[0072] Thus, some embodiments described herein may provide technical advantages, including an online health monitoring system that may automatically identify root causes of faults in the optical system of a DMLM machine. Moreover, embodiments may provide for self-calibrating the system or generating a service advisory as warranted by the degree and the nature of the fault. This may help unplanned, preventable breakdowns and unnecessary scheduled maintenance downtimes. When a machine needs to go off-line for service requirements, a health monitoring engine in accordance with some embodiments described herein might be able to point out the root cause with a relatively high degree of confidence (thereby reducing troubleshooting time).

[0073] The following illustrates various additional embodiments of the invention. These do not constitute a definition of all possible embodiments, and those skilled in the art will understand that the present invention is applicable to many other embodiments. Further, although the following embodiments are briefly described for clarity, those skilled in the art will understand how to make any changes, if necessary, to the above-described apparatus and methods to accommodate these and other embodiments and applications.

[0074] Although specific hardware and data configurations have been described herein, note that any number of other configurations may be provided in accordance with embodiments of the present invention (*e.g.*, some of the information described herein may be combined or stored in external systems). Moreover, although embodiments have been described with respect to industrial systems, note that embodiments might be associated with other types of computing systems, including non-industrial systems, consumer items, *etc.* Similarly, the displays shown and described herein are provided only as examples, and other types of displays and display devices may support any of the embodiments. For example, FIG. 15 illustrates a tablet computer 1500 with a scan path generation design display 1510 that might utilize a graphical user interface. The display 1510 might include a depiction of an optic train calibration curve. Note that selection of an element on the display 1510 might result in a display of further information about that element. Moreover, the display 1510 might comprise an interactive user interface (*e.g.*, via a touchscreen) and includes a “display details” icon 1520 in accordance with any of the embodiments described herein.

[0075] Some embodiments have been described with respect to the creation of an “industrial asset item,” which might be, for example, an engine part, a generator component, *etc.* Note, however, that as used herein the phrase “industrial asset item” might refer to any other type of item, including: consumer electronics parts, toys, household goods, automotive parts, *etc.* In general, embodiments may address the challenges associated is laser systems of additive manufacturing machines.

[0076] According to some embodiments, the additive printing process being monitored is a DMLM process. Note that embodiments might also be associated with types of three-dimensional printing, including, for example, those described in the American Society for Testing and Materials (“ASTM”) group “ASTM F42 – Additive Manufacturing” standards.

[0077] The present invention has been described in terms of several embodiments solely for the purpose of illustration. Persons skilled in the art will recognize from this description that the invention is not limited to the embodiments described but may be practiced with modifications and alterations limited only by the spirit and scope of the appended claims.

CLAIMS

1. A system to facilitate creation of an industrial asset item via an additive manufacturing process, comprising:
 - a laser source to receive a laser power command signal P_C and to generate a laser beam output in accordance with P_C ;
 - a first sensor to measure a power P_D of a laser beam delivered for the additive manufacturing process;
 - a second sensor to measure a power P_O associated with the laser beam output from the laser source, wherein at least a portion of an optic train is located between the first and second sensors;
 - and
 - a monitoring apparatus, coupled to the first and second sensors, adapted to:
 - monitor P_C , P_O , and P_D to facilitate creation of the industrial asset item.
2. The system of claim 1, wherein the monitoring apparatus is further adapted to:
 - control at least one aspect of the additive manufacturing process in response to the monitoring in substantially real time.
3. The system of claim 1, wherein the monitoring apparatus is further adapted to:
 - automatically generate an advisory indication in response to the monitoring.
4. The system of claim 1, wherein the monitoring apparatus is further adapted to:
 - automatically localize a detected problem in the system in response to the monitoring.
5. The system of claim 1, wherein the monitoring apparatus is further adapted to:
 - automatically predict a future performance of the system in response to the monitoring.
6. The system of claim 1, wherein the optic train includes at least one of: (i) an optical fiber, (ii) a collimator, (iii) a galvanometer, (iv) a beam splitter, and (v) a dynamic focusing unit.
7. The system of claim 1, wherein at least one of the first and second sensors are associated with at least one of: (i) a direct power measuring device, (ii) an indirect power measuring device, (iii) a power meter, (iv) a photodiode, (v) a photometer, (vi) a solid-state semiconductor detector, (vii) a photomultiplier tube, (viii) a thermocouple, and (ix) an in-beam profiler.
8. The system of claim 1, wherein said monitoring is associated with a first laser power lookup table representing power loss within the laser and a second laser power lookup table representing power loss within the optic train.

9. The system of claim 8, wherein the first laser power lookup table is associated with a laser calibration curve $TF_{P_C \rightarrow P_O}$.

10. The system of claim 9, wherein the second laser power lookup table is associated with an optic train calibration curve $TF_{P_O \rightarrow P_D}$.

11. The system of claim 10, wherein an overall system calibration curve comprises:

$$TF_{P_C \rightarrow P_D} = TF_{P_C \rightarrow P_O} \times TF_{P_O \rightarrow P_D}.$$

12. The system of claim 1, wherein the first sensor is associated with a laser power monitoring apparatus adapted to:

split off a predetermined percentage of a build beam to define a sample beam,
direct the sample beam to a sensor element,
generate, by the sensor element, a signal proportional to the power of the sample beam, and

scale the signal from the sensor element to generate a laser power measurement representative of a power level of the build beam.

13. The system of claim 12, wherein the build beam is split via transmission through a reflective optic.

14. The system of claim 1, wherein the additive manufacturing process is associated with a Direct Metal Laser Melting (“DMLM”) process.

15. A method to facilitate creation of an industrial asset item via an additive manufacturing process, relative to a print arm, along the vertical axis during printing, comprising:

receiving, at a laser source, a laser power command signal P_C ;

generating a laser beam output in accordance with P_C ;

measuring, at a first sensor, a power P_D of a laser beam delivered for the additive manufacturing process;

measuring, at a second sensor, a power P_O associated with the laser beam output from the laser source, wherein at least a portion of an optic train is located between the first and second sensors; and

monitoring P_C , P_O , and P_D to facilitate creation of the industrial asset item.

16. The method of claim 15, wherein said monitoring includes at least one of: (i) controlling at least one aspect of the additive manufacturing process in response to the monitoring in substantially real time, (ii) automatically generating an advisory indication in response to the monitoring, (iii) automatically localizing a detected problem in the system in response to the

monitoring, and (iv) automatically predicting a future performance of the system in response to the monitoring.

