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DESCRIPTION

BACKGROUND

[0001] Friction stir welding (FSW) plasticizes a piece of metal by rotating a FSW tool against the piece of metal. Friction and pressure from the FSW tool may heat up the piece of metal such that the metal is plasticized, and then the FSW tool is inserted into the piece of metal. If two pieces of metal are being welded together, the FSW tool may be placed at the joint, and both pieces of metal may be plasticized, the pieces of metal joining by the mixing of the plasticized portions of each of the two pieces of metal.

[0002] The present invention relates to a friction welding tool, a system with such tool, and a method of measuring while friction stir welding according to the preamble of claims 1, 10 and 14 respectively (see for example DE 10 2005 032170 A1).

[0003] Further exemplary embodiments of devices, systems, and methods for a friction stir welding (FSW) tool of the prior art are disclosed in:

Bernd Aschenbach: "Entwicklung einer Online-Prozesskontrolle für das Rührreibschweißen auf der Basis einer werkzeugintegrierten Sensorik", XP055546420; http://www.gfe-net.de/wcms/DocsID/3121195E8E41EBD6C1257D64002302E6/$file/Rührreibschweißen.pdf;

Thomas Luhn:" Prozessdiagnose und Prozessüberwachung beim RührreibschweißBen"; XP055546443; Berlin; ISBN: 978-3-86386-963-2;

Gerald Bjorkman et al: "Tool for friction stir tack welding of aluminum alloys - Tech Briefs"; Manufacturing&Prototyping, 2003; XP055546465;

DE 10 2005 032170 A1; and

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SUMMARY

[0004] A friction welding tool, a system with such tool, and a method of measuring while friction stir welding according to the present invention are defined in claims 1, 10 and 14 respectively. Further embodiment of the present invention are defined in the dependent claims. According to the present invention, the friction stir welding (FSW) tool includes a head, a tool holder and a body between the head and the tool holder and attached to the head and the tool holder. In some embodiments, the body may include a plurality of cooling fins. An interior of the body includes a pressure sensor, a temperature sensor, a torque sensor, and a communication node in electronic communication with the pressure sensor, the temperature sensor, and the torque sensor. The communication node may be in Bluetooth communication with a computing device.

[0005] Accoding to the present invention, the system for friction stir welding includes a computing device with a proportional-integral-derivative (PID) controller and a friction stir welding tool as defined in claim 1.

[0006] According to the present invention, the method of measuring while friction stir welding includes rotating a friction stir welding tool. The method further includes measuring pressure on a head of a friction stir welding tool using a pressure sensor, measuring temperature of the friction stir welding tool, and measuring torque of the friction stir welding tool using a torque sensor. The method may include transmitting the measured pressure, the measured temperature, and the measured torque to a computing device using a communication node.

[0007] This summary is provided to introduce a selection of concepts that are further described in the detailed description. This summary is not intended to identify key or essential features of the claimed subject matter, nor is it intended to be used as an aid in limiting the scope of the claimed subject matter. Additional features and aspects of embodiments of the disclosure will be set forth herein, and in part will be obvious from the description, or may be learned by the practice of such embodiments.

BRIEF DESCRIPTION OF THE DRAWINGS

[0008] In order to describe the manner in which the above-recited and other features of the disclosure can be obtained, a more particular description will be rendered by reference to specific embodiments thereof which are illustrated in the appended drawings. For better understanding, the like elements have been designated by like reference numbers throughout the various accompanying figures. While some of the drawings may be schematic or exaggerated representations of concepts, at least some of the drawings may be drawn to scale. Understanding that the drawings depict some example embodiments, the embodiments will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

FIG. 1-1 is a side view of an embodiment of a FSW tool;

FIG. 1-2 is a cross-sectional view of the embodiment of FIG. 1-1 of the FSW tool;

FIG. 2 is an embodiment of a network diagram for measuring and transmitting data while friction stir welding;

FIG. 3 is an embodiment of a method for measuring while friction stir welding; and

FIG. 4 is another embodiment of a method for measuring while friction stir welding.

DETAILED DESCRIPTION

[0009] This present invention generally relates to devices, systems, and methods for a friction stir welding (FSW) tool that measures FSW information near the head of the tool as defined in the claims. More specifically, at least one embodiment of the disclosure relates to devices, systems, and methods for a FSW tool that can be used in a Computer Numerical Control (CNC) machine.

[0010] Referring to FIG. 1-1, the FSW tool 100 includes a head 102, a body 104, and a tool holder 106. In some embodiments, the tool holder 106 may be a CAT tool holder, such as a CAT 30, CAT 40, CAT 50, CAT 60, or other CAT tool holder. In other embodiments, the tool holder 106 may be a BT tool holder, such as a BT 30, BT 40, BT 50, or other BT tool holder. In further embodiments, other CNC machine compatible tool holders may be used.

[0011] In some embodiments, the body 104 may include a plurality of cooling fins 108. During FSW, heat is generated on the head 102. The heat generated on the head 102 may be transferred to the body 104. The heat on the body 104 may then be transferred to at least one of a plurality of cooling fins 108. In some embodiments, the plurality of cooling fins 108 may be circumscribed around an outer circumference of the body 104. In some embodiments, a cooling fin 108 may completely circumscribe the outer circumference of the body 104. In other words, the cooling fin 108 may be continuous around an outer surface of the body 104. In other embodiments, a cooling fin 108 may partially circumscribe, or be partially continuous around, the outer circumference of the body 104. For example connectors 110 connecting two halves of the body 104 may break the continuity of a cooling fin 108. In some embodiments, the body 104 may include cooling fins 108 that both completely circumscribe the body 104 and cooling fins 108 that partially circumscribe the body 104. In some embodiments, an entirety of the body 104 may include cooling fins 108. In other embodiments, a portion of the body 104 may include cooling fins.

