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Apparatus and Method for Three-Dimensional Contouring

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Abstract

A device and method for contouring three-dimensionally curved surfaces includes an elongated contouring assembly that is supported at two locations by height adjustment mechanisms that raise and lower the two locations of the contouring assembly independently of each other. The contouring assembly creates a three-dimensionally curved surface as it passes over an area to be contoured. The control of at least one location of the contouring assembly is based on a comparison of the measured position of one portion of the contouring assembly with a profile of the surface to be leveled that is stored in a computer memory. Control of the height of the other location is preferably based on the height above a physical reference measured with a proximity sensor. A pivot or tilting controller may control the tilting of the contouring assembly to follow the slope of the profile stored in computer memory.

16 Claims, 17 Drawing Sheets
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Fig. 10A
Fig. 10B

- **Computer (72) Calculates Height Error (106)**
- **PWM Processor (74) Outputs Height Correction Control Signal (107)**
- **Right "Lower" Solenoid (88), Right "Raise" Solenoid (86) (108)**
- **Active Control Process for Contoured Leveling Operation**
- **Computer (72) Determines Relative Slope at XY Position of Target (56) (104b)**
- **Computer (72) Calculates Desired Tilt of Assembly (110)**
- **Optional Output Tilt Control Signal to DAC Board (114) (112)**
- **Work Site "Concrete Cures"**
Fig. 11
APPLIANCE AND METHOD FOR THREE-DIMENSIONAL CONTOURING

BACKGROUND OF THE INVENTION

This invention relates generally to methods and devices for contouring or smoothing freshly poured concrete, sand, gravel, dirt, or other like loose, spreadable materials, and, more particularly, to an apparatus and method for contouring and placement of such materials with a vehicle either positioned adjacent the materials to be contoured or driven through the materials to be contoured.

In the past, the screening or smoothing of uncured concrete by screening machines has been primarily limited to flat, one or two dimensional surfaces. In order to screed a three dimensional concrete surface, the screening apparatus was required to follow predetermined or preset forms, such as wires, boards, or rails, stationed along both sides of the surface to be screeded. Each end of the screed would follow the predetermined physical form. By using preset physical forms of different shapes or slopes on either side of the surface to be screeded, it is possible to create a smooth surface having a three dimensional curvature. The use of preset physical forms, however, presents several disadvantages.

The creation of the physical forms is a labor intensive process that increases the time and expense necessary to establish a contoured surface. The preset physical forms also typically only approximate the desired shape of the surface to be contoured, thereby decreasing the quality of the contoured surface. For example, if the physical form consists of a wire, it is virtually impossible to accurately define a desired curvature. Rather, the wire approximates the curvature by a series of successive straight segments. These and other disadvantages of prior screening techniques have led to the desire to reduce reliance on preset physical forms.

In the past, non-concrete contouring machines have been developed for contouring three dimensional surfaces without the use of preset physical forms. These devices, however, require contact sensors for creating a profile of the subbase over which a material is placed and contoured. These devices have also been limited to earth grading, asphalt laying, or other non-concrete leveling tasks. An example of such a prior device is disclosed in U.S. Pat. No. 5,549,412 issued to Maloney. This patent discloses a device for profiling and paving asphalt surfaces in three dimensions. The paving device includes a data storage device for storing the profile of the subbase to be contoured. The accuracy of the profile is dependent upon the frictional and physical characteristics of the contact sensor with respect to the subbase. The contact nature of the sensor may introduce errors into the profile creation that are undesirable.

Some prior art grading machines have also been dependent upon the profile of the subbase. Such machines can only be effectively used after the subbase has been contoured to the desired shape. This increases the amount of work required to screed a concrete surface. Some prior art grading devices have also required the generation of the profile by running the sensors over the subgrade prior to the contouring step. This profile generation step may result in additional inaccuracies due to alignment errors of the contact sensor during the contouring step when compared with the profiling step. This further increases the inaccuracies in the system.

Another disadvantage of the prior art is the required use of multiple sensors to determine the position of the contouring structure in three dimensions. For example, in U.S. Pat. No. 4,807,131 issued to Clegg, a grading system is disclosed that uses a laser reference beam in combination with a pair of wheel encoders. The laser reference beam is used to establish the vertical height of the grading blade while the encoders measure the horizontal position of the grading blade. The use of multiple sensors increases the complexity and associated cost of the grading system, and is therefore undesirable for many applications.

SUMMARY OF THE INVENTION

The present invention is an improved device and method for contouring poured uncured concrete, sand, gravel, dirt, or like loose, spreadable viscous fluid or plastic materials on the ground or on suspended decks, parking structures, or other surfaces. The present invention provides a device and method for contouring three dimensional curved surfaces without the necessity of preset physical forms on both sides of the surface to be contoured. The present invention also provides a simple and effective way for contouring surfaces that overcomes the measurement inaccuracies of various prior art machines.

