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(54) **UNIFORM JOINT WIDTH FORMATION IN
BLOCK CONSTRUCTION**

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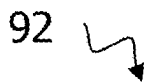
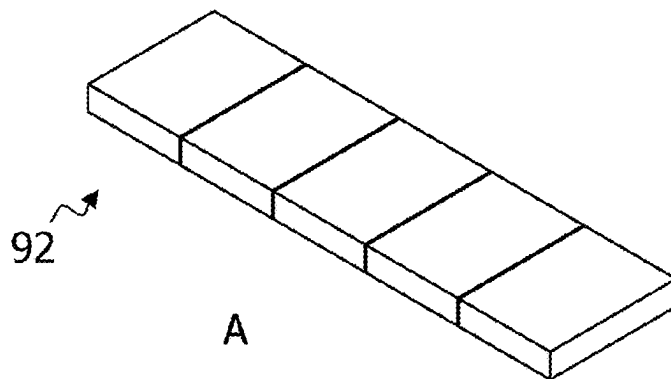
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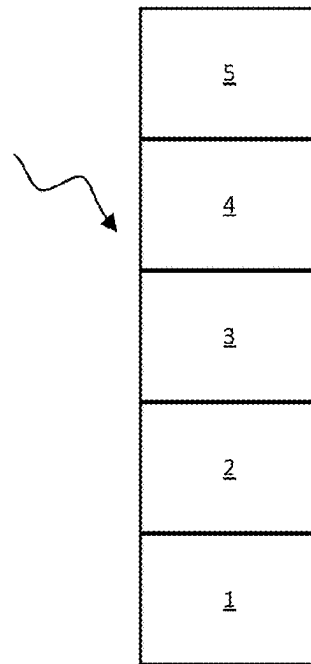
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ABSTRACT

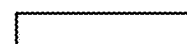
A method and related system for positioning a sequence of bricks in a refractory wall. A measuring station is operable to receive a plurality of bricks in the sequence of bricks, at least two bricks in the sequence of bricks having a predetermined position in the refractory wall. A measurement module 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.



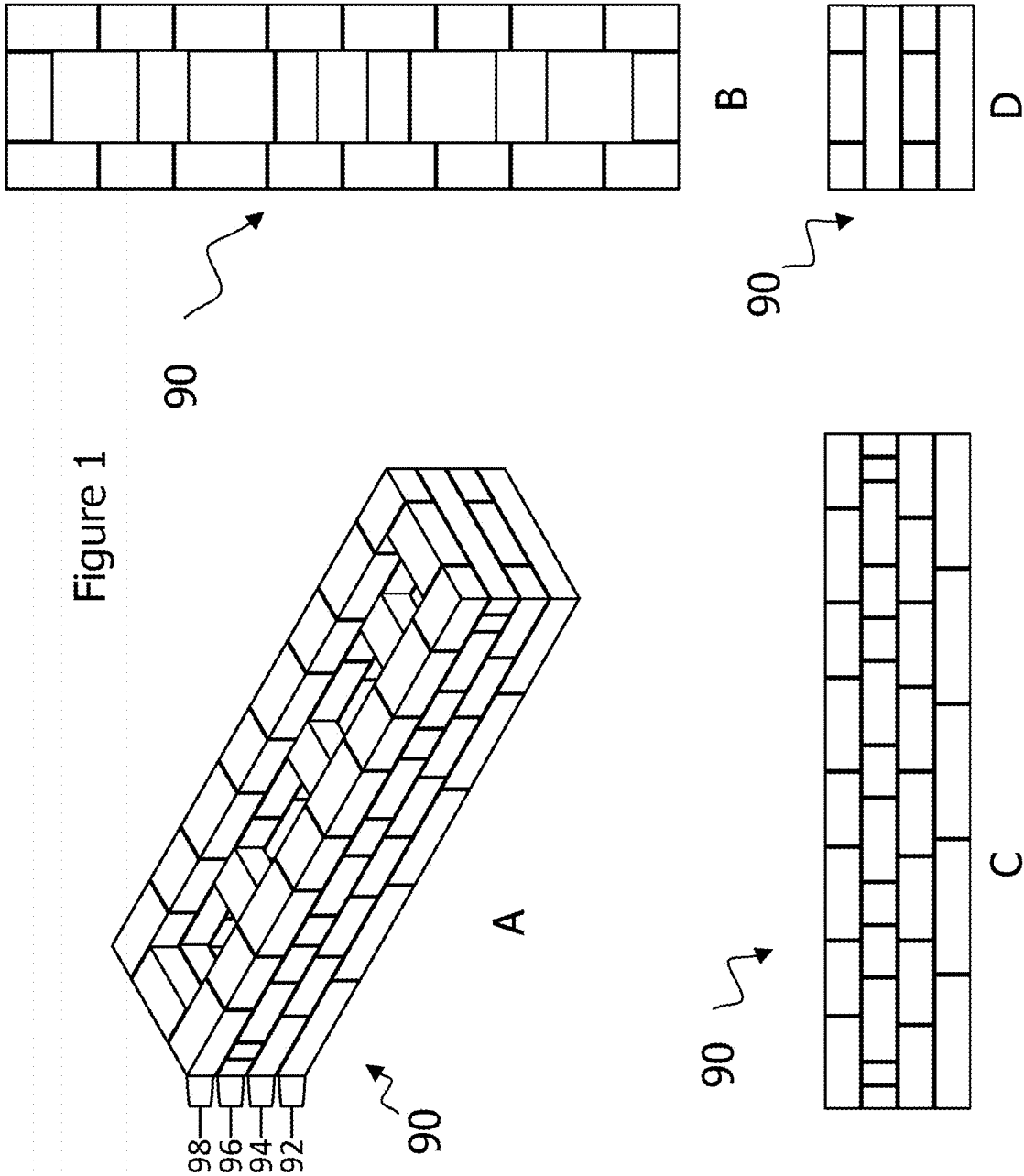
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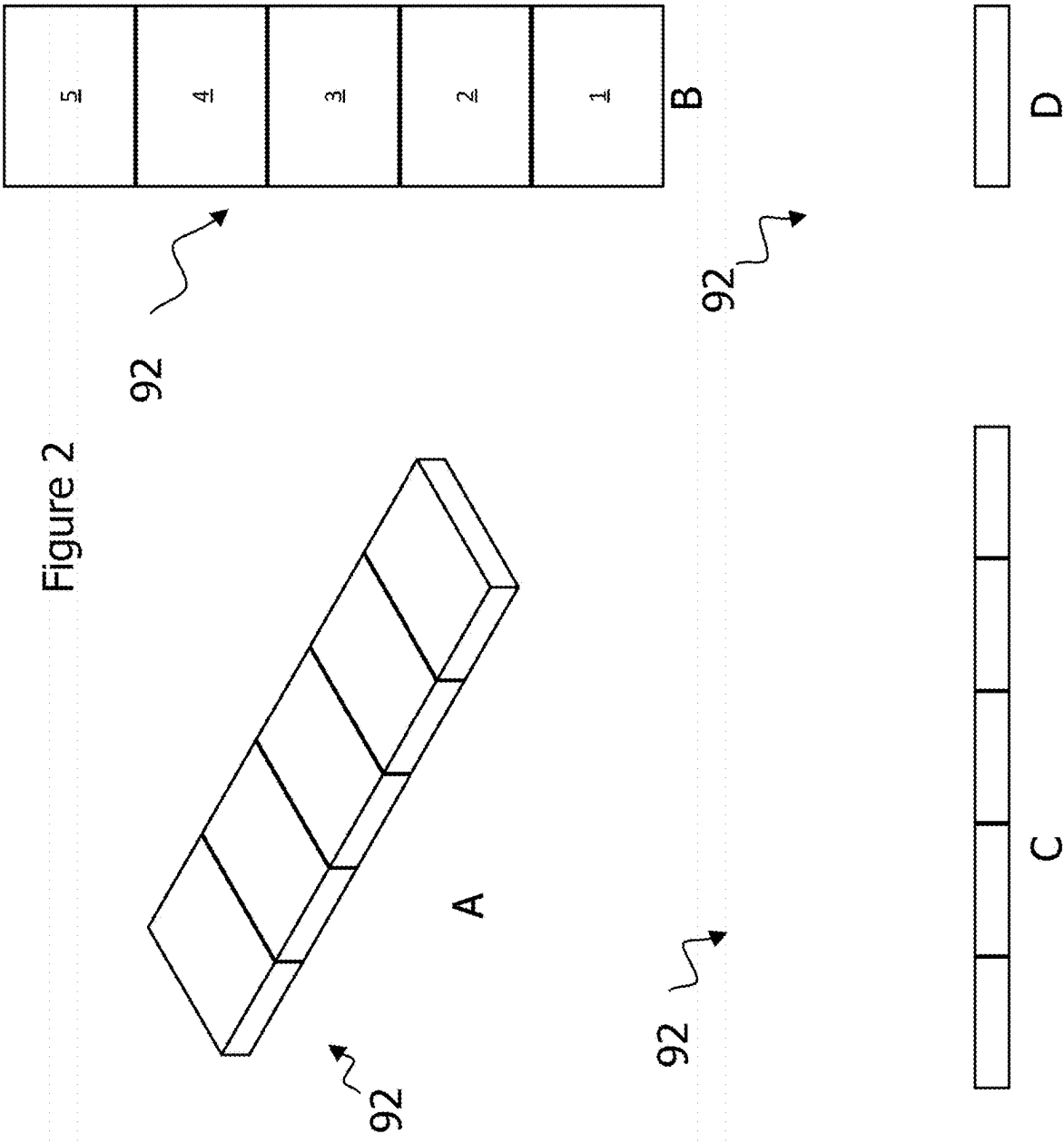


