US 20130105557A1

(54) **QUALITY STATUS DISPLAY FOR A VIBRATION WELDING PROCESS**

(71) Applicant: **GM GLOBAL TECHNOLOGY OPERATIONS LLC**, Detroit, MI (US)

(72) Inventors: **John Patrick Spicer**, Plymouth, MI (US); **Jeffrey A. Abell**, Rochester Hills, MI (US); **Michael Anthony Wincek**, Rochester, MI (US); **Debejyo Chakraborty**, Sterling Heights, MI (US); **Jennifer Bracey**, Holly, MI (US); **Hui Wang**, Highland, MI (US); **Peter W. Tavora**, Sterling Heights, MI (US); **Jeffrey S. Davis**, Grand Blanc, MI (US); **Daniel C. Hutchinson**, Goodrich, MI (US); **Ronald L. Reardon**, Fenton, MI (US); **Shawn Utz**, Washington Twp., MI (US)

(73) Assignee: **GM GLOBAL TECHNOLOGY OPERATIONS LLC**, Detroit, MI (US)

(21) Appl. No.: **13/624,233**

(22) Filed: **Sep. 21, 2012**

Related U.S. Application Data

(60) Provisional application No. 61/551,665, filed on Oct. 26, 2011.

Publication Classification

(51) **Int. Cl.**
B23K 20/10 (2006.01)
(52) **U.S. Cl.**
USPC **228/104**; 228/56.5; 228/1.1
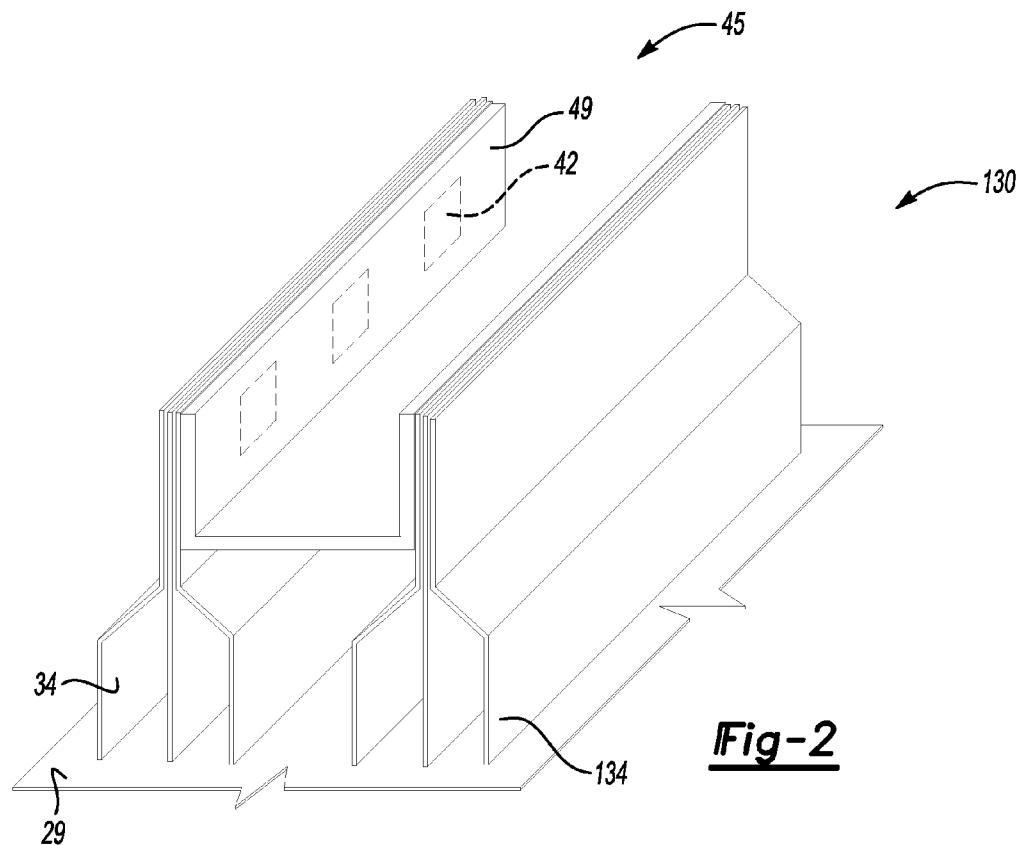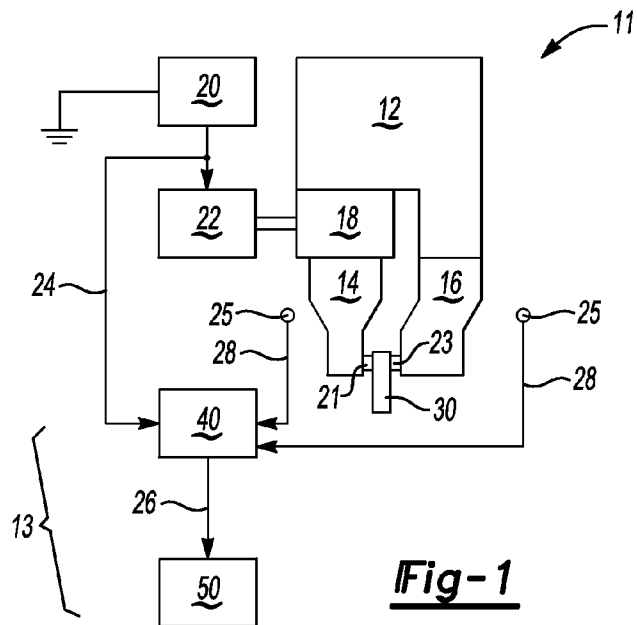
(57) **ABSTRACT**