In one aspect, the invention is an improved control system for controlling a contouring machine while a contouring assembly on the machine is moved over an area to be contoured. The system includes a controller for controlling the height of a first end of the contouring assembly. One of a tracking device and a target are positioned on the first end of the contouring assembly and the other of the tracking device and the target is positioned remotely from the contouring assembly. The tracking device tracks the position of the target and measures the position of the target in three dimensions as the assembly is moved over the area to be contoured. The measurement of the target is used by a controller which adjusts the height of the first end of the contouring assembly to correspond to a stored profile of the desired shape of the surface to be contoured.

According to a second aspect, the invention is a device for contouring a surface which includes a contouring assembly having first and second ends. A first sensing apparatus is positioned on one end of the assembly, while a sensing apparatus that is different from the first sensing apparatus is positioned on the second end of the assembly. A controller adjusts the height of the first end of the assembly based on a stored profile of the desired shape of the surface to be contoured. The controller adjusts the height of the second end of the assembly based on the distance between the second end of the assembly and a reference surface along one side of the area to be contoured.

According to a third aspect, the invention is a device for contouring a surface that includes a boom movably mounted on a base. A contouring assembly is mounted at an end of the boom opposite to the base, and the assembly has a first and second end that are independently adjusted by a control system. As the contouring assembly is moved over the area to be contoured, the independent control of the first and second ends of the assembly allows the device to contour a three dimensional surface.

According to a fourth aspect, the invention is a contouring assembly for contouring a surface to its desired shape. The invention includes a support having first and second ends, an elongated contouring assembly, and a height adjustment...
mechanism attached to the support and the contouring assembly. The height adjustment mechanism is adapted to adjust the height of the contouring assembly with respect to the support based on the desired shape of the surface to be contoured. The contouring assembly is pivotally attached to the support and controlled by a pivot adjustment mechanism that pivots the contouring assembly about a pivot axis based also on the desired shape of the surface to be contouring.

In another aspect, the invention is a method for contouring a surface to a desired three dimensional shape and includes the steps of storing the desired three dimensional shape in a computer memory and providing a contouring assembly having first and second ends. As the contouring assembly is moved over the area to be leveled, the position of the first end of the contouring assembly is determined in three dimensions. The height of the first end of the contouring assembly is then adjusted to correspond to the height of the desired three dimensional shape. The distance between the second end of the contouring assembly and a reference surface is also determined as the contouring assembly is moved over the area to be contoured, and the height of the second end of the contouring assembly is adjusted to maintain a constant height above the reference surface.

In yet another aspect, the invention is a kit for modifying a previously existing one or two dimensional or scraining machine in order to allow it to be capable of contouring three dimensionally curved surfaces. The kit is preferably adapted for use with previous one or two dimensional leveling machines which include a leveling assembly with first and second ends that are each uniformly controlled by height adjustment mechanisms. The kit includes a target for attaching to either the first or the second end of the leveling assembly, and a tracking device that tracks the target and measures its position in three dimensions. A control system is included with the kit that operates each height adjustment mechanism independently of the other based on the measured position of the target. The independent control of the height adjustment mechanisms allows a three dimensionally curved shape to be contoured, if desired. In different embodiments, the kit may include different components. For example, the kit may include a segmented screed in addition to the previously listed components, to allow scraining a surface that approximates a higher degree of curvature. In other embodiments the kit may include a pair of wires for attaching to two separate reference points, a pair of distance encoders that measure the length of the wires as the leveling or smoothing assembly moves, and a pair of angle encoders that measure the angles defined between the wires and the leveling assembly. A control system is included in the kit that determines the position of the leveling assembly based on the length of each of the wires from the two reference points.

In another aspect, the invention is a contouring machine comprising a screed for spreadable materials including poured, uncurved concrete, a height adjustment mechanism for adjusting the height of the screed on the contouring machine, a target, a tracking device which tracks the target and measures the position of the target in at least two dimensions, one of the target and tracking device positioned on the machine and the other of the target and tracking device positioned at a location remote from the machine, and a controller for controlling the height adjustment mechanism based on the position of the target with respect to the tracking device. This aspect of the invention also includes a method for moving the screed over the spreadable material and adjusting the height of the screed as the screed is moved over the spreadable material such that the spreadable material is contoured.

Accordingly, the present contouring device and method provide improvements and advantages over prior contouring devices and methods. The invention allows the smoothing of either a one, two, or three dimensional curved surface without the use of contact sensors, and also without the use of preset physical forms on both sides of the contouring device. The present invention thereby eliminates substantial time and labor expenses while providing improved accuracy in the final, contoured surface. The use of a single measuring device for tracking the position of one end of the contouring assembly further reduces the complexity and cost of the invention. The invention does not require passing the device over the surface to be contoured prior to the actual contouring step, thereby reducing the number of steps involved in the contouring process. Moreover, the contouring device does not have to be moved in a predetermined direction during the contouring process, thereby simplifying the contouring procedure. The invention can smooth a surface either independently of the subbase, or dependent on the subbase, if desired. The invention can also be used as a kit to retrofit existing leveling machines that are only capable of smoothing one or two dimensional surfaces.

These and other objects, advantages, purposes, and features of the invention will become more apparent from the study of the following description when read in conjunction with the drawings.