17. The method of claim 15, wherein said monitoring is associated with:

a first laser power lookup table representing power loss within the laser via a laser calibration curve $TF_{P_C \rightarrow P_O}$, and

a second laser power lookup table representing power loss within the optic train via an optic train calibration curve $TF_{P_O \rightarrow P_D}$.

18. The method of claim 17, wherein an overall system calibration curve comprises:

$$TF_{P_C \rightarrow P_D} = TF_{P_C \rightarrow P_O} \times TF_{P_O \rightarrow P_D}.$$

19. A method of making a workpiece, comprising:

depositing material in a build chamber;

receiving, at a laser source, a laser power command signal P_C ;

generating a laser beam output in accordance with P_C ;

measuring, at a first sensor, a power P_D of a laser beam delivered for the additive manufacturing process;

measuring, at a second sensor, a power P_O associated with the laser beam output from the laser source, wherein at least a portion of an optic train is located between the first and second sensors; and

directing a build beam to selectively fuse or cure the material in a pattern corresponding to a cross-sectional layer of the workpiece;

monitoring P_C , P_O , and P_D ; and

controlling at least one aspect of making the workpiece in response to said monitoring.

20. The method of claim 19, further comprising:

repeating the steps in a cycle of depositing and fusing to build up the workpiece in a layer-by-layer fashion.

21. An apparatus for making a workpiece, comprising:

a build chamber;

a laser source to receive a laser power command signal P_C and to generate a laser beam output in accordance with P_C ;

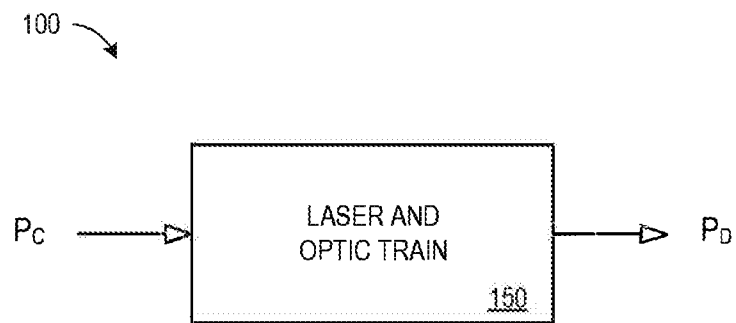
a first sensor to measure a power P_D of a laser beam delivered for the additive manufacturing process via the build chamber;

a second sensor to measure a power P_O associated with the laser beam output from the laser source, wherein at least a portion of an optic train is located between the first and second sensors; and

a monitoring apparatus, coupled to the first and second sensors, adapted to:

monitor P_C , P_O , and P_D to facilitate creation of the industrial asset item.

22. The apparatus of claim 21, wherein said monitoring includes at least one of: (i) controlling at least one aspect of the additive manufacturing process in response to the monitoring in substantially real time, (ii) automatically generating an advisory indication in response to the monitoring, (iii) automatically localizing a detected problem in the system in response to the monitoring, and (iv) automatically predicting a future performance of the system in response to the monitoring.

**FIG. 1**

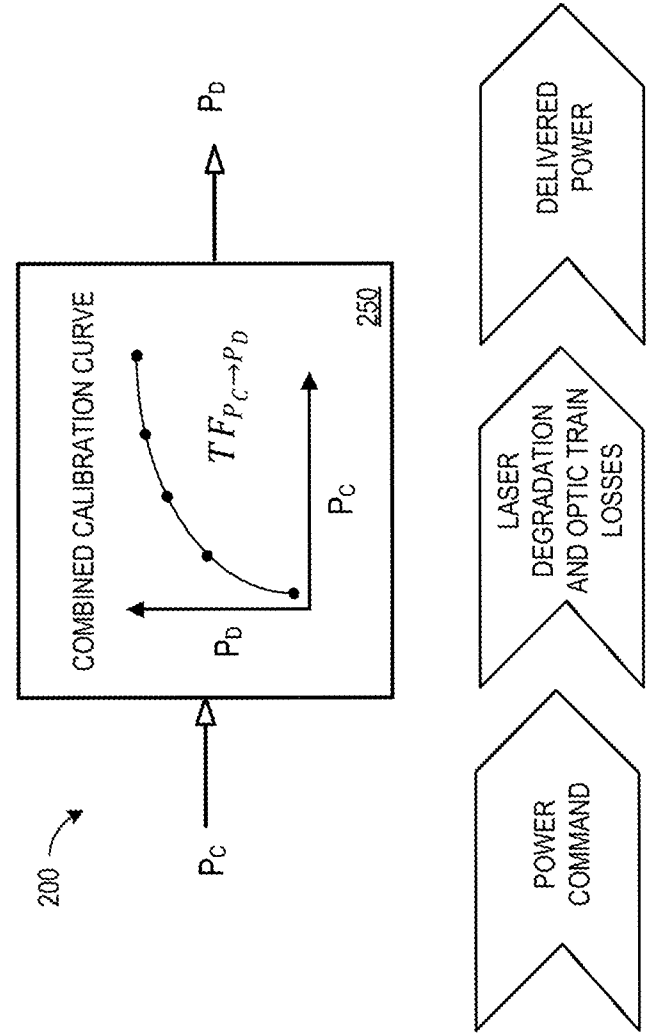
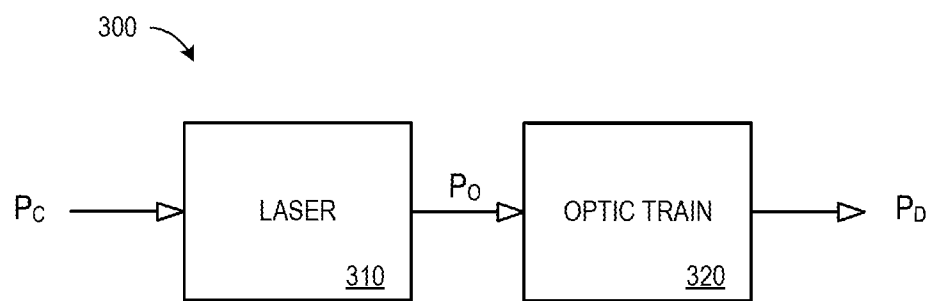