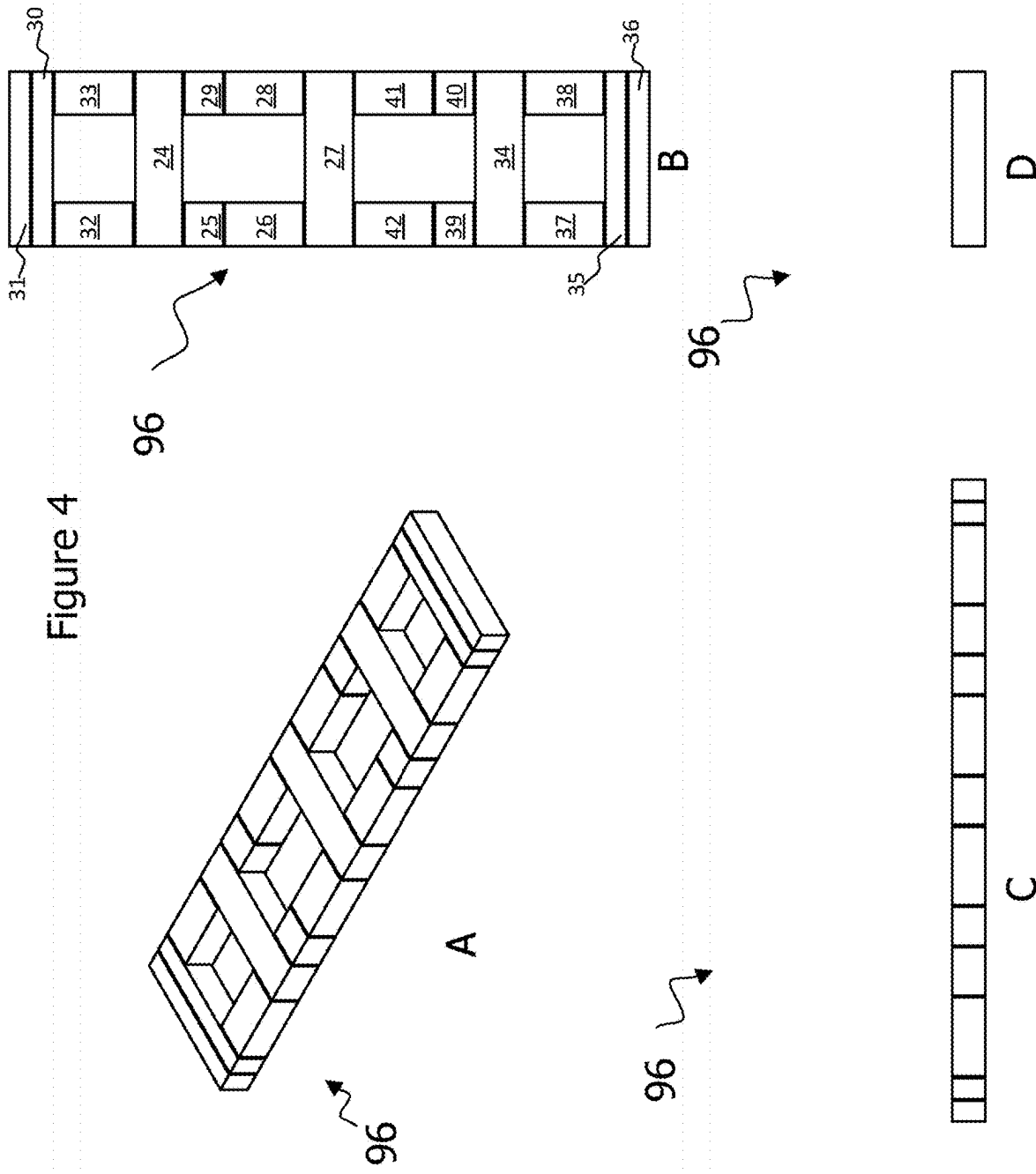
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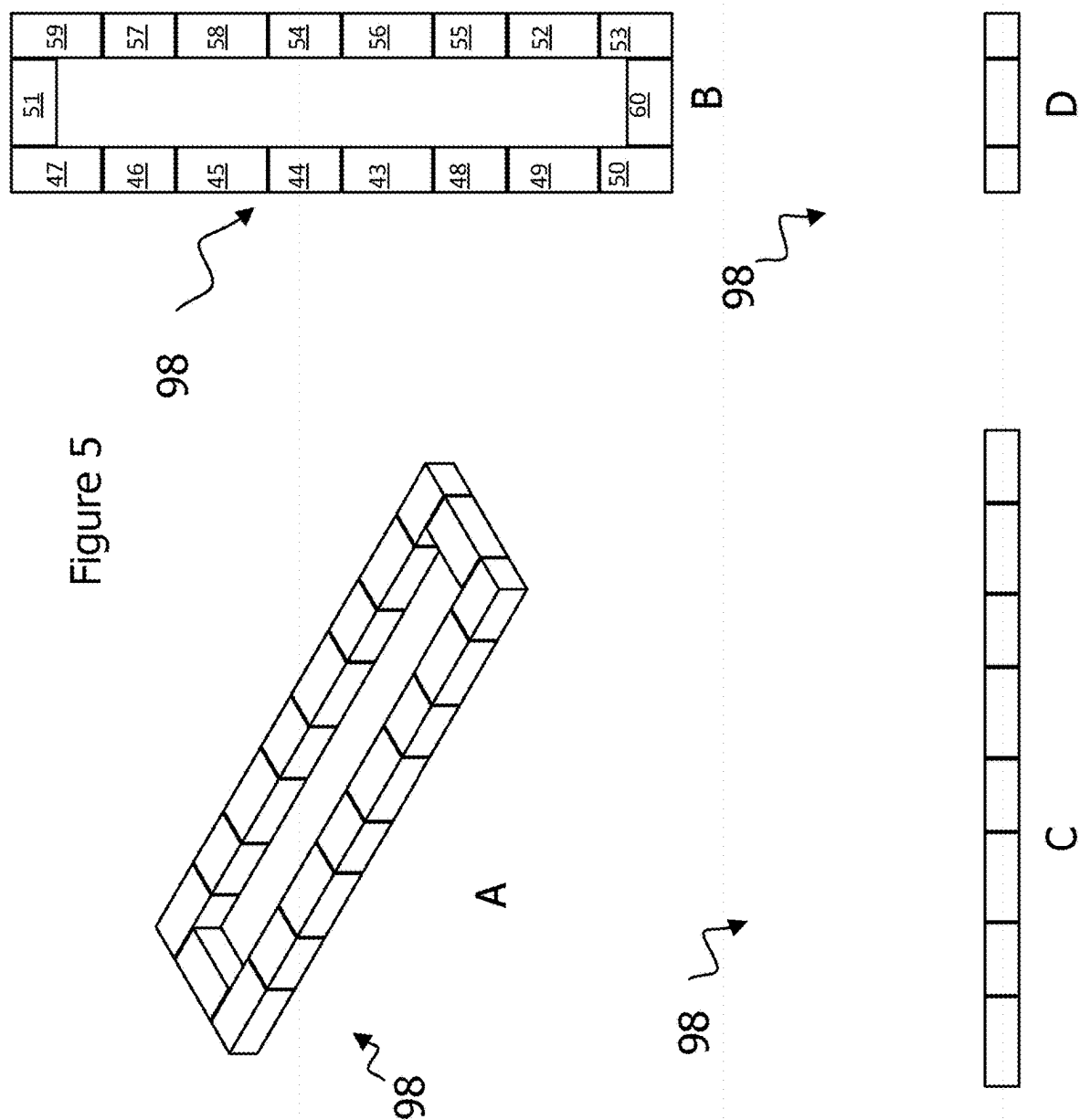


