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UNIFORM JOINT WIDTH FORMATION IN BLOCK CONSTRUCTION

Abstract

A method and related system for positioning a sequence of bricks in a refractory wall. A measuring station is operable to receive a plurality of bricks in the sequence of bricks, at least two bricks in the sequence of bricks having a predetermined position in the refractory wall. A measurement module is operable to individually measure each of the bricks to obtain actual measurements. A processor module is operable to compute an average inter-brick gap value for the sequence of bricks based on the actual measurements and determine an adjusted position for at least one brick in the sequence of bricks based on at least on the computed inter-brick gap value.

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Background/Summary

TECHNICAL FIELD

[0001] The present invention relates to refractory walls and, more particularly, to assembly of refractory walls.

BACKGROUND

[0002] The Hall-Heroult process is the most common industrial process for smelting aluminum. The following simplified reactions take place at the carbon electrodes in an electrolytic bath, comprising alumina (Al.sub.2O.sub.3), contained in cells:

[0003] Cathode: Al.sub.3.sup.++3 e.sup.−.fwdarw.Al

[0004] Anode: O.sup.2−+C.fwdarw.CO+2 e.sup.−

[0005] Overall: Al.sub.2O.sub.3+3 C.fwdarw.2 Al+3 CO

[0006] In reality, much more CO.sub.2 is formed at the anode than CO: 2 O.sup.2− +C.fwdarw.CO.sub.2+4 e.sup.− and 2 Al.sub.2O.sub.3+3 C.fwdarw.4 Al+3 CO.sub.2

[0007] The electrolytic bath is electrolyzed using a low voltage (under 5 V) direct current at 100-600 kA. Liquid aluminum metal is deposited at the cathode, while the oxygen from the alumina combines with carbon from the anode to produce mostly carbon dioxide.

[0008] To avoid solidification of the aluminum, cells are operated 24 hours a day. The electrical resistance within the cell is used to regulate temperature of the electrolytic bath. Electrodes in cells are form mostly from purified coke. A binder such as pitch resin or tar is typically used. There are two primary anode technologies using the Hall-Héroult process: Söderberg technology and prebaked technology. Söderberg or self-baking anodes are not subject to the present discussion.

[0009] Very large ovens are used to bake the anodes (e.g., gas-fired at high temperature). The oven comprises refractory brick walls arranged to receive the preformed anodes to produce finalized anodes having a predetermined shape. Prebaked anodes may be made directly at the smelting operation location or may be brought there. No matter what shape the anodes are expected to take, the assembly of the brick walls in the oven is labor intensive and leads to varying tolerances therethrough.

[0010] Such issues are addressed, at last partly, in the present disclosure.

SUMMARY

[0011] This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the Detailed Description. This Summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used as an aid in determining the scope of the claimed subject matter.

[0012] A system of one or more computers can be configured to perform particular operations or actions by virtue of having software, firmware, hardware, or a combination of them installed on the system that in operation causes or cause the system to perform the actions. One or more computer programs can be configured to perform particular operations or actions by virtue of including instructions that, when executed by data processing apparatus, cause the apparatus to perform the actions. One general aspect includes a method of positioning a sequence of bricks in a refractory wall. The method of positioning also includes receiving a plurality of bricks in the sequence of bricks, at least two bricks in the sequence of bricks having a predetermined position in the refractory wall; individually measuring each of the bricks to obtain actual measurements, computing an average inter-brick gap value for the sequence of bricks based on the actual measurements, and determining an adjusted position for at least one brick in the sequence of bricks based on at least on the computed inter-brick gap value. Other embodiments of this aspect include

corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0013] Implementations may include one or more of the following features. The method where receiving the bricks is performed by sequentially receiving and uniquely identifying each of the bricks in the sequence of bricks. Individually measuring each one of the plurality of bricks to obtain the actual measurements is performed by sequentially measuring and associating a corresponding one of the actual measurements to each of the uniquely identified bricks. Computing the average inter-brick gap value for the sequence of bricks based on the actual measurements is performed by resolving, after measuring a last brick in the sequence of bricks and before the at least one brick in the sequence of bricks having an adjusted position is ready to be positioned:

[00001]$AG = G_t + \frac{.\text{Math.}_{i=1}^{n} (la_n - lt_n)}{n - 1}$

where AG is the average inter-brick gap value for the sequence of bricks, Gt is a theoretical inter-brick gap value for the sequence of bricks, n is the number of bricks in the sequence of bricks and la.sub.n and lt.sub.n are respectively the actual length and the theoretical length of the n.sup.th brick. Sequentially receiving and uniquely identifying each of the plurality of bricks in the sequence of bricks further may include sequentially transporting each of the bricks in the sequence of bricks to a measuring station, the method may include transporting the last brick in the sequence of bricks to a positioning station, the last brick being thereby ready to be positioned. The method may include, after transporting the last brick in the sequence of bricks to a positioning station: positioning, from the positioning station using a controllable mechanical device, each of the bricks in the sequence of bricks: at the corresponding adjusted position in the refractory wall when it exists; and at the corresponding predetermined position in the refractory wall otherwise. The controllable mechanical device may induce, for each of the bricks in the sequence of bricks, a potential positioning error within an error range, the error range being taken into account when computing the average inter-brick gap value to ensure that actual inter-brick gap values are within a tolerance range. The sequence of bricks may be a complete sequence of bricks may include all bricks on a layer of the refractory wall. The sequence of bricks may be a partial sequence of bricks may include all bricks between two fixed bricks in a layer of the refractory wall, the fixed bricks being positioned at a theoretical position in the layer of the refractory wall. The layer of the refractory wall may include a plurality of partial sequences of bricks may include the sequence of bricks. Implementations of the described techniques may include hardware, a method or process, or computer software on a computer-accessible medium.