**BRIEF DESCRIPTION OF THE DRAWINGS**

FIG. 1 is a perspective view of a first embodiment of the contouring device according to the present invention;

FIG. 2 is an elevational view of the contouring device of FIG. 1 illustrating the movement of a boom in phantom;

FIG. 3 is a plan view of the contouring device of FIG. 1 illustrating the movement of the boom in phantom;

FIG. 4 is a schematic illustration of the contouring device and tracking device;

FIG. 5 is a block diagram of a control system for controlling a first end of a contouring assembly on the contouring device;

FIG. 6 is a block diagram of a hydraulic control system for the contouring assembly;

FIG. 7 is an exploded, perspective view of the contouring assembly;

FIG. 8 is an enlarged, fragmentary, perspective, exploded view of a tilting assembly for tilting the contouring assembly;

FIG. 9a is an enlarged, fragmentary, elevational view of the contouring assembly of the present invention depicted in an unrotated orientation;

FIG. 9b is an enlarged, fragmentary, elevational view of the contouring assembly depicted as rotated in a counterclockwise orientation;

FIGS. 10A and 10B are flowcharts illustrating the method of the present invention for contouring a three dimensional surface;

FIG. 11 is a flowchart illustrating a method for creating a stored profile of the desired surface to be contoured;

FIG. 12 is a front, elevational view of a contouring device according to a second embodiment of the present invention;

FIG. 13 is a perspective view of the contouring device of FIG. 12 illustrating the movement of a boom in phantom;

FIG. 14 is a plan view of a contouring device according to a fourth embodiment of the present invention; and
DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention will now be described with reference to the accompanying drawings wherein like reference numerals correspond to like elements in the several drawings. A contouring device or machine 20 according to the present invention is depicted in FIG. 1. Contouring machine 20 includes a base 22 upon which an operator 24 controls contouring machine 20. Base 22 includes a platform 38 upon which an upper frame 40 is rotatably mounted. Base 22 can be moved to any desired location by wheels 42 which are powered by a motor onboard base 22. Platform 38 is securely planted at a desired location by four stabilizer legs 44 that are retractable when contouring machine 20 is driven to different locations. A boom 26 is telescopically mounted on a front end of upper frame 40. A support beam 27 is affixed to boom 26 at an opposite upper frame 40. A contouring member preferably includes a contouring assembly 28 mounted on support 27 by way of a right and left hydraulic cylinder 52 and 54, respectively. Hydraulics cylinders 52 and 54 independently raise and lower the respective ends of contouring assembly 28 with respect to support 27. Other than the controls for independently controlling the individual ends of contouring assembly 28 and tilting it about an axis as depicted in FIGS. 9a-c, the structure of contouring machine 20 is the same as that disclosed in commonly assigned U.S. Pat. No. 4,930,935 issued to Quenzi et al., and which is incorporated herein by reference.

When contouring machine 20 is to be used to contour a surface, it is positioned adjacent an area of raw material 30 which is to be contoured (FIGS. 2 and 3). For purposes of discussion hereafter, it will be assumed that material 30 is freshly poured, uncured concrete, and that the contouring machine includes a screed or contouring unit or member adapted for spreading, distributing, smoothing, leveling and/or grading such uncured concrete. This assumption is for purposes of discussion only, and it will be understood that material 30 can be any of a variety of other loose, gradable materials, such as dirt, sand, or earth. It will also be further understood that contouring machine 20 can be used to smooth material 30 to have one, two, or three dimensional surface. The contouring member could also be a blade or other earth moving or material moving device. In operation, the boom 26 is extended away from upper frame 40. Preferably, concrete 30 is deposited in the area to be contoured prior to boom 26 being extended. Thereafter, boom 26 is extended over the poured concrete without contacting the concrete. The boom is then retracted toward and into upper frame 40 while contouring assembly 28 contours the uncured concrete 30 as boom 26 is retracted. Alternately, machine 20 can be moved through the concrete, or other material, as set forth in Quenzi U.S. Pat. No. 4,930,935.

Contouring assembly 28 includes a right and left side 46 and 48, respectively, as viewed from operator position 24 (FIGS. 1-3). Support 27 extends between right and left sides of contouring assembly 28. Right hydraulic cylinder 52 is mounted at right end 46 of support 27 and adjustably raises and lowers right side 46 of contouring assembly 28 with respect to support 27. Left hydraulic cylinder 54 is mounted on left side 48 of support 27 and adjustably raises and lowers left side 48 of contouring assembly 28 with respect to support 27. By independently controlling right hydraulic cylinder 52 and left hydraulic cylinder 54, the cross slope of contouring assembly 28 can be adjusted as desired in a plane transverse to the direction of motion of contouring assembly 28 when boom 26 is retracted. By adjusting the cross slope of contouring assembly 28, a three dimensional curved surface can be produced over a given large area by contouring machine 20. Alternatively, by adjusting the height of right and left sides 46 and 48 of contouring assembly 28 uniformly, a one or two dimensional surface can be created.