FIG. 2

**FIG. 3**

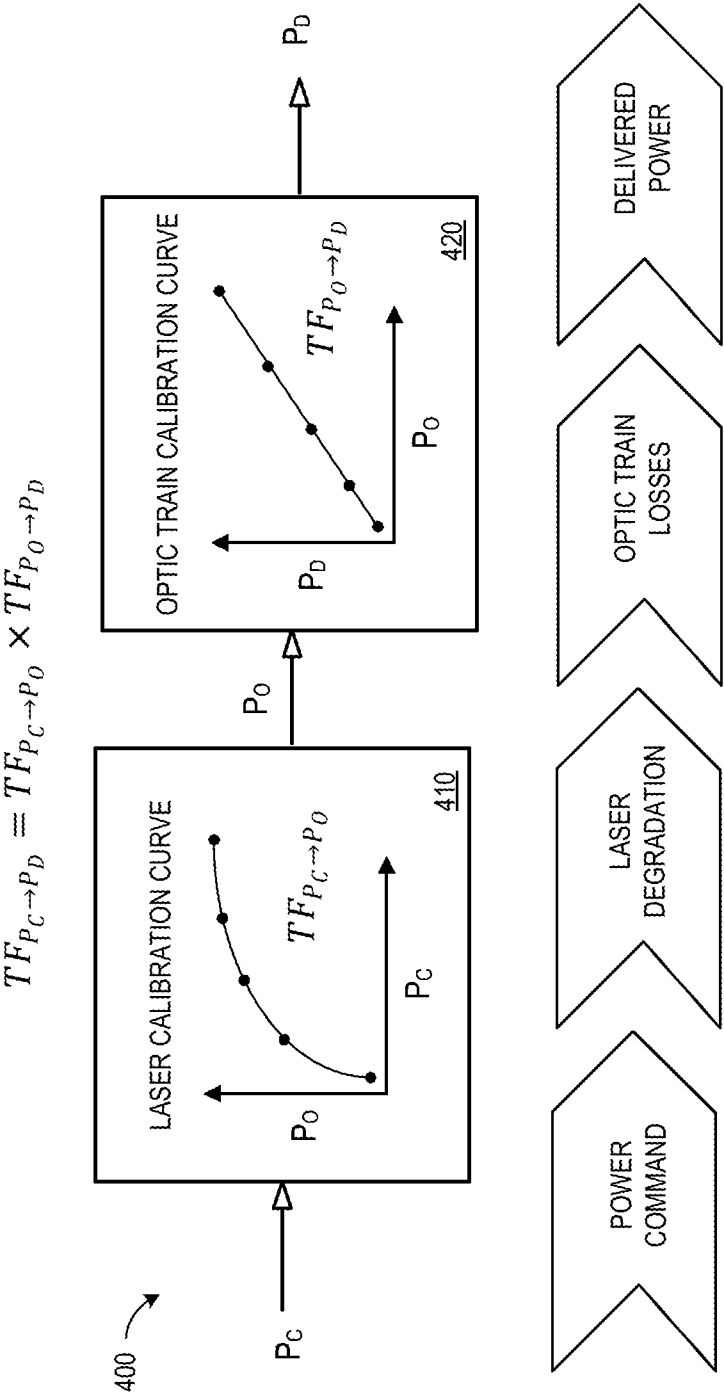
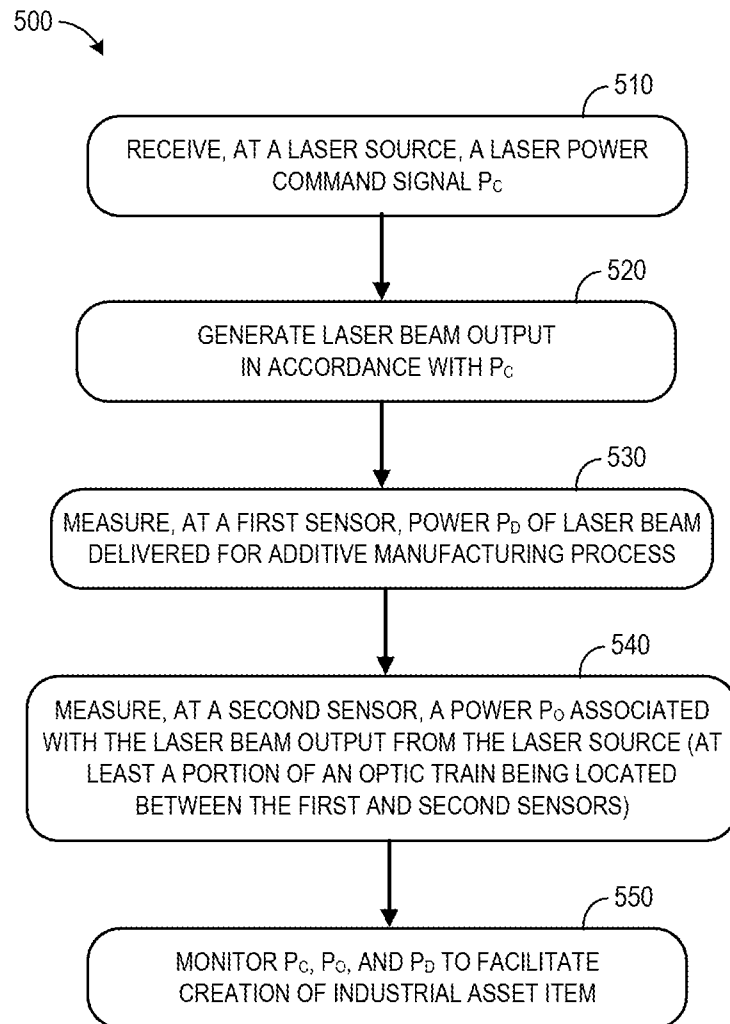