[0012] Heat transferred to the plurality of cooling fins 108 may be diffused using conductive media cooling. In some embodiments, the conductive media may be air, such that the cooling fins 108 cool the FSW tool 100 by air cooling. In other embodiments, the conductive media may be any other conductive media used in conductive media cooling. In at least one embodiment, as the FSW tool 100 rotates, air (e.g., a column or vortex of air) surrounds the FSW tool 100. The air may pass over the cooling fins 108, and the cooling fins 108 may transfer heat to the air, thereby air-cooling the cooling fins 108. As the cooling fins 108 are air-cooled, the body 104 may transfer additional heat to the cooling fins 108. As the body 104 transfers heat to the cooling fins 108, the head 102 may transfer heat to the body 104. Thus, the FSW tool 100 may be air-cooled.

[0013] In some embodiments, the head 102 may be cylindrical. In other embodiments, the head 102 may be pyramidal. In still other embodiments, the head 102 may be conical. In yet other embodiments, the head 102 may include other shapes. In some embodiments, the head 102 may include threads. The threads may be wound opposite the direction of rotation of the FSW tool 100. In other embodiments, the threads may be wound in the same direction of rotation of the FSW tool 100. In some embodiments, the head 102 may include any FSW head.

[0014] FIG. 1-2 is a cross-sectional view of the FSW tool 100 of FIG. 1-1. In some embodiments, the head 102 may be at least partially inserted inside the body 104. The head 102 has a head length 112. In some embodiments, the head length 112 may be in a range having an upper value, a lower value, or upper and lower values including any of 6.0 millimeters, 13 millimeters, 25 millimeters, 50 millimeters, 100 millimeters, 150 millimeters, 200 millimeters, 250 millimeters, 300 millimeters, or any value therebetween. For example, the head length 112 may be greater than 6.0 millimeters. In other examples, the head length 112 may be less than 200 millimeters. In yet other examples, the head length 112 may be in a range of 6.0 millimeters to 300 millimeters. In some embodiments, the head 102 may include a head adapter. The head adapter may interface with the head 102 and the tool holder 106 to extend the length of the head 102.

[0015] The head 102 has a head diameter 114. In some embodiments, the head diameter 114 may be in a range having an upper value, a lower value, or upper and lower values including any of 4 millimeters, 10 millimeters, 14 millimeters, 20 millimeters, 25 millimeters,, 25.4 millimeters, 30 millimeters, 35 millimeters, 38 millimeters, 40 millimeters, 45 millimeters, 50 millimeters, or any value therebetween. For example, the head diameter 114 may be greater than 10 millimeters. In other examples, the head diameter 114 may be less than 50 millimeters. In yet other examples, the head diameter 114 may be in a range of 10 millimeters to 50 millimeters. In some embodiments, the head 102 may include collets to increase the head diameter 114 between premanufactured heads 102.

[0016] A pressure sensor 116 is installed at the base 118 of the head 102, or the pressure sensor 116 contacts the head 102 at the base 118. In other words, the pressure sensor 116 is according to the present invention immediately adjacent to, abut, or directly abut the head 102. For example, pressure from the head 102 may be transferred directly to the pressure sensor 116. In another example, the pressure transferred from the head 102 to the pressure sensor 116 may be within 5% of the actual pressure on the head 102. The pressure sensor 116 has a pressure sensor diameter 120. In some embodiments, the pressure sensor diameter 120 may be the same as the head diameter 114. In embodiments where the pressure sensor 116 has the same diameter as the head 102, more accurate measurements may be provided than a pressure sensor 116 that is larger or smaller than the head 102. In other embodiments the pressure sensor 116 may be larger than the head 102. In sill other embodiments, the pressure sensor 116 may be smaller than the head 102. In some embodiments, the pressure sensor 116 may be shaped to match a profile of the head 102.

[0017] In some embodiments, the pressure sensor 116 may be a piezoresistive strain gauge. In other embodiments, the pressure sensor 116 may be a piezoelectric pressure sensor. In still other embodiments, the pressure sensor 116 may be a Wheatstone bridge. It yet other embodiments, the pressure sensor 116 may be a fluid pressure transducer. In further embodiments, the pressure sensor 116 may be any other pressure sensor. In still further embodiments, the pressure sensor 116 may be a load sensor.

[0018] The pressure sensor 116 has a load capacity. The load capacity is the load above which the pressure sensor 116 may be damaged and/or no longer provide accurate and reliable measurements. In some embodiments, the load capacity may be in a range having an upper value, a lower value, or upper and lower values including any of 0.25 kilonewton (kN), 0.5 kN, 1.0 kN, 2.5 kN, 5.0 kN, 7.5 kN, 15 kN, 30 kN, 60 kN, 150 kN, 300 kN, or any value therebetween. For example, the load capacity may be greater than 0.25 kN. In other examples, the load capacity may be less than 300 kN. In yet other examples, the load capacity may be between 0.25 kN and 300 kN, or between 5.0 kN and 60 kN.