Contouring assembly 28 preferably includes one or more of a plow 32, a vibrating screed or contouring beam 34, and a rotating auger 36 (FIGS. 1, 2, 7 and 9a-c). Plow 32, screed 34, and auger 36 all extend generally parallel to each other and are oriented transverse to the direction of motion of contouring assembly 28 as it is extended and retracted by boom 26. Plow 32, auger 36, and screed 34 are all mounted on a center beam 29 that extends parallel to plow 32, auger 36 and screed 34. Plow 32 is positioned on a leading side 41 of contouring assembly 28 (when boom 26 is being retracted) and serves to push excess concrete away from auger 36 and vibrating screed 34 while also determining the initial grade for the concrete or other material 30. Auger 36 is positioned between plow 32 and vibrating screed 34 and extends downwardly approximately ten inches further than plow 32. A motor 43 attached at left side 48 of center beam 29 rotates auger 36. Auger 36 rotates and moves the excess concrete or material 30 in a direction from left side 48 toward right side 46, although motion in the opposite direction from right side 46 to left side 48 could also be used. Vibrating screed or contouring beam 34 is located adjacent auger 36. Vibrating screed 34 is constructed to vibrate by way of an eccentrically weighted motor system as disclosed in commonly assigned U.S. Pat. No. 4,930,935, and smooths the uncured concrete as it passes over the area to be contoured, after plow 32 and auger 36 have removed excess concrete and spread and distributed the concrete generally evenly across the path of travel of assembly 28. Screed 34 extends downwardly approximately ten inches further than auger 36.

Leveler assembly 28 can also include, if desired, an oscillating engaging member (not shown) of the type described and disclosed in commonly assigned, copending application entitled SCREEDING APPARATUS AND METHOD INCORPORATING OSCILLATING ATTACHMENT, filed Mar. 31, 1998, now U.S. Pat. No. 6,183,160, which is incorporated herein by reference. As described therein, an oscillating engaging member is located between auger 36 and screed 34 and oriented generally parallel thereto. The oscillating member oscillates in its longitudinal direction, parallel to contouring assembly 28, and further serves to smooth and distribute the concrete prior to the final leveling of screed 34.

A target 56 is located atop right hydraulic cylinder 52 (FIGS. 1-5). Target 56 comprises an infrared heat source and corner-cube laser reflecting mirror. The position of target 56 is tracked by an infrared tracking device 58 (FIGS. 4-5) as contouring assembly 28 is moved over the surface to be contoured. In the currently preferred embodiment, tracking device 58 emits a laser beam 60 that is reflected by target 56 back to tracking device 58. From the reflected beam, tracking device 58 computes the distance between itself and target 56. Tracking device 58 further includes servo motors and infrared sensors which control the orientation of emitted laser beam 60 such that it will follow (i.e. track) target 56 wherever it is moved. From the distance measured to target 56 and the angles measured by tracking device 58 at which laser beam 60 is emitted from tracking device 58, tracking device 58 is able to calculate the position of target 56 in three dimensions (e.g. X, Y, and Z) from a known reference point. Tracking device 58 further includes a radio transmitter that transmits the measured position of target 56 to a receiver 62 on base 22. In the currently preferred embodiment, tracking device 58 provides an updated measurement of the position of target 56 approxi-
Right and left hydraulic cylinders 52 and 54 are controlled by a single hydraulic system 80 illustrated in FIG. 6. Hydraulic system 80 includes a hydraulic pump 82 and a manifold 84 that branches out to right and left hydraulic cylinders 52 and 54. A right raise solenoid valve 86 controls the flow of hydraulic fluid to right cylinder 52 such that right cylinder 52 is raised. Right lower solenoid valve 88 controls the flow of hydraulic fluid to right cylinder 52 such that right cylinder 52 is lowered. Left lower solenoid valve 90 and left raise solenoid valve 92 similarly control the lowering and raising of left hydraulic cylinder 54, respectively. As described above, right solenoid valves 86 and 88 are controlled by a control system 55 depicted in FIG. 5. Left solenoid valves 90 and 92 are controlled based upon the output of a distance measuring sensor 78, described below. Solenoid valves 86, 88, 90, 92 may be any of conventional solenoid operated, hydraulic valves which are electrically operated to either fully open or fully close. Alternately, valves 86, 88, 90, 92 may be proportional hydraulic valves which variably adjust between fully open and fully closed positions in proportion to the electrical voltage applied.

Left hydraulic cylinder 54 is controlled by a separate control system than that used to control right hydraulic cylinder 52. Left hydraulic cylinder 54 is controlled based upon a distance detected by a proximity sensor or distance measuring sensor 78 attached at left side 48 of contouring assembly 28 (FIGS. 1, 2, and 9a-9c). Distance measuring sensor 78 measures its vertical distance above whatever reference surface or form it is located over. Typically the distance measuring sensor 78 will be located above a previously contoured section of concrete.