FIG. 4

**FIG. 5**

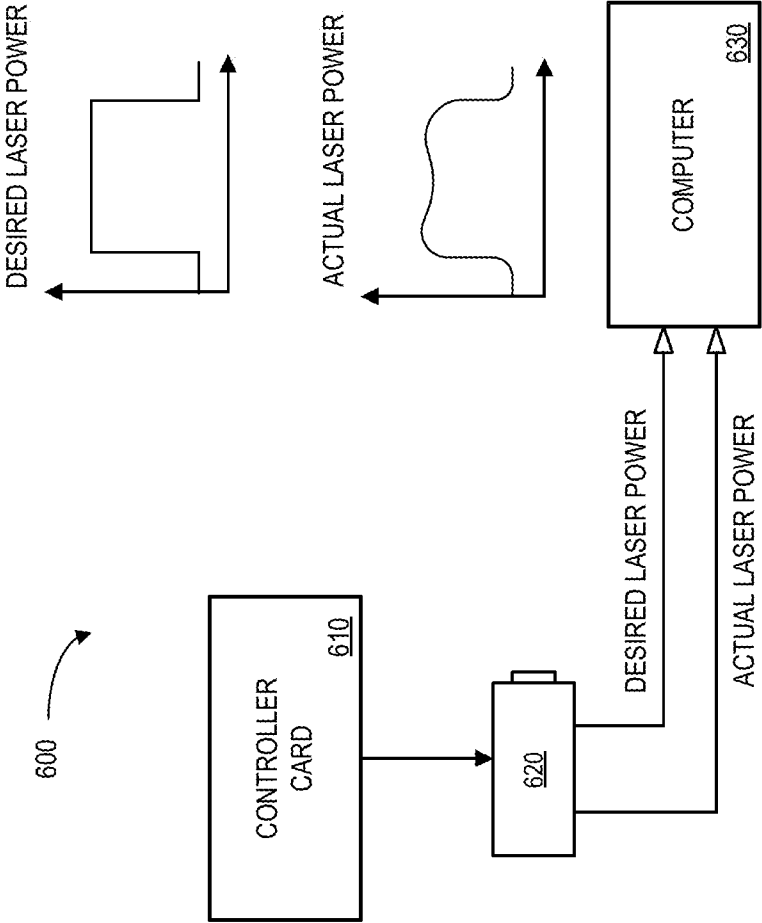


FIG. 6

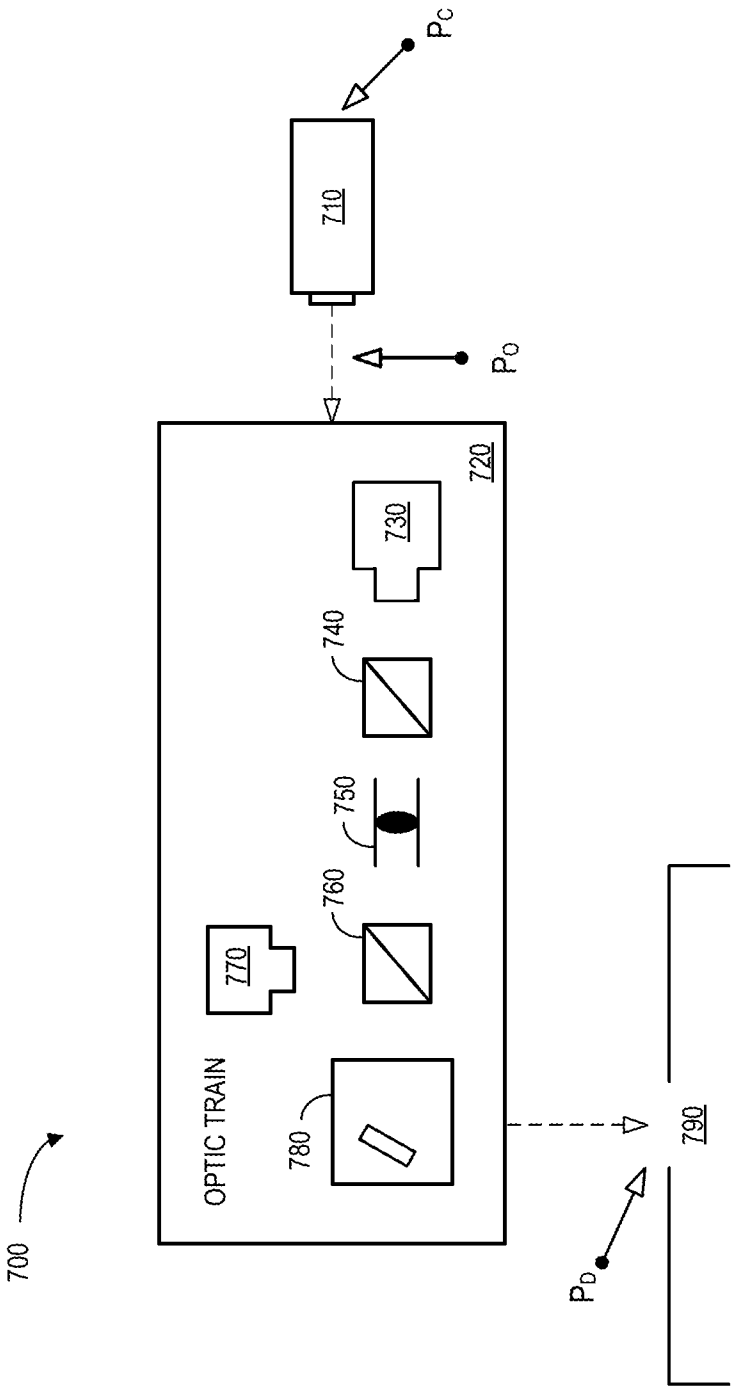