[0019] In some embodiments, the body 104 may surround at least a portion of the tool holder 106. The interior of the body 104 houses a plurality of instruments. For example, the interior of the body 104 houses one or more of a temperature sensor 122, and a torque sensor 124. In some embodiments, each instrument of the plurality of instruments may be located behind the base 118 of the head 102. The plurality of instruments may be located inside the body 104 between the head 102 and the tool holder 106. In some embodiments, at least one of the temperature sensor 122 and/or the torque sensor 124 may be located between a shoulder 126 of the body 104 and the base 118.

[0020] Positioning the plurality of instruments as close as possible to the head may provide more accurate data than placing the plurality of instruments in the motor or rotary machine. In other words, collecting measurements as close to the head 102 as possible may reduce the amount of noise, feedback, extraneous information, or combinations thereof that may be collected closer to the motor or rotary machine.

[0021] In some embodiments, the temperature sensor 122 may be thermocouple. In other embodiments, the temperature sensor 122 may be a laser. In still other embodiments, the temperature sensor may be an infrared camera. The temperature sensor 122 has a temperature sensor capacity. The temperature sensor capacity is the temperature above which the temperature sensor may no longer provide accurate and/or reliable measurements. In some embodiments, the temperature sensor capacity may be in a range having an upper value, a lower value, or upper and lower values including any of 0 °C, 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 700 °C, 800 °C, 900 °C, 1,000 °C, 1,100 °C, 1,200 °C, 1,300 °C, 1,400 °C, 1,500 °C, or any value therebetween. For example, the temperature sensor capacity may be greater than 0 °C. In other examples, the temperature sensor capacity may be less than 1,500 °C. In yet other examples, the temperature sensor capacity may be in a range of 0 °C to 1,500 °C.

[0022] In some embodiments, the torque sensor 124 may be a strain gauge or a plurality of strain gauges designed to measure both static and dynamic torque. For example, the torque sensor 124 may be installed in a collar bolted on the outside of the tool holder. In other embodiments, the torque sensor 124 may be an accelerometer. The torque sensor 124 has a torque sensor capacity. The torque sensor capacity is the torque above which the torque sensor may be damaged and/or no longer provide accurate and reliable measurements. In some embodiments, the torque sensor capacity may be in a range having an upper value, a lower value, or upper and lower values including any of 50 newton-meters (N-m), 100 N-m, 250 N-m, 500 N-m, 1,000 N-m, 2,000 N-m, 3,000 N-m, 4,000 N-m, 5,000 N-m, 6,000 N-m, 7,000 N-m, or any value therebetween. For example, the torque sensor capacity may be greater than 50 N-m. In other examples, the torque sensor capacity may be less than 7,000 N-m. In yet other examples, the torque sensor capacity may be in a range of 50 N-m to 7,000 N-m.

[0023] The body may include a communication node 128 having a communication device. The communication node 128 is in electronic communication with the pressure sensor 116, the temperature sensor 122, and the torque sensor 124. In some embodiments, the communication node 128, the pressure sensor 116, and the torque sensor 124 may have an electronics and instrumentation temperature capacity. The electronics and instrumentation temperature capacity is the temperature above which the communication node 128, the pressure sensor 116, and the torque sensor 124 may be damaged from excessive heat. In some embodiments, the electronics and instrumentation temperature capacity may be in a range having an upper value, a lower value, or upper and lower values including any of 0 °C, 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 700 °C, 800 °C, 900 °C, 1,000 °C, or any value therebetween. For example, the electronics and instrumentation temperature capacity may be greater than 0 °C. In other examples, the electronics and instrumentation temperature capacity may be less than 1,000 °C. In yet other examples, the electronics and instrumentation temperature capacity may be in a range of 0 °C to 1,000 °C.

[0024] In some embodiments, the communication node 128 may have a plurality of communication channels. For example, the communication node 128 may have 1, 2, 3, 4, 5, 6, 7, 8, 16, 32, 64, or more channels of analog input. Information from the channels of analog input may be transmitted to a computing device. Information collected and transmitted by the channels of analog input may include one or more of temperature, torque, and pressure, measured from one or more of the temperature sensor 122, the torque sensor 124, and the pressure sensor 116.

[0025] In some embodiments, the communication node 128 may transmit information wirelessly. For example, the communication node 128 may transmit information on an FM frequency. The FM frequency may have a range of up to 2 kilometers. In other embodiments, the communication node 128 may transmit information via Bluetooth, ZigBee, Z-wave, 802.11x protocols, or other wireless communications.

[0026] In some embodiments, one or more of the pressure sensor 116, the temperature sensor 122, the torque sensor 124 and the communication node 128 may be powered using induction power. In some embodiments, a collar may surround the body during operation of the FSW tool 100. The collar may include a first wire coiled around an inner circumference of the collar. A second wire may be coiled in the body 104. Electric current may be passed through the first wire, creating an electromagnetic field inside the collar. The second wire may generate an electric current from the electromagnetic field. The electric current from the electromagnetic field may provide the power for one or more of the pressure sensor 116, the temperature sensor 122, the torque sensor 124, and the communication node 128. In other embodiments, power may be supplied to one or more components through an internal power source, such as a battery. In some embodiments, the internal power source may be a rechargeable power source. In further embodiments, one or more components may be powered by induction power and one or more other components may be powered by a battery that is not in electrical communication with the induction power source.

[0027] FIG. 2 is a network diagram of the controls for an FSW tool 200. The FSW tool 200 includes a plurality of instruments 230. The plurality of instruments 230 may transmit measured data 232 to a communication node 228. In some embodiments, the communication node 228 may include an internal storage 234. The measured data 232 may be stored in the internal storage 234. In this manner, the FSW tool may perform as a logging-while-welding tool. In some embodiments, the measured data 232 may be stored in an internal storage cache before being transmitted to the computing device 236. In other embodiments, the measured data 232 may be passed through the communication node 228 to the computing device 236 without being stored in the internal storage.