[0014] One general aspect includes a system for positioning a sequence of bricks in a refractory wall. The system also includes a measuring station operable to receive a plurality of bricks in the sequence of bricks, at least two bricks in the sequence of bricks having a predetermined position in the refractory wall; a measurement module operable to individually measure each of the bricks to obtain actual measurements, a processor module operable to compute an average inter-brick gap value for the sequence of bricks based on the actual measurements and determine an adjusted position for at least one brick in the sequence of bricks based on at least on the computed inter-brick gap value. Other embodiments of this aspect include corresponding computer systems, apparatus, and computer programs recorded on one or more computer storage devices, each configured to perform the actions of the methods.

[0015] Implementations may include one or more of the following features. The system where the measuring station receives the bricks by sequentially receiving and uniquely identifying each of the bricks in the sequence of bricks. The measuring module individually measures each one of the plurality of bricks to obtain the actual measurements by sequentially measuring and associating a corresponding one of the actual measurements to each of the uniquely identified bricks. The processor module computes the average inter-brick gap value for the sequence of bricks based on the actual measurements by resolving, after measuring a last brick in the sequence of bricks and before the at least one brick in the sequence of bricks having an adjusted position is ready to be positioned:

[00002]AG = $G_t + \frac{.\text{Math.}_{i=1}^{n} (la_n - lt_n)}{n-1}$;

where AG is the average inter-brick gap value for the sequence of bricks, Gt is a theoretical inter-brick gap value for the sequence of bricks, n is the number of bricks in the sequence of bricks and la.sub.n and lt.sub.n are respectively the actual length and the theoretical length of the nth brick. The system may include one or more conveyors operable, when the measuring station sequentially receive and uniquely identify each of the plurality of bricks in the sequence of bricks, to sequentially transport each of the bricks in the sequence of bricks to the measuring station and to transport the last brick in the sequence of bricks to a positioning station, the last brick being thereby ready to be positioned. The system may include a controllable mechanical device operable to, after transporting the last brick in the sequence of bricks to a positioning station: position, from the positioning station, each of the bricks in the sequence of bricks: at the corresponding adjusted position in the refractory wall when it exists; and at the corresponding predetermined position in the refractory wall otherwise; The controllable mechanical device may induce, for each of the bricks in the sequence of bricks, a potential positioning error within an error range, the error range being taken into account when the processor module computes the average inter-brick gap value to ensure that actual inter-brick gap values are within a tolerance range. The sequence of bricks may be a complete sequence of bricks and include all bricks on a layer of the refractory wall. The sequence of bricks may a partial sequence of bricks and include all bricks between two fixed bricks in a layer of the refractory wall, the fixed bricks being positioned at a theoretical position in the layer of the refractory wall. The layer of the refractory wall may include a plurality of partial sequences of bricks may include the sequence of bricks. Implementations of the described techniques may include hardware, a method or process, or computer software on a computer-accessible medium.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Further features and exemplary advantages of the present invention will become apparent from the following detailed description, taken in conjunction with the appended drawings, in which:

[0017] FIG. **1** presents views of an exemplary refractory wall in accordance with the teachings of the present invention;

[0018] FIG. **2** presents views of a first layer of the refractory wall of FIG. **1** in accordance with the teachings of the present invention;

[0019] FIG. **3** presents views of a second layer of the refractory wall of FIG. **1** in accordance with the teachings of the present invention;

[0020] FIG. **5** presents views of a fourth layer of the refractory wall of FIG. **1** in accordance with the teachings of the present invention;

[0021] FIG. **6** is a perspective view of the exemplary refractory wall of FIG. **1** in accordance with the teachings of the present invention;

[0022] FIG. **7** is a front view of the exemplary refractory wall of FIG. **1** in accordance with the teachings of the present invention;

[0023] FIG. **8** is a side view of the exemplary refractory wall of FIG. **1** in accordance with the teachings of the present invention;

[0024] FIG. **9** is a sectional side view of the exemplary refractory wall of FIG. **1** along the cut line defined in FIG. **7** in accordance with the teachings of the present invention;

[0025] FIG. **10** presents views of a first exemplary refractory brick in accordance with the teachings of the present invention;

[0026] FIG. **11** presents views of a second refractory brick in accordance with the teachings of the present invention;
[0027] FIG. **12** is a flow chart of an exemplary method in accordance with the teachings of the present invention;
[0028] FIG. **13** is a logical representation of an exemplary system in accordance with the teachings of the present invention;
[0029] FIG. **14** is a modular representation of an exemplary controller in accordance with the teachings of the present invention; and
[0030] FIG. **15** is a modular representation of an exemplary system in accordance with the teachings of the present invention.

DETAILED DESCRIPTION

[0031] In a set of embodiments in accordance with a first set of invention points, refractory bricks are positioned horizontally to form a layer of refractory wall in order to create a controlled horizontal gap therebetween. The bricks of a sequence of bricks are provided in an orderly manner considering the design of the wall to be built. After measuring the bricks in the sequence of bricks (e.g., weight, length, width, height, etc.), an average gap is calculated for the sequence and a position for each of the bricks in the sequence is determined. The bricks are positioned one by one mechanically (e.g., by a robot arm) to fit the determined positioned within a tolerance distance, thereby providing a uniform gap, considering a gap tolerance, between the bricks of the sequence.

[0032] Reference is made to the drawings in which FIG. **1** shows an exemplary refractory wall **90** with four layers **92**, **94**, **96** and **98** (see concurrently FIGS. **2** to **11**). FIGS. **1** to **5**, **10** and **11** are divided into four (4) views A, B, C and D respectively representing a perspective view, a top view, a front view and a side view. FIG. **6** is a close-up perspective view of the refractory wall **90**. FIG. **7** is a close-up side view of the refractory wall **90** showing cut line A-A. FIG. **8** is a close-up side view of the refractory wall **90**. FIG. **9** is a close-up side view of the refractory wall **90** along the cut line A-A from FIG. **7**.