However, distance measuring sensor 78 may alternatively be positioned over any of a variety of different preset physical forms. In either case, distance measuring sensor 78 will provide a signal representing its distance from the surface below it. The signal provided by distance measuring sensor 78 is communicated to a separate controller (not shown) that adjusts the height of left side 48 of contouring assembly 28 in order to maintain it at a desired height. The controller for left side 48 of contouring assembly 28 adjusts the height of left side 48 by controlling left hydraulic cylinder 54. Distance measuring sensor 78, along with its associated controller, ensures that the surface contoured by contouring machine 20 will smoothly correspond to a previously contoured surface to the left of and adjacent to the surface currently being contoured. In the currently preferred embodiment, distance measuring sensor 78 is an ultrasonic sensor, which may be of the type sold by Spectra-Physics of Dayton, Ohio under model no. ST2-20. It will be understood, however, that distance measuring sensor 78 can be any of a variety of different technology based sensors, such as laser sensors, mechanical sensors, or other types.

As best seen in FIG. 8, contouring assembly 28 is preferably pivotally mounted about a pair of orthogonal pivot axes at each end of the contouring assembly 28 with respect to support beam 27 by means of a tilting assembly 83. The mechanical structure for tilting contouring assembly 28 is the same as that disclosed in commonly assigned U.S. Pat. No. 4,930,935 issued to Quenzi et al. Each tilting assembly 83 includes a rectangular pivot yoke 85 that is fitted between laterally spaced portions of a pair of end plates 87, 87a and that is secured for pivotal movement in a vertical plane on a generally horizontal axis 118 extending parallel to the direction of elongation of the contouring assembly 28 by means of securing bolts 89 and bushings 91 passing through end plates 87, 87a and pivot yoke 85 (FIGS. 7 and 8). A hydraulic fluid cylinder 95 is pivotally secured to the upright end plates 87,
The steps of operation of contouring machine 20 are depicted in FIG. 10 in flowchart form. An initial step 94 requires the creation of a computer map of the desired surface profile to be contoured. The surface profile information can be taken from either actual measurement data from the work site (step 120), or it may be based on architectural data from a theoretical work site plan (step 122). Regardless of its source, the surface profile map is then loaded and stored in a computer on board the contouring machine 20 during an initial step 96. An example of the general algorithm for creating this profile is described below, although it will be understood that a variety of different algorithms may be used within the scope of the invention.

In initialization step 98, the location of tracking device 58 with respect to the site is determined (FIG. 10). Initialization step 98 is required because tracking device 58 can be positioned anywhere within approximately a one mile radius in sight of the surface to be contoured. Without knowing the position of tracking device 58 relative to the site, the position information transmitted from tracking device 58 would be of no value to contouring machine 20. Therefore, the position of tracking device 58 must be determined relative to the work site. While initialization step 98 can be done in a variety of ways, one acceptable way is to carry a portable target 56A (not shown) to several known site locations and read and record the measurements produced by tracking device 58. By taking at least three such measurements, the correlation between the tracking device 58 frame of reference and the work site frame of reference can be established.

After initialization, the retraction of boom 26 begins the movement of contouring assembly 28 over the area to be contoured. As contouring assembly 28 moves over the surface to be contoured, the three dimensional location (i.e. X, Y, and Z) of target 56 is continuously measured by tracking device 58 (step 100) (FIG. 10). The position of target 56 relative to tracking device 58 is transmitted to tracking processor 70 where this position information is translated to the frame of reference of the site (step 102). The translation of step 102 is based upon the information obtained during initialization step 98. At step 104, main processor 72 looks up the height (Z value) of the stored profile corresponding to the X, Y location of target 56 as determined by tracking device 58. From the stored work site map profile, main processor 72 determines what Z value target 56 should be at for that X, Y location.

Main processor 72 then compares the desired Z value from the stored profile with the measured Z value transmitted from tracking device 58. At step 106 (FIG. 10) main processor 72 calculates a height error signal, which is the difference between the desired Z value from the stored work site map profile and the measured Z value from tracking device 58. The error signal is transmitted from main processor 72 to pulse width modulated processor 74. At step 107 pulse width modulated processor 74 computes a pulse width modulated control signal that is transmitted to either right raise solenoid valve 86 or right lower solenoid valve 88, depending upon the sign of the error signal. The width of the pulse width modulated signal corresponds to the magnitude of the error signal calculated by main processor 72. The width of the pulse width modulated signal is also dependent upon the sign of the error signal calculated by main processor 72 because different volumes of hydraulic fluid have to be metered depending upon which direction (up piston side or down rod side) of right hydraulic cylinder 52 is to be moved. The up or down movement of right hydraulic cylinder 52 moves right side 46 of contouring assembly 28 up or down independently of left side 48. Contouring machine 20 is thereby capable of not only contouring flat surfaces, but also approximating three dimensionally curved surfaces.