A system includes a host machine and a status projector. The host machine is in electrical communication with a collection of sensors and with a welding controller that generates control signals for controlling the welding horn. The host machine is configured to execute a method to thereby process the sensory and control signals, as well as predict a quality status of a weld that is formed using the welding horn, including identifying any suspect welds. The host machine then activates the status projector to illuminate the suspect welds. This may occur directly on the welds using a laser projector, or on a surface of the work piece in proximity to the welds. The system and method may be used in the ultrasonic welding of battery tabs of a multi-cell battery pack in a particular embodiment. The welding horn and welding controller may also be part of the system.

Fig-1

Fig-2

**Fig-3**
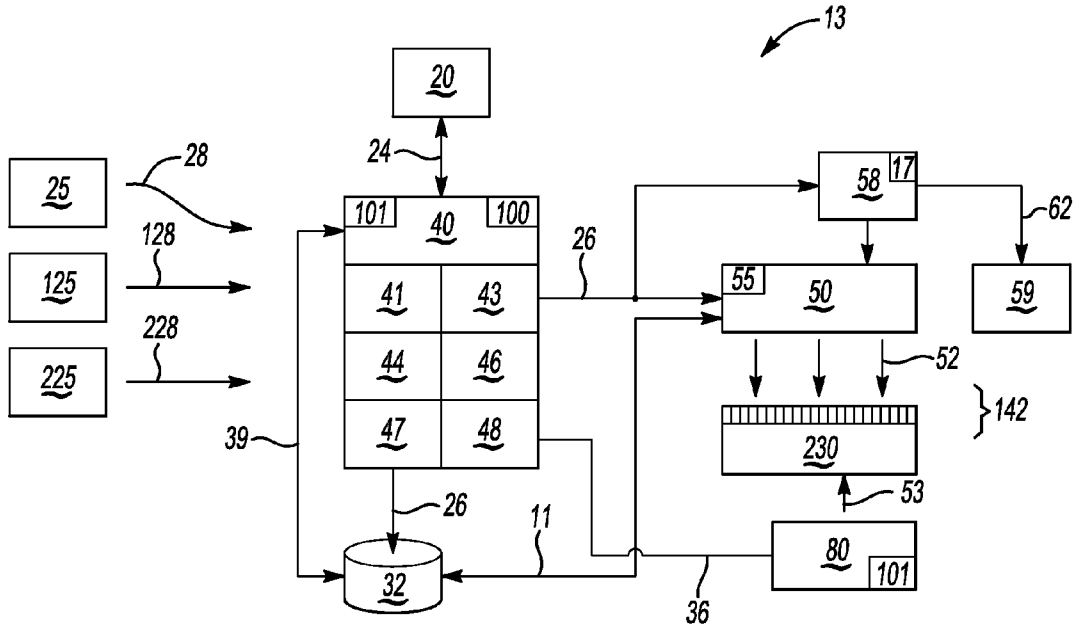

**Fig-4**

100

102

104
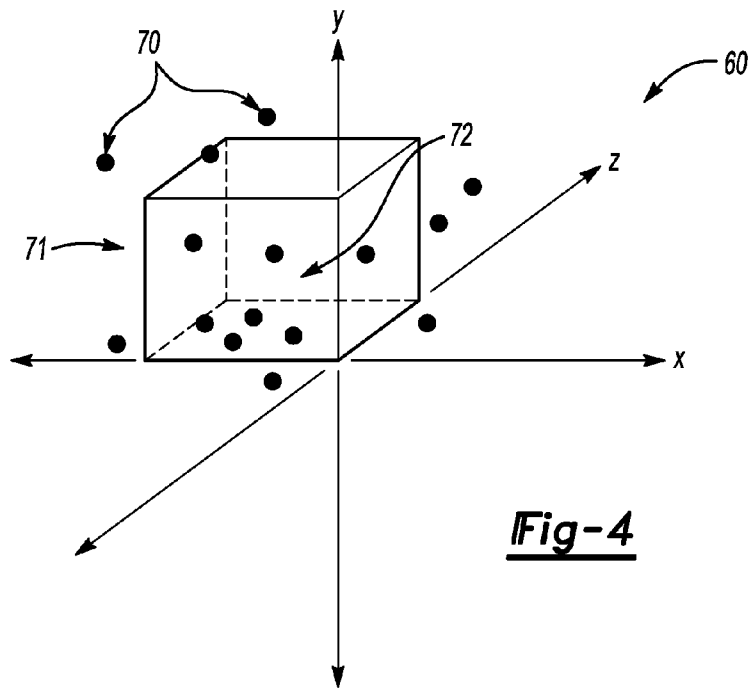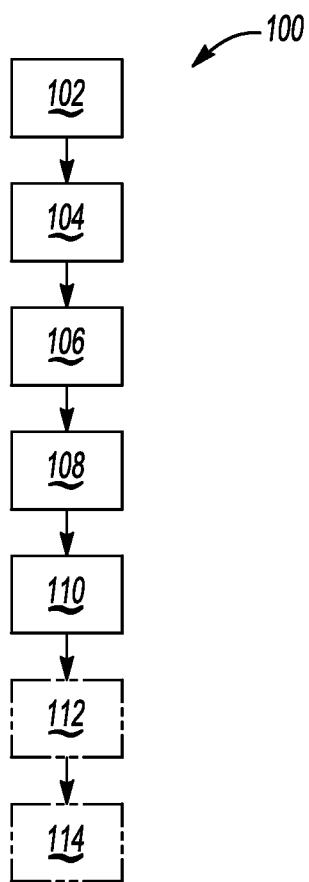
106

