

Aug. 9, 1966

J. W. BABB ETAL

3,264,958

SLOPE AND GRADE CONTROL FOR PAVING MACHINES

Filed April 19, 1962

6 Sheets-Sheet 1

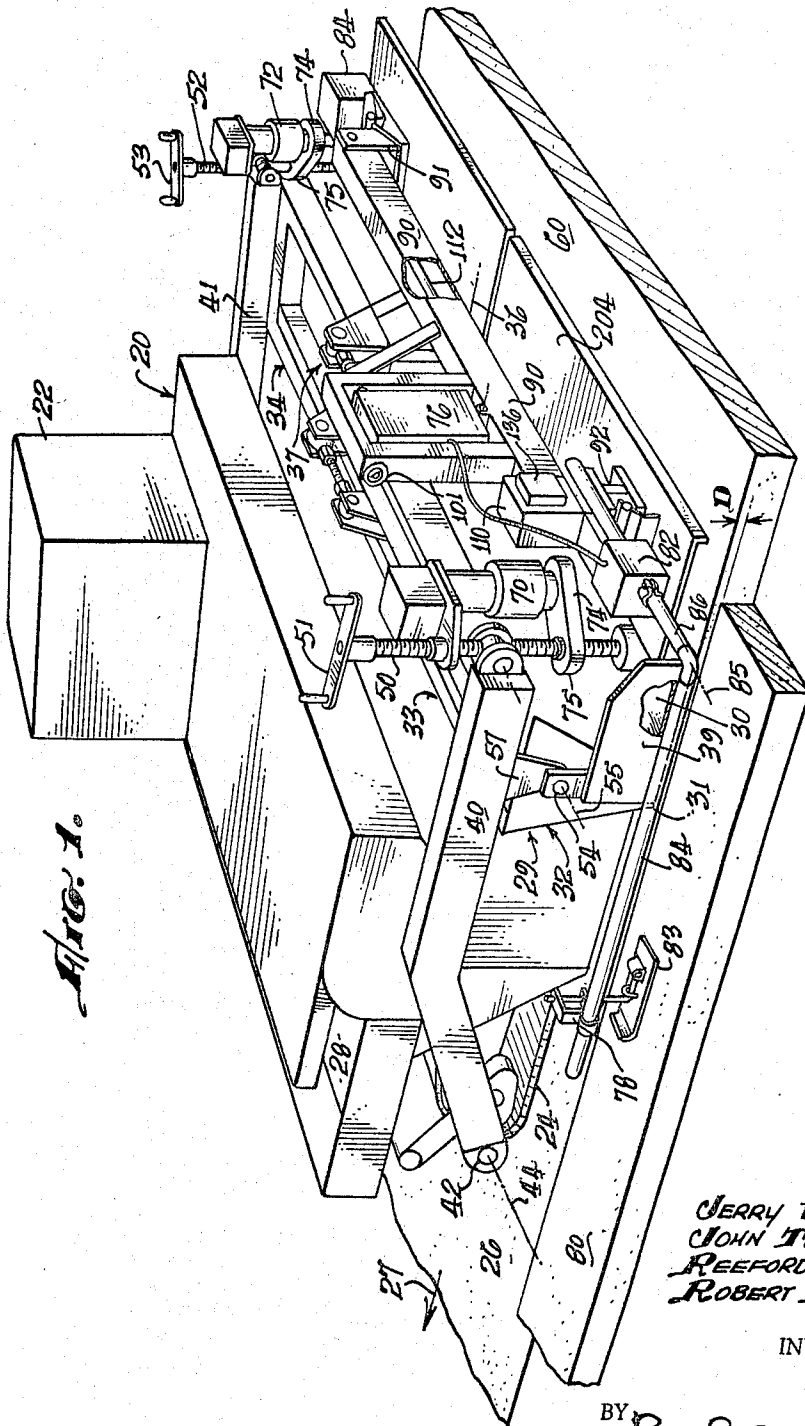


FIG. 1.

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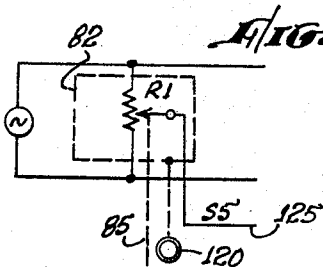
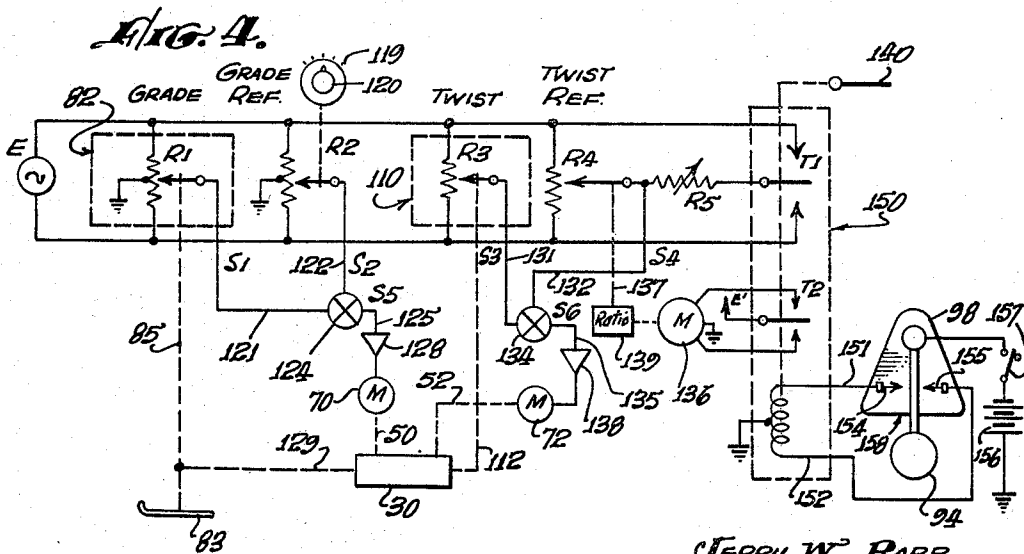
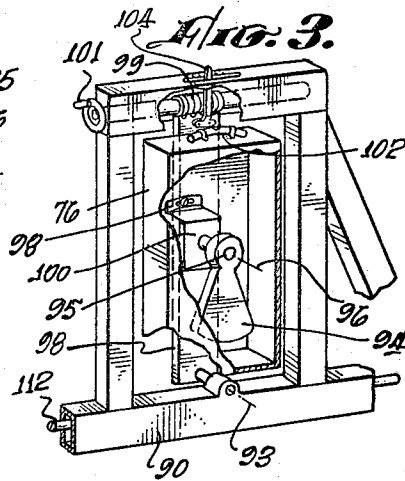
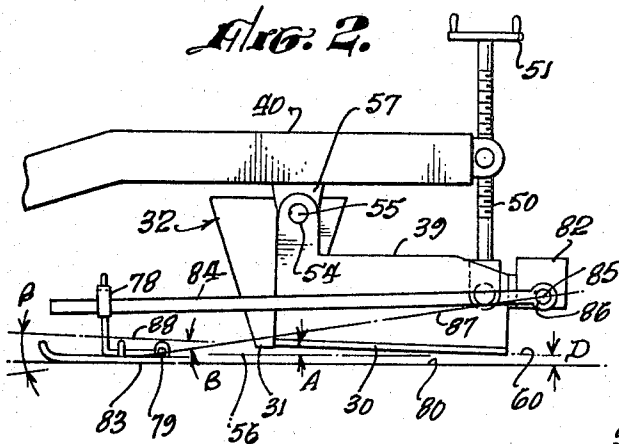
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SLOPE AND GRADE CONTROL FOR PAVING MACHINES