[0033] FIG. **10** and FIG. **11** present views of two exemplary refractory bricks **2000**, **3000** in accordance with the teachings herefrom. The brick **2000** has top ridges **2100**, **2120** and bottom channels **2200**, **2220** while the brick **3000** has top ridges **3100**, **3120** without bottom channels. The brick **3000** presents a configuration that would typically be used for foundation bricks, such as the bricks **1** to **5** of the refractory wall **90**, while the brick **2000** would typically be used everywhere else. In some embodiments, the brick **2000** may be used everywhere, including for the foundation. In the depicted example of FIG. **10** and FIG. **11**, a single configuration of the ridges and channels **2100**, **2120**, **2200**, **2220**, **3100**, **3120** is presented at the center of their respective faces. In typical embodiments where ridges and channels are used, the ridges and channels **2100**, **3100**, **2200** parallel to a longitudinal axis of the refractory wall **90** may be positioned at a predetermined distance from a reference edge of the brick **2000**, **3000** or of the refractory wall **90** (e.g., outer perimeter edge of the refractory wall **90**) thereby allowing for varying brick configurations without creating additional alignment issues (e.g., transverse bricks). Likewise, the ridges and channels **2120**, **3120**, **2220** may be positioned at a predetermined intervals from a reference edge of the refractory wall **90** (e.g., outer edge of the refractory wall **90**) considering the expected position of the brick once positioned in the refractory wall **90**, thereby allowing for varying brick configurations. Alternatively or in addition, only certain ones of the bricks may be provided with the ridges and channels **2100**, **3100**, **2200** and/or **2120**, **3120**, **2220**. Furthermore, positioning and dimensioning of the ridges and channels **2100**, **3100**, **2200** and/or **2120**, **3120**, **2220** is done considering a target adjustability in lateral and/or longitudinal adjustment of the theoretical position of the bricks. Said differently, if the ridges and channels **2100**, **3100**, **2200** and/or **2120**, **3120**, **2220** were of the same dimension, it would be more complicated to adjust the position of the bricks from a predetermined position to an adjusted position as the bricks would tend to move, after positioning, towards corresponding ones of the ridges and channels.

[0034] As can be appreciated from FIGS. **1** to **9**, bricks **1-60** of the refractory wall **90** do not show ridges and channels as they are optional and could clutter the views, but skilled persons will recognize that such features may optionally be provided, in one direction (e.g., **2100**, **3100** or **2220**, **3220**) or in both directions (**2100**, **2120**, **2200** and **2220**) without departing from the teachings presented herein. For greater certainty concerning the ridges and channels, it may be added that position and sizes of the ridges and channels as well as physical characteristics of the mortar (e.g., thickness, fluidity, . . .) should be chosen considering expected variability of brick positioning, as will be detailed described hereinbelow.

[0035] Exemplary measurements are added to different bricks **1** to **60** of the refractory wall **90** to enhance the understandability of the description and not as a limitation to the present teachings. Likewise, only the four layers **92**, **94**, **96** and **98** are presented, for conciseness and clarity, while typical actual refractory walls comprise many more layers (e.g., **55**), which may also be built in accordance with teachings found herein, as skilled persons will readily recognize. In the depicted example, the refractory wall **90** measures 1472 mm×400 mm. The measurements of the bricks **1-60** and the refractory wall **90** were chosen to illustrate the teachings presented herein and skilled persons will readily recognize that many other options are possible while remaining within such teachings. Furthermore, actual measurements of bricks are expected to vary and teachings are presented to accommodate such variations, as will described in greater details in relation to different embodiments.

[0036] Layer **92** comprises bricks **1** to **5** of equivalent size (290,40 mm×400 mm×76 mm, as indicated by measurements added on the figures). In the depicted example, the layer **92** represents a foundation of the refractory wall **90**. Typically, the foundation bricks are bigger than other bricks, as depicted, but skilled persons will readily recognize that many other possibilities exist that do not affect the present teachings.

[0037] Layer **94** comprises bricks **6** to **23** of equivalent size (180 mm×100 mm×76 mm, as indicated by measurements added on the figures). Such dimensions were chosen as a means of illustration and skilled persons will readily recognize that other possibilities exist that do not affect the present teachings.

[0038] Layer **96** comprises bricks **24** to **42** of various sizes, as indicated by measurements added on the figures. Again, such dimensions were chosen as a means of illustration and skilled persons will readily recognize that other possibilities exist that do not affect the present teachings.

[0039] Layer **96** comprises bricks **43** to **60** of two sizes, as indicated by measurements added on the figures. Again, such dimensions were chosen as a means of illustration and skilled persons will readily recognize that other possibilities exist that do not affect the present teachings.

[0040] The layers **92-98** are shown with a vertical distance of 4 mm therebetween. Again, this has been chosen as an illustrative value and other possibilities exist that do not affect the present teachings. The exemplary uniform vertical distance of 4 mm has been chosen as an illustrative value and may be seen, with reference to the following description of different embodiments, as a target vertical value. Likewise, the bricks **1** to **60** are shown with a uniform horizontal distance of 4 mm therebetween chosen to illustrate the present teachings. In exemplary refractory walls built in accordance with the teachings of the present invention, actual inter-brick gap values will be determined based on different factors, as will be described in greater details hereinbelow. The exemplary uniform horizontal distance of 4 mm has been chosen as an illustrative value and may be seen, with reference to the following description of different embodiments, as a target inter-brick gap value. Skilled persons will recognize that other possibilities exist and that the present teachings can readily be adapted thereto.

[0041] Reference is made to FIG. **13** and FIG. **15** showing a specific embodiment, in the form of a logical representation, of an exemplary system **1000** of positioning a sequence of bricks in a refractory wall.

[0042] The numbering of the elements on FIGS. **13** and **15** is done for different categories of equipment. More specifically, items **000** are part of a general or overview category. Items **100** are part of the loading/storing raw materials category. Items **200** are part of a feeding/characterising raw materials (RBR/RER) category. Items **300** are part of a preparing raw materials; general wall building equipment category. Items **400** are part of a brick placement system (RBR or BPR) category. Items **500** are part of a mortar spreading system (RER or MSR) category. Items **700** are part of an equipment related to the wall category. Items **800** are part of a general equipment for control/automation category.