[0028] In some embodiments, the computing device 236 may include a proportional-integral-derivative (PID) controller 238. The PID controller 238 may be in communication with the communication node. In some embodiments, the PID controller 238 may compare the measured data 232 to stored data. In response to the comparison, the PID controller 238 may issue a command 240 to the FSW machine. The command 240 may be, for example, to change a welding parameter, such as pressure applied to the FSW tool 200 (e.g., plunge rate) and/or rotational velocity of the FSW tool 200.

[0029] For example, the PID controller 238 may compare measured pressure with an optimal pressure stored in a memory of the computing device. The optimal pressure is the pressure at which FSW is the most effective. If the measured pressure is greater than the optimal pressure, then the PID controller 238 may issue a command 240 to a FSW machine 242 (e.g., a CNC machine) to reduce downward pressure on the FSW tool 200 (e.g., by decreasing the plunge rate). If the measured pressure is less than the optimal pressure, then the PID controller 238 may issue a command 240 to the FSW machine 242 to increase downward pressure on the FSW tool 200 (e.g., by increasing the plunge rate).

[0030] In some embodiments, the optimal pressure may be in a range having an upper value, a lower value, or upper and lower values including any of 1 gigapascals (GPa), 2 GPa, 4 GPa, 6 GPa, 8 GPa, 10 GPa, 12 GPa, 14 GPa, 16 GPa, 18 GPa, 20 GPa, 22 GPa, 24 GPa, 26 GPa, or any value therebetween. For example, the optimal pressure may be greater than 1 GPa. In other examples, the optimal pressure may be less than 26 GPa. In yet other examples, the optimal pressure may be in a range of 1 GPa to 26 GPa.

[0031] In other examples, the PID controller 238 may compare a measured load with an optimal load. The optimal load is the load at which FSW is the most effective. If the measured load is greater than the optimal load, then the PID controller 238 may issue a command 240 to a FSW machine 242 (e.g., a CNC machine) to reduce downward pressure on the FSW tool 200 (e.g., by decreasing the plunge rate). If the measured load is less than the optimal load, then the PID controller 238 may issue a command 240 to the FSW machine 242 to increase downward pressure on the FSW tool 200 (e.g., by increasing the plunge rate).

[0032] In some embodiments, the optimal load may be in a range having an upper value, a lower value, or upper and lower values including any of 0.25 kN, 0.5 kN, 1.0 kN, 2.5 kN, 5.0 kN, 7.5 kN, 15 kN, 30 kN, 60 kN, 150 kN, 300 kN, or any value therebetween. For example, the optimal load may be greater than 0.25 kN. In other examples, the optimal load may be less than 300 kN. In yet other examples, the optimal load may be in a range of 0.25 kN to 300 kN.

[0033] In other examples, the PID controller 238 may compare measured torque with an optimal torque stored in a memory of the computing device. The optimal torque is the torque at which FSW is most effective for the conditions. If the measured torque is greater than the optimal torque, then the PID controller 238 may issue a command 240 to the FSW machine 242 to reduce the downward pressure and/or rotational velocity of the FSW tool 200. If the measured torque is less than the optimal torque, then the PID controller 238 may issue a command 240 to the FSW machine 242 to increase downward pressure and/or rotational velocity of the FSW tool 200. In some embodiments, optimal values may include a tolerance band. The tolerance band may be in a range having a lower value, an upper value, or lower and upper values including any of 0.1%, 0.5%, 1.0%, 2.0% 5.0%, 10%, or any value therebetween. For example, the tolerance band may be greater than 0.1%. In other examples, the tolerance band may be less than 10%. In yet other examples, the tolerance band may be in a range of 0.1% to 5%.

[0034] In some embodiments, the tolerance band may be dependent on the materials and geometries being welded. For example, a narrower tolerance band for temperature may be used for materials with a high heat capacity, such as steel, or for thick sections of material that may absorb more heat. In other examples, a wide tolerance band for pressure and/or torque may be used for softer materials, such as aluminum, or for thinner sections of materials that are more susceptible changes in pressure and torque.

[0035] In some embodiments, one measurement may be the primary measurement, and the other two measurements may be leading indicators of the primary measurement. For example, temperature may be the primary measurement, and pressure and torque may be leading indicators that may indicate when a deviation from the optimal temperature may be near. In other examples, pressure may be the primary measurement, and temperature and torque may be the leading indicators. In still other examples, torque may be the primary measurement, and temperature and pressure may be the leading indicators.

[0036] In some embodiments, the optimal torque may be in a range having an upper value, a lower value, or upper and lower values including any of 1 newton-meters (N-m), 10 N-m, 500 N-m, 750 N-m, 1,000 N-m, 1,500 N-m, or any value therebetween. For example, the optimal torque may be greater than 5 N-m. In other examples, the optimal torque may be less than 1,500 N-m. In yet other examples, the optimal torque may be in a range of 1 N-m to 1,500 N-m.

[0037] In still other examples, the PID controller 238 may compare measured temperature with an optimal temperature stored in a memory of the computing device. The optimal temperature is the temperature at which FSW is most effective. If the measured temperature is greater than the optimal temperature (or above the tolerance band, if included, for optimal temperature), then the PID controller 238 may issue a command 240 to the FSW machine 242 to reduce the downward pressure and/or rotational velocity of the FSW tool 200. If the measured temperature is less than the optimal temperature (or below the tolerance band, if included, for optimal temperature), then the PID controller 238 may issue a command 240 to the FSW machine 242 to increase downward pressure and/or rotational velocity of the FSW tool 200.