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6 Sheets-Sheet 2



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3,264,958

SLOPE AND GRADE CONTROL FOR PAVING MACHINES

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6 Sheets-Sheet 3

Fig. 5.

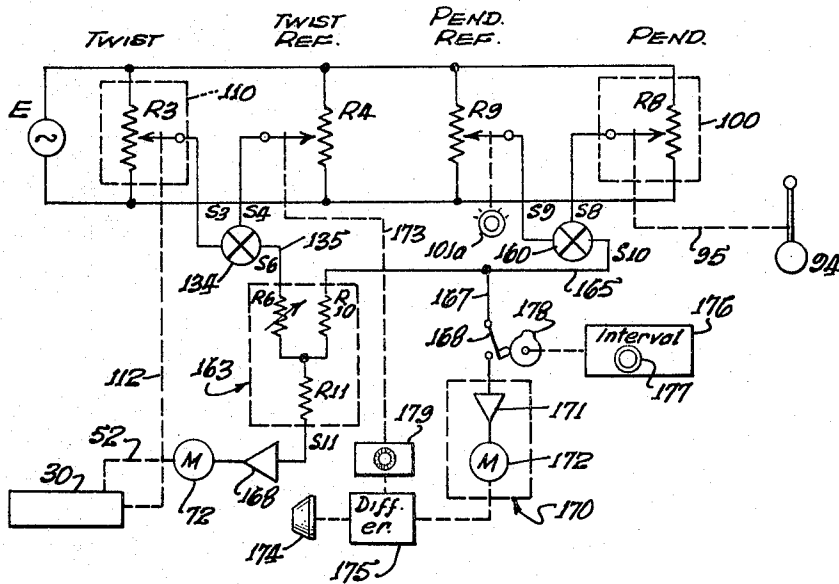
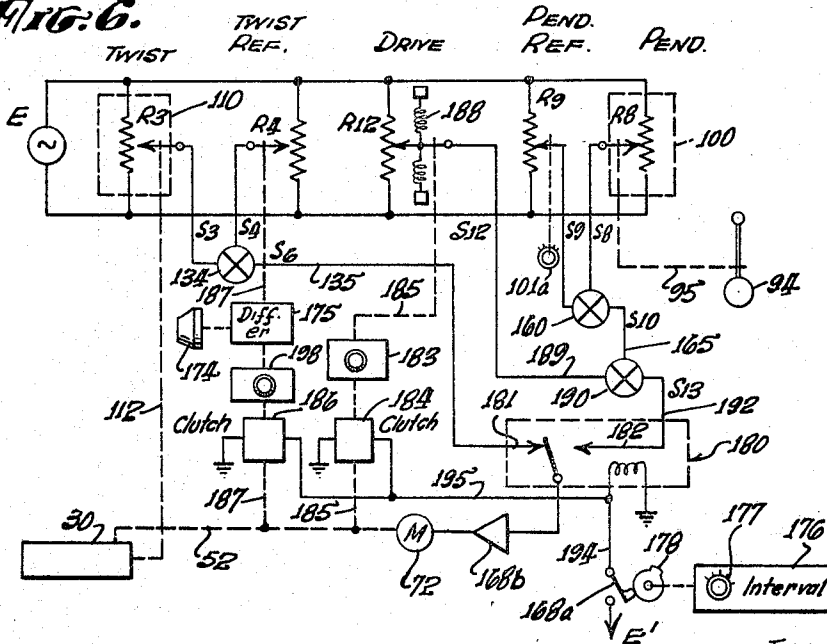


Fig. 6.