FIG. 7

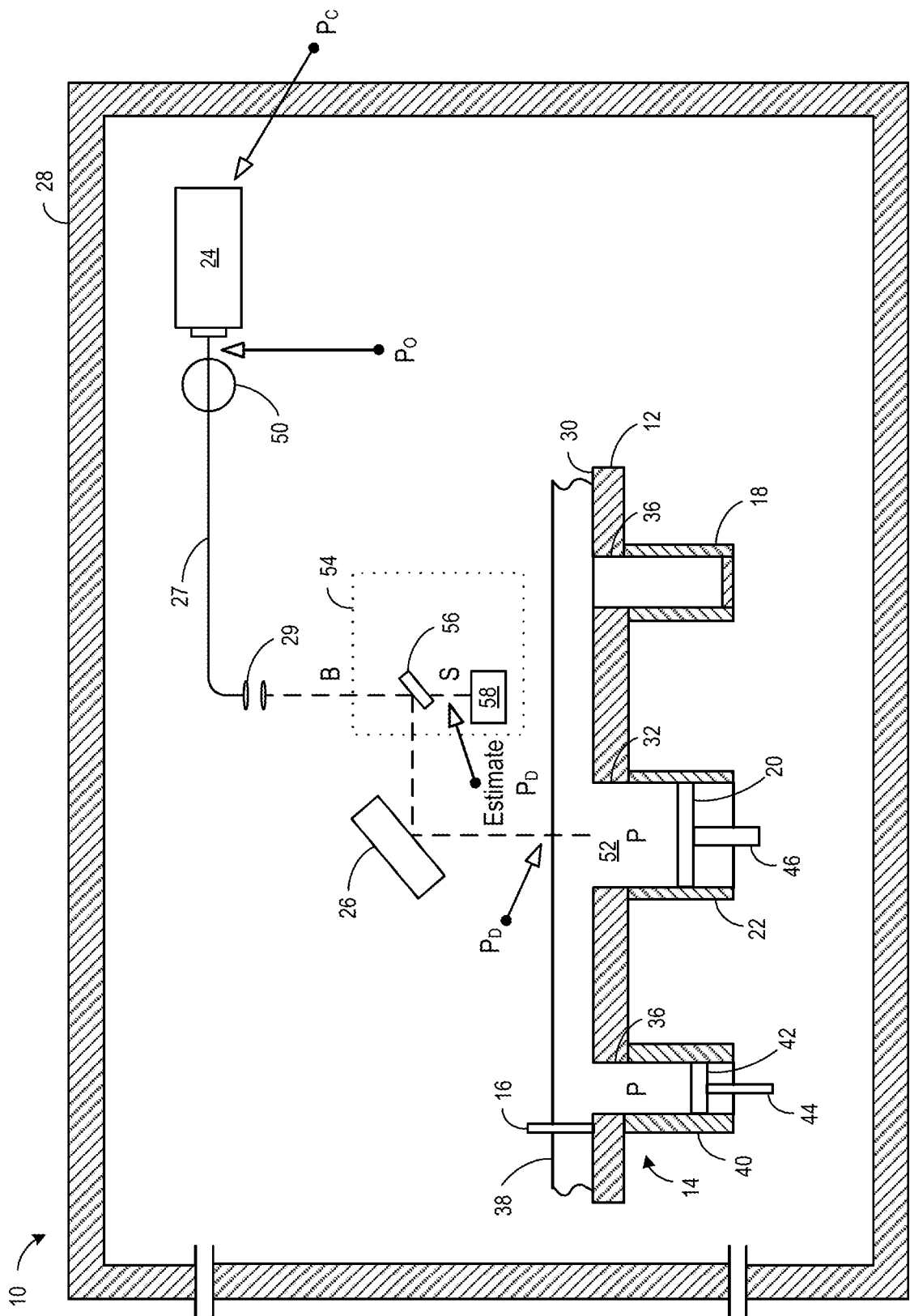
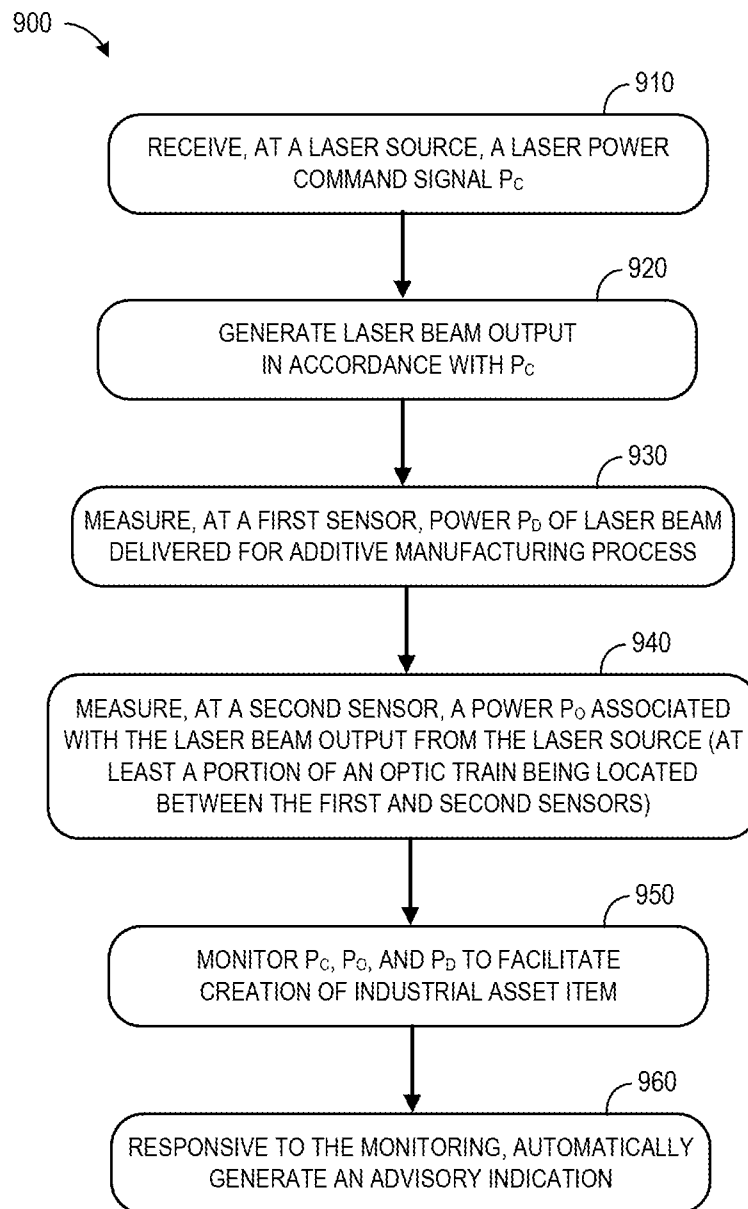