In addition to the vertical adjustability of contouring assembly 28 via hydraulic cylinders 52 and 54, contouring assembly 28 can also be pivoted or tilted about an axis 118, as...
measuring tilt, such as tilt sensor 31. In step 110 main pro-
to smooth a surface that more accurately corresponds to
the thickness of the concrete) can be automatically added in
follow the contours of the subbase.
selecting nodes that are located at a desired, constant height
above the subbase. Alternatively, nodes defining the subbase
be selected and a predetermined height (corresponding to
the thickness of the concrete) can be automatically added in
software to each of the Z values for the nodes. In either case,
node file 124, a user selects three or four of these
of the contoured concrete. If the profile is to
independent of the subbase, nodes are selected having what-
independent of the subbase. If the contoured surface is to be
the Z value is desired without regard to the subbase. Varia-
tions in the height of the subbase will show up as variations in
the thickness of the contoured concrete. If the profile is to
follow the shape of the subbase, the profile is created by
selecting nodes that are located at a desired, constant height
above the subbase. If the number of nodes that have been selected is four, then the
computer divides the nodes into two pairs and calculates a
line connecting each pair. The computer then calculates two
additional lines joining each pair of nodes to each other to
thereby define a quadrilateral. At step 128, the computer
calculates all the heights, or Z values, for the areas circumscribed
by the triangle or quadrilateral. The calculated Z values are displayed in step 130. In step 132 the calculated
profile is stored in computer memory for use by contouring
machine 20. Control of the profile creation process is returned
to step 126, where a user can select additional nodes to create
additional surfaces, or to otherwise complete the profile. The
more nodes that are selected, the more complex the curvature
of the profile can be. While the calculation of the triangles or
quadrilaterals joining the selected nodes, along with the Z
values defined by these shapes, has been described as utilizing
the calculation of lines, it will be understood that other
calculation algorithms can be used within the scope of the
invention, such as the calculation of arcs, interpolation, splin-
ing, or any other suitable technique.

The generated profile of the desired shape of the surface to
be contoured can either follow the profile of the subbase or be
independent of the subbase. If the contoured surface is to be
independent of the subbase, nodes are selected having whatever
Z value is desired without regard to the subbase. Variations
in the height of the subbase will show up as variations in
the thickness of the contoured concrete. If the profile is to
follow the shape of the subbase, the profile is created by
selecting nodes that are located at a desired, constant height
above the subbase. Alternatively, nodes defining the subbase
can be selected and a predetermined height (corresponding to
the thickness of the concrete) can be automatically added in
software to each of the Z values for the nodes. In either case,
the contoured surface of the concrete or other material will
follow the contours of the subbase.

The independent control of right side 46 and left side 48 of
contouring assembly 28 allows contouring machine 20 to
contour a three dimensionally curved surface, if desired. If
right and left sides 46 and 48 are controlled to remain at
the same height throughout the screeding process, a two-di-
sional surface can be screeded. If right and left sides 46 and 48
are controlled to have different heights throughout the screed-
ing process, a three dimensionally curved surface can be
screeded. Distance measuring unit 78 ensures that left side 48
of contouring assembly 28 will follow a reference surface,
such as a previously screeded section of concrete, or another
surface as desired, such as the ground, or other physical form.
Alternative Embodiments

FIG. 12 illustrates an alternative embodiment of contouring or screeding machine 220. Parts corresponding to the previous embodiment are referenced by the same number increased by 200. In this embodiment an additional target 256a is included at left side 248 of contouring assembly 228. A second tracking device 258 (not shown) can be used to track second target 256b. When used in this manner, distance measuring unit 278 does not need to be used and the requirement for a preset form or surface along one side of the surface is not present. The control for left hydraulic cylinder 254 is the same as that disclosed above with respect to right hydraulic cylinder 54. Alternatively, distance measuring unit 278 can be used when desired to control left hydraulic cylinder 54. Screeding machine 220 therefore has the option of controlling left side 48 of contouring assembly 228 with reference to either a stored profile or a preset physical form, depending upon what is most suitable for the application.

Contouring machine 220 can also be modified to include a plurality of intermediate targets 256a and 256b (FIG. 12). In this alternative embodiment contouring machine 220 includes a contouring assembly 228 that is divided into segments 239a-c, which are pivotally connected to each other. Each end of each segment 239, or the pivot joint between the segments, is independently controlled by a separate target 256 mounted on a hydraulic cylinder. A separate tracking device 258 is used for each target 256. The use of a segmented contouring assembly 228 allows a higher degree of lateral (i.e. side-to-side) curvature to be approximated in the contoured surface. Alternately, the height of each segment can be controlled by reference to the relative height of the neighboring segments. In this variation, only a single target and tracking device are used rather than a separate target and tracking device for each segment.

In yet another embodiment, contouring machine 320 utilizes a pair of wires 435a, 435b attached at one end to the center of contouring assembly 428. The other ends of wires 435 are attached at reference points 437a and 437b, respectively, which are of known location. The wires are preferably made of titanium or other sufficiently strong material. A laser beam 459 is rotated to define a horizontal plane that is detected by a vertical array of laser sensors (not shown) on contouring assembly 428. The Z position of left side 348 is determined from the gyroscope in combination with the known location of right side 346. Contouring machine 320 has the advantage of not requiring a tracking device 358 that can track target 356 in three dimensions. Tracking device 358 can therefore be a simpler and more inexpensive device than tracking device 58. Contouring machine 320 includes a base 322 and a telescoping boom 326, and is similarly used to smooth uncured concrete 330 or other loose, spreadable material to a desired shape or contour. As with contouring machine 20, the concrete or other material 331 is contoured either independently of, or with reference to, the subgrade 333.

