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(54) **AUTOMATIC MONITORING OF THE ALIGNMENT AND WEAR OF VIBRATION WELDING EQUIPMENT**

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(Continued)

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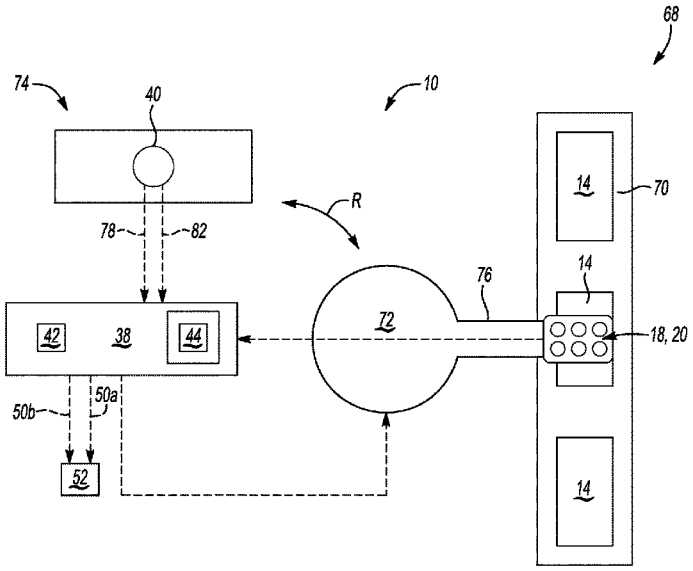
(57) **ABSTRACT**

A vibration welding system includes vibration welding equipment having a welding horn and anvil, a host machine, a check station, and a welding robot. At least one displacement sensor is positioned with respect to one of the welding equipment and the check station. The robot moves the horn and anvil via an arm to the check station, when a threshold condition is met, i.e., a predetermined amount of time has elapsed or a predetermined number of welds have been completed. The robot moves the horn and anvil to the check station, activates the at least one displacement sensor, at the check station, and determines a status condition of the welding equipment by processing the received signals. The status condition may be one of the alignment of the vibration welding equipment and the wear or degradation of the vibration welding equipment.

19 Claims, 6 Drawing Sheets



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B23K 20/26 (2006.01)
B23K 31/12 (2006.01)
B23K 101/36 (2006.01)

(52) **U.S. Cl.**
CPC ***B23K 31/12*** (2013.01); *B23K 2201/36* (2013.01); *G05B 2219/45146* (2013.01)

(58) **Field of Classification Search**
USPC 700/160
See application file for complete search history.

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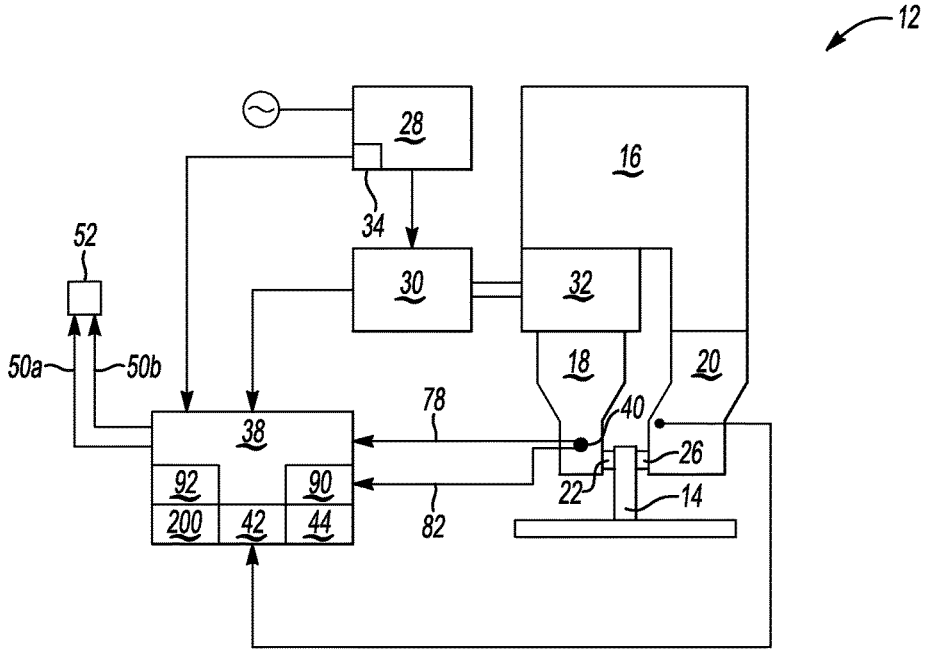
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Fig-1

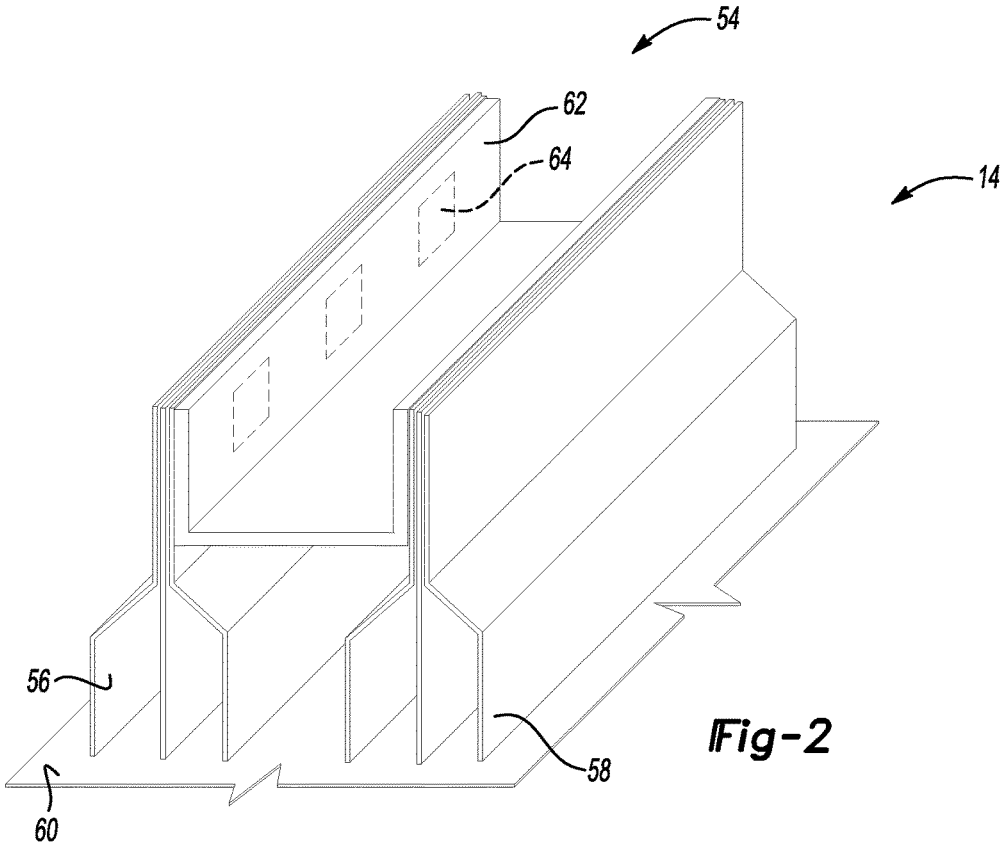
54
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Fig-2