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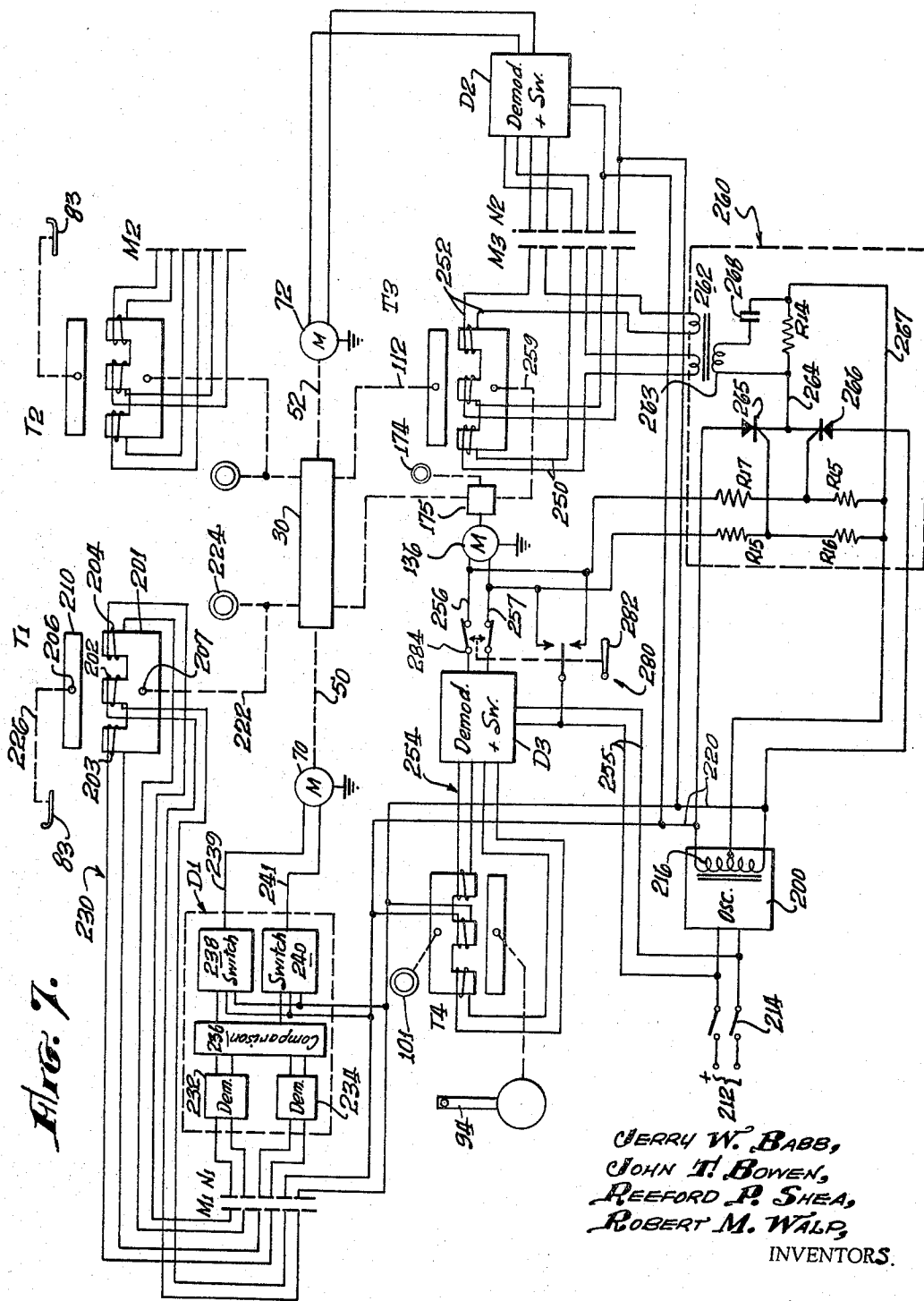
J. W. BABB ETAL

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SLOPE AND GRADE CONTROL FOR PAVING MACHINES

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6 Sheets-Sheet 4



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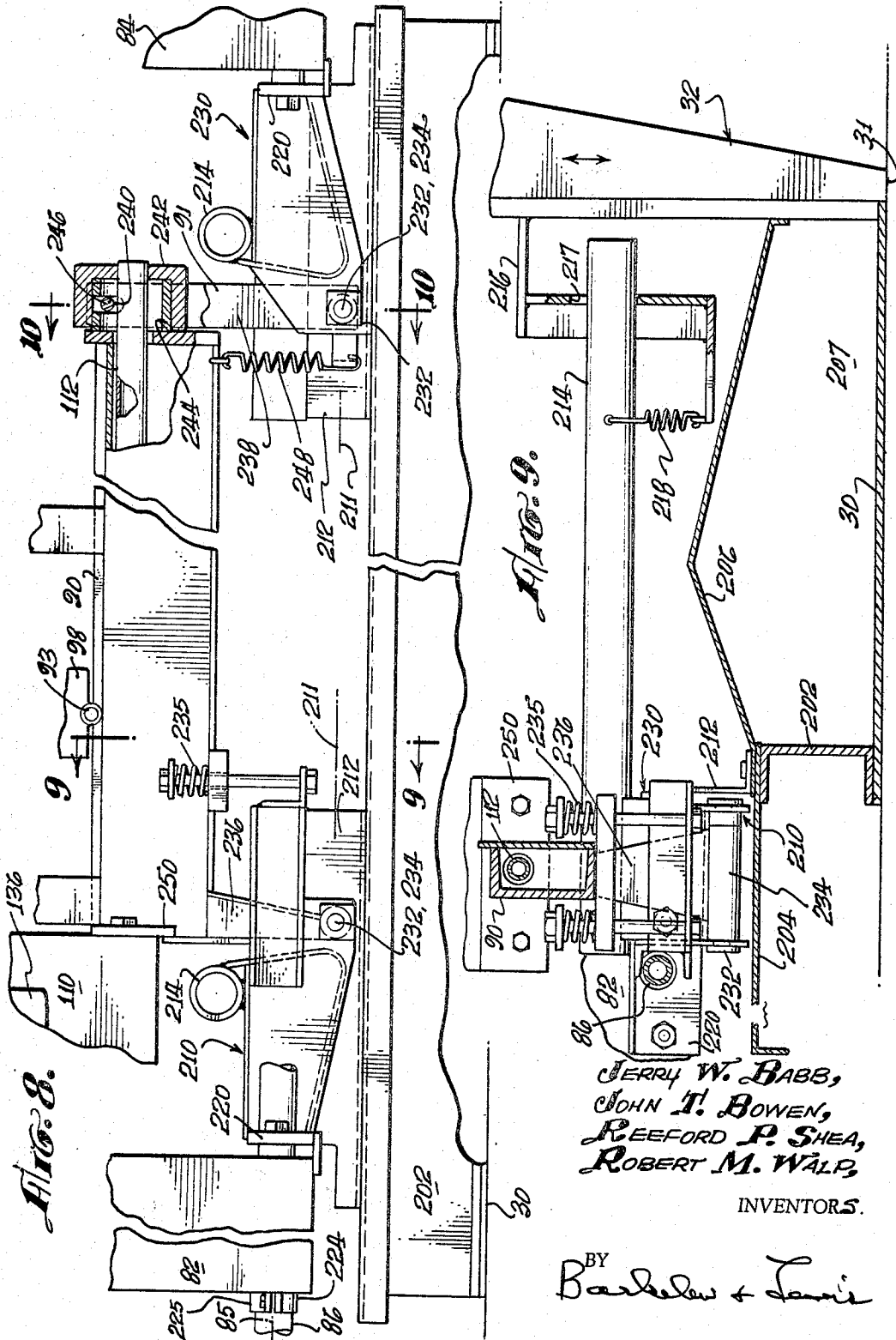
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SLOPE AND GRADE CONTROL FOR PAVING MACHINES