[0043] More specifically, in the category **000**, a water supply/pressurization module **040** may be provided (optional). In the category **200**, a brick loading station **210** (optional), a loading collection conveyor **220** (optional) may be provided, a measurement station **230**, an inspection station **240** (optional), a sorting station **250** (optional), a rejection bin **255** (optional), a brick cleaning station **260** (optional), an elevating conveyor **270**, a production collection conveyor **280** (optional) and a positioning station **290** may be provided. In some embodiments, a structure **280-**S (optional) for the production collection conveyor **280** may also be provided. In the **300** category, a safety enclosure **310**, a vertical mortar station **320** (optional), a linear rail **330** and a maintenance station **350** may be provided. In some embodiments, a brick placement robot (RBR or BPR) superstructure **330-**S (optional) may also be provided. In the **400** category, a brick placement controller **402**, a BPR **410**, BPR claws **420**, and a BPR tool stand **430** (optional) may be provided. In the **500** category, a mortar spreading controller **502** (optional), a mortar spreading robot (RER or MSR) **510** (optional), a MSR spreader head **520** (optional), a MSR tool stand **530** (optional) and a MSR filling station **540** (optional) may be provided. In the **700** category, a wall superstructure **710-**S, a wall cleaning station **720** (optional), a quality management system **730** (optional) and a quality control system **740** (optional) may be provided. In the **800** category, a programmable logic controller (PLC) **810** and a Human Machine Interface (HMI) **820** may be provided.

[0044] FIG. **14** shows a modular representation of the system **1000** for positioning of bricks **1-60** in a refractory wall **90**, in accordance with the teachings of the present invention. A controller **1100** is presented on FIG. **14** (not shown on FIG. **13**) logically representing different elements of the system **1000** (e.g., as depicted on FIG. **13**) as well as showing logical interactions between modules. The controller **1100**, as will be explained hereinbelow, comprises the brick placement controller **402** and the PLC **810** and, in some embodiments, the mortar spreading controller **502**. The system **1000** may also comprise a remote monitoring station **1600** not presented in FIG. **13**. In some embodiments, the controller **1100** may exchange data with the remote monitoring station **1600** and the controller **1100** is therefore able to exchange one or more message and/or one or more commands with the remote monitoring station **1600** (e.g., via a network **1400**).

[0045] In the depicted example of FIG. **14**, the controller **1100** comprises a memory module **1120**, a processor module **1130** and a network interface module **1140**. The modules **1120**, **1130** and **1140** may be dedicated or distributed over different ones of the elements of FIG. **13**. The processor module **1130** may represent a single processor with one or more processor cores or an array of processors, each comprising one or more processor cores. The memory module **1120** may comprise various types of memory (different standardized or kinds of Random Access Memory (RAM) modules, memory cards, Read-Only Memory (ROM) modules, programmable ROM, etc.). The network interface module **1140** represents at least one physical interface that can be used to communicate with other network nodes. The network interface module **1140** may be made visible to the other modules of the controller **1100** through one or more logical interfaces. The actual stacks of protocols used by the physical network interface(s) and/or logical network interface(s) **1142**, **1144**, **1146**, **1148** of the network interface module **1140** do not affect the teachings of the present invention. The variants of processor module **1130**, memory module **1120** and network interface module **1140** usable in the context of the present invention will be readily apparent to persons skilled in the art.

[0046] A bus **1170** is depicted as an example of means for exchanging data between the different modules of the controller **1100**. The bus **1170** or another logical connections may be provided between elements of FIG. **13**. The present invention is not affected by the way the different modules exchange information between them. For instance, the memory module **1120** and the processor module **1130** could be connected by a parallel bus, but could also be connected by a serial connection or involve an intermediate module (not shown) without affecting the teachings of the present invention.

[0047] Likewise, even though explicit mentions of the memory module **1120** and/or the processor module **1130** are not made throughout the description of the various embodiments, persons skilled in the art will readily recognize that such modules are used in conjunction with other modules of the controller **1100** to perform routine as well as innovative steps related to the present invention.

[0048] The system **1000** may comprise a data storage system **1500** that comprises data related to brick positioning and may further log data while the production is performed. The data storage system is not depicted on FIG. **13**. FIG. **14** shows examples of the storage system **1500** as a distinct database system **1500**A, a distinct module **1500**B of the controller **1100** or a sub-module **1500**C of the memory module **1120** of the controller **1100**. The storage system **1500** may also comprise storage modules (not shown) on the remote monitoring station **1600**. The storage system **1500** may be distributed over different systems A, B, C and/or the remote monitoring station **1600** or may be in a single system. The storage system **1500** may comprise one or more logical or physical as well as local or remote hard disk drive (HDD) (or an array thereof). The storage system **1500** may further comprise a local or remote database made accessible to the controller **1100** by a standardized or proprietary interface or via the network interface module **1140**. The variants of the storage system **1500** usable in the context of the present invention will be readily apparent to persons skilled in the art.

[0049] The controller **1100** may also comprise an optional Human machine Interface (HMI) module **820**, which may comprise one or more graphical user interfaces (GUI), comprising one or more display screen(s) forming a display system, for the controller **1100**. The HMI module **820** could also comprise functions such as Report Management and Operator Desk Control. Data stored in the data storage system **1500** can then be used to display trends of process data on charts, create reports, or perform data analysis. The display screens of the HMI module **820** could be split into one or more display elements, but could also be a single flat or curved screen visible from an expected user position (not shown). The Operator Desk Control function may be used, for instance, to input commands towards the control module **1161** described hereinbelow.