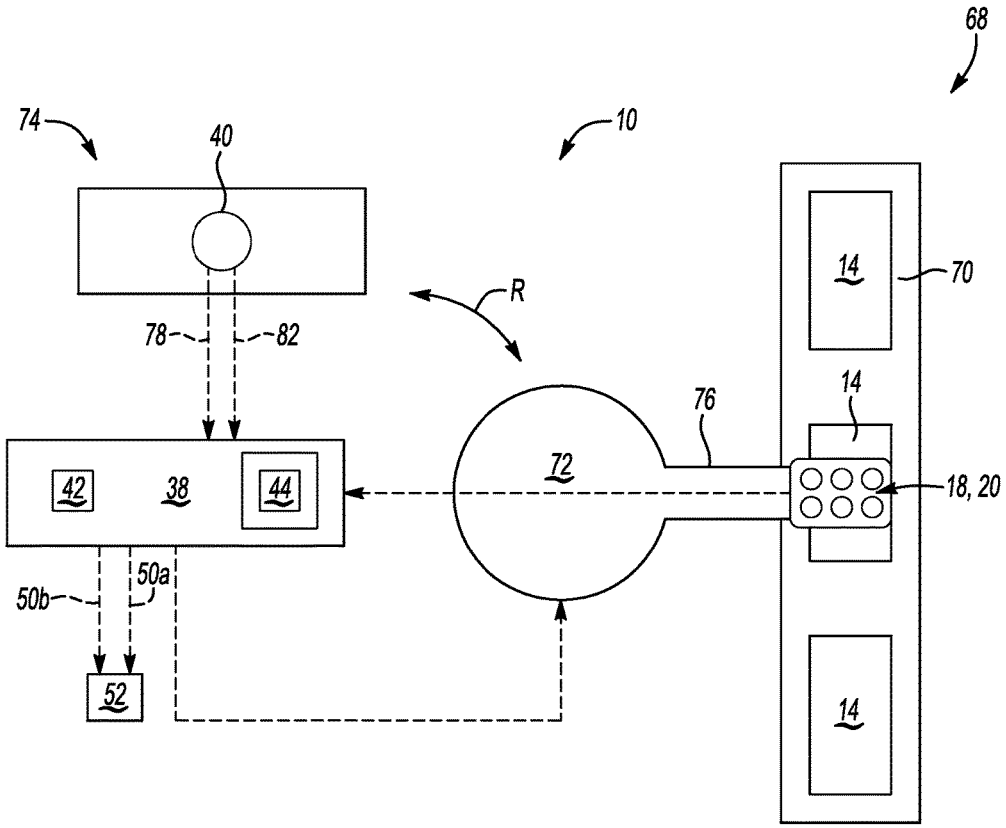


Fig-3

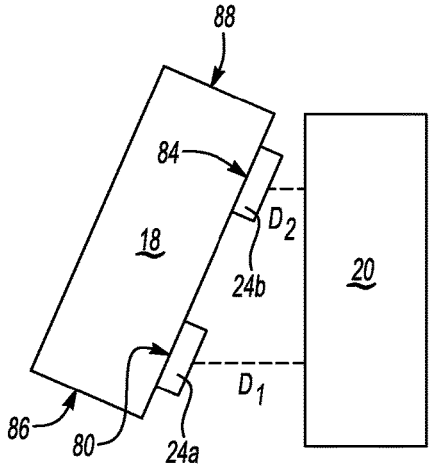


Fig-4A

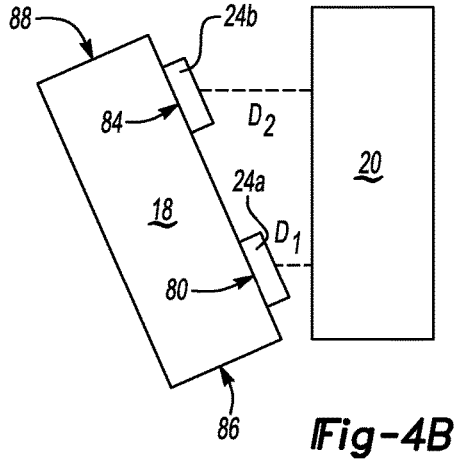


Fig-4B

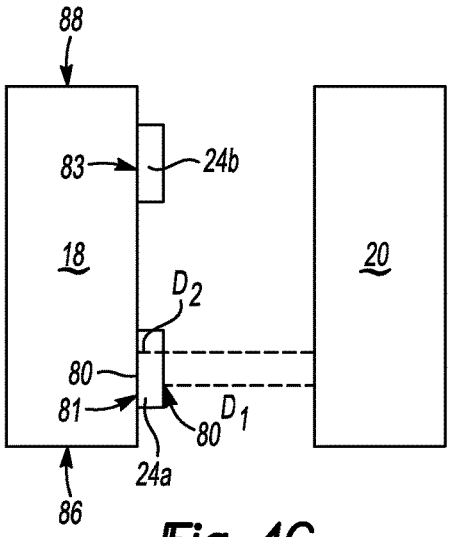


Fig-4C

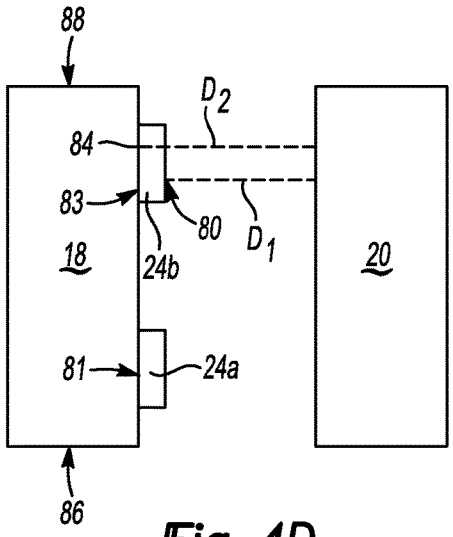


Fig-4D