If parallel sections of concrete are screeded, distance measuring unit 78 ensures that new sections are screeded seamlessly with the adjacent, existing screeded sections. It will be understood that target 256 and distance measuring unit 78 can be switched to opposite sides, if desirable. It will also be understood that distance measuring unit 78 on left side 48 can be either replaced or supplemented with another target 256a that is tracked by another tracking device, as illustrated in FIG. 12.
The leveling machine includes a leveler assembly with an

The kit also includes a tracking device 58 which is

The GPS or DGPS receiver detects its movement in three dimensions as contouring assembly 28 is moved over the material to be contoured. The three dimensional position information of the GPS or DGPS receiver is communicated to tracking processor 70 and utilized in the same manner the target 56 position information is utilized.

In still another embodiment, the present invention is a kit for retrofitting existing leveling or smoothing machines in order to give them the capability of contouring three dimensionally curved surfaces. The kit is preferably used with existing leveling machines, such as that disclosed in U.S. Pat. No. 4,930,935. Such existing leveling machines include a leveler assembly that is controlled uniformly at both of its ends, thereby leveling only one or two dimensionally curved surfaces. The existing machines typically include a pair of laser sensors disposed at the ends of the leveler assembly. A rotating laser beam is positioned at a location remote from the leveling machine and at a designated height. The pair of sensors extend in a vertical direction and detect the rotating laser beam. Based on where the laser beam impinges the sensors, the height of the leveler with respect to the rotating laser beam is determined. The height of the leveler is then adjusted to correspond to the desired height of the surface to be smoothed. The kit includes target 56 that can either be positioned on the leveler assembly or remotely from the leveling machine. The kit also includes tracking device 58 which is positioned at the opposite location from target 56, i.e. either on the leveler assembly or remote from it. A control system 67 (FIG. 5) is further included with the kit to control the right and left sides of the leveling assembly independently, thereby transforming the assembly into a contouring assembly, such as contouring assembly 28. The control system 67 also controls the pivot or tilt of the leveler as explained above in the event the contouring assembly is pivotally mounted. The control system can either control a pair of hydraulic cylinders 52 and 54 based solely on the position of one or more targets 56, or it can control cylinders 52 and 54 based on the combination of the position of target 56 and the output of proximity sensor 78. Proximity sensor 78 is also included in the kit if one end of contouring assembly 28 is to follow a physical form. If the leveling machine includes a leveler assembly with an adjustable tilt or pitch, control system 67 can be programmed to control the pitch of the leveler assembly based on the slope of the surface to be smoothed.

The kit can also include other components when used to modify an existing leveling machine to one of the alternative embodiments described previously. For example, the kit may include a segmented contouring assembly in which the height of each of the segments of the assembly is individually adjustable, thereby allowing a greater degree of three dimensional curvature to be contoured. Such a kit for a segmented contouring assembly may also include additional targets and tracking devices to be used to measure the position of each of the segments. The position of each segment is fed into a control system that controls each individual segment. In other embodiments, the kit may include a pair of extendable wires that are mounted at one end on the leveler assembly and attached at their other ends to two separate reference points. Such a kit further includes a pair of distance encoders that measure the length of the wires and a pair of angle encoders that measure the angles defined by the wires and the leveling assembly. A control system is included that calculates the position of the leveler assembly based on the length of the wires and adjusts the height of the ends of the leveler independently, thereby allowing the previously existing leveling machine to contour three dimensional surfaces.

While the present invention has been described in terms of the preferred embodiments depicted in the drawings and discussed in the above specification, it will be understood by one skilled in the art that the present invention is not limited to these particular preferred embodiments, but includes any and all such modifications that are within the spirit scope of the present invention as defined in the appended claims.

The embodiments of the invention in which an exclusive property or privilege is claimed are as follows:

1. A contouring machine control system comprising:
   - a contouring member able to contour uncured concrete, said contouring member having first and second ends and able to be moved over an area to be contoured, said contouring member being supported in at least a first location and a second location, said contouring member including a vibrating contouring beam;
   - a controller for controlling the height of said first and second locations of said contouring member;
   - an auger positioned adjacent one side of said vibrating contouring beam, said auger oriented substantially parallel to said vibrating contouring beam;
   - a plow positioned adjacent a side of said auger opposite said vibrating contouring beam such that said auger is intermediate said plow and said vibrating contouring beam, said plow oriented substantially parallel to said auger;
   - a pivoting device for pivoting said vibrating contouring beam, said auger, and said plow about a pivot axis oriented substantially parallel to said auger;

2. A contouring machine comprising:
   - a contouring member able to contour uncured concrete, said contouring member having first and second ends and able to be moved over an area to be contoured, said contouring member being supported in at least a first location and a second location, said contouring member including a vibrating contouring beam;
   - a controller for controlling the height of said first and second locations of said contouring member;
   - an auger positioned adjacent one side of said vibrating contouring beam, said auger oriented substantially parallel to said vibrating contouring beam;
   - a plow positioned adjacent a side of said auger opposite said vibrating contouring beam such that said auger is intermediate said plow and said vibrating contouring beam, said plow oriented substantially parallel to said auger;
   - a pivoting device for pivoting said vibrating contouring beam, said auger, and said plow about a pivot axis oriented substantially parallel to said auger;