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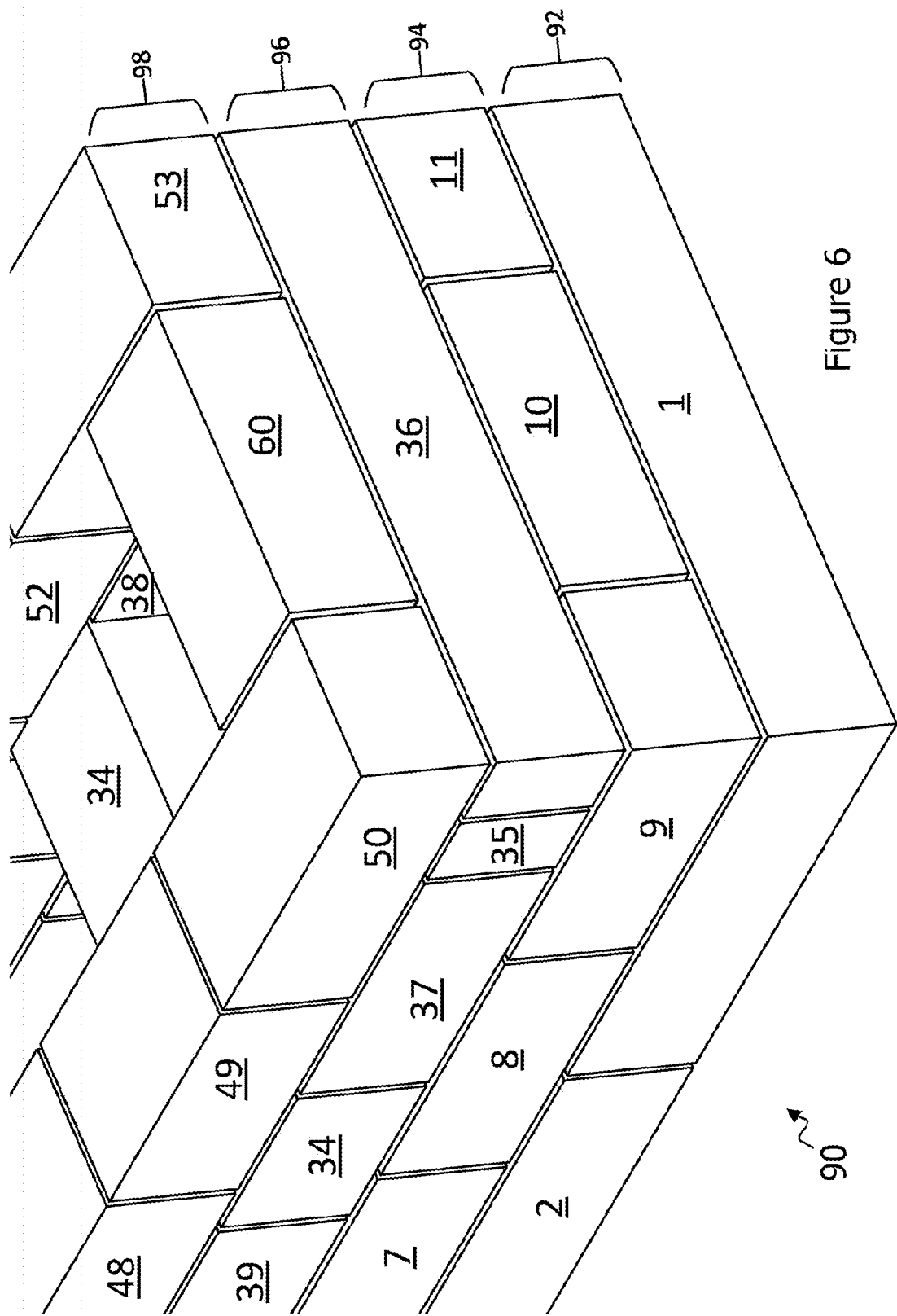