108

110

112

114

Fig-5

QUALITY STATUS DISPLAY FOR A VIBRATION WELDING PROCESS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims the benefit of U.S. Provisional Application Ser. No. 61/551,665, which was filed on Oct. 26, 2011, and which is hereby incorporated by reference in its entirety.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] This invention was made with U.S. Government support under an Agreement/Project DE-EE0002217, Department of Energy Recovery and Reinvestment Act of 2009, Battery Pack Manufacturing B511. The U.S. government may have certain rights in this invention.

TECHNICAL FIELD

[0003] The present disclosure relates to the display of weld quality status in a vibration welding process.

BACKGROUND

[0004] The process of vibration welding involves the controlled application of high frequency vibration energy to a clamped work piece. Surface friction generates heat at a weld interface, which ultimately softens and bonds adjacent work piece surfaces at the interface. The efficiency, consistency, and long term reliability/durability of a vibration welded assembly depends largely on the welding tools and control methodology used to form the various welds.

[0005] Various closed-loop parameter-based control techniques are typically applied during a vibration welding process to keep certain weld parameters within calibrated limits. This approach can produce reasonably consistent welding parameters over time. However, stable welding process parameters may still fail to produce welds of a consistently high quality. In addition, external factors such as material quality can also impact weld quality. Moreover, a premature failure of just one weld can affect the performance of a welded system. It is therefore common practice in such systems to determine weld integrity by visual inspection and a laborious process known as picking, wherein each of the formed welds is physically tested by an operator using a picking tool.

SUMMARY

[0006] A vibration welding monitoring system and method are disclosed herein that can be used in conjunction with a vibration welding process. An example work piece whose manufacturing process may be enhanced by the present approach is a multi-cell battery module having a series of welded battery cell tabs. Such a battery module may be configured for use as a power source, e.g., for an electric traction motor aboard an electric, hybrid electric, or extended-range electric vehicle. While the present approach is not limited to weld process monitoring of battery cell tabs, the battery module described herein is representative of the type of system in which the present invention may have utility. Therefore, an example battery module is used throughout the remainder of this disclosure for illustrative consistency.

[0007] In particular, a system is disclosed herein that includes a host machine and a status projector. The host machine is in electrical communication with a collection of sensors that generates one or more sensory signals describing various aspects of the welding process, and with a welding controller that generates control signals for controlling the welding horn. The host machine processes the sensory and control signals to predict a quality status of welds that are formed using the welding horn, possibly including identifying any suspect welds. The host machine then activates the status projector to display the predicted quality status of the welds on or adjacent to the welds.

[0008] A method is also disclosed herein that includes receiving a set of sensory signals from the sensor(s) during formation of one or more welds on or within a work piece. The method also includes receiving control signals from a welding controller of the vibration welding system, with the control signals causing the welding horn to vibrate at a calibrated frequency. The host machine predicts the quality status of the various welds being formed. The predicted quality status is thereafter displayed on a surface of the work piece using the status projector.

[0009] Another system is disclosed that also includes the welding horn, the welding controller, and the collection of sensors.

[0010] The above features and advantages and other features and advantages of the present invention are readily apparent from the following detailed description of the best modes for carrying out the invention when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 is a schematic illustration of a monitoring system for a vibration welding process configured as disclosed herein.

[0012] FIG. 2 is a schematic perspective view illustration of a portion of an example multi-cell battery module whose weld quality may be monitored and predicted in real-time via the monitoring system shown in FIG. 1.

[0013] FIG. 3 is another schematic illustration of the monitoring system shown in FIG. 1.

[0014] FIG. 4 is an example diagram of a mapped set of extracted features in multiple dimensions.

[0015] FIG. 5 is a flow chart describing an example method for monitoring and indicating weld quality in a vibration welding process.