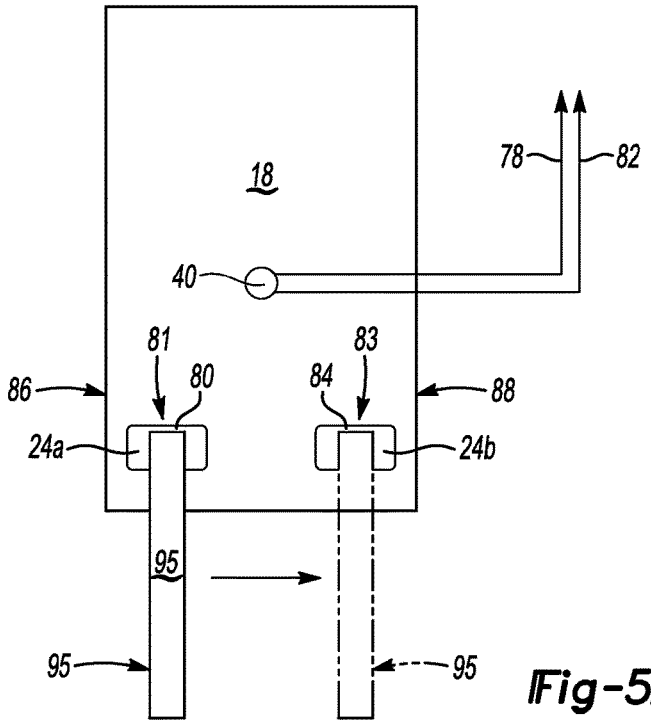


Fig-5A

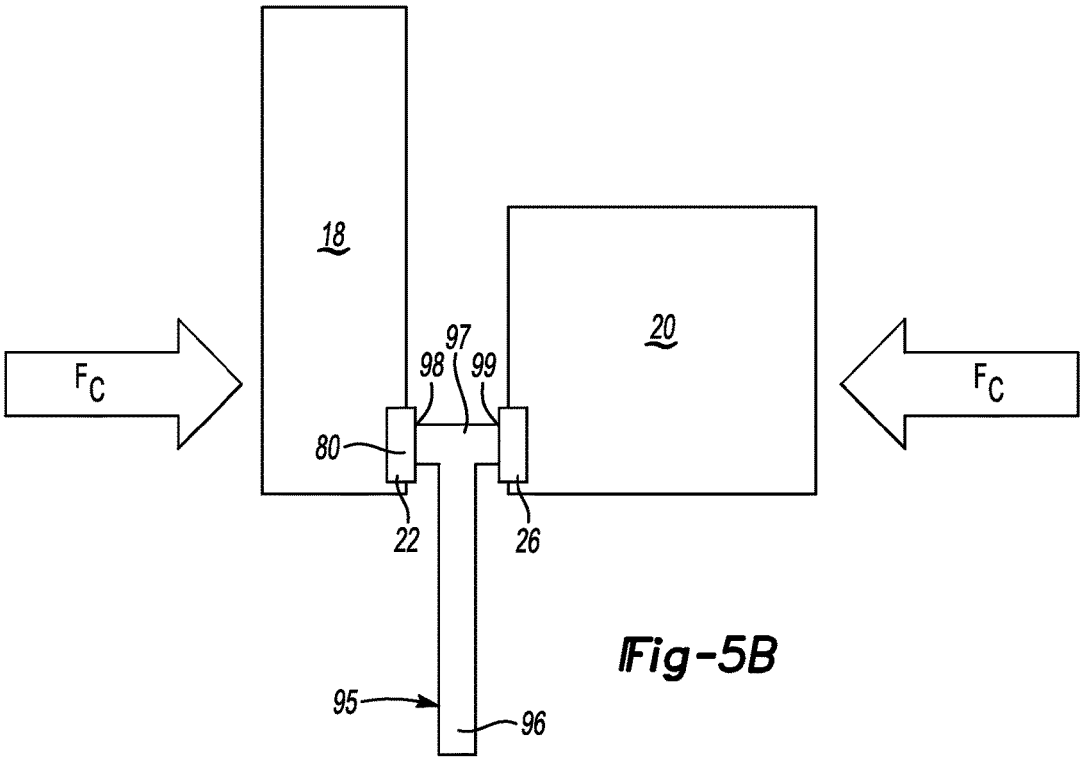


Fig-5B

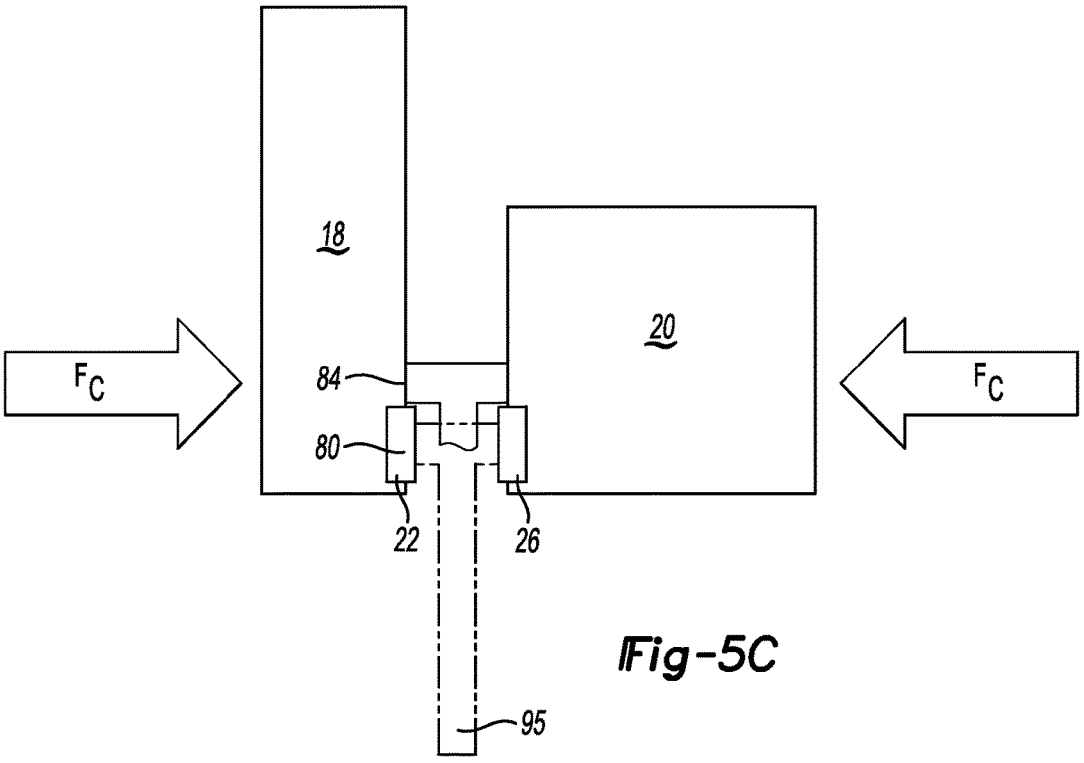


Fig-5C

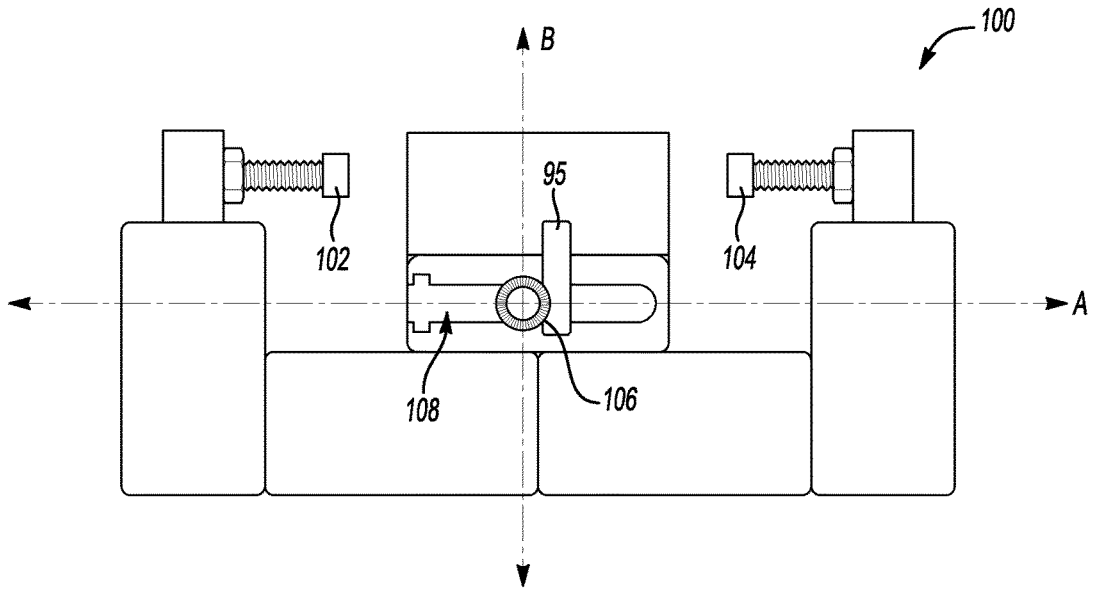


Fig-6

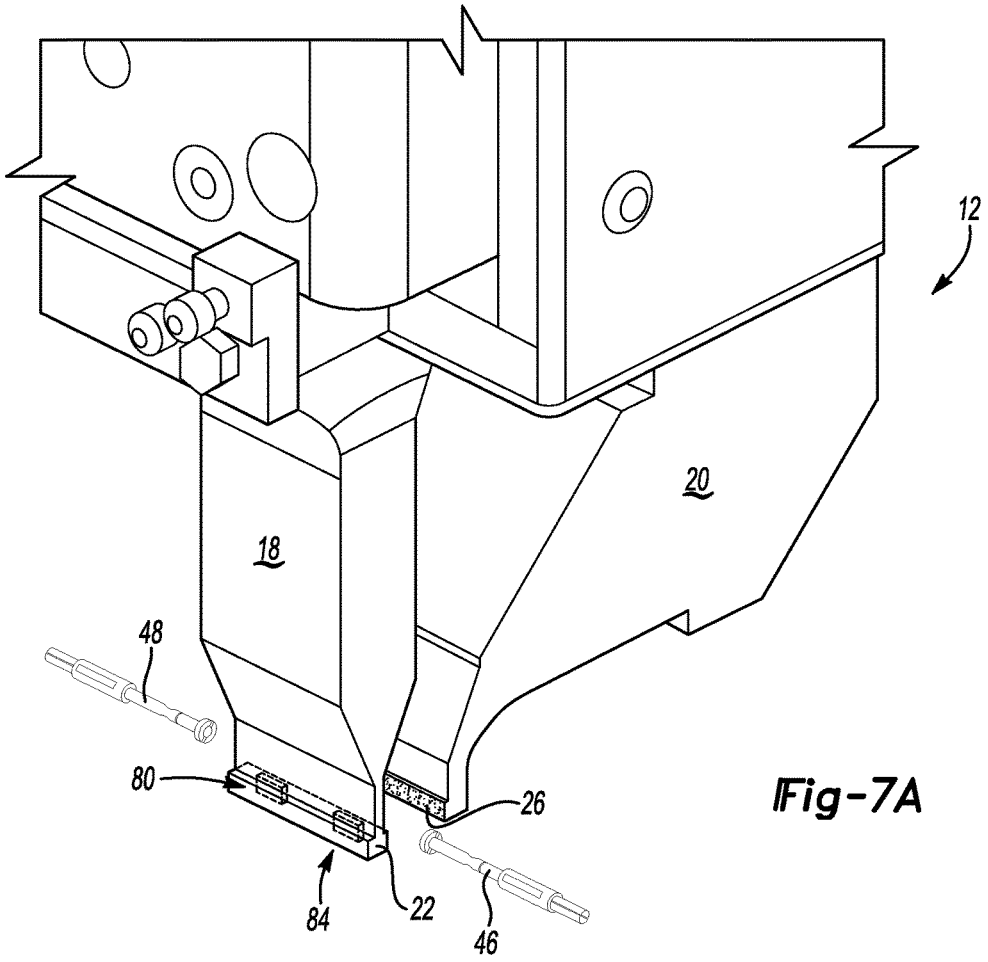
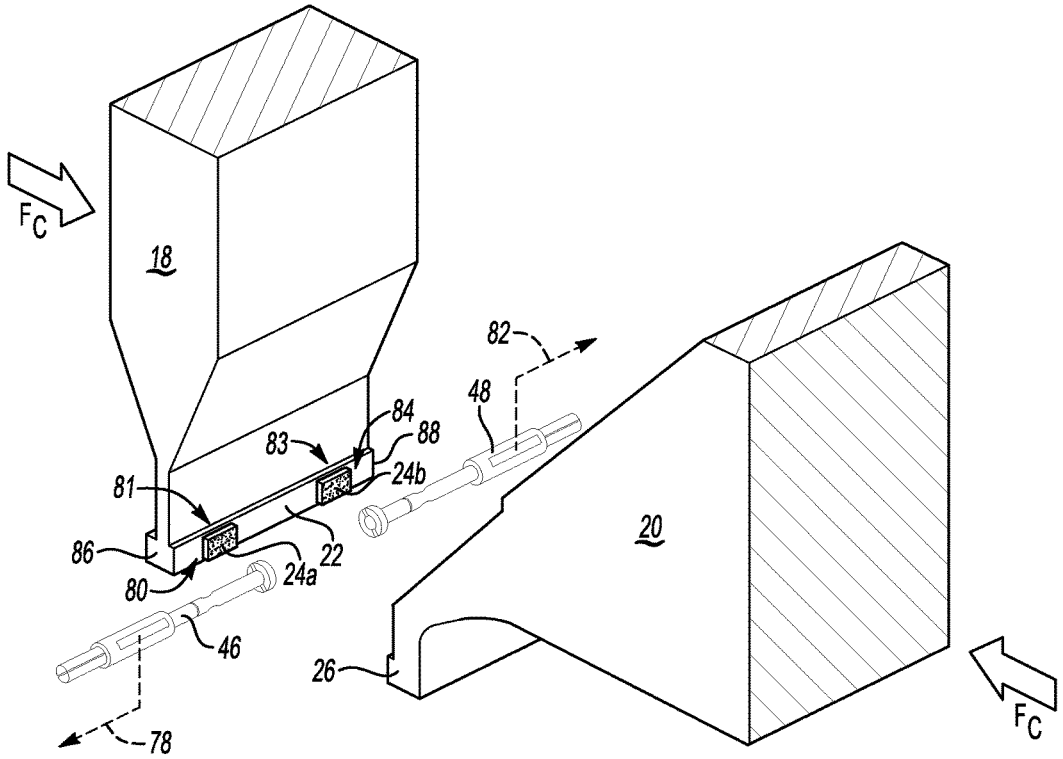