Figure 6

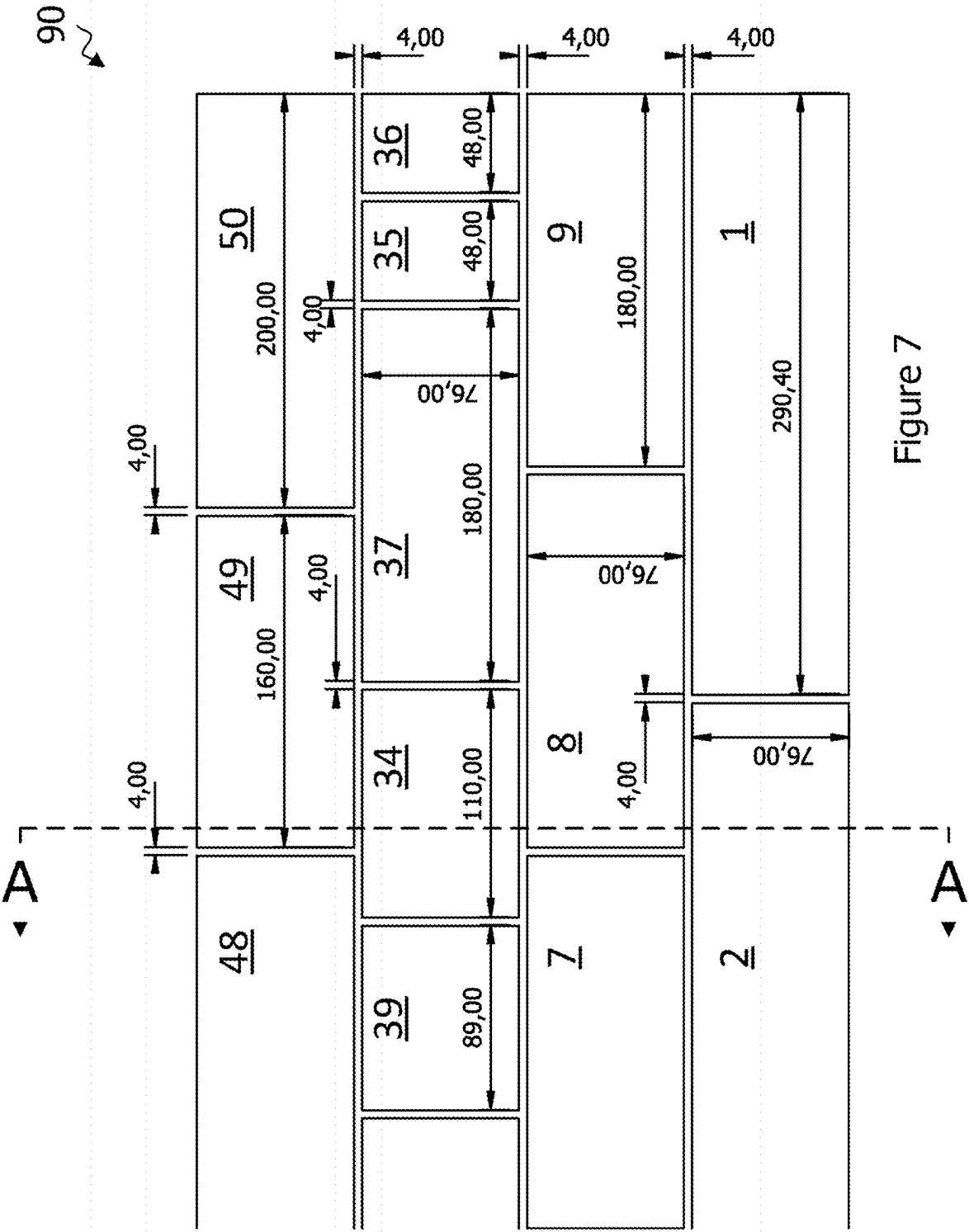


Figure 7