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6 Sheets-Sheet 5



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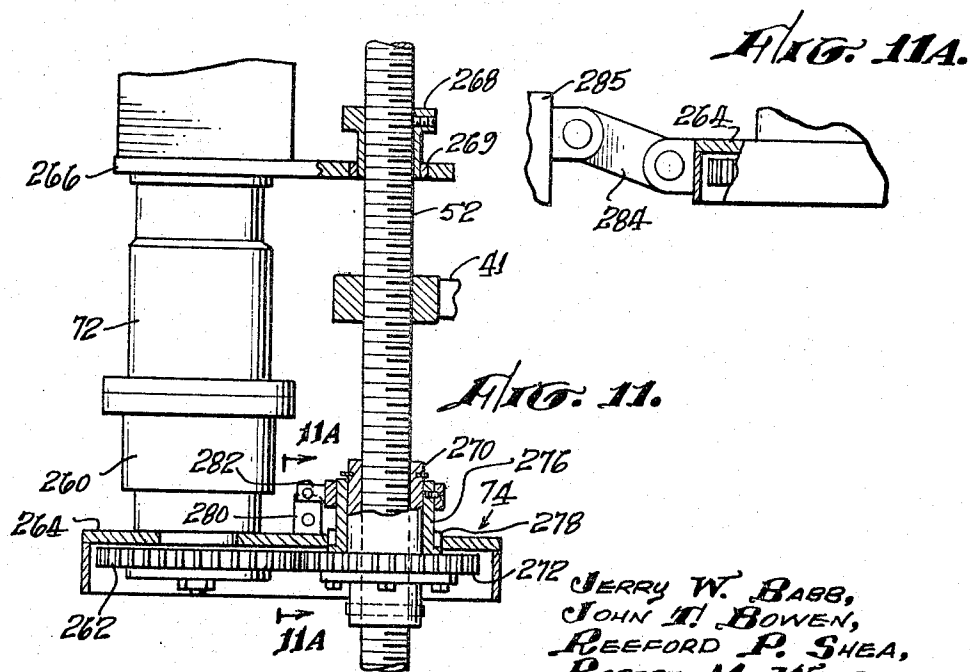
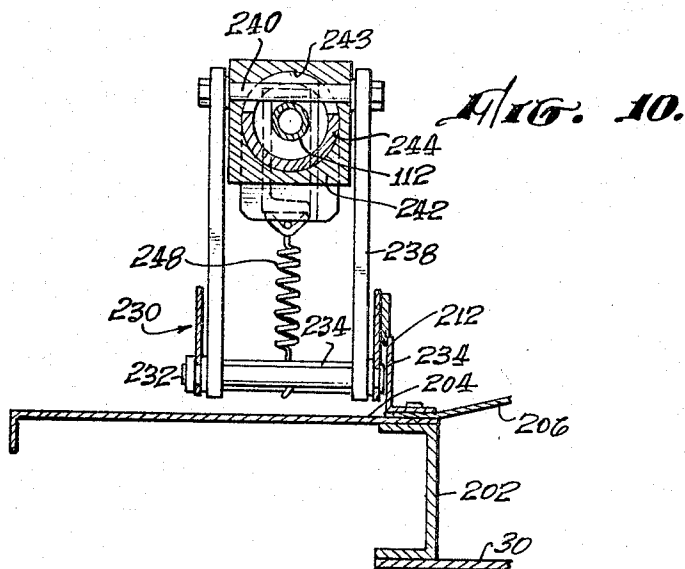
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SLOPE AND GRADE CONTROL FOR PAVING MACHINES

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6 Sheets-Sheet 6



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3,264,958

SLOPE AND GRADE CONTROL FOR PAVING MACHINES

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Filed Apr. 19, 1962, Ser. No. 188,635

21 Claims. (Cl. 94-46)

This invention has to do with improved control systems for paving machines which deposit a layer or mat of paving material such, for example, as gravel, earth or bituminous mix.

The invention relates more particularly to such machines wherein the paving material is deposited at the leading edge of a transverse screed that is supported on the freshly laid mat, and wherein the screed is adjustable to vary its inclination in the direction of travel. An important feature of such machines is that as the machine moves forward an abrupt change in the screed inclination or "angle of attack" produces only a gradual change in the mat thickness. Whereas that characteristic is helpful in avoiding sudden irregularities of mat surface, it complicates the problem of producing a finished mat having precisely the desired grade and transverse slope. Such control is particularly difficult when the base on which the mat is laid is irregular, as is typically true in refinishing old pavements.

The present invention permits simultaneous control of both the transverse slope and the grade of the pavement, whereby, for example, the screed inclination is automatically controlled at one side of the machine in accordance with the desired grade, and at the other side of the machine in accordance with the desired transverse slope. The invention further provides particularly convenient interchangeable connecting means by which those two types of control can readily be interchanged between the two sides of the machine.

An important object of the invention is to provide more accurate and reliable control of the transverse slope of the finished mat than has been available previously. That is accomplished by dividing the slope control function in a unique manner between two separately measured variables. One of those variables is typically the screed twist, that is, the difference in angle of attack of the screed adjacent its two ends. The other variable is the actual transverse slope of the finished mat surface. That slope is typically measured in practice in terms of the screed inclination in a vertical plane transverse of the direction of machine travel. Alternatively, for example, the transverse mat slope can be measured as the difference in level of two pans supported on the mat immediately behind the screed.

In a typical form of the invention, the screed adjustment on one side of the machine, designated the slope controlled side, is driven under primary control of a sensing device responsive to screed twist. The measurement of screed twist is utilized for control of a primary servo system to drive the slope controlled end of the screed in such a way that the screed twist maintains a definite equilibrium relationship. For example, the screed twist may simply be maintained equal to a definite equilibrium value. Or the maintained relationship may involve one or more other variables in addition to the screed twist. As an example, a predetermined linear function of screed twist and transverse mat slope may be maintained equal to a definite equilibrium value. In accordance with the invention, the primary servo system includes adjusting or trimming means for modifying the equilibrium relationship that is maintained; and that trimming means is adjusted in accordance with the actual measured value of the trans-

verse mat slope. That adjustment of the trimming means may be either manual or automatic, and may be carried out either continuously or intermittently.