DETAILED DESCRIPTION

[0016] Referring to the drawings, wherein like reference numbers refer to like components throughout the several Figures, a vibration welding system 11 is shown schematically in FIG. 1. The vibration welding system 11 includes a welding assembly 12 and a monitoring system 13. The monitoring system 13 is in communication with the welding assembly 12. Use of the monitoring system 13 is intended to improve production efficiency by substantially eliminating instances of false accepts during a vibration welding process, and by reducing the need for direct manual inspection or picking of every weld in a completed assembly.

[0017] The welding assembly 12 shown in FIG. 1 includes a sonotrode/welding horn 14 and an anvil 16, along with other welding tools and components as described below. The monitoring system 13 is configured to monitor various control signals provided by a power supply/welding controller 20 and/or measured by a collection of sensors 25 positioned with

respect to the welding apparatus **12**. The monitoring system **13** predicts, online and in real time, whether the welding assembly **12** has produced an objectively passing/good weld or a suspect weld. The suspect welds may then be subjected to direct end-of-line inspection, such as manual picking or other testing of the weld, to verify the presence of and isolate any unsatisfactory/bad welds. The verified bad welds may be marked and imaged as explained below with reference to FIG. **3**.

[0018] The monitoring system **13** of FIG. **1** may include a status projector **50** and an optional display **59** (see FIG. **3**). The status projector **50** interacts with a host machine **40** and a work piece **30** by illuminating any suspect welds. The status projector **50** may optionally highlight good welds. Such highlighting may be performed directly on the weld itself or on another surface of the work piece **30**, for instance adjacent to the weld, upon formation of the welds. The structure and function of the status projector **50** is described in more detail below with reference to FIG. **3**.

[0019] As will be understood by those of ordinary skill in the art, a welding controller/power supply used for vibration welding, such as the welding controller **20** of FIG. **1**, may be electrically-connected to a suitable energy source, typically a 50-60 Hz wall socket. The welding controller **20** may include, for example, voltage rectifiers, transformers, power inverters, and/or other hardware which ultimately transforms the source power, whatever its form, into vibration control signals (arrow **24**). The control signals (arrow **24**) 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. Other process information may be included in the control signals (arrow **24**), including but not limited to power traces, displacement of the horn **14**, vibration frequency, trigger signals, parameter limit alarms, weld controller fault information, etc., as is well understood in the art.

[0020] Still referring to FIG. **1**, the welding system **11** may include a converter **22** having mechanical structure sufficient for producing a mechanical vibration of the horn **14** in response to the control signals (arrow **24**). The horn **14** typically includes a knurl pattern **21**, typically bumps and/or ridges, which are suitable for gripping and holding the work piece **30** when the work piece **30** is clamped between the horn **14** and anvil **16**. The anvil **16** typically includes a similar knurl pattern **23**. The welding system **11** of FIG. **1** may also include a booster **18**, i.e., an amplifier, which increases the amplitude of any commanded mechanical vibration from the welding controller **20** as needed.

[0021] Within the monitoring system **13** shown in FIG. **1**, the host machine **40** receives various signals from the sensors **25** positioned with respect to the welding assembly **12**. The specific functionality and structure of the host machine **40** is described in greater detail below with reference to FIGS. **3** and **5**. In general terms, the host machine **40** is a computer device in electrical communication with the welding controller **20**. The host machine **40** is continuously apprised, via receipt of the control signals (arrow **24**), of instantaneous values of any waveforms transmitted to the horn **14** by the welding controller **20**, as well as of other values known by or internal to the welding controller **20**. The collection of sensors **25** is "external" with respect to the internally-generated control signals (arrow **24**) from the welding controller **20**, and therefore is referred to hereinafter as the external sensors **25**. The host machine **40** shown in FIG. **1** thus receives a set of external signals (arrows **28**) from the external sensors **25** and internal control signals (arrow **24**) from the welding controller **20**. The host machine **40** then processes the signals (arrows **24**, **28**) to predict the quality of the weld being formed.

[0022] In an example embodiment, the host machine **40** may automatically extract a preliminary set of (n) signal features and map a predetermined number of the extracted signal features, or alternatively another feature which is determined as a function of the predetermined number of features, to a dimensional space having demarcated pass/suspect boundaries, a process referred to hereinafter as a box-void method. The host machine **40** then predicts the weld quality of the weld from the map. Other approaches may be used to predict quality of a weld without departing from the intended inventive scope, e.g., threshold comparisons, neural network processing, etc. Example extraction and mapping steps for a basic box-void method are described in detail below with reference to FIGS. **3** and **4**.

[0023] However it is determined, the predicted weld quality may be provided as an output signal (arrow **26**) to the status projector **50**, whereupon the predicted quality of a given weld is visually indicated, e.g., via direct projection of a beam of light onto the work piece **30**. The status display process is also described below with reference to FIG. **3**.

[0024] Referring to FIG. **2**, a non-limiting example embodiment of the work piece **30** of FIG. **1** is a multi-cell battery module **130** having an elongated conductive interconnecting member **45**. For illustrative simplicity, only a portion of the battery module **130** is shown, however the battery module **130** as a whole may include an extended series of interconnecting members **45** arranged side by side in one or more rows. Each interconnecting member **45** joins oppositely-charged battery cell tabs **34**, **134**, of adjacent battery cells, with the battery cell tabs **34**, **134** forming individual electrode extensions of a given battery cell.