Fig-7A


F_C
18
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24b
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F_C

Fig-7B

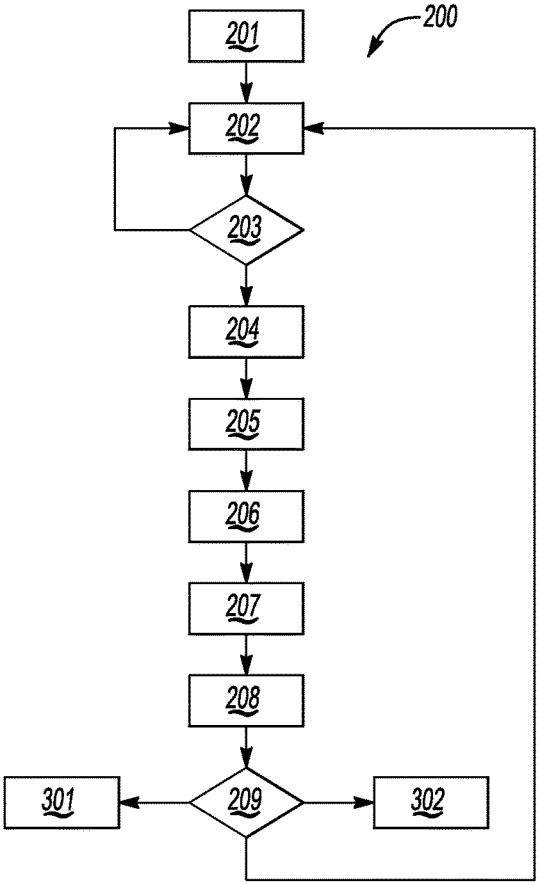
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Fig-8

AUTOMATIC MONITORING OF THE ALIGNMENT AND WEAR OF VIBRATION WELDING EQUIPMENT

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 61/915,870, filed Dec. 13, 2013, which is hereby incorporated by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

This invention was made with U.S. Government support under an Agreement/Project DE-EE0002217, Department of Energy American Recovery and Reinvestment Act (ARRA) of 2009, Battery Pack Manufacturing B511. The U.S. government may have certain rights in this invention.

TECHNICAL FIELD

The present disclosure relates to the automatic monitoring of the alignment and wear of vibration welding equipment.

BACKGROUND

Vibration welding is a technique in which vibration energy is applied in a particular frequency range to a clamped work piece. The frequency range is typically ultrasonic. Surface friction between vibrating adjacent surfaces of the clamped work piece generates heat, which ultimately softens and bonds the adjacent surfaces of the work piece.

In a vibration welding system, a weld horn or sonotrode is directly connected to one or more welding pads. The welding pad(s) may have a knurled surface that physically contacts the work pieces as they are being welded. The work pieces are supported by a stationary welding anvil.

Vibration welding has utility in industry, for example in the joining of various components during the manufacturing of structures and devices, such as, but not limited to, automobiles, aircraft, watercraft, containment vessels, electronic devices, and the like. Vibration welding is a well-controlled process, using properly functioning welding equipment, which typically produces welds having a highly consistent and repeatable weld quality. However, while various approaches exist for ensuring control of a vibration welding process, such approaches may be less than optimal for the purposes of ongoing monitoring of a maintenance status or other status conditions of the vibration welding equipment.

SUMMARY

Accordingly, a system and method for monitoring a status condition of vibration welding equipment are provided herein. The vibration welding system includes vibration welding equipment, a check station, a welding robot, at least one displacement sensor, and a host machine in communication with at least, the welding equipment, the at least one displacement sensor, and the welding robot.

The vibration welding equipment includes a welding horn and a welding anvil. The vibration welding equipment is configured to form a weld on a work piece clamped between the welding horn and the welding anvil.

The welding robot may be a component of the vibration welding system. The welding robot may include a robot arm on which the welding horn and the welding anvil are disposed. The welding robot is configured to selectively move the welding horn and welding anvil, via the robot arm, between a work station and a check station. The welding robot moves the welding horn and welding anvil to the check station to determine a status condition of the vibration welding equipment upon the trigger of a threshold event. The welding robot returns the welding horn and welding anvil to the work station to resume welding applications.

The at least one displacement sensor is configured to measure a plurality of distances at a plurality of evaluation points, which include a first distance measured at a first evaluation point and a second distance measured at a second evaluation point.

The host machine is in communication with the at least one displacement sensor and includes a processor and tangible, non-transitory memory on which is recorded instructions for monitoring the vibration welding equipment to determine a status condition. The monitored status condition may be one of alignment of the welding horn with respect to the welding anvil and wear or degradation of the welding horn and the weld pads disposed thereon.

The host machine is configured to, i.e., programmed and equipped in hardware, to execute a set of recorded instructions from the memory, such that executing the recorded instructions causes the processor to perform the steps of the present method. In the execution of the recorded instructions, the processor will first determine a first time period representing the amount of time elapsed since an evaluation of the status condition was completed and determine the number of welds performed since an evaluation of the status condition was completed. The processor will then repeatedly compare the first time period to a predetermined threshold time period and repeatedly compare the number of welds performed to a predetermined threshold number of welds. Upon making the iterative comparisons, the processor will determine if a threshold condition is met, i.e., the first time period exceeds the predetermined threshold time period or the number of welds exceed the predetermined threshold number of welds.

If the threshold condition is met, the processor will signal that the welding equipment needs to be monitored or checked and command the welding robot to move the welding equipment to the check station for monitoring and evaluation.

During the monitoring process the host machine processor will receive a first signal from the at least one displacement sensor representing the first distance and receive a second signal from the at least one displacement sensor representing the second distance.

The processor will then calculate the difference between the first distance and the second distance and evaluate the difference between the first distance and the second distance by comparing the difference between the first distance and the second distance to one of a plurality of look-up tables representing predetermined operating threshold values for the difference between the first distance and second distance.

If the status condition is the alignment of the vibration welding equipment, the difference between the first and second distance will be defined as a misalignment value. If the misalignment value exceeds the corresponding predetermined threshold operating value defined by one of the plurality of look-up tables the processor will output or transmit a control signal to an external device to indicate the condition of the vibration welding equipment as mis-aligned and temporarily stop the vibration welding process until the welding equipment is re-aligned, by an operator.

If the status condition is the wear or degradation of the vibration welding equipment, the difference between the first and second distance will be defined as a weld pad thickness. If the weld pad thickness of a respective weld pad falls below a predetermined threshold operating value defined by one of the plurality of look-up tables, the processor may output or transmit a control signal to an external device to indicate the condition of the vibration welding equipment as worn and requiring replacement and temporarily stop the vibration welding process until the welding horn is replaced, by an operator.

The above features and advantages and other features and advantages of the present disclosure are readily apparent from the following detailed description of the best modes for carrying out the disclosure when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic illustration of an example suite of vibration welding equipment which may be monitored as set forth herein.

FIG. **2** is a schematic perspective view of an example work piece in the form of a multi-cell battery pack portion which may be welded using the vibration welding equipment shown in FIG. **1**.

FIG. **3** is a schematic illustration of a vibration welding system for monitoring a condition of the vibration welding equipment shown in FIG. **1**.

FIGS. **4**A and **4**B are schematic illustrations of example welding horns and welding anvils that are misaligned.

FIGS. **4**C and **4**D are schematic illustrations of example welding horns and welding anvils wherein weld pad thickness is measured.

FIGS. **5**A, **5**B, and **5**C are schematic illustrations of an optional gauge tool for determining one of alignment and wear of the welding equipment having a LVDT sensor therein capable of determining the linear displacement of the welding horn.

FIG. **6** is a schematic illustration of an example gauge tool placement device;

FIGS. **7**A and **7**B are schematic perspective views of the vibration welding system wherein the at least one displacement sensor is a plurality of precision mechanisms for measuring displacement disposed at the check station.

FIG. **8** is a flow chart describing an example method for monitoring a condition of the vibration welding equipment shown in FIG. **1**.

DETAILED DESCRIPTION

Referring to the drawings, wherein like reference numbers refer to like components throughout the several Figures, a system and method for monitoring a status condition of vibration welding equipment are provided herein. The vibration welding system **10** (FIG. **3**) may include vibration welding equipment **12** shown schematically in FIG. **1**. The vibration welding equipment **12** may be used, for instance, to form welds in the fabrication of a work piece **14**, such as a portion of a multi-cell battery pack, shown for illustrative purposes in FIG. **2**. While other types of work pieces **14** may be ultrasonically welded without departing from the intended inventive scope, the example work piece **14** of FIG. **2** is typical of the type of welded system in which high-quality/durable welds must be formed in a repeatable process.

Referring to FIG. **1**, the example vibration welding equipment **12** of FIG. **1** may include a welder device **16** having a sonotrode/welding horn **18** and a welding anvil **20**, with the welder device **16** including a backing structure and support for the welding horn **18** and the welding anvil **20**. The welding horn **18** typically includes a weld head **22** having a plurality of weld pads **24***a*, **24***b* (shown in FIGS. **4**A, **4**B, **4**C, **4**D, **5**A, **5**B, **5**C, **7**A, **7**B).