Previous systems for controlling the transverse slope of the mat produced by paving machines of the present type have been described in United States Letters Patents 3,029,716, filed February 27, 1958, by Reeford P. Shea, entitled "Paving Machine Control System," and 3,029,715, filed February 27, 1958, by John T. Bowen, entitled "Control System for Paving Machine," both assigned to the assignee of the present application. In those previous systems a control signal is typically developed which depends both upon the existing transverse slope of the mat being laid and upon a condition of the screed adjustment, such as screed twist, which determines the rate at which that slope is changing as the machine progresses forward. The resulting combined signal is then utilized as a criterion for adjusting the angle of attack at one end of the screed, either manually or automatically.

Such previous control systems for paving machines have many outstanding advantages, and are effective and useful under ordinary conditions. In particular, they effectively prevent irregularities in the base from acting through the tractor unit of the paving machine to disturb the transverse slope of the mat. However, we have discovered that they are subject to certain disadvantages, especially under various abnormal conditions. We have found, for example, that a given value of the screed angle of attack may produce a mat of uniform grade under one set of conditions, but cause a gradual change in the grade under other conditions. Variations of mat thickness are particularly likely to cause such an effect. Hence, when a mat is being laid on an irregular base, so that it is thicker sometimes at one side and sometimes at the other, for example, the control signal developed in the previous systems may require correction from time to time.

The present invention, like the previous systems just described, controls transverse slope by adjusting the screed in response both to the existing transverse slope of the mat and to a variable, such for example as the screed twist itself, that determines the rate of change of that slope. However, in the system of the present invention, the control function is not shared uniformly in a continuous manner by those two variables. Instead, distinct types of control function are exercised by the two variables. Measurement of the screed twist is utilized to control directly the drive of the screed twist adjustment, that control typically being such as to maintain a definite equilibrium value of some function that includes screed twist. Measurement of the transverse mat slope is utilized to modify the control system in such a way as to change the equilibrium condition of the system, thereby effectively altering the maintained value of screed twist.

Moreover, each type of control action need not respond solely to the particular variable mentioned above, but each may respond to a function of several variables, such, for example, as a linear combination of screed twist and mat slope. However, it is preferred that the function utilized to control the actual screed adjustment be dominated by screed twist; and for clarity that function will sometimes be referred to as "screed twist" without intending to exclude possible dependence upon other variables also. And it is ordinarily preferred that the described modification of the equilibrium condition of the system be controlled substantially purely by the measured mat slope.

By thus maintaining the screed twist in accordance with a definite function or value that is variable in response to a substantially pure measurement of the transverse slope actually being produced, there is no possibility that a permanent error of slope can result from a change in the response of the machine to screed twist. That is, if

any change of condition occurs whereby the equilibrium function or value of twist that is being maintained tends to produce an incorrect value of the transverse slope, the control system provides the required correction of that equilibrium function or value.

In accordance with a further aspect of the invention, two distinct types of correction are produced in the equilibrium function of screed twist in response to a measured or observed error in the existing slope. One of those corrections is temporary in nature, and is adapted to restore the mat slope to its correct value. The other correction is relatively permanent in nature, and is adapted to correct the condition that led to the slope error. In other words, the first type of correction is intended to eliminate the slope error; the second to prevent repetition of the same error.

In one form of the invention, the described monitoring action, whereby the equilibrium screed twist value or function is corrected in accordance with a measured error in mat slope, is effectively continuous. In other forms of the invention such monitoring may be intermittent, the screed twist, or a function including screed twist, being maintained at a fixed value between successive periods of adjustment. Those periods of adjustment may, for example, be spaced in accordance with time under control of a conventional timer; or may be spaced in accordance with distance traveled by the paving machine under control of an odometer.

Under intermittent monitoring of the equilibrium twist value, it is ordinarily preferred to maintain twist control continuously while correction of the twist value is made. However, it is sometimes more convenient to interrupt normal control of the screed twist during the correction phase. The duration of that phase is then preferably short compared to the time between successive corrective actions. Any slight errors of twist that can occur, due to irregularities of the base, for example, are then small, and are eliminated before they can have appreciable effect on the mat.

The present invention further provides particularly reliable and effective mechanism for sensing the value of screed twist. Another aspect of the invention provides mechanism for mounting a pendulum or other vertical-sensing means in such a way as to respond to the average value of transverse slope independently of the setting of the regular crown adjustment of the paving machine. A further aspect of the invention provides especially effective mechanism for sensing grade of the mat surface relative to a reference grade such as a previously placed curb, mat or special grade indicator.

A full understanding of the invention and of its further objects and advantages will be had from the following description of certain illustrative manners in which it may be carried into effect. The particulars of that description, and of the accompanying drawings which form a part of it, are intended only as illustration, and not as a limitation upon the scope of the invention, which is defined in the appended claims.

In the drawings:

FIG. 1 is a schematic perspective representing an illustrative paving machine embodying the invention;

FIG. 2 is a schematic diagram illustrating certain aspects of the invention;

FIG. 3 is a schematic perspective representing a slope sensing device;

FIG. 4 is a schematic diagram representing an illustrative grade and slope control system in accordance with the invention;

FIG. 4A is a fragmentary diagram representing a modification;

FIG. 5 is a schematic diagram corresponding generally to a portion of FIG. 4 and illustrating a modification;

FIG. 6 is a schematic diagram corresponding generally to FIG. 5 and illustrating a further modification;

FIG. 7 is a schematic diagram representing a further

slope and grade control system in accordance with the invention;

FIG. 8 is a fragmentary rear elevation, partly broken away, representing portions of FIG. 1 at enlarged scale;

FIG. 9 is a section on line 9—9 of FIG. 8;

FIG. 10 is a section on line 10—10 of FIG. 8;

FIG. 11 is a fragmentary section illustrating motor mounting; and

FIG. 11A is a fragmentary section of line 11A—11A of FIG. 11.

FIG. 1 represents in schematic perspective an illustrative paving machine of the type with which the invention is particularly concerned. The tractor unit of the paving machine is represented generally at 20, with power plant 22 and crawler tracks 24 by which it is driven forward along the roadbed 26 in the direction of travel indicated by the arrow 27. Paving material is deposited in the hopper 28 and then delivered automatically by mechanism of known type to the roadbed 26 directly in advance of the distributing and compacting unit 29. The resulting mat of paving material is indicated at 60. For clarity of illustration, many conventional details of the illustrative paving machine, not directly concerned with the present invention, are omitted from FIG. 1.