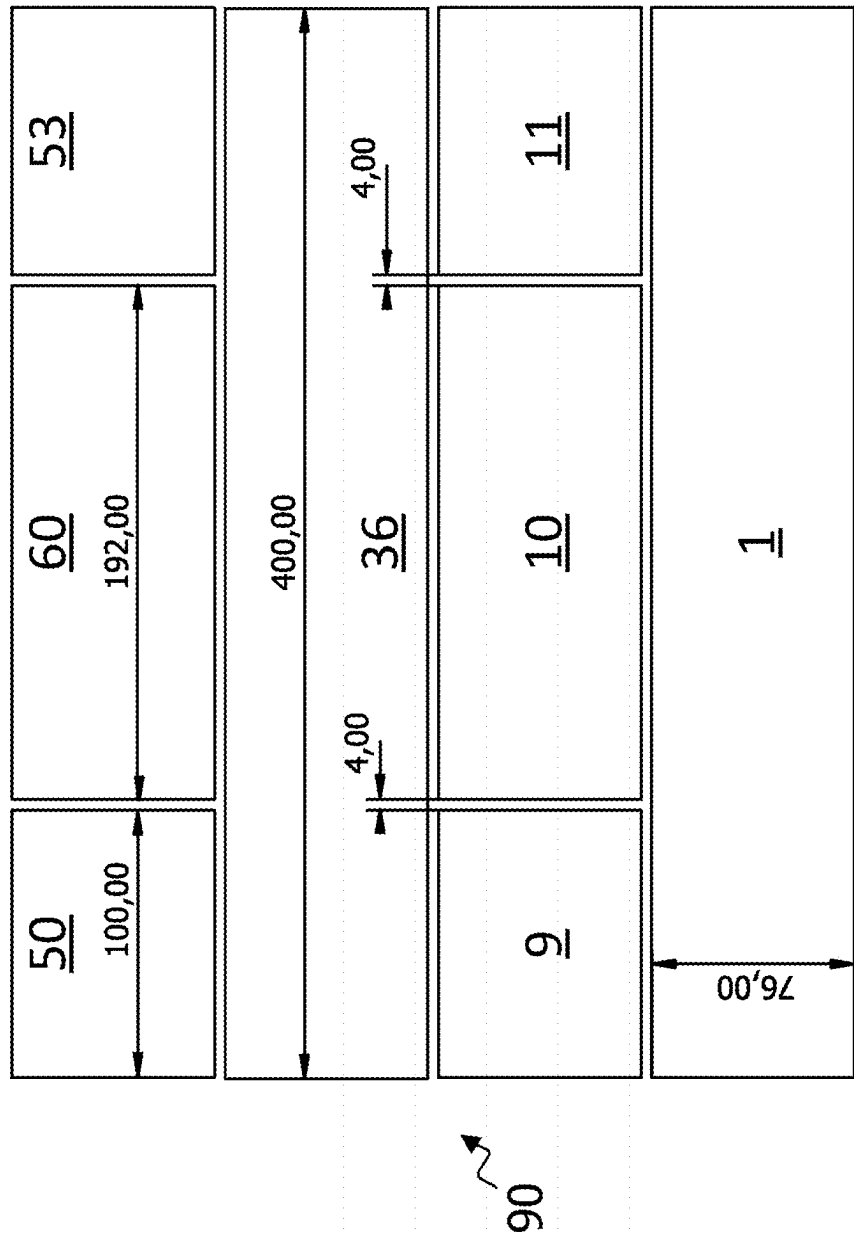
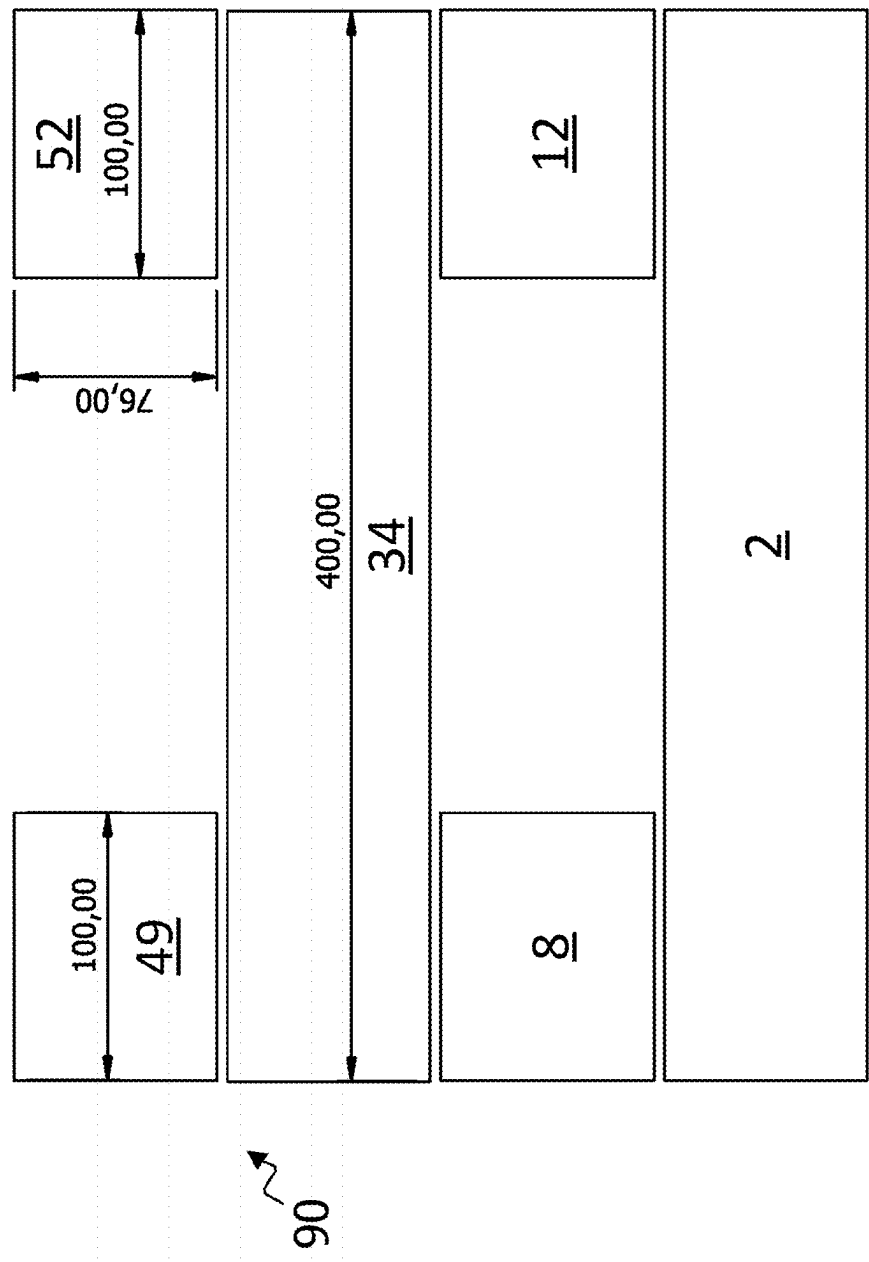