[0038] In some embodiments, the optimal temperature may be in a range having an upper value, a lower value, or upper and lower values including any of 0 °C, 100 °C, 200 °C, 300 °C, 400 °C, 500 °C, 600 °C, 700 °C, 800 °C, 900 °C, 1,000 °C, 1,100 °C, 1,200 °C, 1,300 °C, 1,400 °C, 1,500 °C, or any value therebetween. For example, the optimal temperature may be greater than 0 °C. In other examples, the optimal temperature may be less than 1,500 °C. In yet other examples, the optimal temperature may be in a range of 0 °C to 1,500 °C. In some examples, for FSW of two pieces of 6061 aluminum, an optimal temperature may be 300 °C, an optimal torque may be 70 N-m, and an optimal pressure may be 4.5 kN. In some embodiments, any or each of the optimal values for FSW joining of two 2061 aluminum pieces may be varied by 10%, 20%, or more. In other examples, for FSW carbon steel to tool steel, an optimal temperature may be 800 °C, an optimal torque may be 400 N-m, and an optimal pressure may be 115 kN. In some embodiments, any or each of the optimal values for FSW joining of carbon and tool steel may be varied by 10%, 20%, or more.

[0039] FIG. 3 is an embodiment of a method 344 of method of measuring while friction stir welding. The method 344 includes rotating 346 a FSW tool. Rotating 346 has a maximum rotational velocity. In some embodiments, the maximum rotational velocity may be in a range having an upper value, a lower value, or upper and lower values including any of 9,000 rotations per minute (RPM), 10,000 RPM, 12,000 RPM, 14,000 RPM, 16,000 RPM, 18,000 RPM, 20,000 RPM, 22,000 RPM, 24,000 RPM, 26,000 RPM, 28,000 RPM, 30,000 RPM, or any value therebetween. For example, the maximum rotational velocity may be greater than 9,000 RPM. In other examples, the maximum rotational velocity may be less than 30,000 RPM. In yet other examples, the maximum rotational velocity may be in a range of 9,000 RPM to 30,000 RPM.

[0040] The method 344 includes the act of measuring 348 the state of the FSW tool. The method 344 includes measuring 348 pressure on a head of the FSW tool using a pressure sensor (e.g., a load cell). The method 344 includes measuring 348 temperature of a body of the FSW tool using a temperature sensor. The method 344 includes measuring 348 torque of the FSW tool using a torque. In some embodiments, other states of the FSW tool may be measured 348.

[0041] According to the invention, the method 344 includes transmitting 350 the measured 348 information to a computing device. In some embodiments, transmitting 350 the information may include transmitting 350 via wireless communication (e.g., via FM radio transmission, Bluetooth, Zigbee, Z-wave, 802.11x wireless protocols, or other wireless communication protocols). In other embodiments, transmitting 350 the information may include transmitting 350 using a wired connection. In further embodiments, transmitting the information may include transmitting 350 by any type of transmission.

[0042] FIG. 4 is another embodiment of a method 452 of measuring while friction stir welding. In some embodiments, the method 452 may include the same or similar acts of rotating 446, measuring 448, and transmitting 450, as described in relation to FIG. 3. In some embodiments, the method 452 may include cooling 454 a body of a FSW tool. The body may include a plurality of cooling fins on an exterior of the body. Heat may be transmitted to the fins, and as the tool rotates, the fins may be cooled 454 by radiating heat into the surrounding air.

[0043] In some embodiments, the FSW tool may include a memory. In some embodiments, the communication node may record the measured pressure, the measured temperature, and the measured torque on the memory. In some embodiments, the pressure sensor, the temperature sensor, and the torque sensor may record directly on the memory. The communication node may then transmit the measured information from the memory.

[0044] In some embodiments, the method 452 may include controlling 456 the FSW tool using a PID controller. The PID controller may be in communication with the communication node. The communication node may communicate the measured 448 information to the PID controller. In some embodiments, the PID controller may have a memory. The memory may include, for a given FSW regime, an optimal pressure for FSW, an optimal temperature for FSW, an optimal torque for FSW, tolerance bands for one or more values, or combinations thereof. The PID controller may compare measured values against the optimal values (and associated tolerance bands, in some embodiments), and adjust the pressure and/or rotational velocity of the FSW tool to improve FSW performance. Controlling 456 using the PID controller may include any or each of the acts described in relation to FIG. 3, which is incorporated herein.

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Patentkrav

1. Friktionssvejseværktøj (100), der omfatter:

et hoved (102),
en værktøjsholder (106),
kendetegnet ved, at:

værktøjsholderen (106) har en central fordybning, i hvilken hovedet modtages;
et legeme (104) mellem hovedet (102) og værktøjsholderen (106), hvilket legeme (104) er fastgjort til hovedet (102) og værktøjsholderen (106), idet et indre af legemet (104) indbefatter:

en tryksensor (116), der modtages i værktøjsholderens (106) centrale fordybning, hvilken tryksensor (116) er umiddelbart tilstødende, ligger an mod eller ligger direkte an mod hovedet (102),
en temperatursensor (122),
en momentsensor (124), og
et kommunikationsknudepunkt (128) i elektronisk kommunikation med tryksensoren (116), temperatursensoren (122) og momentsensoren (124), hvilket kommunikationsknudepunkt (128) er konfigureret til trådløs kommunikation med en computerindretning.