Unit 29 includes the elongated, generally horizontal plate or screed 30, which extends transversely of the machine, and mechanism indicated schematically at 32 for striking off and compacting the paving material at the leading edge 31 of the screed. The weight of unit 29 is supported by screed 30 directly on the surface of the freshly laid mat 60. The unit is connected to tractor unit 20 by the draft arms 40 and 41. Those arms are pivotally connected at their forward ends to tractor unit 20 at the trunnions 42 at the left and right sides of the machine, permitting free independent swinging movement about the transverse trunnion axes 44. The movement of the draft arms and the torsional flexibility of the screed structure accommodate variations of relative level of the tractor unit and mat surface as the machine moves forward.

Compacting mechanism 32 is ordinarily constructed as separate left and right units 33 and 34. Those units are connected at the midplane of the machine in a manner permitting mutual adjustment through a small angle about a fore-and-aft axis such as 36. Such adjustment is controlled by the screw mechanism indicated at 37, and varies the crown of the mat surface. The leading edge 31 of screed 30 is substantially positively defined by mechanism 32, the central portion of the screed being sufficiently flexible to accommodate the crown adjustment.

In the present embodiment the two ends of screed 30 are rotationally adjustable with screed end plates 39 relative to the respective draft arms 40 and 41, about the pivot axes 55 on arm brackets 57, as by the left and right screws 50 and 52, respectively. In conventional machines those screws are independently adjustable by manipulation of the respective handles 51 and 53. As shown in diagrammatic form in FIG. 2, adjustment of screw 50, for example, alters the value of the angle A between the plane of the screed end portion and a horizontal line 56 in the direction of travel. That angle, which is exaggerated in FIG. 2 for clarity of illustration, will be referred to as the angle of attack of the screed. The screed is sufficiently flexible in torsion to accommodate considerable screed twist, or difference in angle of attack at the two ends of the screed, such as is typically produced by a difference of adjustment between the screws 50 and 52. In many machines the screed length can be extended, as by bolting a relatively rigid section to end plate 39. Even with such extension the screed adjustment may be considered for most purposes to act at the screed end.

A corresponding adjustment of screed angle of attack is effected in some paving machines by raising or low-

ering the forward ends of the respective drawbars relative to the tractor unit. For example, the trunnions 42 may be mounted in vertical guides along which they are movable by mechanical or hydraulic drive. The present invention is useful for controlling the screed angle of attack regardless of the particular mechanism by which that angle is varied.

Under normal conditions of operation on a flat horizontal base 26, there is an equilibrium value of the angle of attack A for which the mat surface maintains uniform grade as the machine progresses, thus having zero inclination and curvature in a vertical longitudinal plane. If A is increased or decreased from that equilibrium value, as by adjustment at 50 or 52, for example, the mat surface tends to rise or fall from its previous level as the machine moves forward. However, such change alters the mat thickness and thus causes the entire assembly of draft arms and screed to rotate about trunnions 42 in a direction tending to restore the angle of attack to approximately its previous equilibrium value. Thus, if A is increased by some definite amount, the mat surface gradually rises, approaching asymptotically a new equilibrium level. If the two screws are shifted in opposite directions, the mat surface tends to rise at one side and decline at the other, producing a change in transverse slope of the finished pavement.

Thus the grade of the mat surface can be maintained at the desired value by suitable adjustment of both screws 50 and 52 together; and the transverse slope can be maintained at the desired value by opposite or differential adjustment of the screws. However, when such coordinated adjustment is made manually, it is difficult in practice to anticipate errors in grade or slope before they have become large. When an error is noticed there is a tendency to overcorrect, leading to oscillation about the desired value. And the described corrections must often be combined with frequent adjustments due to irregularities in the roadbed on which the tractor operates.

For example, if the tractor encounters a hump in the roadbed, one or both of the trunnions 42 is raised relative to unit 29. That causes a corresponding increase in angle of attack A at one or both ends of the screed. It is theoretically possible for the screedman to correct such a change before it has produced any error in the mat surface. In practice, however, that is extremely difficult or impossible, particularly since there is no direct indication of the change in A until the resulting error in mat surface appears. By that time, the tractor may have passed the initial hump and have fallen into a hollow, so that the actual error in the angle of attack is opposite to that indicated by the observed error in mat surface. Under such conditions, the normal corrective action by the screedman will only increase the irregularity in the mat surface. That difficulty is encountered not only in controlling the grade, for example by reference to set grade stakes or an adjoining completed lane; but also in controlling transverse slope by reference to a spirit level or pendulum. Observation of an existing error of either type is no guide whatsoever whether the error is increasing or decreasing. Consequently the normal corrective adjustment proves incorrect approximately half the time.

The present invention avoids those difficulties by completely divorcing the action of the screed from the elevation of the draft arm trunnions, and consequently from the elevation of the paver tracks or wheels. That is done in preferred form of the invention by placing the adjustment of the two screed screws under continuous automatic control, so that the screed angle of attack is always maintained at the proper value. The angle of attack at one end of the screed is typically adjusted automatically to produce the desired grade; that at the other end to produce the desired transverse slope. However, many advantages of the invention are obtainable by manual adjustment of the screws in accordance with suitable signals developed by automatic means to be described.

In the illustrative embodiment of FIG. 1, electric drive motors and reduction gears 70 and 72 are mounted on the respective draft arms 40 and 42 and are coupled to the respective screws 50 and 52 by the gear drives 74. When the motors are not energized, the screws can be operated in the usual manner by handles 51 and 53. Control circuitry for motors 70 and 72 is housed partly in a control cabinet 76, which may also contain indicating and control devices to be described.

The control system of the invention typically employs sensing devices responsive to three distinct conditions. The grade-controlled end of the screed is driven in response to one of those conditions, which may be defined as the angular position of a forwardly spaced point of a grade reference surface with respect to the screed.