The plurality of weld pads **24***a*, **24***b* may include at least a first weld pad **24***a* and a second weld pad **24***b*. The plurality of weld pads **24***a*, **24***b* may be disposed on the weld head **22** or formed integrally therewith. The weld pads **24***a*, **24***b* may have a textured knurl pattern, e.g., bumps and/or ridges (shown in FIG. **7**B), which are suitable for gripping and holding a work piece **14** clamped between the welding horn **18** and the welding anvil **20**.

The welding anvil **20** typically includes an anvil head **26**. The anvil head **26** may also include a similar knurl pattern formed thereon (shown in FIG. **7**A).

The vibration welding equipment **12** may also include a welding controller **28**. The welding horn **18** is typically connected to a transducer **30**, for instance a piezoelectric stack. Signals from the welding controller **28** cause the transducer **30** to vibrate at a calibrated frequency, which in turn vibrates the welding horn **18** at that same frequency, possibly amplified by a booster **32** i.e., a mechanical amplifier, which increases the amplitude of any commanded mechanical vibration from the transducer **30** as needed.

As will be understood by those of ordinary skill in the art, a welding controller/power supply of the type used for vibration welding, such as the welding controller **28** of FIG. **1**, may be electrically-connected to a suitable energy source, typically a 50-60 Hz wall socket. The welding controller **28** may include, for example, an oscillator or timer **34**, as well as voltage rectifiers, transformers, power inverters, and/or other hardware which ultimately transforms the source power, whatever its form, into vibration control signals. The control signals ultimately command predetermined waveform characteristic(s), for example a periodic signal having a frequency of about 20 kHz to about 40 kHz or more depending on the particular welding application.

The vibration welding system **10** of FIG. **3** may further include at least one displacement sensor **40**. The at least one displacement sensor **40** may be positioned, as shown in FIG. **1**, with respect to the vibration welding equipment **12**. In such an example, the at least one displacement sensor **40** may be an LVDT (Linear Variable Displacement Transformer) based sensor positioned on or integral with the welding horn **18**. This LVDT sensor **40** (shown in FIG. **1**) may be configured to measure the displacement of the welding horn **18**, and thereby interpret a distance between the welding horn **18** and welding anvil **20**.

The at least one displacement sensor **40** may, alternatively, be positioned with respect to a check station **74**, external to the vibration welding equipment **12**, but electrically connected to the host machine **38**. In such an example, the at least one displacement sensor **40** may include a plurality of precision mechanisms **46**, **48** or sensors for translating displacement. The plurality of precision mechanisms or sensors **46**, **48** may include at least a first precision mechanism **46** and a second precision mechanism **48** (shown in FIGS. **7**A and **7**B).

A host machine **38** is in communication with the vibration welding equipment **12** and the at least one displacement sensor **40**. The host machine **38**, i.e., a computer, also includes a processor **42** and tangible, non-transitory memory **44** on which is recorded instructions embodying the present

method **200**, an example of which is shown in a flow chart representation in FIG. **8**. The host machine **38** may include, as noted, the processor **42** and tangible, non-transitory memory **44**, such as read-only memory (ROM) or flash memory. The host machine **38** may also have random access memory (RAM), electrically erasable programmable read only memory (EEPROM), a high-speed clock, analog-to-digital (A/D) and/or digital-to-analog (D/A) circuitry, and any required input/output circuitry and associated devices, as well as other signal conditioning and/or signal buffering circuitry.

Therefore, host machine **38** can include all software, hardware, memory, algorithms, connections, sensors, etc., necessary to monitor a status condition of the vibration welding equipment **12**, such as the alignment of the vibration welding equipment **12** and the wear or degradation of the vibration welding equipment **12**.

In general, computing systems and/or devices, such as the host machine **38**, may employ any of a number of computer operating systems and generally include computer-executable instructions, where the instructions may be executable by one or more computing devices such as those listed above. Computer-executable instructions may be compiled or interpreted from computer programs created using a variety of well-known programming languages and/or technologies, including, without limitation, and either alone or in combination, Java™, C, C++, Visual Basic, Java Script, Perl, etc. In general, the processor **42** receives instructions, e.g., from the memory **44**, a computer-readable medium, etc., and executes these instructions, thereby performing one or more processes, including one or more of the processes described in the present method **200**. Such instructions and other data may be stored and transmitted using a variety of known computer-readable media.

The host machine **38** periodically executes the instructions via the processor **42** to thereby monitor a maintenance status or other status condition of the vibration welding equipment **12**. As part of this process, the vibration welding equipment **12** may be tested at the nearby check station **74** (shown in FIG. **3**). The host machine **38** receives signals **78**, **82** from the at least one displacement sensor **40** and then processes the received signals **78**, **82** in the execution of the method **200**.

The host device **38** may also output control signals **50***a*, **50***b* to an external device **52**, e.g., a quality indicator, which will be discussed in more detail herein below with respect to FIG. **8**. In an instance when the status condition is the alignment of the vibration welding equipment, the host machine **38** via the processor **42** will output or transmit a control signal **50***a* to the external device **52** to indicate that the vibration welding equipment **12** is one of aligned or misaligned, and if misaligned, the host machine **38** will temporarily stop the vibration welding process until the welding equipment **12** is adequately re-aligned, by an operator. When the status indicator is the wear or degradation of the vibration welding equipment **12**, the host machine **38**, via the processor **42**, will output or transmit a control signal **50***b* to the external device **52** to indicate that the welding horn **18** is one of fit for use or unfit for use, and if unfit for use, the host machine **38** temporarily stops the vibration welding process until the welding horn **18** is replaced, by an operator.

Referring to FIG. **2**, in a non-limiting example embodiment, a work piece **14** is shown as a portion of a multi-cell battery having an elongated conductive interconnecting member **54**. A full battery module may include an extended series of interconnecting members **54** arranged side-by-side in multiple rows. Each interconnecting member **54** joins oppositely-charged battery cell tabs **56**, **58**, of adjacent battery cells, with the battery cell tabs **56**, **58** forming individual electrode extensions of a given battery cell. Each battery cell tab **56**, **58** is internally-welded, below an interconnect board **60** to the various anodes or cathodes comprising that particular battery cell, as is well understood by those of ordinary skill in the art. The battery cell tabs **56**, **58** may be welded using the vibration welding equipment **12** of FIG. **1** to a longitudinal side wall **62** of a given interconnecting member **54**, with substantially identical welds **64** formed at each interconnecting member **54**.

Referring to FIG. **3**, in an example vibration welding process **68**, the vibration welding equipment **12** of FIG. **1** may be used to form welds on a set of work pieces **14** as the work pieces **14** move along a conveyor **70**. A welding robot **72** may move between the conveyor **70** and the check station **74** as indicated by arrow R. Some components of the vibration welding equipment **12** of FIG. **1** may be disposed on an arm **76** of the robot **72**, including at least the welding horn **18** and welding anvil **20** described above. In normal operation, the robot **72** can be used to form welds on the work pieces **14** as the work pieces **14** move on the conveyor **70**, or alternatively as the robot **72** moves with respect to the work pieces **14**.

Periodically, e.g., once per a predetermined time period such as once per shift or once per a specified number of hours, minutes, etc. or once per a predetermined, calibrated number of welds, it is advisable to examine the condition of the vibration welding equipment **12**. In some instances, the condition of the equipment may be checked via the performance of certain condition and monitoring steps while the equipment **12** remains on the line. In other instances the robot **72** may rotate toward the check station **74** and perform certain condition monitoring steps. The host machine **38**, by executing the present method **200**, may take a series of displacement signals **78**, **82** from the at least one displacement sensor **40** and perform the present method **200**, thereby returning results **50***a*, **50***b* as to a status condition. The status condition may be one of alignment of the vibration welding equipment **12** and wear or degradation of the vibration welding equipment **12**.

It is advisable to monitor the alignment of the vibration welding equipment **12**, namely the alignment of the welding horn **18** with respect to the welding anvil **20**, as a misaligned arrangement may result in an uneven clamping force during production, which can lead to welds having a less consistent and repeatable weld quality. It is further advisable to monitor the wear on the welding equipment, as uneven wear may result in uneven distribution of weld energy, which may change the signal profiles and lead to cold welds, particularly between cell tabs **56**, **58** of FIG. **2**. Wear is usually addressed by limiting the use of a given tool to a number of cycles before replacement. The present approach directly measures tool wear to thereby extend tool life.

Once the robot **72** has rotated toward the check station **74**, a status condition, including each of vibration welding equipment **12** alignment and vibration welding equipment **12** wear or degradation can be monitored and evaluated. In monitoring the status condition of the vibration welding equipment **12**, the at least one displacement sensor **40** measures a first distance D_1 (shown in FIGS. **4**A, **4**B, **4**C, **4**D) at a first evaluation point **80**. After taking the measurement, the at least one displacement sensor **40** returns a first signal **78** representing the first distance D_1 to the host machine **38**. The at least one displacement sensor **40** measures a second distance D_2 (shown in FIGS. **4**A, **4**B, **4**C, **4**D)

at a second evaluation point **84** and returns a second signal **82** representing the second distance D_2 to the host machine **38**. After receiving the first signal **78** and the second signal **82**, the host machine **38** calculates the difference between the first distance D_1 and the second distance D_2 and evaluates the status condition of the vibration welding equipment **12**.