[0025] Each cell tab **34**, **134** is internally-welded, below an interconnect board **29** of the battery module **130**, to the various anodes or cathodes comprising that particular battery cell, as is well understood by those of ordinary skill in the art. Multiple battery modules **130** may be arranged to form a complete battery pack of the type used to power an electric traction motor in a vehicle, or in other relatively high-power applications. The interconnecting member **45** may be constructed of a suitable conductive material, e.g., copper and/or nickel, to form a conductive rail for completing an electric circuit. Each interconnecting member **45** is positioned adjacent to the interconnect board **29** of the battery module **130**.

[0026] The battery cell tabs **34**, **134** extending from the interconnect board **29** may be ultrasonically welded to a longitudinal side wall **49** of a given interconnecting member **45**, with substantially identical welds **42** formed at each interconnecting member **45** that is used in constructing the overall battery module **130**. The high number of outwardly identical welds **42**, e.g., on a series of substantially identical interconnecting members **45**, is a structural feature that may be monitored effectively using the system **11**.

[0027] Referring to FIG. **3**, the present monitoring system **13** is described in greater detail as it may be used for predicting weld quality in a work piece **230**, e.g., a multi-cell battery pack having an extended weld series **142** of outwardly identical welds. The host machine **40** may include a microprocessor/CPU **47** and a tangible, non-transitory memory device **48** possibly including read only memory (ROM), optical, and/or other magnetic memory. The host machine **40** may also

include transitory memory, e.g., any required random access memory (RAM), electrically-programmable read-only memory (EPROM), etc.

[0028] The host machine 40 may include additional circuitry such as a high-speed clock (not shown), analog-to-digital circuitry, digital-to-analog circuitry, a digital signal processor, and the necessary input/output devices and other signal conditioning and/or buffer circuitry. The host machine 40 is configured to execute process instructions embodying the present method 100, an example of which is shown in FIG. 5, from the memory device 48.

[0029] The host machine 40 of FIG. 3 may receive the control signals (arrow 24) from the welding controller 20 and other signals (arrows 28, 128, 228) from the external sensors 25, 125, and 225, respectively. As part of the control signals (arrow 24), the welding controller 20 may provide certain historical information such as welding power over time, welding frequency over time, and other possible waveforms or values, as well as peak values, slopes, areas, area ratios, moving averages, and the like.

[0030] In an example embodiment, one external sensor, e.g., the sensors 25, may be configured as an acoustic sensor, for instance a microphone or an acoustic emission sensor positioned in direct contact with a surface of a welding tool, e.g., the horn 14 of FIG. 1. The sensors 25 may measure the acoustic frequency of the vibrating horn 14 of FIG. 1 over time, with this value used by the host machine 40 as a base signal from which features may be extracted and modeled. Another example external sensor 125 may measure a changing linear displacement of the horn 14 of FIG. 1 over time. Yet another example external sensor 225 may be used to detect any other desirable value, such as changing welding temperature and/or other atmospheric information such as relative humidity that might affect weld quality. Each collection of sensors 25, 125, 225 may include one or more individual sensors as noted above.

[0031] The host machine 40 shown in FIG. 3 may include a recorded feature library 41. The CPU 47 processes the control signals (arrow 24) and the external signals (arrows 28, 128, 228) into one or more of the features that are contained in the recorded feature library 41. A preliminary set of signal features may be extracted, i.e., calculated or otherwise derived, for instance as a function of the base power, frequency, displacement, and acoustic signals provided from the welding controller 20 and/or from the various sensors 25, 125, or 225. The extracted features may be mapped as set forth below, or some/all of the extracted features may be combined to form another signal feature which is mapped.

[0032] Some non-limiting example extracted features include the total welding energy, i.e., the area under a power curve or input waveform commanded from the welding controller 20. Other extracted features may include the elapsed time in forming a given weld in the weld series 142, peak power, rise time, ramp rate, or even correlation data, for instance between the acoustic signal and the power signal. Any number of desired features may be extracted and used, either directly as extracted or indirectly by calculating a derived signal feature as a function of the extracted features, without departing from the intended inventive scope. However, as explained below, the more features that are extracted and used, the more complex the dimensional space needed for mapping these features, thus requiring more processing power.

[0033] The host machine 40 may also include a mapping module 43. The mapping module 43 includes computer-executable instructions, executable via the CPU 47, for processing the extracted features so as to identify the best subset of features that separates a good weld from a suspect weld. The mapping module 43 may also determine suitable upper and/or lower limits for any monitored features.

[0034] Referring briefly to FIG. 4, an example dimensional space 60 is shown as a simplified illustrative embodiment of an output generated, in the box-void method noted above, using the mapping module 43 shown schematically in FIG. 3. Various data points 70 are plotted, with each data point 70 representing a formed weld. Here, three features (n=3) are used to create an example three-dimensional space. As noted above, n features can be used to produce an n-dimensional space, although the n-features may be combined to form a number of signal features that may be less than n. Therefore, there may be a tradeoff between the number of extracted features and the resultant complexity of the processing steps undertaken by the mapping module 43 and CPU 47. Each dimension/axis x, y, and z shown in FIG. 4 corresponds to a separate feature, with the location of a given data point 70 described by its location with respect to each of the axes. No other spatial meaning is attributed to these particular designators.