In FIGS. 1 and 2 a grade reference surface is indicated at 80, typically comprising a curb or a previously laid mat adjacent the current mat 60. The variable to be controlled is then the vertical offset D between the surface of mat 60 and grade reference surface 80. When no reference surface is already available, the grade may be marked by a rail or wire set for that purpose. A guide element 83, typically in the form of a slide or ski, moves along surface 80 at a fixed distance in advance of the screed. That distance is defined by the coupling arm 84, and is preferably adjustable. The forward end of arm 84 carries the bracket 78 which is pivotally connected to ski 83 on pivot axis 79. The rearward end of arm 84 is mounted on compacting and finishing unit 29 for free swinging movement about a transverse axis, shown at 85. A transducer of any suitable type is coupled to arm 84 in a manner to develop an electrical signal that represents the angular position of the arm with respect to the end portion of screed 30. In the present illustrative structure, a rotary transducer 82 is mounted on the screed assembly in a manner to be more fully described, with its input shaft 86 on axis 85; and arm 84 is mounted directly on the transducer shaft. The transducer signal, with suitable zero adjustment, substantially represents the angle B (FIG. 2) between an extension 88 of the screed surface and the line 87, drawn between axis 85 and ski pivot 79. That angle is measured in a vertical plane parallel to the direction of travel.

That angle B varies with the angle of attack of the screed, and therefore does not give a direct indication of the value of the offset D, which is to be controlled. It does, however, provide a measure of the rate at which that offset D is changing. For any given value of offset D, there is some definite equilibrium value of angle B for which the screed angle of attack A maintains the surfaces 60 and 80 parallel, so that offset D is held constant. In accordance with one aspect to the present invention, the screed screw at the grade controlled end of the screed is automatically driven under control of transducer 82 in such a way as to maintain a constant equilibrium value of angle B. Means are provided for conveniently adjusting that equilibrium value of B. By such adjustment, any selected value of offset D can be produced.

The slope controlled end of the screed is driven in novel manner in response to two distinct variables. One of those variables is the actual transverse slope of the mat surface being produced. That actual slope can be measured, for example, by a pendulum or equivalent device that is responsive to the difference of elevation of the finished mat near the two ends of the screed. Such a device may be mounted directly on the screed.

In accordance with the invention the slope measuring device is preferably mounted on a transverse beam, the ends of which are mounted on the rear edge of the screed at fixed distances above the screed surface and at equal distances from the midplane of the machine. That arrangement avoids the inconvenience of correcting for changes in setting of crown adjustment 37. In FIG. 1, for example, the entire cabinet 76 is mounted on such

a beam 90, supported at its ends from the screed structure by the links 91 and 92. Those links are of fixed length, but are sufficiently flexible or are mounted with sufficient pivotal freedom to accommodate the normal flexing and crown adjustment of the screed. Illustrative link structure is more fully described below.

In FIG. 3, a pendulum is indicated schematically at 94, rotatably mounted within cabinet 76. Pendulum axis 96 is parallel to the direction of travel 27 of the machine. A slope transducer 100 of any suitable type is mounted in cabinet 76 with its input shaft 95 coupled to pendulum 94, and produces a signal that represents the inclination of beam 90 and hence the actual transverse slope of mat 60. A zero adjustment is preferably provided, as by mounting the entire cabinet 76 on a bracket plate 98 which is adjustable about the pivot axis 93. Such adjustment is typically driven by manual rotation of the worm 99 by handle 101. The adjusted angle of bracket 98, corresponding typically to the desired transverse slope of the mat, may be indicated visually if desired, as by the pointer and scale shown schematically at 104. Transducer 100 is thus settable to produce zero signal at any desired reference value of transverse slope. The transducer output then represents directly the departure of the true transverse slope from the reference value. Alternatively, the electrical transducer signal may be compared electrically to an adjustable signal representing the reference value of slope. The result is a difference signal that represents the slope error.

A suitable indicator is also preferably provided to give the operator a visual indication of the actual slope. Such an indicator may, for example, comprise a scale and pointer coupled to pendulum 94; or may comprise a meter connected to the transducer output. In the present embodiment, the spirit level 102 is mounted on the top wall of cabinet 76 and therefore moves with bracket 98. Spirit level 102 thus provides a visual indication of the actual slope, measured relative to the desired slope angle for which transducer 100 has been set.

The second variable utilized for slope control represents a condition of screed adjustment that determines the rate at which the transverse mat slope changes as the machine moves forward. In the present embodiment the variable selected for measurement is the difference of screed inclination or angle of attack adjacent its two ends, which has already been referred to for convenience as the screed twist. A typical screed twist transducer is indicated at 110 in FIG. 1. It comprises a rotary transducer mounted in adjustable rotational relation to the screed adjacent one end, with its input shaft coupled to the other end portion of the screed via the shaft 112. Shaft 112 is preferably housed within beam 90. The output signal from transducer 110 then represents the departure of the screed twist angle from the reference value set in at the adjustment. Illustrative mounting and coupling structure for transducer 110 will be more fully described below. Alternatively, the twist transducer may measure twist relative to a fixed reference value, and the resulting signal may be compared to a variable reference signal to provide effectively a variable zero or base value.

Illustrative control circuit arrangements are represented schematically in FIG. 4, wherein the reference values of the variables are represented in the alternative manners described above. Grade transducer 82 is shown illustratively as a potentiometer R1 with its winding supplied with alternating current voltage from a source E. The wiper of R1 is driven by ski arm 85 in accordance with changes in angle B (FIG. 2), which depends upon the level of ski 83 and also upon the angle of attack of the grade controlled end of screed 30, taken illustratively as the left end. A second potentiometer R2 is also energized from source E. Its wiper is adjustable in any convenient manner, as by the manual knob 120 and the scale 119, to represent a reference value of grade angle B. The out-

put signals S1 and S2 tapped from the respective potentiometers R1 and R2 are supplied via the lines 121 and 122 to a differential device of any suitable type, represented at 124, from which an output control signal S5 is produced on the line 125. That signal typically corresponds in magnitude and phase to the difference of the signals S1 and S2. The windings of potentiometers R1 and R2 may be center tapped and grounded, as illustrated, so that S1 and S2 are definitely zero at those positions. Grounded center taps may similarly be provided for the other signal potentiometers to be described, such as R3, R4, R8, R9 and R12.

Output signal S5 is supplied to a phase sensitive servo amplifier 128, which may be of conventional type. The amplifier output controls drive motor 70 at the grade controlled end of the screed. In FIG. 4, the action of motor 70 is reversibly driving screed 30 via screw 50 schematically indicated by a dashed line 50; and the effect of screed movement upon the relative angle of ski arm 85 is represented by the dashed line 129. Thus the described grade control may be considered as a closed loop servo drive controlling the angle of screed 30 at its left end. The direction of drive is such that angle B formed by the screed with the line 87 (FIG. 2) is maintained at a definite value corresponding to the position of manual knob 120.