When the status condition is alignment of the vibration welding equipment **12**, as will be understood by those skilled in the art, while the system **10** has, at least, a first evaluation **80** point and a second evaluation point **84** for the purposes of determining a misalignment value, the system **10** may also include a plurality of intermediate evaluation points between the first evaluation point **80** and the second evaluation point **84** at which the distance between the welding horn **18** and the welding anvil **20** may be measured. Readings taken at each of the respective evaluation points may be utilized in determining the misalignment value. In the simplest form, the calculated difference between the first distance D_1 measured at the first evaluation point **80** and the second distance D_2 measured at the second evaluation point **84** defines the misalignment value. Referring to FIGS. **4**A and **4**B, in one example, the first evaluation point **80** may be a first weld pad **24***a* and the second evaluation point **84** may be a second weld pad **24***b*. The first weld pad **24***a* and the second weld pad **24***b* may be placed distanced from one another on the welding horn **18**, such as at a first side **86** of the welding horn **18** and at a second side **88** of the welding horn **18**. In another example, the first evaluation point **80** may be a designated smooth surface **81** (also shown in FIGS. **5**A-**5**C) of the welding horn **18** located at a first side **86** of the welding horn **18** proximate a first weld pad **24***a* and the second evaluation point **84** may be a smooth surface **83** (also shown in FIGS. **5**A-**5**C) of the welding horn **18** located at a second side **88** of the welding horn **18**, proximate a second weld pad **24***b*. The smooth surfaces **81**, **83** may be a flat area that is parallel to an interface between the welding horn **18** and the welding anvil **20**.

The alignment of the welding horn **18** with respect to the welding anvil **20** is evaluated by comparing the difference between the first distance D_1 and the second distance D_2, i.e. the misalignment value, to a first look-up table **90**, written on the tangible non-transitory memory **44** of the host machine **38**. The first look-up table **90** contains a set of predetermined threshold alignment operating values for the difference between the first distance D_1 and the second distance D_2. If the misalignment value exceeds the corresponding predetermined threshold alignment operating value defined by the first look-up table **90**, then the welding horn **18** is misaligned with respect to the welding anvil **20** and requires realignment by an operator.

Referring to FIGS. **4**C and **4**D, when the status condition is the wear or degradation of the welding horn **18** the calculated difference between the first distance D_1 and the second distance D_2 indicates a thickness of the respective weld pad **24***a*, **24***b*. In one example, the first evaluation point **80** may be one of a plurality of weld pads **24** and the second evaluation point **84** may be a smooth surface **81**, **83** of the welding horn **18** proximate the respective weld pad **24***a*, **24***b*. The smooth surfaces **81**, **83** may be a flat area that is parallel to an interface between the welding horn **18** and the welding anvil **20**. The smooth surfaces **81**, **83** do not contact the work piece **14** during welding, and thus do not experience any wear or degradation. The difference between the first distance D_1 and the second distance D_2 indicates the thickness of the respective weld pad **24***a*, **24***b*.

The wear or degradation of the welding horn **18** is evaluated by comparing the difference between the first distance D_1 and the second distance D_2, i.e., the thickness of the respective weld pad, to a second look-up table **92**, written on the tangible non-transitory memory **44** of the host machine **38**. The second look-up table **92** contains predetermined threshold operating values for the thickness of the respective weld pads **24***a*, **24***b*. If the thickness of the respective weld pad **24***a*, **24***b* falls below the corresponding predetermined threshold operating value defined by the second look-up table **92**, the weld pads **24***a*, **24***b* are worn and the welding horn **18** may require replacement by an operator.

In one example embodiment as shown in FIGS. **5**A-**5**C, for instance, on a welding horn **18** having two weld pads **24***a*, **24***b*, the host machine **38** may be programmed to move the welding horn **18** and clamp the welding horn **18** onto a customized gauge tool **95**. In such an example, the displacement sensor **40** is shown as an LVDT sensor disposed on the welding equipment **12**. The customized gauge tool **95** may be formed of hardened steel or the like. The customized gauge tool **95** may be t-shaped, having a first member **96**, a second member **97**, and free ends **98**, **99**. In another example, the customized gauge tool **95** may include a first member **96** and a rounded head portion (not shown). The customized gauge tool **95** may take on a variety of configurations wherein the second member **97** or the rounded head portion, create a large enough contact area with the welding horn **18**, so as to avoid contact interruption from the knurls forming a knurled surface, in the event that the first evaluation point **80** and second evaluation point **84** are defined upon a knurled surface. FIGS. **5**A-**5**C are not to scale. In actuality, the gauge tool **95** may be relatively small, e.g., maximum dimensions of 40 mm tall×4 mm wide×2-4 mm thick.

As shown in FIGS. **5**B and **5**C, the free ends **98**, **99** of the gauge tool **95** should be perpendicular to the respective weld pads **24***a*, **24***b* or the designated smooth surfaces **81**, **83** and the welding anvil **20** between which the gauge tool **95** is positioned. Various means for accomplishing this may be used, including fixtures, a rotating device, or a wobble table, which allows the gauge tool **95** to rotate in the presence of a clamping force (arrows F_C) until the free ends **98**, **99** are perpendicular to the respective clamp points.

Referring to FIG. **6**, an operator may be assisted in moving the gauge tool **95** from the first evaluation point **80** to the second evaluation point **84** via a gauge tool placement device **100**. The gauge tool placement device **100** may be placed at the check station **74** for alignment with the welding equipment **12** when present at the check station **74**. The placement device **100** may include at least a first stop **102**, which is aligned with the first evaluation point **80**, along axis A. The gauge tool placement device **100** may also include a second stop **104**, which is aligned with the second evaluation point **84**, along axis A. The gauge tool placement device **100** may be moved along axis B to account for whether the first and second evaluation points **80**, **84** are defined as the weld pads **24***a*, **24***b* or the smooth surfaces **81**, **83** of the welding horn **18** located at a first side **86** and second side **88** of the welding horn **18** respectively, depending upon the embodiment, status condition, and other instructions from the host machine **38**. The gauge tool placement device **100** may also include a gauge tool receiving port **106**, wherein the operator may place the gauge tool **95** and secure the gauge tool **95** to the gauge tool placement device **100**. The gauge tool receiving port **106** may be disposed on a slide **108** disposed between the first stop **102** and the second stop **104**, such that

the operator may easily move the gauge tool **95** from the first evaluation point **80** to the second evaluation point **84**.

Referring to FIGS. **5**A and **5**B, when the status condition is alignment of the welding equipment **12**, the host machine **38** may instruct the welding horn **18** to clamp the gauge tool **95** between the weld horn **18** and the welding anvil **20** at the gauge tool free ends **98**, **99** with as much pressure as needed to take an accurate reading. Generally, the clamping pressure used to clamp the gauge tool **95** should be less than the full clamping pressure used for welding to protect the gauge tool **95** and/or the welding horn **18** and welding anvil **20**.

The LVDT displacement sensor **40** measures the displacement of the welding horn **18** from its idle position to a clamped position, wherein the gauge tool **95** is clamped at a first evaluation point **80**, and generates a first signal **78**, representing the first distance D_1. The welding horn **18** may be instructed by the host machine **38** to move away from the welding anvil **20** and back to its idle position, such that the gauge tool **95** is moved and placed at the second evaluation point **84**, by an operator. The LVDT displacement sensor **40** then measures the displacement of the welding horn **18** from its idle position to its clamped position on the gauge tool **95** at the second evaluation point **84** and generates a second signal **82**, representing the second distance D_2.

The host machine **38** may calculate the misalignment value by calculating the difference between the first distance D_1 and the second distance D_2. The host machine **38** can then execute a first control action **301** with respect to the welding equipment **12** when the misalignment value exceeds the corresponding predetermined threshold operating value defined by the first look-up table **90**. If the misalignment value exceeds the predetermined threshold operating value, the host machine **38** will output or transmit a control signal **50***a* to an external device **52** to indicate the status condition of the vibration welding equipment **12** as misaligned, and thereby temporarily stop the vibration welding process **68** until the welding equipment **12** is re-aligned by an operator. The operator may then, realign the welding horn **18** with respect to the welding anvil **20** and upon realignment initiate the restart of the vibration welding process. If the misalignment value does not exceed the predetermined threshold, the host machine **38** will instruct the robot **72** to return the vibration weld equipment **12** to the conveyor **70**, such that the vibration welding process may proceed.

In all embodiments, the welding horn **18** should be aligned properly with respect to the work piece **14** and the welding anvil **20**. If not properly aligned, welding might occur differently in one part of the welding horn **18** relative to another. For example, if misaligned, the welding horn **18** may create a weld at the first evaluation point **80** and not at the second evaluation point **84** (FIG. **4**B), assuming the latter is not contacting the work piece with sufficient force due to misalignment. Conversely, as shown in FIG. **4**A, if misaligned the welding horn **18** may create a weld at the second evaluation point **84** and not at the first evaluation point **80**, assuming the latter is not contacting the work piece with sufficient force due to misalignment.

Another embodiment may include taking multiple readings at multiple positions between the first evaluation point **80** and the second evaluation point **84** and performing a least squares regression operation to determine the amount of misalignment.