[0050] The HMI module **820** may be linked to a historian database stored in the storage system **1500**. The historian database may be provided as a time-series database designed to efficiently collect and store process data from a Supervisory Control and Data Acquisition (SCADA) or automation system (e.g., measurements module **1160** and control module **1161** described hereinbelow). The stored data from the historian database may be used to display trends of process data on charts, create reports, or perform data analysis (e.g., through the Report Management function of the HMI module **820**). Skilled persons will readily understand that the HMI module **820** may be used in a variety of contexts not limited to the previously mentioned examples. In some embodiments, the HMI module **820** is distributed over elements of FIG. **13** and/or the remote monitoring station **1600** (e.g., partially distributed and/or made available using remote desktop capabilities or the likes). In some other embodiments, the HMI module **820** is implemented in the remote monitoring station **1600** and the linked to the controller **1100** through the network **1400**.

[0051] A measurement input module **1160** and a control module **1161** are provided in the controller **1100**. The measurements module **1160** and the control module **1161** will be referred to hereinbelow as distinct logical modules, but skilled person will readily recognize that a single logical module may have been shown instead.

[0052] In some embodiment, an optional external input/output (I/O) module **1162** and/or an optional internal input/output (I/O) module **1164** may be provided with the measurement input module **1160** and the control module **1161**. The external I/O module **1162** may be required, for instance, for interfacing with one or more robots, one or more input device (e.g., measurement probe) and/or one or more output device (e.g., printer).

[0053] In the context of the example of FIG. **13** and FIG. **14**, the measurements module **1160** may have capacities distributed between different elements of FIG. **13**. For instance, the measurement module **1160** has one or more measurement function implemented at the measuring station **230** and may have additional measuring functions at the inspection station **240** (when present). Furthermore, the BPR **410** and MSR **510** may also have measurement capabilities (e.g., using different tools or as a permanent feature) and therefore implement one or more measurement functions of the measurement module **1160**. The BPR **410** and MSR **510** have registered positions at all time in the system **1000** (typically stored in the data storage system **1500**). The position itself may be considered when taking different measurements from the BPR **410** and/or the MSR **510**.

[0054] Likewise, the control module **1161** may have capacities distributed between different elements of FIG. **13**. The brick placement controller **402** and the mortar spreading controller **502** (when present) implement one or more of the control function of the control module **1161** and, in doing so, interact with different elements from FIG. **13** in order to provide the control functions. For instance, the brick loading station **210**, the loading collection conveyor **220**, the sorting station **250**, the brick cleaning station **260**, the elevating conveyor **270**, the production collection conveyor **280**, the positioning station **290** and the maintenance station **350** just like the BPR **410** and the MSR **510** (when present) may receive commands from the brick placement controller **402** and/or the mortar spreading controller **502** and react accordingly. The brick placement controller **402** and the mortar spreading controller **502** also store current position and related data for the BPR **410** and the MSR **510** in one or more position registers of the storage system **1500**. Control functions from the control module **1161** may include, for instance, advancing a brick on the brick loading station **210** to a designated position; verifying conformity of a brick at the inspection station **240** (e.g., using one or more measurement functions); positioning a brick from the positioning station **290** by the BPR **410** into the refractory wall **90** (e.g., further using a path management function and a brick handling function).

[0055] The internal input/output (I/O) module **1164** may be required, for instance, for interfacing the controller **1100** with one or more instruments or controls (not shown) typically used in the context of brick positioning. The I/O module **1164** may comprise necessary interface(s) to exchange data, set data or get data from such instruments or controls.

[0056] The PLC **810** is implemented as a function over the controller **1100** and therefore is

[0057] performed thereon, e.g., through the processor module **130** using the memory module **1120** and the data storage system **1500** as well as other module of the controller **1100**.

[0058] For instance, Brick IDs and related specifications may be stored in the data storage system **1500**. The desired layout of the refractory wall **90** may also be stored therein. The PLC **810** may then implement different functions of the system **1000** such as a sequence management function, a brick sourcing management function, a brick tolerance anticipated positioning function, a mortar disposition function, etc.

[0059] In some embodiments, the HMI **820** allow one or more operator to interact with the system **1000** to access and/or provide information to the system **1000** and to provide instructions and receive feedback from the instructions. The PLC **810**, using different modules of the controller **1100** and elements of the system **1000**, implement the instructions.

[0060] The measurement input module **1160** and the control module **1161** are tightly related to the positioning of bricks. In the example of the system **1000**, the measurement input module **1160** and the control module **1161** may be involved in various step of a method **1200** described herein below.

[0061] Reference is now concurrently made to FIGS. **1** to **9**, **12**, **13** and **14**. An exemplary method **1200** is depicted on FIG. **13** for determining an adjusted position for a sequence of bricks in a refractory wall. In the context of the method **1200**, at least two of the bricks in the sequence of bricks have a predetermined position in the refractory wall (i.e., at least the first and the last one in the sequence). That is, it is possible to determine a position for each brick where the brick is meant to be positioned in the refractory wall, which could mean that each brick has one and only one position being predetermined, that each type of brick (e.g., all bricks of equivalent theoretical measurements) is associated to predetermined positions or that the predetermined position can be computed knowing one or more dimensions of the brick and reference points (e.g., the first and last brick in a sequence). The layout of the refractory wall **90** may be retrieved from the storage system **1500**.

[0062] The method **1200** comprises receiving **1210** a plurality of bricks in the sequence of bricks and individually measuring **1220** each of the bricks to obtain actual measurements (e.g., while the bricks are being received (one by one) or after more than one brick is received). Receiving the bricks **210** may be performed at the brick loading station **210**. Individually measuring **1220** each of the bricks may be performed at the measurement station **230**. The method **1200** then follows with computing **1230** an average inter-brick gap value for the sequence of bricks based on the actual measurements and determining **1240** an adjusted position for at least one brick in the sequence of bricks based on the computed inter-brick gap value. Computing **1230** the average inter-brick gap value and determining **1240** the adjusted position may be performed by the PLC **810** on the controller **1100**. Thereafter, positioning **1250** may be performed (e.g., using a controllable mechanical device such as the BPR **410** controller by the brick placement controller **402**) for each of the bricks in the sequence of bricks at the corresponding adjusted position in the refractory wall **90**, if it exists, or at the predetermined position otherwise (e.g., first and last bricks in the sequence). The method **1200** may then repeat **1260** itself when an additional sequence of bricks is received (e.g., until the refractory wall or a portion thereof is completed). It should be understood by skilled persons that the last brick in a sequence of bricks is, de facto, the first brick in the next sequence of bricks.