[0035] A data point 70 corresponding to the feature set of a given weld is mapped to a dimensional space, e.g., the space 60, by the mapping module 43. Thus, each data point 70 in the 3D space example of FIG. 4 is defined by a triplet [x, y, z] in the three-feature example of the same Figure. Using arbitrary designations for additional axes, a four-axis example could be defined by a set [x, y, z, q], etc. The mapping module 43 of FIG. 3 may access the recorded feature library 41, information stored in memory device 48, and/or may otherwise determine calibrated limits for each feature. The upper/lower limits define the boundaries of the dimensional space 60, e.g., the cube 71 or a less/more complex geometric shape in other embodiments mapping fewer/more than three features, respectively. It is also possible that each feature is bounded in only one direction, for instance having a lower limit with no upper limit or vice versa.

[0036] Referring again to FIG. 3, the host machine 40 may also include a training library 44. One may train the host machine 40 to recognize good and suspect welds by preloading previously-validated good and suspect data points 70 (see FIG. 4). These data points 70 can also be used to set the boundaries of the dimensional space used by the mapping module 43. The feature library 41 may include all of the data points 70 of FIG. 4 in the training library 44, or only some of these points. For example, if the corresponding weld quality of certain data points 70 is not known but may be knowable over time given a sufficient number of additional similar samples, the data points 70 of unknown quality may continue to reside in the training library 44 for some time until they are validated. Once validated, a new data point 70 in the training library 44 may be used to update the boundaries of the dimensional space.

[0037] The monitoring system 13 shown in FIG. 3 may also include a quality prediction module 46. Referring again to FIG. 4, the quality prediction module 46 of FIG. 3 may be embodied as a set of computer-executable instructions, recorded in memory device 48 and executable via the CPU 47, for comparing the location of a given data point 70 to the limits or boundaries of the dimensional space, e.g., the cube

71. If a data point **70** lies outside of the cube **71**, the quality prediction module **46** of FIG. **4** may designate these data points **70** as corresponding to a suspect weld. Likewise, if a data point **70** lies within the cube **71**, such as in the case of the data points **72**, the quality prediction module **46** may designate this data point **70** as corresponding to a good weld.

[0038] Referring again to FIG. **3**, as will be understood in the art, various tracking technologies exist which enable identification and tracking of a component as it moves through various production stages, for instance RFID tagging, such that the host machine **40** of FIGS. **1** and **3** may be informed as to the identity of the particular weld that is currently being formed. This allows the good/suspect status for each weld to be accurately tracked regardless of the number of welds formed before or after formation of that particular weld.

[0039] As noted above, the host machine **40** transmits a quality output signal (arrow **26**) which captures the status of a weld. Such a signal may be output by the quality prediction module **46** described above. The output signal (arrow **26**) may be transmitted to a programmable logic controller (PLC) **58**, with the good/suspect status viewable in real time by production operators via an associated human-machine interface (HMI) **17**, or captured and recorded in a database **32**. The PLC **58** is in two-way communication with the host machine **40**, e.g., via a data bus (not shown). The HMI **17** may be a touch-screen display so as to facilitate direct user interaction with the host machine **40**, the status projector **50**, the display **59**, and/or a camera **80** that executes image processing instructions **101**, and that is in communication with the host machine **40** over a bus **36**, or otherwise in communication with database **32**.

[0040] The database **32** of FIG. **3** is shown as a single device for simplicity. However, the database **32** may be embodied as a distributed database management system. For instance, the database **32** may be embodied as a data server storing a calibrated number of signal files from the external sensors **25**, **125**, **225** and/or the welding controller **20**, a data acquisition/DAQ database, a structured query library/SQL database containing metadata and quality data for a calibrated time period, etc. Any data in the database **32** may be extracted by the host machine **40**, as is indicated by double-headed arrow **39**.

[0041] The host machine **40** of FIG. **3** may also transmit the output signal **26** status to the status projector **50** and PLC **58**. As described above, certain types of work pieces, such as an assembled battery module **230** shown schematically in FIG. **3**, include a lengthy series of outwardly identical welds. These are collectively illustrated as a weld series **142**. Each weld in the weld series **142** is typically manually inspected in a laborious picking process after weld formation, wherein the various welds are physically pulled or prodded with a picking tool to stress the weld and thus directly verify weld quality. Use of the status projector **50** may help minimize the amount of time spent and ergonomic stresses of manually picking welds in the battery module **230**, and may facilitate or expedite the minimal picking of suspect welds that still occurs.

[0042] Specifically, the status projector **50** includes a processor **55**. The projector **50** displays status information using one or more light beams (arrows **52**) by projecting the light beams (arrows **52**) onto a surface, for instance on or adjacent to the work piece **230** on or adjacent to suspect welds in the weld series **142**. The status projector **50** may be embodied as a conventional light projector, or as a laser projector which projects concentrated or collimated beams of visible or other wavelengths of light as explained below.