3. A control system for controlling a contouring member comprising:
   - a controller for controlling the height of said first and second locations of said contouring member;
   - an auger positioned adjacent one side of said vibrating contouring beam, said auger oriented substantially parallel to said vibrating contouring beam;
   - a plow positioned adjacent a side of said auger opposite said vibrating contouring beam such that said auger is intermediate said plow and said vibrating contouring beam, said plow oriented substantially parallel to said auger;
   - a pivoting device for pivoting said vibrating contouring beam, said auger, and said plow about a pivot axis oriented substantially parallel to said auger;
a stored profile of a desired surface to be contoured; wherein said controller adjusts the height of said first location of said contouring member as a function of the stored profile and the three-dimensional position of said one portion of said contouring member as determined by said tracking device and target, and said controller adjusts the height of said second location of said contouring member as a function of the current height of the proximity sensor above the reference; and a tilt controller that activates said pivoting device to tilt said vibrating contouring beam, said auger, and said plow about said pivot axis based upon said stored profile.

2. The control system of claim 1 wherein said proximity sensor is an ultrasonic sensor.

3. The control system of claim 1 wherein said controller includes a fluid cylinder for changing the height of the first location of said contouring member.

4. The control system of claim 3 further including a second fluid cylinder for raising and lowering said second location of said contouring member.

5. The control system of claim 1 including a base having a cantilevered movable boom on which said contouring member is mounted, said contouring member being able to be moved toward said base on said boom for spreading and smoothing the uncured concrete.

6. The control system of claim 5 wherein said contouring member is telescopingly mounted to said base.

7. The control system of claim 1 wherein said tracking device emits a laser beam that is reflected by said target back to said tracking device, said tracking device able to determine the distance of said target from said tracking device based on the reflected laser beam.

8. The control system of claim 7 wherein said target includes an infrared source and said tracking device includes infrared sensors for following said target whereby the angular position of said target is determined.

9. The control system of claim 1 wherein said target is positioned on said contouring member, and said tracking device is positioned remotely from said contouring member and measures the position of said target in three dimensions as said contouring member is moved over the area to be contoured; said tracking device including a transmitter for transmitting the three-dimensional position information of said target to said controller.

10. The control system of claim 1 wherein said tracking device is positioned on said contouring member, and said target is positioned remotely from said contouring member.

11. A method for smoothing material to a desired shape, comprising:

- providing a contouring assembly for contouring said material over a given area, said contouring assembly including a longitudinal dimension and having first and second ends and being supported in at least first and second locations;
- providing a base upon which said contouring assembly is movably mounted;
- providing a target;
- providing a tracking device that tracks said target;
- providing a proximity sensor adjacent one of the first and second ends of said contouring assembly, said proximity sensor being able to detect its height above a physical reference at different positions with respect to the reference as said contouring assembly moves over the given area, said reference being separate from said contouring assembly; storing a profile of the desired shape of the material to be smoothed;
- positioning one of said target and said tracking device at said contouring assembly and the other of said tracking device and said target remotely from said contouring assembly;
- moving said contouring assembly over said material;
- measuring the position of one portion of said contouring assembly in three dimensions with said tracking device and target as said contouring assembly moves;
- adjusting the height of said first location of said contouring assembly as a function of the stored profile and the three-dimensional position of said one portion of said contouring assembly as measured by said tracking device and target;
- adjusting the height of said second location of said contouring assembly as a function of the current height of the proximity sensor above the reference; and calculating a slope of the stored profile in the direction of movement of said contouring assembly;
- moving said contouring assembly in a direction transverse to said longitudinal dimension of said contouring assembly, said tilting based upon the calculated slope of the stored profile.

12. The method of claim 11 including positioning said target on said contouring assembly, positioning said tracking device remotely from said contouring assembly, measuring the position of said target in three dimensions with said tracking device as said contouring assembly moves, and adjusting the height of said first location of said contouring assembly as a function of said stored profile and the three-dimensional position of said target.

13. The method of claim 12 wherein said measuring of the position of the target includes:

- emitting a laser beam from said tracking device to said target;
- reflecting said laser beam from said target back to said tracking device; and
- detecting said laser beam reflected back from said target.

14. The method of claim 13 wherein said measuring of the position of the target further includes emitting an infrared signal from said target, detecting said infrared signal with said tracking device, and adjusting the direction in which said laser beam is emitted from said tracking device based on said detected infrared signal.

15. The method of claim 12 wherein said measuring of the position of the target further includes emitting an infrared signal from said target, detecting said infrared signal with said tracking device, and adjusting the direction in which said laser beam is emitted from said tracking device based on said detected infrared signal.

16. The method of claim 11 including positioning said tracking device on said contouring assembly and positioning said target remotely from said contouring assembly.

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