FIG. 8

**FIG. 9**

1000

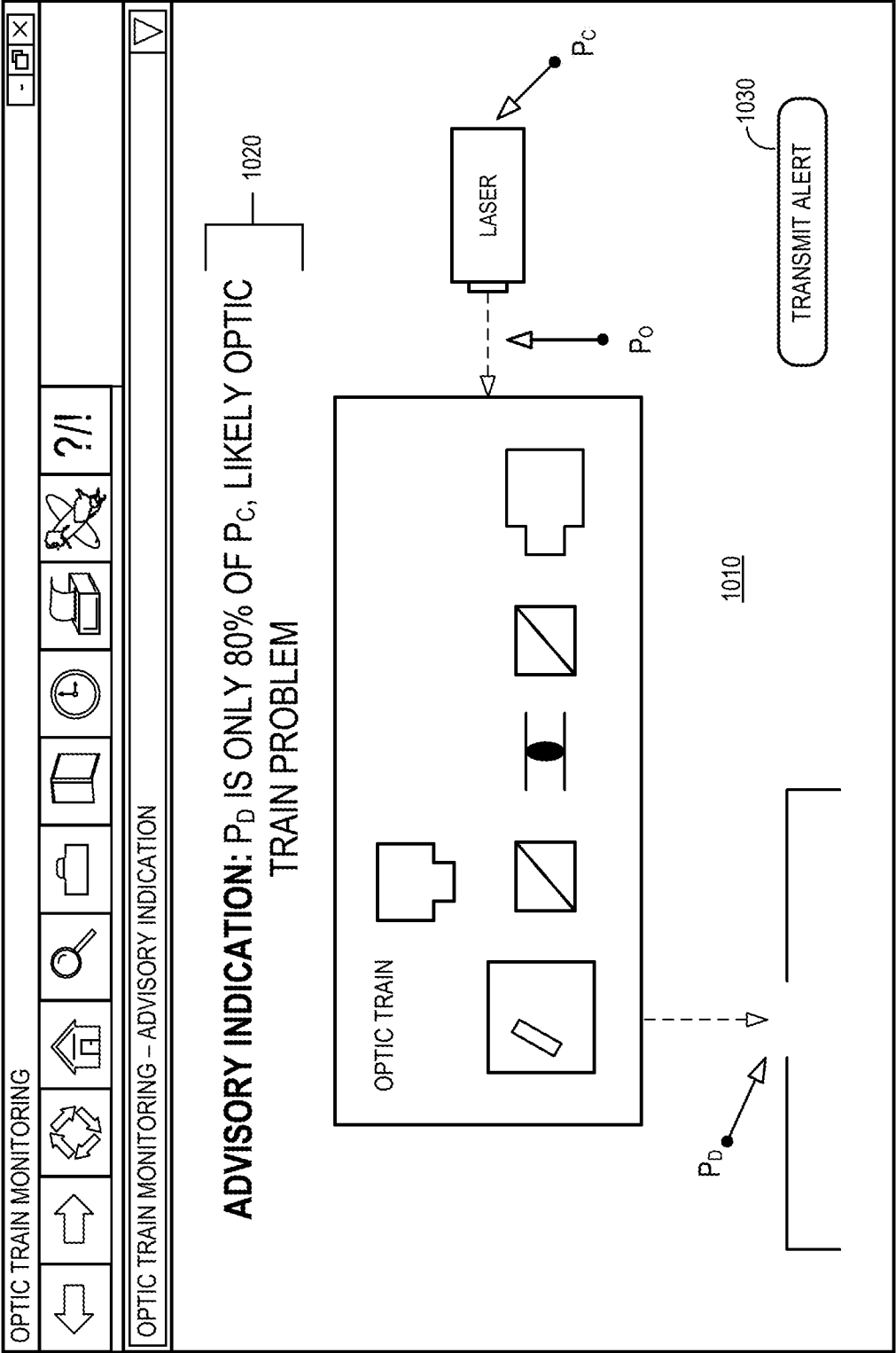
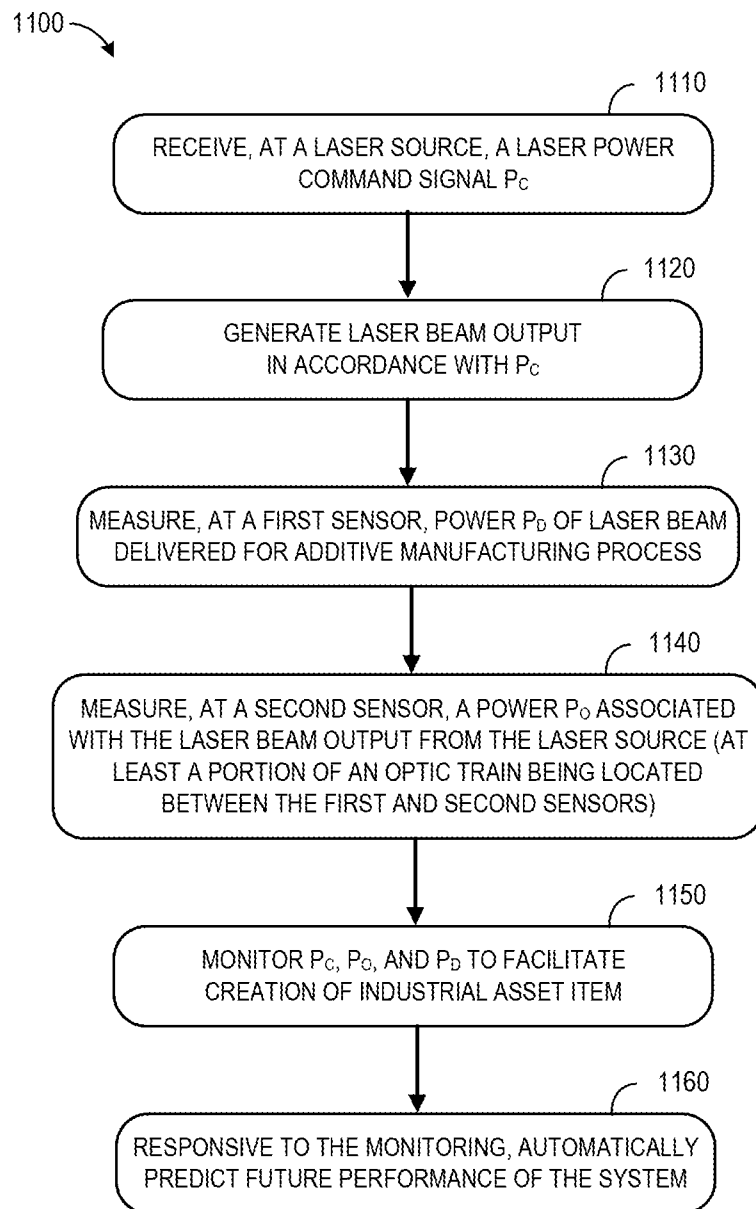