[0043] The processor **55** receives the output signal (arrow **26**) from the PLC **58** and/or from the host machine **40**. The output signal (arrow **26**) may include the associated identifying information such as the serial number of the battery module **230** and identifying information for each weld in the weld series **142**. The processor **55** then projects a light beam(s) (arrows **52**) onto or adjacent to a weld. Optionally, display **59** may be placed in communication with the PLC **58** and positioned with respect to the work piece **230**, with text or other information (arrow **62**) from the PLC **58** presented via the display **59**, such as the weld status, serial number of the work piece **230**, alert messages, status information, etc.

[0044] For instance, a light beam (arrows **52**) may be projected onto a portion of the example interconnecting member **45** of FIG. **2**, or onto the weld **42** that is deemed to be suspect. The status projector **50**, when configured as an optional laser projector, may use a red/green/blue (RGB) laser projector to project a specific color laser indicating the suspect welds, or a gas laser with a switched color filter. The color of the beam should provide sufficient contrast with the materials onto which the light beam **52** is directed, with optional mixing of the beams (arrows **52**) enabling use of colors such as yellow, magenta, cyan, etc.

[0045] Using the light beams (arrows **52**) in this manner, line operators may be visually queued to the suspect welds. Other embodiments may be conceived, such as coating work piece surfaces, such as the interconnecting member **45** of FIG. **2**, with a fluorescent layer and using ultraviolet light rather than visible light as the light beams (arrows **52**). Visible light is then emitted from the irradiated surfaces similar to approaches used in certain heads up display (HUD) systems.

[0046] An example method **100** is shown in FIG. **5**. The method **100** may be embodied as computer-executable instructions that are executed by the host machine **40** of FIG. **3** and other components of the monitoring system **13** to monitor weld quality in a welded assembly, e.g., the example battery module **130** of FIG. **2**.

[0047] Beginning with step **102**, the work piece **30** of FIG. **1** is clamped into position between the horn **14** and the anvil **16**, and calibrated vibrations are applied to the clamped work piece **30**.

[0048] As step **102** is executed, the power supply **20** and the external sensors **25** measure certain parameters and environmental data at step **104**, with this information being relayed to and recorded by the host machine **40**.

[0049] At step **106**, the host machine **40** processes the received data, i.e., the control signals (arrow **24**) and the external signals (arrows **28**) of FIG. **1**, and predicts the quality of the weld being formed. Step **106** may entail execution of the box-void method noted above, or any other predictive approach, including possibly threshold parameters comparisons, neural network processing, and the like. Once the predicted quality of a given weld is recorded, the method **100** proceeds to step **108**.

[0050] At step **108**, the quality status is displayed on or adjacent to the welds of the work piece using the status projector **50**, e.g., by projecting light beams (arrows **52**) directly onto the welds from overhead or onto part of the interconnecting member **45** shown in FIG. **2**. The light beams (arrows **52**) visually highlight or indicate the suspect welds **42** directly on or adjacent to the welds **42**. The method **100** then proceeds to step **110**.

[0051] At step **110**, an inspector may manually pick the welds **42** that are indicated as being suspect at step **108**. The inspector may then records the locations of the welds **42** that are in fact unsatisfactory/bad, either as part of step **110** or by proceeding to optional step **112**.

[0052] At optional step **112**, as shown in phantom, the inspector may physically mark the confirmed bad welds from step **110**. Step **112** may entail physically placing stickers, imprints, paint, or any other suitable marker. The marker may be placed over or next to a confirmed unsatisfactory weld. As accurate identification of the weld locations is essential, the markers used in step **112** should be designed in such a way that the position of the placed marker can be readily and accurately determined via operation of the camera **80** and the image processing instructions **101**, even under varying lighting conditions. Likewise, the work piece, e.g., a battery section, should be located consistently in the field of view (arrow **53**) of the camera **80** to ensure that the locations of the welds are determined accurately. Alternatively, additional visual locating features can be added to the battery section to make locating of the part more accurate for the image processing instructions **101**. The method **100** then proceeds to optional step **114**.

[0053] At optional step **114**, the camera **80** may be used to image any marked bad welds **42** by executing the instructions **101**. The captured images of the confirmed bad welds are processed by executing the instructions **101**. Processing may include identifying the locations in or on the work piece of each confirmed bad weld, e.g., by comparing the location of the imaged markers to a baseline/calibrated image or using other position or pattern recognition techniques. The locations of the unsatisfactory welds may be recorded in the database **32** for use by a repair technician in a subsequent repair operation.

[0054] The repair technician may be restricted to updating of the repair status only of the unsatisfactory welds. For instance, the HMI **17** of the PLC **58** or another HMI may display the unsatisfactory weld locations and/or images of these welds instead of displaying all of the welds and allowing the technician to pick from a list of all welds. Given the number of welds in the weld series **142**, restriction of data entry to only confirmed unsatisfactory welds may reduce errors, such as by selecting the wrong weld location from a global list. If other positions require data entry, a warning message may be given to the repair person requesting manual confirmation of the position.