[0063] The example drawn from FIGS. **1** to **9**, **12**, **13** and **14** and the exemplary refractory wall **90** will be used with the sequence of bricks representing bricks **6** to **23** on the layer **94**, which implies that the layer **93** has been previously completed (i.e., with or without using the technology described herein). In the example, an overall design of the refractory wall **90** is known because each of the bricks **1** to **60** have a respective predetermined position. As such, before receiving any bricks, the controller **1100** can perform a mapping of the bricks **1** to **60** to predetermined position and divide the bricks into a plurality of sequences, each comprising a plurality of bricks. A sequence of bricks may be defined as a plurality of bricks comprising two bricks that are to be positioned based only on the predetermined position. For instance, on the layer **94**, the sequences of bricks may be determined to be 6-9 (i.e., 6 and 9 having a predetermined position and **7** and **8** having an adjusted position), **9-11**, **11-18**, **18-20** and **20-6**. The sequences may be completely computed (not shown) by the controller **1100** considering the predetermined position of each of the bricks, partially computed (not shown) by the controller **1100** (e.g., the bricks to be positioned based only on the predetermined position are identified by a human operator) or the sequences may be provided to the controller **1100** (e.g., stored in the storage system **1500**) by the human operator. In some embodiments, some bricks are arbitrarily selected to be at a predetermined position rather than an adjusted position, which may be needed for limiting the number of bricks in a sequence of bricks considering limitations of other elements in the system (e.g., number of bricks simultaneously on an elevating conveyor **270** or a production collection conveyor **280**, as will be seen later on).

[0064] With reference to the example of FIGS. **1** to **9**, **12**, **13** and **14**, bricks are loaded onto the brick loading station **210** by an operator and/or by a programmable automate. The bricks may be ordered in accordance with the plurality of sequences at the time of loading onto the brick loading station **210** or may be ordered at the brick loading station **210** considering the plurality of sequences. In the discussed example, the bricks **6-9** in the sequence are received **1210** at the brick loading station **210** and are sequentially transferred to the measurement station **230** by the loading collection conveyor **220** to be individually measured **1220** to obtain individual actual measurements for each of the bricks. In other embodiments, the measurement station **230** and the brick loading station **210** may form a single station that does not require the loading collection conveyor **220**.

[0065] The measurement station **230** provides actual measurements using one or a combination of measurements techniques. For instance, the bricks may be positioned at know coordinates in the measurement station **230** (e.g., using hydraulic piston(s) and/or conveyor(s)) before being measured using one or more lasers. In some embodiments, the laser measurement is counter-verified using estimation provided by one or more hydraulic piston (e.g., using measured piston displacement) and or one or more conveyors, which may be performed by calculating the displacement of the bricks until reaching the known coordinates using the steps motors actuating the conveyor(s).

[0066] In some embodiments, the bricks are sequentially measured before being transferred to the production collection conveyor **280** or, when there is a need for matching different height between the stations **230-280**, the elevating conveyor **270**. The production collection conveyor **280** and/or elevating conveyor **270** may therefore need to be dimensioned considering the longest possible sequence of bricks. In some embodiments, more than one brick may be measured at once (e.g., using a scanning system and/or by using a brick buffer at the measurement station **230**) and the ordering of the sequences of bricks may therefore be determined (and/or verified) at the brick measurement station **230** before transfer onto the production collection conveyor **280** and/or elevating conveyor **270**.

[0067] In some embodiments, an inspection station **240** may be provided for inspecting the bricks before and/or after measurement. The inspection may be related to respect for expected measurement tolerance (e.g., modified or shifting tolerances), edges quality of the brick (e.g., edges not having chips larger than a maximum error), weight of the brick within tolerance. The bricks that are unfit may be treated at an optional sorting station **250** (integrated or not with the sorting station **250**) and rejected into a rejection bin **255**. An optional brick cleaning station **260** may also be provided for cleaning the bricks (e.g., air-based and/or water-based cleaning) at any point between the brick loading station **210** and the production collection conveyor **280**.

[0068] The production collection collector **280** delivers the bricks to the positioning station **290**. Depending on how the sequence of bricks was prepared, the bricks may be delivered and treated sequentially at the positioning station **290** or may be buffered and rearranged when needed on the production collection conveyor **280** and/or at the positioning station **290**. In some embodiments, a structure **280**-S may be provided to mechanically support, for instance, the production collection conveyor **280** and/or the positioning station **290**. In some embodiments, the positioning station **290** may not be required at all when, for instance, the bricks have a defined transit position throughout the path between the stations **230-280** (e.g., between the measurement station **230** and the production collection conveyor **280**, between the elevation conveyor **270** and the production collection conveyor **280**, . . .), whereby the brick placement robot (BPR) **410** is able to pick a desired brick based on the known transit position.

[0069] Concerning the conveyors **220**, **270**, **280**, skilled persons will recognize that various technologies may be used without fundamentally affecting the teachings found herein and that different technologies may be used for different ones of the conveyors **220**, **270** and **280** considering design choices made on peripheral elements of the innovative solutions described herein. More than one conveyor may form any one of the conveyors **220**, **270**, **280** even though reference is made to individual conveyors **220**, **270**, **280**, for the sake of readability. As examples of conveyor technologies, bidirectional and/or unidirectional belt or chain conveyors having one or more tracks, with or without sorting capabilities, may be used. Additionally or alternatively, motorized rollers (e.g., individually, in groups or as a whole) and/or gravitational roller conveyors