FIG. 10

Sheet 11/15

**FIG. 11**

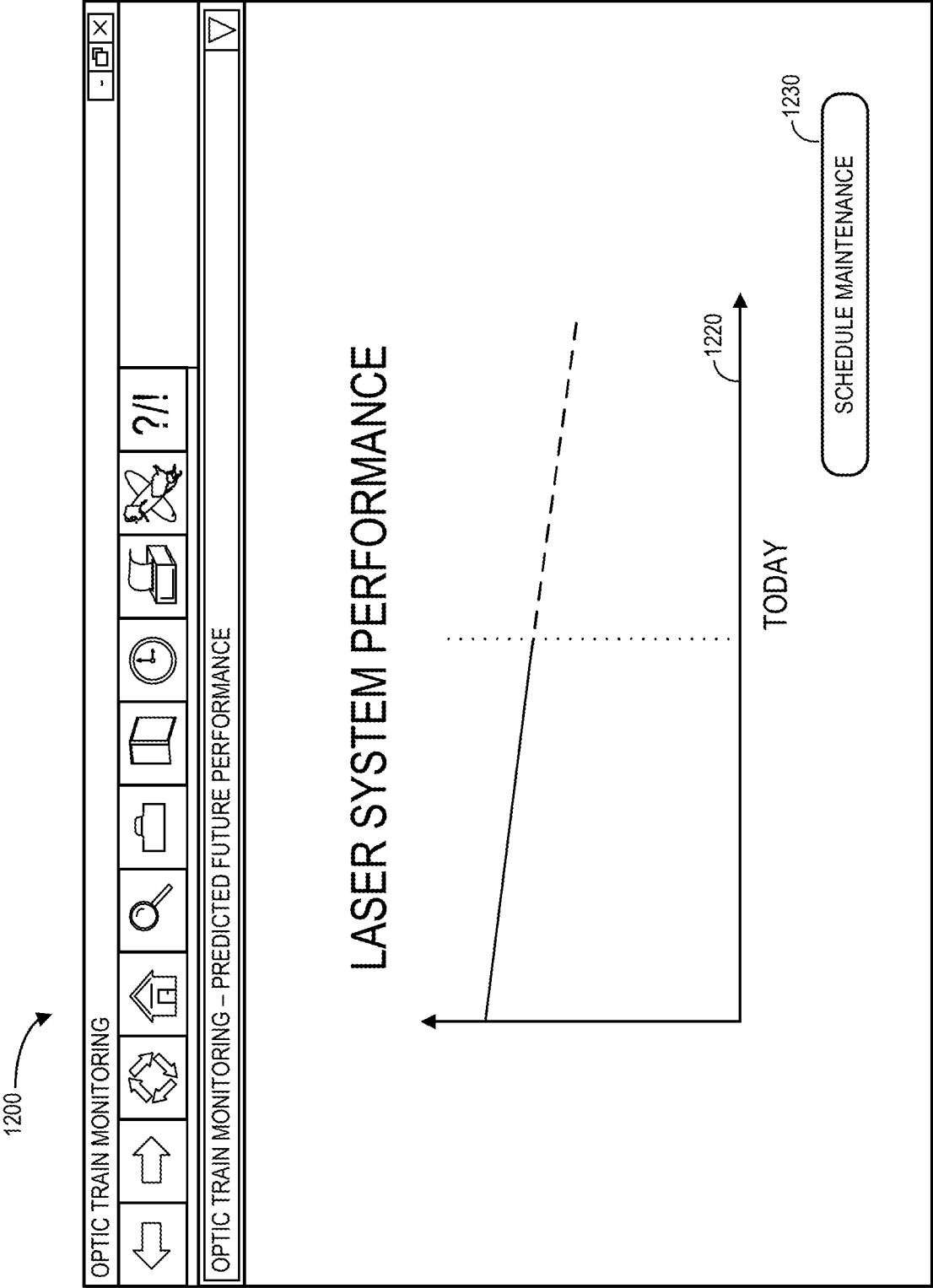
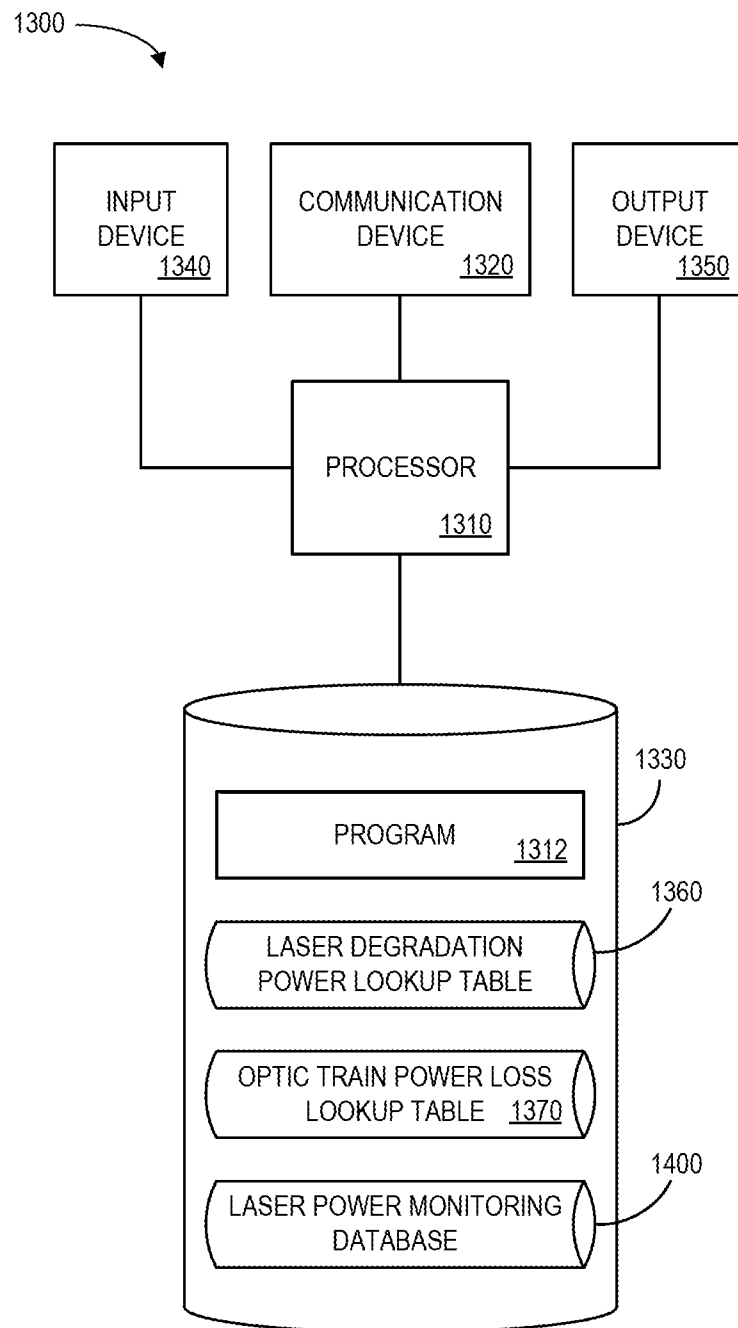


FIG. 12

**FIG. 13**

1400 

LASER SYSTEM IDENTIFIER 1402	P _c 1404	P _o 1406	P _b 1408	DATE AND TIME 1410	ADVISORY INDICATION 1412
LS_101				4/5/2019 (12:55:31)	NO
LS_102				4/5/2019 (13:29:42)	YES
LS_101				4/6/2019 (09:14:43)	NO