2. Friktionssvejseværktøj (100) ifølge krav 1, der endvidere omfatter en genopladelig strømkilde til én eller flere af tryksensoren (116), temperatursensoren (122), momentsensoren (124) og kommunikationsknudepunktet (128).

3. Friktionssvejseværktøj (100) ifølge krav 1, hvor kommunikationsknudepunktet (128) har otte kanaler med analoge udgange.

4. Friktionssvejseværktøj (100) ifølge krav 1, hvor kommunikationsknudepunktet (128) har en trådløs rækkevidde på 2 kilometer.

5. Friktionssvejseværktøj (100) ifølge krav 1, hvor friktionssvejseværktøjet (100) har en belastningskapacitet på 30 kilonewton.

6. Friktionssvejseværktøj (100) ifølge krav 1, hvor computerindretningen indbefatter en proportional-integreret-derivativ (PID)-regulator, hvilken PID-regulator er i kommunikation med kommunikationsknudepunktet.

7. Friktionssvejseværktøj (100) ifølge krav 1, hvor tryksensoren (116) er formet, så den passer til en profil af hovedet (102).

8. Friktionssvejseværktøj (100) ifølge krav 7, hvor hovedet (102) er cylindrisk og har en diameter på 25 millimeter.

9. Friktionssvejseværktøj (100) ifølge krav 1, hvor tryksensoren (116), temperatursensoren (122), momentsensoren (124) og kommunikationsknudepunktet (128) er drevet af induktionsstrøm.

10. System til friktionssvejsning, der omfatter:

en computerindretning, hvilken computerindretning indbefatter en proportional-integreret-derivativ (PID)-regulator, og
er kendetegnet ved:
et friktionssvejseværktøj (100) ifølge krav 1, hvor tryksensoren (116) har en belastningskapacitet på 30 kilonewton, og kommunikationsknudepunktet (128) er i elektronisk kommunikation med tryksensoren (116), temperatursensoren (122), momentsensoren (124) og PID-regulatoren, idet kommunikationsknudepunktet (128) er konfigureret til trådløs kommunikation med computerindretningen.

11. Friktionssvejsesystem ifølge krav 10, hvor kommunikationsknudepunktet (128) har otte kanaler med analoge udgange.

12. Friktionssvejsesystem ifølge krav 10, hvor kommunikationsknudepunktet (128) har en trådløs rækkevidde på 2 kilometer.

13. Friktionssvejsesystem ifølge krav 10, hvor tryksensoren (116), temperatursensoren (122), momentsensoren (124) og kommunikationsknudepunktet (128) er drevet under anvendelse af induktionsstrøm.

14. Fremgangsmåde til måling under friktionssvejsning, hvilken fremgangsmåde omfatter:

rotation af et friktionssvejseværktøj (100);
og **kendetegnet ved**:

måling af tryk på et hoved (102) af friktionssvejseværktøjet (100) under anvendelse af en tryksensor (116), hvilken tryksensor (116) er i et indre af et legeme (104), hvilket legeme (104) er mellem hovedet (102) og en værktøjsholder (106), idet tryksensoren (116) modtages i en central fordybning af værktøjsholderen (106), der også modtager hovedet (102), hvor tryksensoren (116) er umiddelbart tilstødende, ligger an mod eller ligger direkte an mod hovedet (102),
måling af friktionssvejseværktøjets (100) temperatur under anvendelse af en temperatursensor (122), hvilken temperatursensor (122) er i det indre af legemet (104);
måling af friktionssvejseværktøjets (100) moment under anvendelse af en momentsensor (124), hvilken momentsensor (124) er i legemets (104) indre, og
transmission af det målte tryk, den målte temperatur og det målte moment til en computerindretning under anvendelse af et kommunikationsknudepunkt (128).

15. Fremgangsmåde ifølge krav 14, der endvidere omfatter registrering af det målte tryk, den målte temperatur og det målte moment i hukommelse, der er placeret inde i legemet (104).

16. Fremgangsmåde ifølge krav 14, der endvidere omfatter afkøling af legemet (104) med en flerhed af køleribber (108) på en yderside af legemet (104) ved at føre luft hen over flerheden af køleribber (108).

17. Fremgangsmåde ifølge krav 14, der endvidere omfatter regulering af friktionssvejseværktøjet (100) med en proportional-integreret-derivativ (PID)-regulator, hvilken PID-regulator er i kommunikation med kommunikationsknudepunktet (128).

18. Fremgangsmåde ifølge krav 17, hvor PID-regulatoren regulerer friktionssvejseværktøjet (100) som reaktion på:
en sammenligning mellem det målte tryk og et optimalt tryk, der er lagret i en hukommelse af computerindretningen,

en sammenligning mellem den målte temperatur og en optimal temperatur, der er lagret i hukommelsen, og
en sammenligning mellem det målte moment og et optimalt moment, der er lagret i hukommelsen.

19. Fremgangsmåde ifølge krav 14, hvor friktionssvejseværktøjet (100) roterer med en maksimal rotationshastighed på 12.000 omdrejninger pr. minut.

20. Fremgangsmåde ifølge krav 14, hvor kommunikationsknudepunktet (128) indbefatter en Bluetooth-forbindelse, og transmission af det målte tryk, den målte temperatur og det målte moment til computerindretningen via Bluetooth-forbindelsen.