Figure 8



A-A
Figure 9

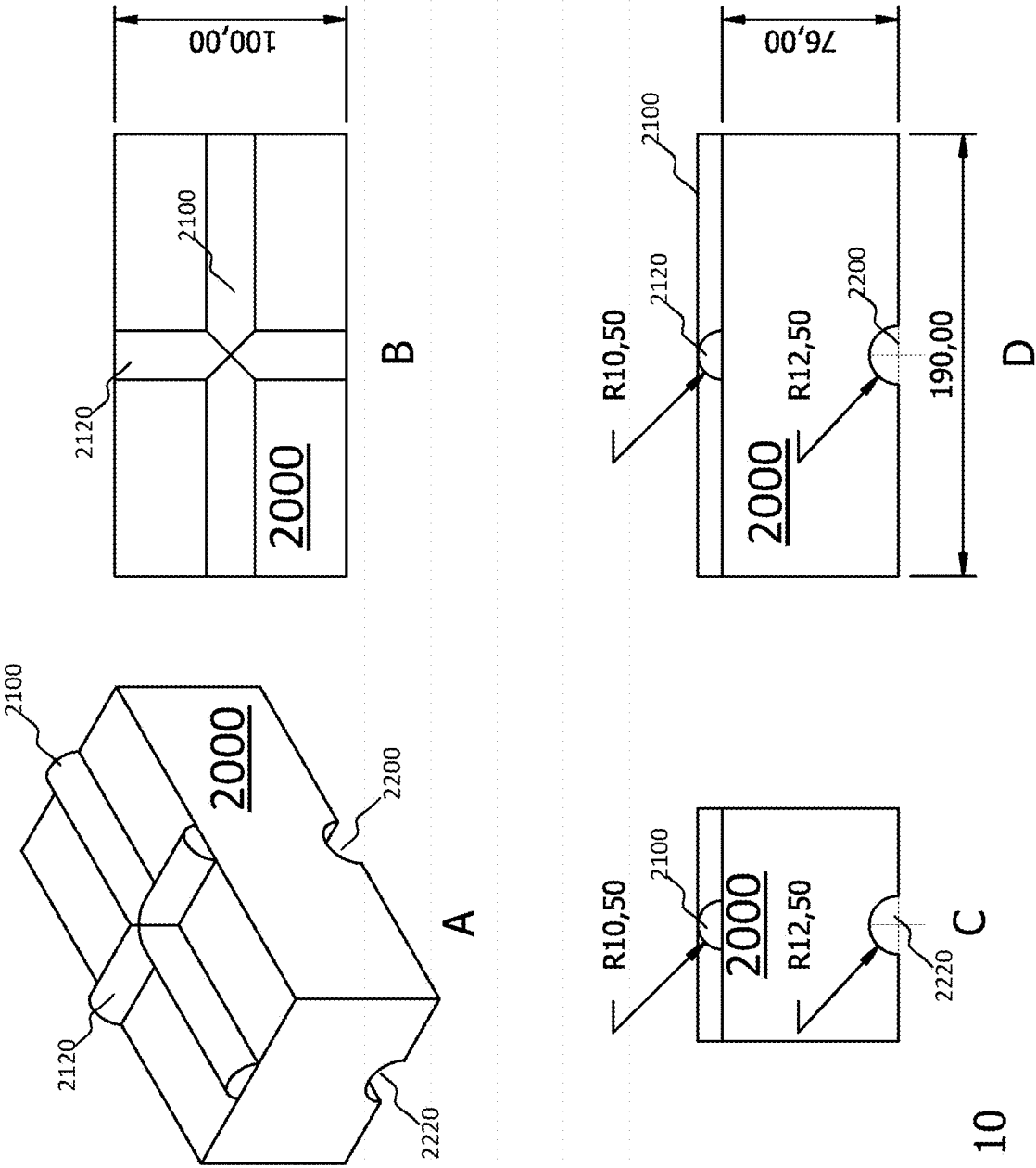


Figure 10

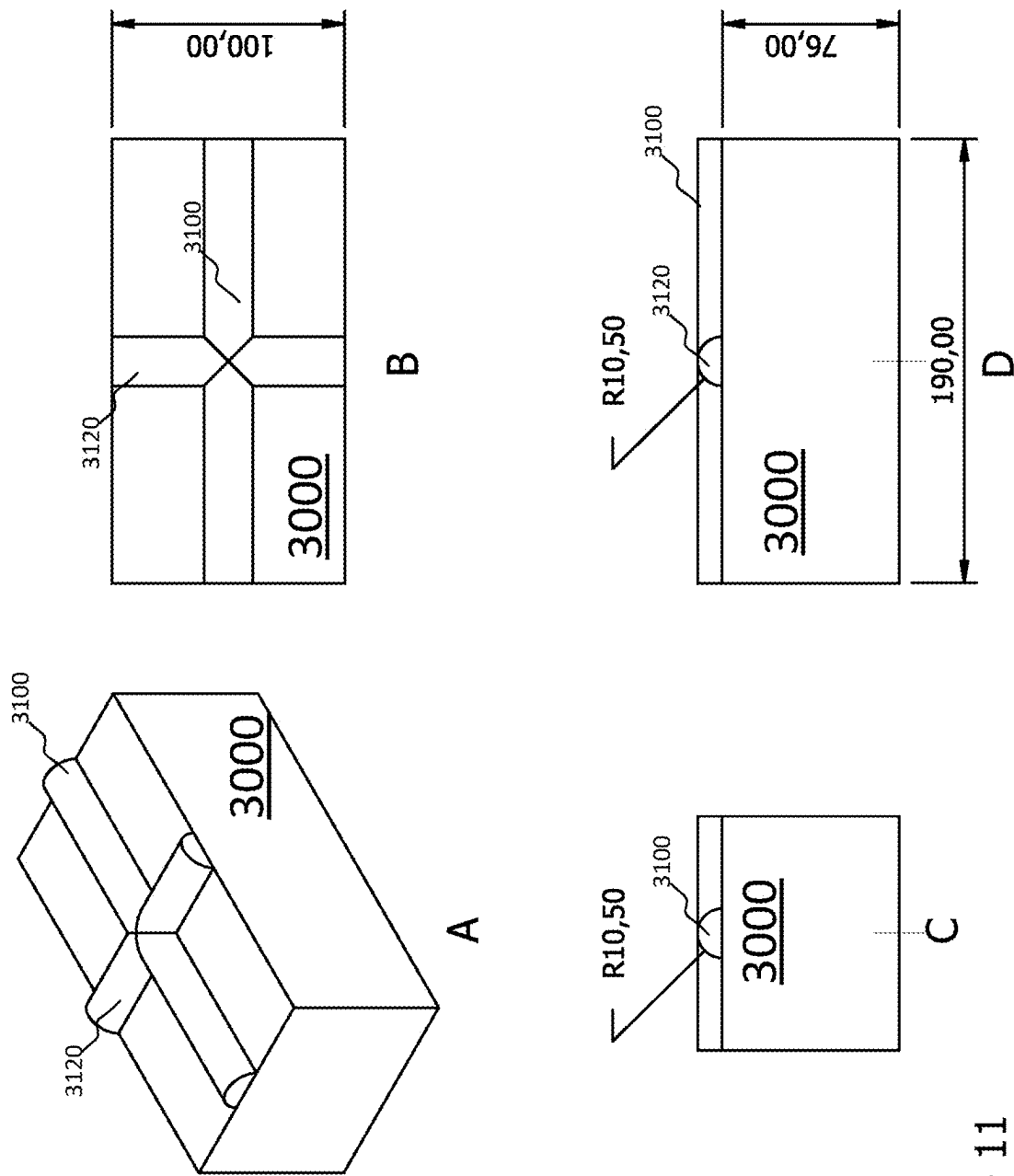


Figure 11

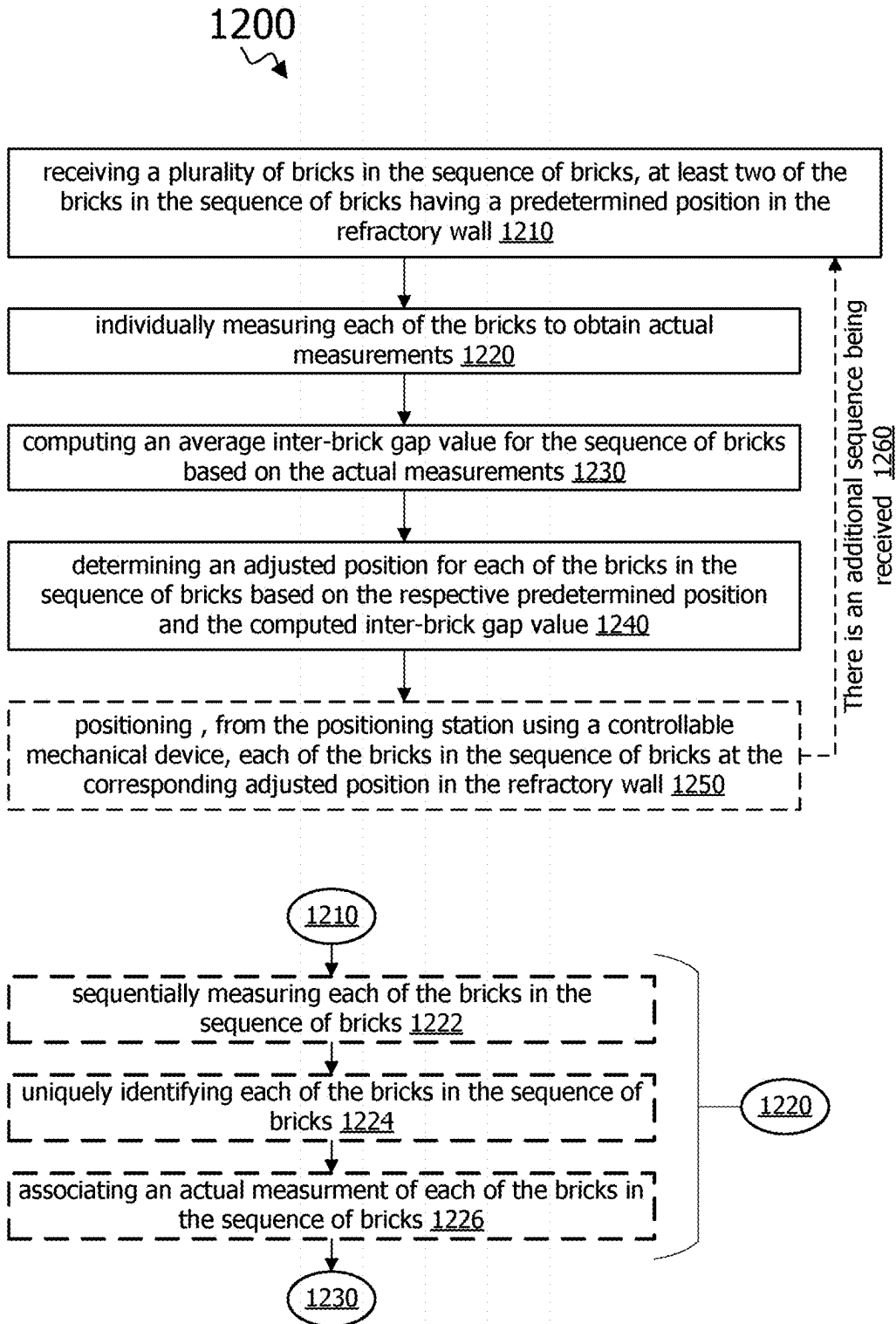


Figure 12

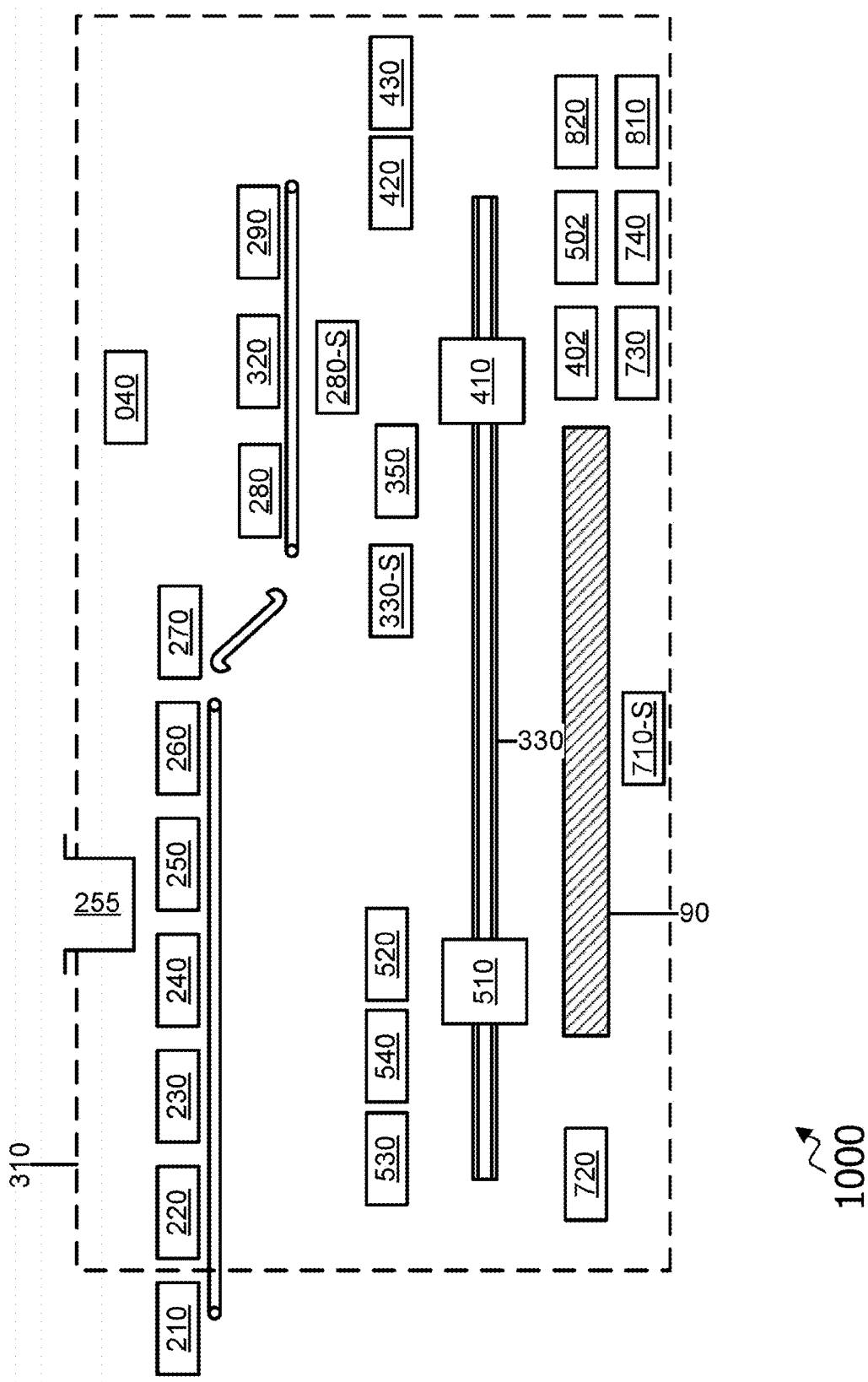


Figure 13

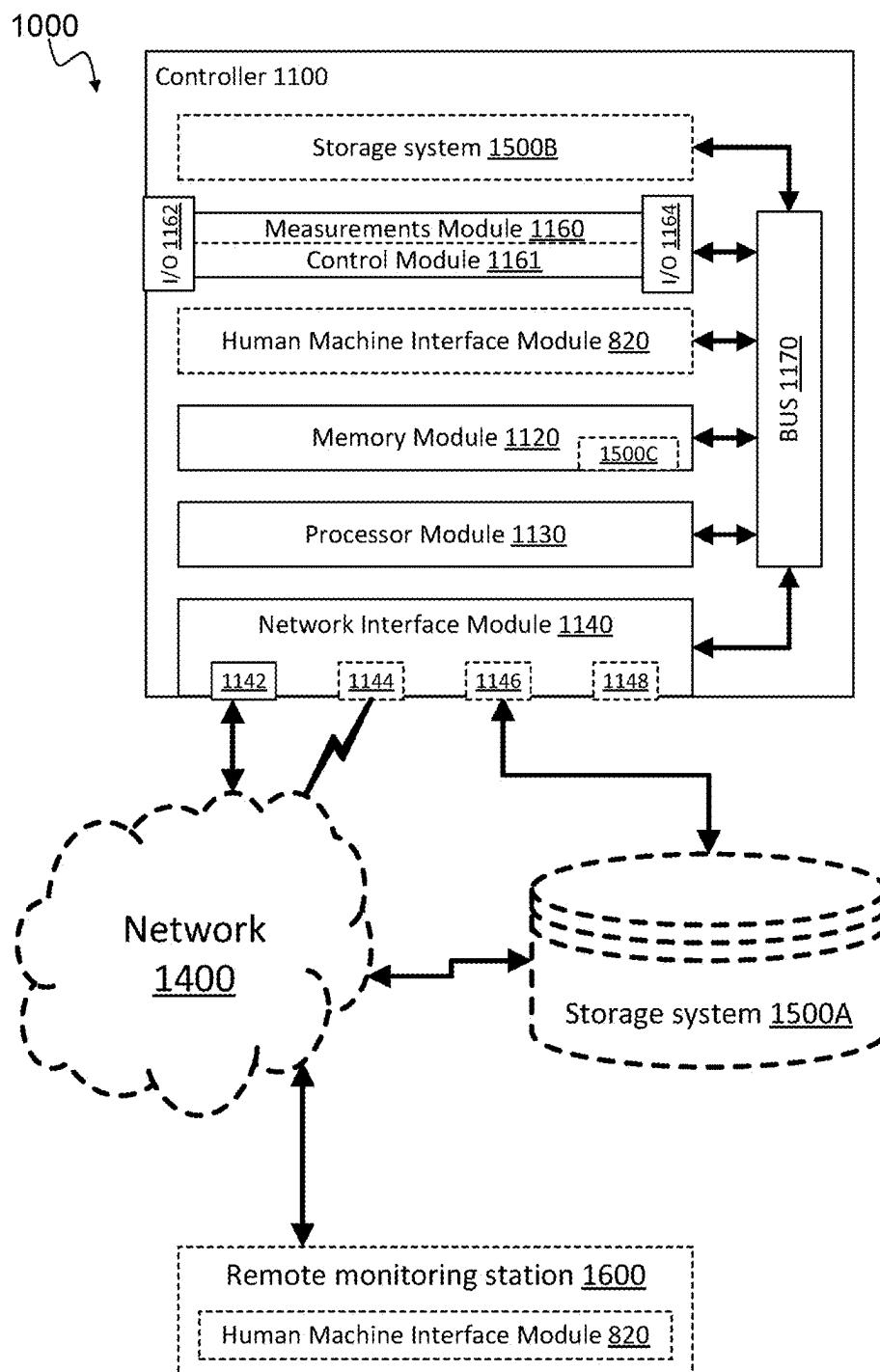


Figure 14

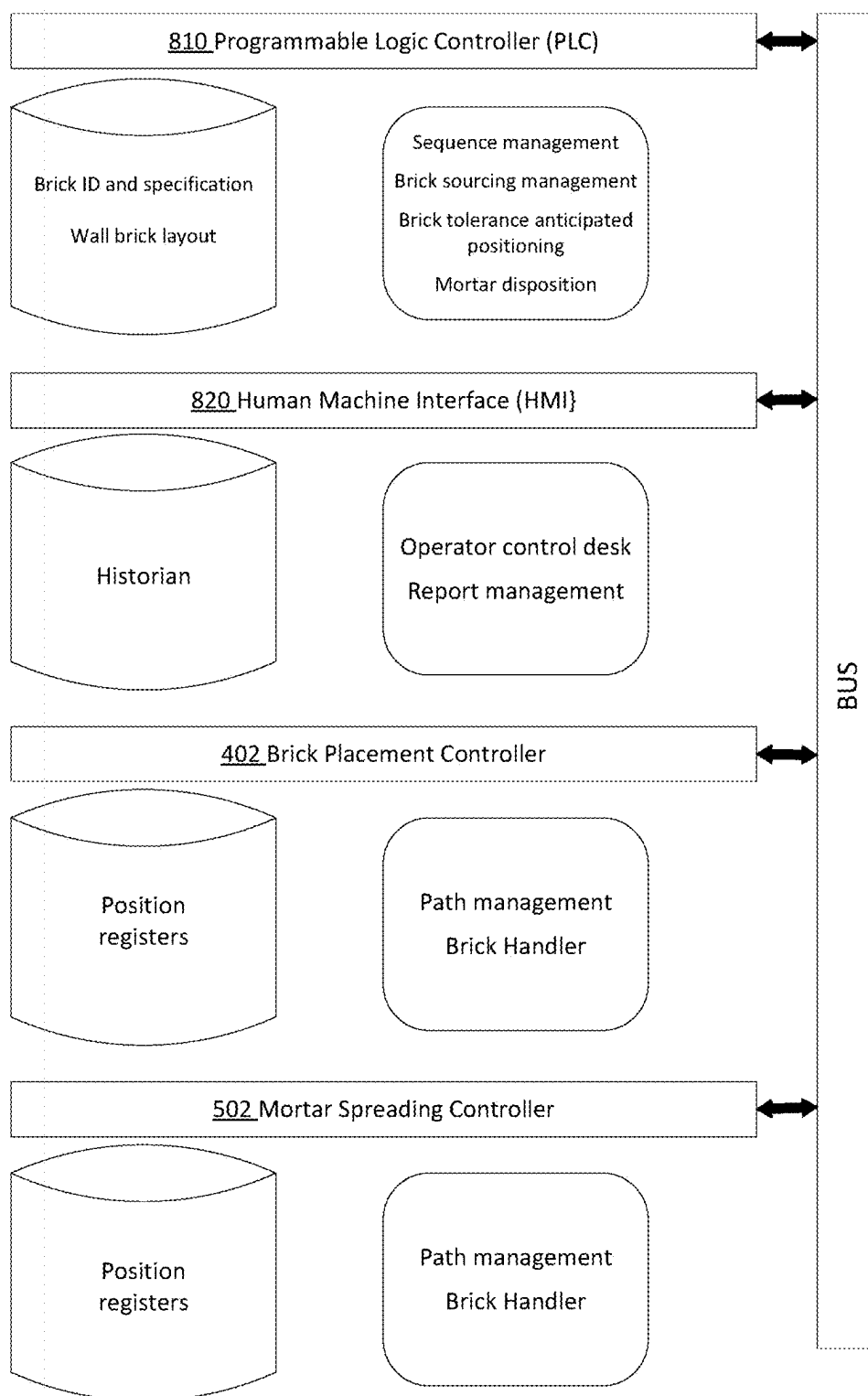


Figure 15

UNIFORM JOINT WIDTH FORMATION IN BLOCK CONSTRUCTION

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_2O_3), contained in cells:

[0003] Cathode: $\text{Al}_3^{+} + 3 \text{e}^{-} \rightarrow \text{Al}$

[0004] Anode: $\text{O}^{2-} + \text{C} \rightarrow \text{CO} + 2 \text{e}^{-}$

[0005] Overall: $\text{Al}_2\text{O}_3 + 3 \text{C} \rightarrow 2 \text{Al} + 3 \text{CO}$

[0006] In reality, much more CO_2 is formed at the anode than CO : $2 \text{O}^{2-} + \text{C} \rightarrow \text{CO}_2 + 4 \text{e}^{-}$ and $2 \text{Al}_2\text{O}_3 + 3 \text{C} \rightarrow 4 \text{Al} + 3 \text{CO}_2$

[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-Heroult 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:

$$AG = G_t + \frac{\sum_{i=1}^n (la_n - lt_n)}{n - 1}$$

where AG is the average inter-brick gap value for the sequence of bricks, G_t 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_n and lt_n are respectively the actual length and the theoretical length of the n^{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 tech-

niques 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:

$$AG = G_t + \frac{\sum_{i=1}^n (la_n - lt_n)}{n - 1};$$

where AG is the average inter-brick gap value for the sequence of bricks, G_t 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_n and lt_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.

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 position 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 be 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 98 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 1500A, a distinct module 1500B of the controller 1100 or a sub-module 1500C 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 known 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 clean-

ing) 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:

$$AG = G_t + \frac{\sum_{i=1}^n (la_n - lt_n)}{n - 1}$$

[0076] where AG is the average inter-brick gap value for the sequence of bricks, G_t 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_n and lt_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.

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:

$$AG = G_t + \frac{\sum_{i=1}^n (la_n - lt_n)}{n - 1}$$

where AG is the average inter-brick gap value for the sequence of bricks, G_t 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_n and lt_n are respectively the actual length and the theoretical length of the n th 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:

$$AG = G_t + \frac{\sum_{i=1}^n (la_n - lt_n)}{n - 1}$$

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_n and lt_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.

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