may be used. Of course, skilled persons will understand that the conveyor technologies may be mixed together, considering usual engineering practices. Furthermore, one or more of the conveyors **220**, **270**, **280** may be operable to allow for eventual gaps between bricks while on the conveyors **220**, **270** and/or **280** to be partially or completely eliminated during displacement of the bricks thereon.
[0070] The example of FIG. **13** also depicts a safety enclosure **310** that would typically be present to protect people around the system **1000**, but that is not required in regards to the teachings presented herein. One or more linear rails **330** may be provided when appropriate for the technology of the BPR **410** and/or the mortar spreading robot (RER or MSR) **510** (e.g., for longitudinal movements of the BPR **410** and/or MSR **510** along the refractory wall **90**). A maintenance station **350** may be provided. A BPR structure **330**-S may be provided to mechanically position and support the BPR **410**. A vertical mortar station **320** may be provided when some of the bricks need to receive mortar on vertical surfaces.
[0071] A brick placement controller **402** is provided for controlling the BPR **410**. BPR claws **420** are provided with the BPR **410** and operable to controllably manipulate the bricks **1-60**. A BPR tool stand **430** may be provided if and when more than one attachment tool is to be actuated by the BPR **410**. Of course, skilled persons will understand how to select and dimension various elements related to the BPR **410** considering the task expected to be performed thereby.
[0072] While it is not the present focus, most the walls to be built using the teachings found herein are expected to have horizontal mortar layers. While the mortar layers may be applied manually, there are advantages, albeit no necessity, to provide a mortar spreading robot (RER or MSR) **510**. A mortar spreading controller **502**, an MSR spreader head **520**, an MSR tool stand **530** and an MSR Filling station **540** may also be provided. In the example discussed herein, for simplicity and clarity, the mortar will be considered in place before bricks are lowered onto the refractory wall **90**.
[0073] In the example of FIGS. **1** to **9**, **12**, **13** and **14**, the refractory wall **90** has a wall superstructure **710**-S, which may be a metal tray having forklift pockets, allowing movement of the wall once completed. A wall cleaning station **720**, a quality management system **730** and a quality control system **740** may be provided.
[0074] A Programmable Logic Controller (PLC) **810** may be provided.
[0075] Referring to the example of FIGS. **1** to **9**, **12**, **13** and **14** and the sequence of bricks **6-9**, once the first brick **6** reaches the positioning station **290**, the controller **1100** instructs the BPR **410** to position the brick **6** at a predetermined position. The brick **7** reaches the positioning station **290**. Before the brick **7** is positioned by BPR **410**, the controller **1100** computes **1230** an average inter-brick gap value for the sequence of the bricks **6-9** based on the actual measurements of the bricks **6-9**. In some embodiments, the brick **9** may receive at the positioning station **290** and thereafter be positioned before the brick **7**, thereby allowing more time for the computation **1230** to be completed. One manner of expressing the computation **1230** mathematically is:
[00003]$AG = G_t + \frac{\text{.Math.}_{i=1}^{n} (\mathrm{la}_n - \mathrm{lt}_n)}{n-1}$
[0076] where AG is the average inter-brick gap value for the sequence of bricks, Gt is a theoretical inter-brick gap value for the sequence of bricks, n is the number of bricks in the sequence of bricks and la.sub.n and lt.sub.n are respectively the actual length and the theoretical length of the nth brick.
[0077] Of course, other mathematical representations of the computing **1230** may be provided. For instance, theoretical inter-brick gap value may not be known and the computation **1230** may directly provide the inter-brick gap value instead of a variation from the theoretical value. Likewise, the theoretical length of the bricks may not be provided and position of the bricks **6** and **9** may be used to determine a length on the refractory wall **90** to be covered by the bricks **7-8** that has n+1 (i.e., 2+1=3) gaps. Following the computing **1230**, the controller **1100** determines **1240** an adjusted position for at least one brick in the sequence of bricks based on the computed inter-brick gap value and, in some embodiments, also based on the respective predetermined position. In the

example of the sequence of bricks **6-9**, the bricks **7** and **8** have an adjusted position while the bricks **6** and **9** are positioned at a predetermined position.

[0078] In some embodiments, individually measuring **1220** each one of the plurality of bricks at the measurement station **230** to obtain the actual measurements is performed by sequentially measuring **1222**, uniquely identifying **1224** each of the bricks in the sequence of bricks and associating **1226** a corresponding one of the actual measurements to each of the uniquely identified bricks. The unique identifier may be local to the controller **1100** (e.g., counter in a first-in-first-out (FIFO) chain) or may be permanently associated to the bricks. For instance, in some embodiments, a physical identifier may be printed or engraved onto the brick, which may be as simple as a number or as complex as a QR code further comprising data and/or metadata related to the brick (e.g., dimensions, weight, position, timestamp, pointer to a public ledger (e.g., blockchain technology), etc.).

[0079] The BPR **410** may induce, for each of the bricks in the sequence of bricks, a potential positioning error within an error range. The error range may therefore be taken into account when computing **1230** the average inter-brick gap value to ensure that actual inter-brick gap values are within a tolerance range.

[0080] Various network links may be implicitly or explicitly used in the context of the present invention. While a link may be depicted as a wireless link, it could also be embodied as a wired link using a coaxial cable, an optical fiber, a category 5 cable, and the like. A wired or wireless access point (not shown) may be present on the link between. Likewise, any number of routers (not shown) may be present and part of the link, which may further pass through the Internet.

[0081] The present invention is not affected by the way the different modules exchange information between them. For instance, the memory module and the processor module could be connected by a parallel bus, but could also be connected by a serial connection or involve an intermediate module (not shown) without affecting the teachings of the present invention.

[0082] A method is generally conceived to be a self-consistent sequence of steps leading to a desired result. These steps require physical manipulations of physical quantities. Usually, though not necessarily, these quantities take the form of electrical or magnetic/electromagnetic signals capable of being stored, transferred, combined, compared, and otherwise manipulated. It is convenient at times, principally for reasons of common usage, to refer to these signals as bits, values, parameters, items, elements, objects, symbols, characters, terms, numbers, or the like. It should be noted, however, that all of these terms and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. The description of the present invention has been presented for purposes of illustration but is not intended to be exhaustive or limited to the disclosed embodiments. Many modifications and variations will be apparent to those of ordinary skill in the art. The embodiments were chosen to explain the principles of the invention and its practical applications and to enable others of ordinary skill in the art to understand the invention in order to implement various embodiments with various modifications as might be suited to other contemplated uses.