FIG. 14

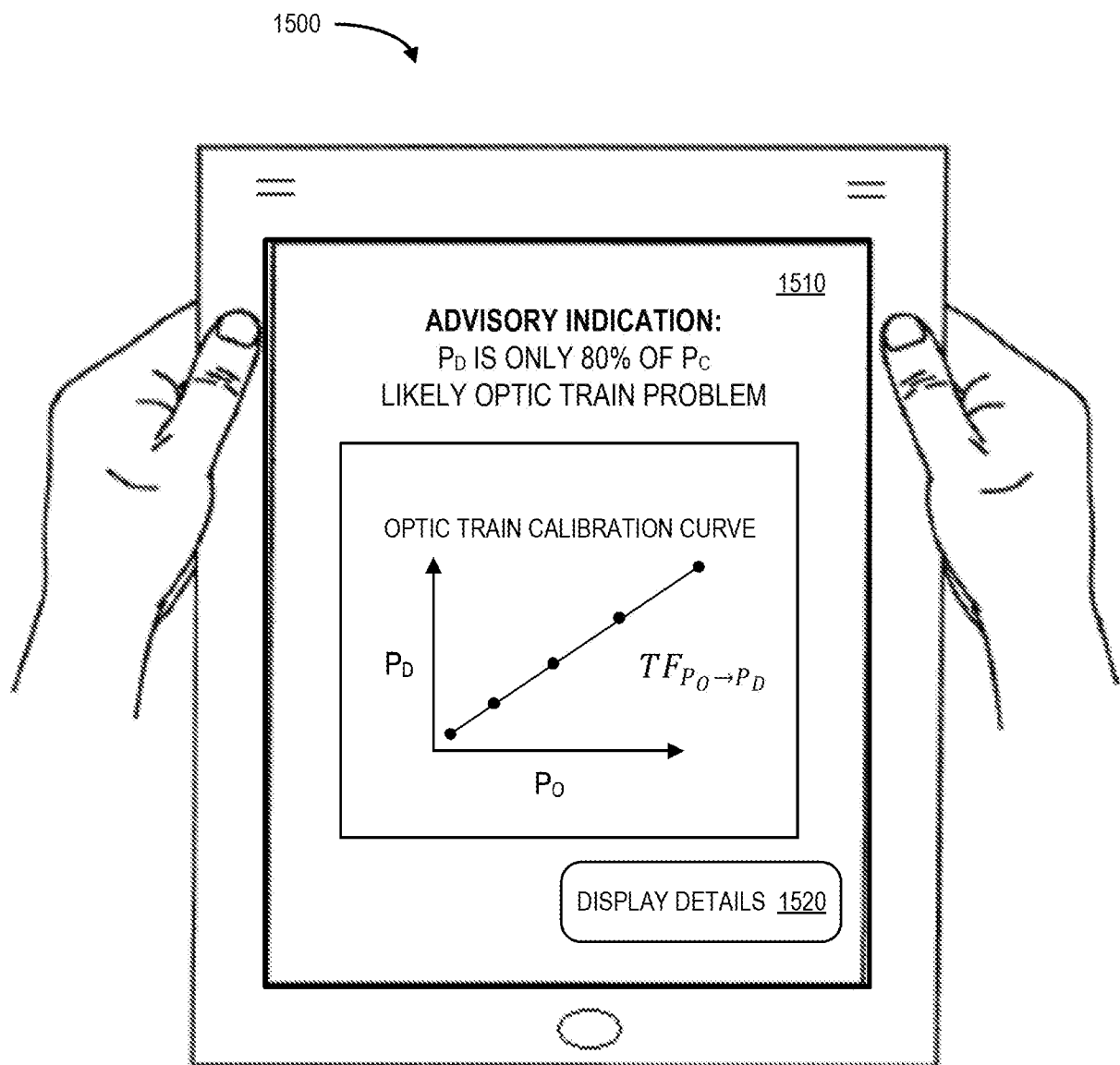


FIG. 15

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2018/051842**A. CLASSIFICATION OF SUBJECT MATTER****G01J 1/42(2006.01)i, H01S 3/00(2006.01)i**

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)

G01J 1/42; B29C 35/08; G01J 1/32; G05B 19/4099; H01S 3/131; H01S 3/134; H01S 3/00

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

Korean utility models and applications for utility models

Japanese utility models and applications for utility models

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

eKOMPASS(KIPO internal) & Keywords: additive manufacturing, laser source, laser beam, sensor, power, monitoring

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US 2017-0242424 A1 (GENERAL ELECTRIC COMPANY) 24 August 2017 See paragraphs [0002], [0009]–[0036], claims 1, 4, 10–11, 18 and figure 1.	1–22
Y	US 2013-0154160 A1 (GUTHRIE COOPER) 20 June 2013 See claims 1, 6.	1–22
A	US 2009-0179353 A1 (JOCHEN PHILIPPI) 16 July 2009 See paragraphs [0013]–[0017] and figure 1.	1–22
A	US 2008-0277564 A1 (XINYAN WU) 13 November 2008 See claims 1, 6 and figure 1.	1–22
A	JP 2012-174720 A (FANUC LTD.) 10 September 2012 See paragraphs [0017]–[0021] and figure 1.	1–22



Further documents are listed in the continuation of Box C.



See patent family 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 application or patent 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

11 January 2019 (11.01.2019)

Date of mailing of the international search report

11 January 2019 (11.01.2019)

Name and mailing address of the ISA/KR

International Application Division

Korean Intellectual Property Office

189 Cheongsa-ro, Seo-gu, Daejeon, 35208, Republic of Korea

Facsimile No. +82-42-481-8578

Authorized officer

KANG, Sung Chul

Telephone No. +82-42-481-8405



INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2018/051842

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2017-0242424 A1	24/08/2017	CN 107101717 A EP 3210713 A1 JP 2017-144484 A	29/08/2017 30/08/2017 24/08/2017
US 2013-0154160 A1	20/06/2013	None	
US 2009-0179353 A1	16/07/2009	AT 490073 T BR PI0809286 A2 CN 101668625 A CN 101668625 B DE 102007062129 B3 EP 2101987 A1 EP 2101987 B1 HK 1138236 A1 JP 2011-506145 A JP 5015326 B2 RU 2009136174 A RU 2459704 C2 US 8303886 B2 WO 2009-083122 A1	15/12/2010 14/10/2014 10/03/2010 22/05/2013 18/06/2009 23/09/2009 01/12/2010 27/09/2013 03/03/2011 29/08/2012 10/04/2011 27/08/2012 06/11/2012 09/07/2009
US 2008-0277564 A1	13/11/2008	CN 101310333 A CN 101310333 C EP 1952397 A2 JP 2009-516320 A KR 10-2008-0068742 A TW 200822102 A WO 2007-054913 A2 WO 2007-054913 A3	19/11/2008 19/11/2008 06/08/2008 16/04/2009 23/07/2008 16/05/2008 18/05/2007 02/08/2007
JP 2012-174720 A	10/09/2012	CN 102646919 A CN 102646919 B DE 102012101144 A1 DE 102012101144 B4 JP 5068863 B2 US 2012-0213238 A1 US 8428092 B2	22/08/2012 09/10/2013 23/08/2012 09/04/2015 07/11/2012 23/08/2012 23/04/2013