[0055] Communication may be made with the PLC **58** to indentify when a particular weld **42** has been identified for repair. Any such image displayed on the HMI **17** or other display should be taken such that buttons on the touch screen of HMI **17** properly with the location of weld positions in the image. This alignment can help ensure that image processing software of projector **50** or another device can confirm that the inspector/repair person is selecting the correct weld position when entering data on bad welds. Information on bad welds may be fed automatically via the HMI **17** to the host machine **40** of FIG. 1 to improve estimation/prediction results over time.

[0056] While the best modes for carrying out the invention have been described in detail, those familiar with the art to which this invention relates will recognize various alternative designs and embodiments for practicing the invention within the scope of the appended claims.

1. A system comprising:
   a host machine having a processor and tangible, non-transitory memory on which is recorded instructions for predicting a quality status of welds formed via a vibration welding process, wherein the host machine is in electrical communication with a collection of sensors and a welding controller; and
   a status projector in communication with the host machine;
   wherein the host machine is configured to execute the instructions using the processor to thereby:
      receive and process signals from the sensors and the welding controller;
      predict the quality status of each of the welds; and
      display the predicted quality status of the welds, on or adjacent to the welds, using the status projector.

2. The system of claim **1**, wherein the status projector includes a laser projector that illuminates the welds using a laser beam to display the predicted quality status.

3. The system of claim **2**, wherein the host machine predicts the quality status in part by predicting which of the welds are suspect welds, and wherein the laser projector projects the laser beam directly onto or immediately adjacent to the suspect welds.

4. The system of claim **3**, wherein the laser projector is one of a red, green, blue laser projector and a gas laser having a switched color filter.

5. The system of claim **3**, wherein the laser projector is an ultraviolet light projector.

6. The system of claim **1**, wherein the host machine is configured to map a predetermined number of signal features from the signals to a dimensional space having a number of dimensions that is equal to the predetermined number.

7. The system of claim **1**, further comprising a camera, wherein the camera is configured to image and identify the location of a physical marker positioned with respect to some of the welds.

8. A method comprising:
   receiving, during a vibration welding process, a set of sensory signals from a collection of sensors positioned with respect to a work piece during formation of a weld on or within the work piece;
   receiving control signals from a welding controller during the vibration welding process, wherein the control signals cause the welding horn to vibrate at a calibrated frequency;
   processing the received sensory and control signals using a host machine;
   predicting, via the host machine, a quality status of the weld; and
   displaying the predicted quality status on a surface of the work piece using a status projector.

9. The method of claim **8**, wherein predicting the quality status of the weld includes identifying at least one suspect weld, and wherein displaying the predicted quality status includes displaying the quality status of the at least one suspect weld.

10. The method of claim **8**, further comprising displaying the quality status of only the at least one suspect weld.

11. The method of claim **8**, wherein predicting the quality status includes mapping a predetermined number of signal

features of at least some of the signals to a dimensional space having a number of dimensions that is proportional to the predetermined number.

12. The method of claim **8**, wherein displaying the quality status on a surface of the work piece includes projecting visible light onto or adjacent to the weld using a laser projector.

13. The method of claim **8**, wherein displaying the quality status on a surface of the work piece includes projecting non-visible light onto or adjacent to the weld.

14. The method of claim **8**, further comprising:
identifying at least one suspect weld;
positioning a marker on each weld of the at least one suspect weld; and
recording an image of each positioned marker using a camera.

15. The method of claim **14**, further comprising:
automatically determining the position of each positioned marker within the work piece using a processor; and
recording the position in memory of the host machine.

16. The method of claim **8**, wherein the work piece is a battery module having a conductive interconnecting member that is connected, via a plurality of the welds, to a set of battery tabs, and wherein displaying the quality status includes projecting visible light directly onto or immediately adjacent to the conductive interconnecting member.

17. A system comprising:
a welding horn;
a welding controller that generates control signals for controlling the welding horn in a vibration welding process in which at least one weld is formed on or within a work piece;

a collection of sensors positioned with respect to the welding horn, wherein the sensors are configured to generate sensory signals describing a quality of the vibration welding process;
a status projector positioned with respect to the work piece; and
a host machine in electrical communication with the sensors and with the welding controller, wherein the host machine is configured to execute instructions from tangible, non-transitory memory to thereby:
process the sensory and control signals;
predict, using the sensory and control signals, a quality status of the at least one weld being formed using the welding horn, including identifying any suspect welds; and
illuminate the indentified suspect welds using the status projector.

18. The system of claim **17**, wherein the work piece is a multi-cell battery having a conductive interconnecting member to which battery tabs are connected via the at least one weld, and wherein the status projector includes a laser projector that projects a beam of visible light directly onto the identified suspect welds or onto the interconnecting member adjacent to the identified suspect welds.

19. The system of claim **18**, wherein the laser projector is one of a red, green, blue laser projector and a gas laser with a switched color filter.

20. The system of claim **17**, wherein the host machine is configured to map a predetermined number of signal features from the sensory and control signals to a dimensional space having a number of dimensions that is proportional to the predetermined number.

* * * * *