Claims

1. A method of positioning a sequence of bricks in a refractory wall comprising: receiving a plurality of bricks in the sequence of bricks, at least two bricks in the sequence of bricks having a predetermined position in the refractory wall; individually measuring each of the bricks to obtain actual measurements; computing an average inter-brick gap value for the sequence of bricks based on the actual measurements; and determining an adjusted position for at least one brick in the sequence of bricks based on at least on the computed inter-brick gap value.

2. The method of claim 1, wherein receiving the bricks is performed by sequentially receiving and uniquely identifying each of the bricks in the sequence of bricks.

3. The method of claim 2, wherein individually measuring each one of the plurality of bricks to obtain the actual measurements is performed by sequentially measuring and associating a corresponding one of the actual measurements to each of the uniquely identified bricks.
4. The method of claim 3, wherein computing the average inter-brick gap value for the sequence of bricks based on the actual measurements is performed by resolving, after measuring a last brick in the sequence of bricks and before the at least one brick in the sequence of bricks having an adjusted position is ready to be positioned: AG = $G_t + \frac{.Math._{i=1}^{n} (la_n - lt_n)}{n-1}$ where AG is the average inter-brick gap value for the sequence of bricks, Gt is a theoretical inter-brick gap value for the sequence of bricks, n is the number of bricks in the sequence of bricks and la.sub.n and lt.sub.n are respectively the actual length and the theoretical length of the nth brick.
5. The method of claim 3, wherein sequentially receiving and uniquely identifying each of the plurality of bricks in the sequence of bricks further comprises sequentially transporting each of the bricks in the sequence of bricks to a measuring station, the method further comprising transporting the last brick in the sequence of bricks to a positioning station, the last brick being thereby ready to be positioned.
6. The method of claim 5, further comprising, after transporting the last brick in the sequence of bricks to a positioning station: positioning, from the positioning station using a controllable mechanical device, each of the bricks in the sequence of bricks: at the corresponding adjusted position in the refractory wall when it exists; and at the corresponding predetermined position in the refractory wall otherwise;
7. The method of claim 6, wherein the controllable mechanical device induces, for each of the bricks in the sequence of bricks, a potential positioning error within an error range, the error range being taken into account when computing the average inter-brick gap value to ensure that actual inter-brick gap values are within a tolerance range.
8. The method of claim 1, wherein the sequence of bricks is a complete sequence of bricks comprising all bricks on a layer of the refractory wall.
9. The method of claim 1, wherein the sequence of bricks is a partial sequence of bricks comprising all bricks between two fixed bricks in a layer of the refractory wall, the fixed bricks being positioned at a theoretical position in the layer of the refractory wall.
10. The method of claim 9, wherein the layer of the refractory wall comprises a plurality of partial sequences of bricks comprising the sequence of bricks.
11. A system for positioning a sequence of bricks in a refractory wall comprising: a measuring station operable to receive a plurality of bricks in the sequence of bricks, at least two bricks in the sequence of bricks having a predetermined position in the refractory wall; a measurement module operable to individually measure each of the bricks to obtain actual measurements; a processor module operable to compute an average inter-brick gap value for the sequence of bricks based on the actual measurements and determine an adjusted position for at least one brick in the sequence of bricks based on at least on the computed inter-brick gap value.
12. The system of claim 11, wherein the measuring station receives the bricks by sequentially receiving and uniquely identifying each of the bricks in the sequence of bricks.
13. The system of claim 12, wherein the measuring module individually measures each one of the plurality of bricks to obtain the actual measurements by sequentially measuring and associating a corresponding one of the actual measurements to each of the uniquely identified bricks.
14. The system of claim 13, wherein the processor module computes the average inter-brick gap value for the sequence of bricks based on the actual measurements by resolving, after measuring a last brick in the sequence of bricks and before the at least one brick in the sequence of bricks having an adjusted position is ready to be positioned: AG = $G_t + \frac{.Math._{i=1}^{n} (la_n - lt_n)}{n-1}$ where AG is the average inter-brick gap value for the sequence of bricks, Gt is a theoretical inter-brick gap value for the sequence of bricks, n is the number of bricks in the sequence of bricks and la.sub.n and lt.sub.n are respectively the actual length and the theoretical length of the nth brick.

15. The system of claim 13, further comprising one or more conveyors operable, when the measuring station sequentially receive and uniquely identify each of the plurality of bricks in the sequence of bricks, to sequentially transport each of the bricks in the sequence of bricks to the measuring station and to transport the last brick in the sequence of bricks to a positioning station, the last brick being thereby ready to be positioned.
16. The system of claim 15, further comprising a controllable mechanical device operable to, after transporting the last brick in the sequence of bricks to a positioning station: position, from the positioning station, each of the bricks in the sequence of bricks: at the corresponding adjusted position in the refractory wall when it exists; and at the corresponding predetermined position in the refractory wall otherwise;
17. The system of claim 16, wherein the controllable mechanical device induces, for each of the bricks in the sequence of bricks, a potential positioning error within an error range, the error range being taken into account when the processor module computes the average inter-brick gap value to ensure that actual inter-brick gap values are within a tolerance range.
18. The system of claim 11, wherein the sequence of bricks is a complete sequence of bricks comprising all bricks on a layer of the refractory wall.
19. The system of claim 11, wherein the sequence of bricks is a partial sequence of bricks comprising all bricks between two fixed bricks in a layer of the refractory wall, the fixed bricks being positioned at a theoretical position in the layer of the refractory wall.
20. The system of claim 19, wherein the layer of the refractory wall comprises a plurality of partial sequences of bricks comprising the sequence of bricks.