With reference again to FIGS. **4**C, **4**D, and **5**C, when the status condition is the wear or degradation of the welding equipment **12**, the host machine **38** may instruct the welding horn **18** to clamp the gauge tool **95** between the weld horn **18** and the welding anvil **20** at the gauge tool free ends **98**, **99** with as much pressure as needed to take an accurate reading. Generally, the clamping pressure used to clamp the gauge tool **95** should be less than the full clamping pressure used for welding to protect the gauge tool **95** and/or the welding horn **18** and welding anvil **20**.

The LVDT displacement sensor **40** measures the displacement of the welding horn **18** from its idle position to its clamped position, wherein the gauge tool **95** is clamped at a first evaluation point **80**, defined in this instance as one of the weld pads **24***a*, **24***b*. The LVDT displacement sensor **40** then generates a first signal **78**, representing the first distance D_1. The welding horn **18** may be instructed by the host machine **38** to move away from the welding anvil **20** to its idle position, such that the gauge tool **95** may be moved and placed at the second evaluation point **84**, by an operator. In this instance the second evaluation point is defined as one of the smooth surfaces **81**, **83** proximate the weld pads **24***a*, **24***b*. The LVDT displacement sensor **40** then measures the displacement of the welding horn **18** from its idle position to its clamped position on the gauge tool **95** at the second evaluation point **84** and generates a second signal **82**, representing the second distance D_2.

The host machine **38** may calculate the difference between the first distance D_1 and the second distance D_2, i.e., the respective weld pad **24***a*, **24***b* thickness value. A substantially reduced thickness indicates tool wear, which may require the tool to be replaced. If the thickness of the respective weld pad **24***a*, **24***b* falls below the corresponding predetermined operating threshold value defined by the second look-up table **92**, the host machine **38** will output or transmit a control signal **50***b* to an external device **52** to indicate the status condition of the vibration welding equipment **12** as worn, and thereby temporarily stop the vibration welding process **68** until the welding horn **18** is replaced by an operator. The operator may then replace the welding horn **18** and initiate the restart of the vibration welding process. If the thicknesses of the respective weld pads **24***a*, **24***b* do not fall below the corresponding predetermined operating threshold values defined by the second look-up table **92**, the host machine **38** will instruct the robot **72** to return the vibration welding equipment **12** to the conveyor **70**, such that the vibration welding process may proceed.

In another example embodiment as shown in FIGS. **7**A and **7**B, the at least one displacement sensor **40** may be a plurality of precision measurement sensors **46**, **48** inserted between the welding horn **18** and welding anvil **20**. The host machine **38** may be programmed to move the welding horn **18** into a finite position with respect to the anvil **20**, having the precision measurement sensors **46**, **48** disposed therebetween. The first precision measurement sensor **46** being disposed at the first evaluation point **80** and the second precision measurement sensor **48** disposed at a second evaluation point **84**. The first precision measurement sensor **46** will then generate the first signal **78** representing the distance between the welding horn **18** and the welding anvil **20** at the first evaluation point **80**. The second precision measurement sensor **48** will then generate the second signal **82** representing the distance between the welding horn **18** and the welding anvil **20** at the second evaluation point **84**.

When the status condition is alignment of the vibration welding equipment **12**, in one instance, the first evaluation point **80** is defined as the first weld pad **24***a*, and the second evaluation point is defined as the second weld pad **24***b*. In a second instance, the first evaluation point **80** is defined as the smooth surface **81** proximate the first weld pad **24***a*, and the second evaluation point **84** is defined as the smooth surface **83** proximate the second weld pad **24***b*.

When the status condition is the wear or degradation of the welding equipment **12**, in one instance, the first evaluation point **80** is defined as the first weld pad **24***a*, and the second evaluation point is defined as the smooth surface **81** proximate the first weld pad **24***a*. In a second instance, the first evaluation point **80** is defined as the second weld pad **24***b*, and the second evaluation point **84** is defined as the smooth surface **83** proximate the second weld pad **24***b*.

An example embodiment of the present method **200** will now be described with reference to FIG. **8**. Commencing at step **201**, the vibration welding process **68** proceeds in the typical manner. For instance, when manufacturing multi-cell batteries of the type shown in FIG. **2**, the conveyor **70** of FIG. **3** may move the work pieces **14** to place them in front of the robot **72** shown in the same Figure. The welding horn **18** and the welding anvil **20** of FIG. **1** routinely clamp onto the work piece **14** and form the required welds. During step **201**, the host machine **38** determines a first time period, by referencing a timer, clock, or other time keeping device. The first time period represents the amount of time elapsed since an evaluation of a status condition of the vibration welding equipment **12** was completed, such that the status condition is one of welding equipment alignment and welding equipment wear or degradation. Further, at step **201**, the host machine **38** simultaneously determines a number of welds performed, by referencing a counter or the like, since an evaluation of the status condition of the vibration welding equipment **12** was completed.

At step **202**, the host machine **38** repeatedly compares the first time period determined at step **201** to a predetermined threshold time period programmed into the host machine **38** and written on the tangible non-transitory memory **44** thereof. The predetermined time period may be, for example, the length of a work shift, or a more discrete time value such as a predetermined number of hours or minutes. Additionally, the host machine **38** simultaneously repeatedly compares the number of welds performed, as determined in step **201**, to a predetermined threshold number of welds programmed into the host machine **38** and written on the tangible non-transitory memory **44** thereof.

At step **203**, the host machine **38** determines if at least one threshold condition is met, i.e., at least one of the following is true: 1) the first time period exceeds the predetermined threshold time period; and 2) the number of welds exceeds the predetermined threshold number of welds. In some embodiments, step **203** may also be triggered manually, e.g., by an operator at the beginning or end of a shift. If the host machine **38** determines that the threshold condition has been met, i.e., the requisite amount of time has elapsed or the requisite number of welds have been performed, the method **200** proceeds to step **204**. Otherwise, if neither threshold condition is met at step **203**, steps **202** and **203** are repeated until at least one of the threshold conditions is met.

If at least one of the threshold conditions is met, the method **200** proceeds to step **204**. At step **204**, the host machine **38** commands the welding robot **72** (shown in FIG. **3**) to move the welding horn **18** and the welding anvil **20**, collectively the welder device **16** (shown in FIG. **1**) to the check station **74** for evaluation. As part of step **204**, the conveyor **70** of the FIG. **3** is temporarily stopped.

At step **205**, the welding horn **18** and the welding anvil **20** are repositioned at the check station by the welding robot **72**. The method **200** proceeds to step **206** when the robot **72** has moved the welder device **16** into position at the check station **74**.

At step **206**, the at least one displacement sensor **40**, measures the first distance D_1 at the first evaluation point **80** and returns a first signal **78** representing the first distance D_1 to the host machine **38**.

At step **207**, the at least one displacement sensor **40**, measures the second distance D_2 at the second evaluation point **84** and returns a second signal **82** representing the second distance D_2 to the host machine **38**, as described herein above.

At step **208**, the host machine **38** calculates the difference between the first distance D_1 and the second distance D_2, as described herein above.

At step **209**, the host machine **38** evaluates the difference between the first distance D_1 and the second distance D_2 by comparing the difference between the first distance D_1 and the second distance D_2 to one of a plurality of look-up tables **90**, **92** representing accepted operating values for the difference between the first distance D_1 and the second distance D_2.

When the status condition is the alignment of the vibration welding equipment **12**, the difference is defined as a misalignment value. In such an instance the difference between the first distance D_1 and the second distance D_2 is compared to predetermined threshold operating values in a first look up table **90**. If the misalignment value does not exceed the corresponding predetermined threshold operating value defined by the first look-up table **90**, the host machine **38** commands the robot **72** to return the welder device **16** to the conveyor **70** so that the welding process **68** may continue. As such, the method **200** returns to step **202** and completes method steps **202-209**. If the misalignment value does exceed the corresponding predetermined threshold operating value defined by the first look-up table **90**, the host machine **38** executes a first control action **301** with respect to the welding equipment **12**. The first control action **301** includes outputting or transmitting a control signal **50***a* to the external device **52** to indicate the condition of the vibration welding equipment as misaligned and temporarily stopping the vibration welding process **68** until the welding equipment is re-aligned by an operator. Upon alignment of the welding horn **18** with respect to the welding anvil **20**, the operator may signal or initiate the restart of the vibration welding process.

When the status condition is the wear or degradation of the vibration welding equipment **12**, the difference is defined as the thickness of a respective weld pad **24***a*, **24***b*. In such an instance, the difference between the first distance D_1 and the second distance D_2 is compared to predetermined threshold operating values in a second look up table **92**. If the measured weld pad **24***a*, **24***b* thicknesses does not fall below the corresponding predetermined threshold operating value defined by the second look-up table **92**, the host machine **38** commands the robot **72** to return the welder device **16** to the conveyor **70** so that the welding process **68** may continue. As such, the method **200** returns to step **202** and completes steps **202-209**. If the measured weld pad **24***a*, **24***b* thicknesses does fall below the corresponding predetermined threshold operating value defined by the second look-up table **92**, the host machine **38** executes a second control action **302** with respect to the welding equipment **12**. The second control action **302** includes outputting or transmitting a control signal **50***b* to an external device **52** from the host machine **38** to indicate the condition of the vibration welding equipment as worn or in need of replacement. The host machine **38** temporarily stops the vibration welding process **68** until the welding horn **18** is replaced by an

operator. Upon replacement of the welding horn **18**, the operator may signal or initiate the restart of the vibration welding process.