21. Fremgangsmåde ifølge et hvilket som helst af kravene 14 til 20, der udføres under anvendelse af friktionssvejseværktøjet (100) ifølge et hvilket som helst af kravene 1 til 9 eller systemet ifølge et hvilket som helst af kravene 10 til 13.

DRAWINGS

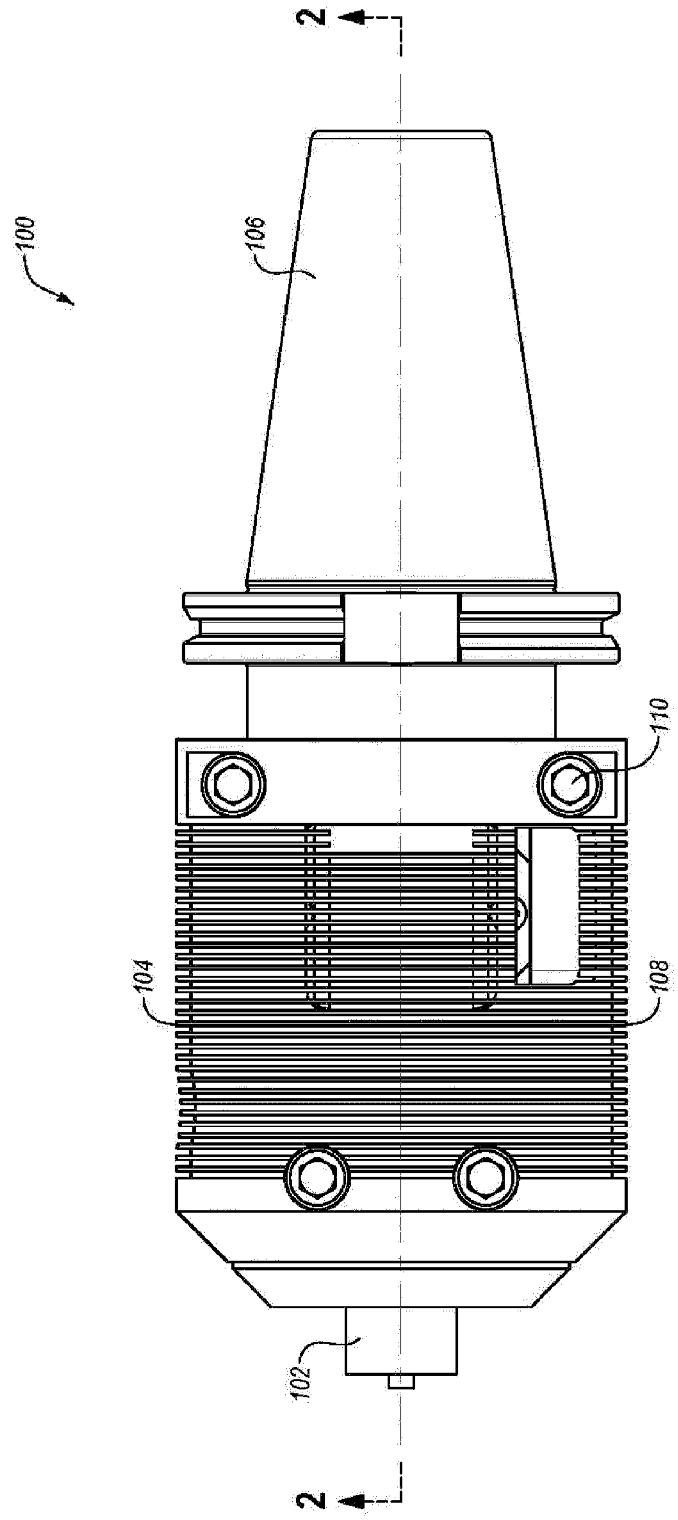

FIG. 1-1

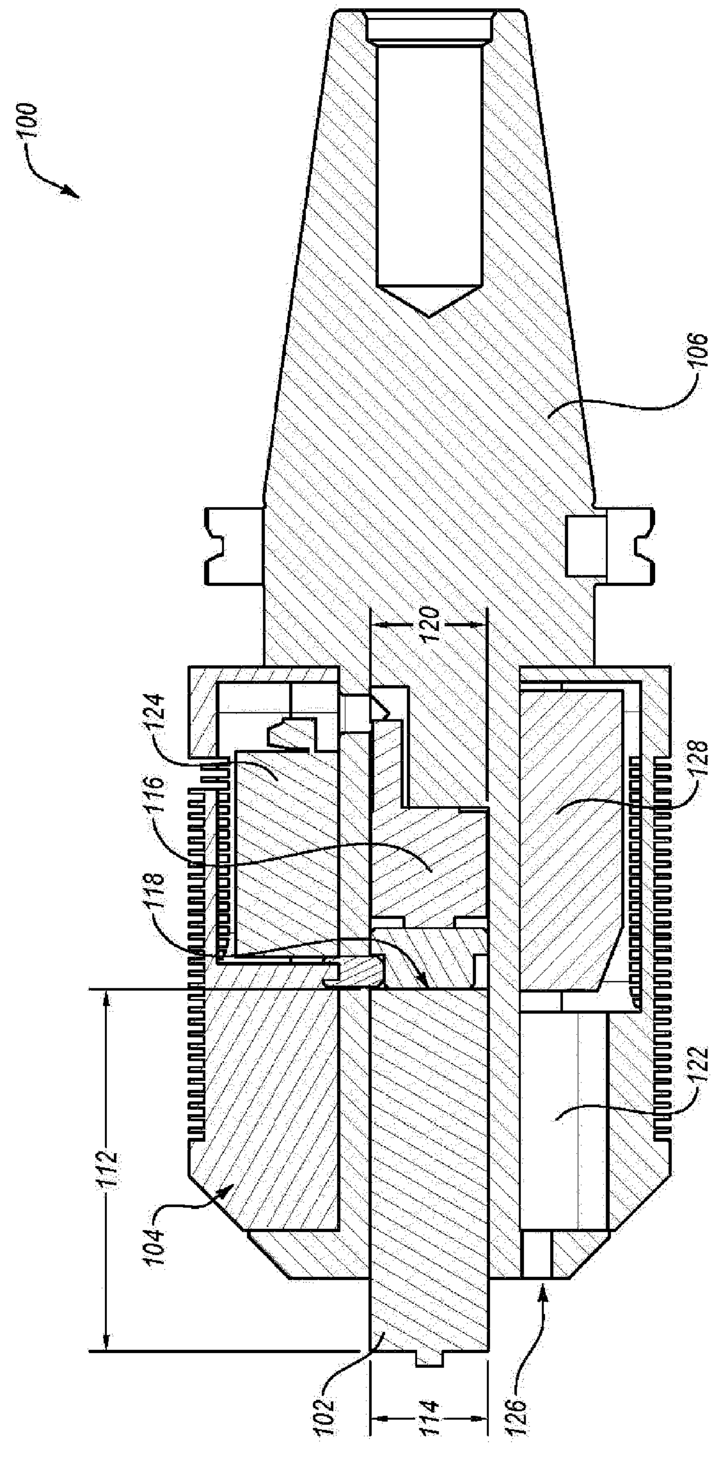

FIG. 1-2

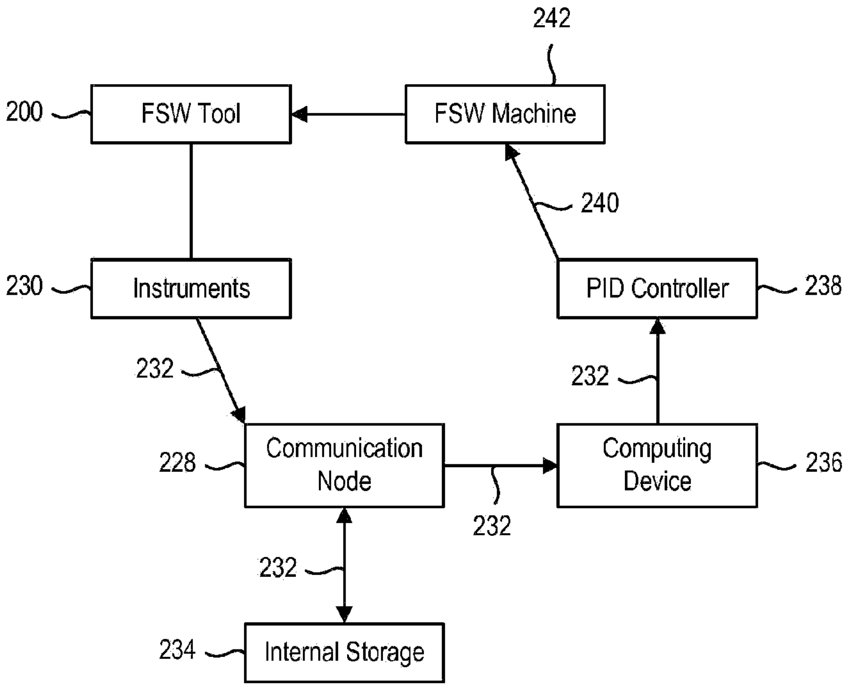
242
200
FSW Tool
FSW Machine
240
230
Instruments
PID Controller
238
232
232
228
Communication Node
Computing Device
236
232
232
234
Internal Storage

FIG. 2

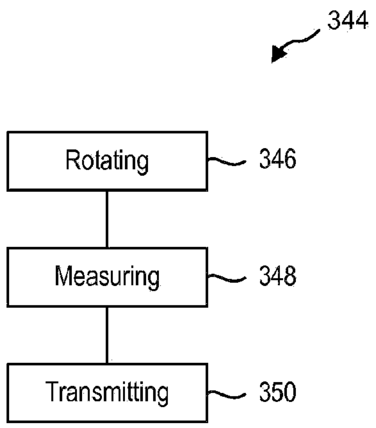
344
Rotating
346
Measuring
348
Transmitting
350

FIG. 3

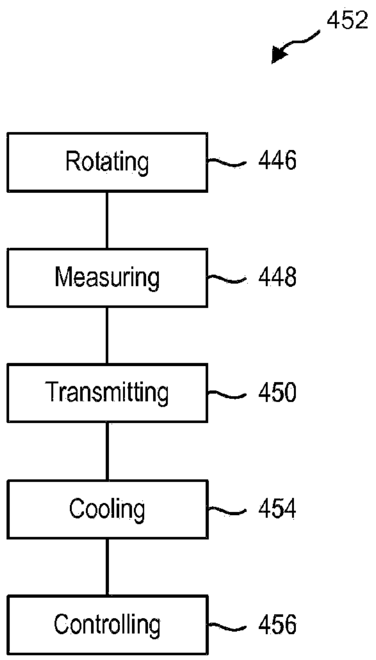
452
Rotating
446
Measuring
448
Transmitting
450
Cooling
454
Controlling
456

FIG. 4