Additional control actions may be taken, alone or concurrently with those noted above, including activating the external device **52** shown in FIG. **1** via additional control signals such as illuminating a light, transmitting a maintenance message, and the like.

While the best modes for carrying out the disclosure have been described in detail, those familiar with the art to which this disclosure relates will recognize various alternative designs and embodiments for practicing the disclosure within the scope of the appended claims.

The invention claimed is:

1. A method of monitoring a status condition of vibration welding equipment, wherein the vibration welding equipment includes a welding horn and a welding anvil, the method comprising:

determining, via a host machine, a first time period representing the amount of time elapsed since an evaluation of the status condition of the vibration welding equipment was completed and determining the number of welds performed since an evaluation of the status condition of the vibration welding equipment was completed;

repeatedly comparing, via the host machine, the first time period to a predetermined threshold time period and repeatedly comparing the number of welds performed to a predetermined threshold number of welds;

determining, via the host machine, if a threshold condition is met, wherein the threshold condition is met when at least one of the first time period exceeds the predetermined threshold time period and the number of welds exceeds the predetermined threshold number of welds;

commanding, with a host machine, a welding robot to move the welding horn and the welding anvil to a check station when the threshold condition is met;

repositioning the welding horn and welding anvil at the check station, with the welding robot;

measuring, with at least one displacement sensor, a first distance between the welding horn and the welding anvil at a first evaluation point and returning a first signal representing the first distance to the host machine, wherein the at least one displacement sensor is disposed at the check station;

measuring, with the at least one displacement sensor, a second distance between the welding horn and the welding anvil at a second evaluation point and returning a second signal representing the second distance to the host machine;

calculating, via the host machine, a difference between the first distance and the second distance, wherein the status condition corresponds to the difference between the first distance measured by the at least one displacement sensor and the second distance measured by the at least one displacement sensor;

evaluating, via the host machine, the calculated difference between the first distance and the second distance by comparing the calculated difference between the first distance and the second distance to a plurality of threshold operating values for the calculated difference between the first distance and second distance contained in one of a first look-up table and second look-up table; and

executing a control action with respect to the vibration welding equipment when the difference between the first distance and the second distance exceeds the corresponding threshold operating value contained in one of the first look-up table and the second look-up table.

2. The method of claim **1** wherein the monitored status condition is the alignment of the welding horn with respect to the welding anvil, and wherein the calculated difference between the first distance and the second distance defines a misalignment value.

3. The method of claim **2** wherein the first evaluation point is a first weld pad and the second evaluation point is a second weld pad, the first and second weld pads disposed on the welding horn.

4. The method of claim **2** wherein the first evaluation point is a designated smooth surface of the welding horn located at a first side of the welding horn, proximate a first weld pad, and the second evaluation point is a smooth surface of the welding horn located at a second side of the welding horn, proximate a second weld pad.

5. The method of claim **2** wherein the control action is a first control action, which includes:

transmitting a control signal to an external device to indicate the status condition of the vibration welding equipment, when the misalignment value exceeds a predetermined threshold defined by the first look-up table; and

stopping a vibration welding process until the welding equipment is aligned.

6. The method of claim **5** further including:

aligning the welding horn with respect to the welding anvil; and

restarting the vibration welding process when the welding horn is aligned.

7. The method of claim **1** wherein the status condition is the degradation of a plurality of weld pads disposed on the welding horn.

8. The method of claim **7** wherein the first evaluation point is at one of a plurality of weld pads and the second evaluation point is a smooth surface of the welding horn, proximate the respective weld pad, such that the difference between the first distance and the second distance indicates the thickness of the respective weld pad.

9. The method of claim **7** wherein the control action is a second control action, which includes:

transmitting a control signal to an external device to indicate the status condition of the vibration welding equipment as worn, when the thickness of the respective weld pad falls below a predetermined threshold operating value defined by the second look-up table; and

stopping a vibration welding process until the welding horn is replaced.

10. The method of claim **9** further including:

replacing the welding horn; and

restarting the vibration welding process when the welding horn is replaced.

11. The method of claim **1** wherein the at least one displacement sensor is a plurality of precision mechanisms for measuring displacement, such that the plurality of precision mechanisms includes at least a first precision mechanism and a second precision mechanism.

12. The method of claim **11** wherein measuring the first distance at the first evaluation point further includes inserting the first precision mechanism between the welding anvil and the welding horn at the first evaluation point, such that the first precision mechanism evaluates the distance between the welding horn and the welding anvil at the evaluation point and generates the first signal; and

wherein measuring the second distance between at the second evaluation point further includes inserting the second precision mechanism between the welding anvil and the welding horn at the second evaluation point, such that the second precision mechanism evaluates the distance between the welding horn and the welding anvil at the second evaluation point and generates the second signal.

13. A vibration welding system comprising:

vibration welding equipment including a welding horn and a welding anvil, the vibration welding equipment configured to form a weld on a work piece clamped between the welding horn and the welding anvil;

a check station;

a welding robot having an arm on which the welding horn and the welding anvil are disposed, wherein the welding robot is configured to selectively move the welding horn and the welding anvil to the check station to determine a status condition of the vibration welding equipment;

at least one displacement sensor disposed at the check station, the at least one displacement sensor configured to measure a first distance between the welding horn and the welding anvil at a first evaluation point and measure a second distance between the welding horn and welding anvil at a second evaluation point;

a host machine in communication with the at least one displacement sensor, wherein the host machine includes a processor and tangible, non-transitory memory on which is recorded instructions for monitoring the vibration welding equipment to determine the status condition;

wherein the host machine is configured to execute the recorded instructions from the memory, such that executing the recorded instructions causes the processor to:

determine a first time period representing the amount of time elapsed since an evaluation of the status condition of the vibration welding equipment was completed and determine the number of welds performed since an evaluation of the status condition of the vibration welding equipment was completed;

repeatedly compare the first time period to a predetermined threshold time period and repeatedly compare the number of welds performed to a predetermined threshold number of welds;

determine if a threshold condition is met, such that the threshold condition is met when at least one of the first time period exceeds the predetermined threshold time period and the number of welds exceeds the predetermined threshold number of welds;

command the welding robot to move the welding horn and the welding anvil to the check station, when the threshold condition is met;

receive a first signal from the at least one displacement sensor representing the first distance between the welding horn and welding anvil, at the first evaluation point;

receive a second signal from the at least one displacement sensor representing the second distance between the welding horn and the welding anvil, at the second evaluation point;

calculate a difference between the first distance and the second distance, wherein the status condition corresponds to the calculated difference between the first distance measured by the at least one displacement sensor and the second distance measured by the at least one displacement sensor;

evaluate the calculated difference between the first distance and the second distance by comparing the calculated difference between the first distance and the second distance to one of a first look-up table and a second look-up table, each of the respective look-up tables representing a plurality of threshold operating values for the difference between the first distance and second distance; and

execute a control action with respect to the vibration welding equipment when the difference between the first distance and the second distance exceeds the corresponding threshold operating value contained in one of the first look-up table and the second look-up table.

14. The vibration welding system of claim **13** wherein the monitored status condition is the alignment of the welding horn with respect to the welding anvil, such that the first evaluation point is a first weld pad disposed on the welding horn and the second evaluation point is a second weld pad disposed on the welding horn, and wherein the calculated difference between the first distance and the second distance defines a misalignment value.

15. The vibration welding system of claim **14**, wherein the control action is a first control action, which includes:

transmitting a control signal to an external device to indicate a condition of the vibration welding equipment, when the misalignment value exceeds the respective predetermined operating threshold value defined by first look-up table; and

stopping a vibration welding process until the welding horn is aligned with the welding anvil.

16. The vibration welding system of claim **13** wherein the monitored status condition is the degradation of a plurality of weld pads disposed on the welding horn, such that the first evaluation point is at one of a plurality of weld pads and the second evaluation point is at a smooth surface of the welding horn proximate the respective weld pad, such that the calculated difference between the first distance and the second distance indicates the thickness of the respective weld pad.

17. The vibration welding system of claim **16** wherein the control action is a second control action, which includes:

transmitting a control signal to an external device to indicate a condition of the vibration welding equipment, when the thickness of the respective weld pad falls below the respective predetermined operating threshold value defined by the second look-up table; and

stopping a vibration welding process until the welding horn is replaced.

18. The vibration welding system of claim **13** wherein the at least one displacement sensor is a plurality of precision mechanisms for measuring displacement, such that the plurality of precision mechanisms includes at least a first precision mechanism and a second precision mechanism.

19. The vibration welding system of claim **18** wherein measuring the first distance at the first evaluation point further includes inserting the first precision mechanism between the welding anvil and the welding horn at the first evaluation point, such that the first precision mechanism evaluates the distance between the welding horn and the welding anvil at the first evaluation point and generates the first signal; and

wherein measuring the second distance at the second evaluation point further includes inserting the second

precision mechanism between the welding anvil and the welding horn at the second evaluation point, such that the second precision mechanism evaluates the distance between the welding horn and the welding anvil at the second evaluation point and generates the second signal.

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