Under that condition, as already indicated, the surface of mat 60 asymptotically approaches and then maintains a fixed offset D with respect to grade reference surface 80. Any desired change in that offset may be gradually brought about by suitable adjustment of knob 120. It is particularly noteworthy that the described grade control is completely independent of irregularities in the base on which tractor unit 20 operates. Such irregularities are transmitted as usual via draft arm 40 to the screed supporting structure, tending to change the screed angle of attack A. However, any such change also appears in angle B. It is immediately detected by transducer 82 and is corrected by suitable automatic drive of screed screw 50 before it can produce any detectable change in the value of offset D.

In the illustrative circuit of FIG. 4, twist transducer 110 is represented as the potentiometer R3, supplied with alternating current power from source E. The potentiometer wiper is driven in accordance with screed twist by the shaft 112 (FIG. 1), and supplies to the line 131 an output signal S3 which is typically zero when the screed twist is zero. A twist reference signal S4 is developed on the line 132 by the reference potentiometer R4.

Signals S3 and S4 are supplied by the lines 131 and 132 to the differential device represented schematically at 134. The resulting difference signal S6 on the line 135 is supplied as control signal to the servo amplifier 138. That amplifier controls the drive motor for the screed screw that is to control transverse slope of the mat, taken in the present instance as motor 72, driving screw 52. The resulting movement of the right end of screed 30 changes the screed twist and moves potentiometer R3 via shaft 112 in a direction to reduce the value of S6. The resulting screed drive has the effect of maintaining the screed twist at the value corresponding to the adjusted position of twist reference potentiometer R4. Thus, for example, if the right-hand crawler of the tractor should encounter an irregularity in the base, changing the height of right trunnion 42, the resulting alteration of screed twist is immediately sensed by R3, causing motor 72 to reestablish the previous value of screed twist. Also, if the angle of attack of the left end of the screed is altered, as by actuation of left drive motor 70 to correct a grade error sensed by transducer 82, the resulting change in screed twist causes right motor 72 to reestablish the previous value of screed twist. Hence, the control system for motor 72, as so far described, effectively eliminates the torsional flexibility of the screed, maintaining a fixed value of screed

twist substantially as if the screed were torsionally rigid. So long as twist reference potentiometer R4 remains fixed at a definite adjustment, the screed twist is maintained at a corresponding value independently of other variables, such as actual transverse slope of the mat surface, for example. In that respect, the present system as thus far described is distinct from the systems of the above identified copending applications, wherein screed twist and mat slope exercise joint control.

In accordance with a further aspect of the invention, two distinct trimming mechanisms are provided for modifying the value of screed twist that is thus maintained. The wiper of R4 is coupled to the reversible motor 136 via a coupling mechanism 137 which preferably includes a variable ratio device indicated schematically at 139. Motor 136 is selectively actuated in the respective direction by any suitable means, shown illustratively as the double-throw switch T2 and the power source E'. Motor 136 may comprise a reversible stepping motor of conventional type, in which case each switch actuation causes a shift of definite magnitude and direction in potentiometer R4, changing S4 by a corresponding definite increment, and correspondingly changing control signal S6. Alternatively, motor 136 may represent a reversible motor of clock type incorporating a reduction gear of high ratio. The magnitude of the increment in S4 is then proportional to the time that switch T2 remains closed during each cycle of its operation. In either case, the change may be made adjustable if desired, for example by adjustment of variable ratio device 139. The increment in S4 produced by switch T2 is permanent in the sense that return of T2 to neutral position does not remove it.

The system of FIG. 4 also includes means for producing a temporary trimming effect or change in the servo system that controls screed twist. In the present instance that is done by operation of the double throw switch T1, which connects the variable resistance R5 in shunt to that portion of the winding of potentiometer R4 on one side or the other of the wiper. The magnitude of the increment in signal S4 produced by T1 is conveniently adjustable by variation of R5. Switch T1 might alternatively be arranged to connect R5 in shunt to part of R3, for example, instead of R4, the switch leads being interchanged so that the polarity of the change in control signal S6 remains the same. It is usually preferable for the temporary signal increment to exceed the permanent increment produced by T2 by a factor of from about 5 to about 10. In the present illustrative system, switches T1 and T2 are coupled together for simultaneous manual operation by the handle 140, the respective increments in signal S4 being additive.

In operation of the slope control system of FIG. 4, as thus far described, the screed twist is automatically maintained at the value represented by reference signal S4. Under normal conditions that twist is substantially zero, and is such that the transverse slope of the finished mat remains constant. However, the transverse slope may slowly drift away from the desired value, perhaps due to a slight error in initial screed twist. That is corrected, or required changes of slope may be introduced, by action of the operator, who typically manipulates switch control 140 in accordance with his visual observation of the actual transverse slope. For example, he may observe the spirit level 102 of FIG. 3 from time to time. If the indicated slope is incorrect, he then operates handle 140 to close both switches T1 and T2 in the appropriate direction to correct the error. The value of signal S4 is thereby changed, both by action of R5 shunting one end of R4 and by the direct movement of the wiper of R4 by motor 136. Differential signal S6 is thereby displaced from zero, immediately actuating motor 72 to drive the screed twist through a definite angular increment, such that the resulting change in S3 restores S6 to zero. The screed twist is thereby altered by a corresponding amount. Op-

eration of the machine with that trimmed or modified value of screed twist causes the actual transverse slope to change progressively toward its correct value.

When the operator observes that the slope error has been corrected, or when he otherwise considers it proper, he releases handle 140, opening T1 and T2. The shunting action of R5 is thereby removed, but the wiper of R4 remains in its shifted position. The servo drive immediately removes the major part of the corrective twist, produced by switch T1, but retains the smaller part produced by T2. The relatively rapid corrective action is thereby terminated. But the permanent change in setting of R4 tends to prevent repetition of the same error.

In the system operation as just described, the operator may be considered to act as a link between the pendulum, or other slope indicator, and the mechanism for correcting the slope. When that link is inactive, the mechanism continues to perform the highly useful function of effectively isolating the screed twist adjustment from possible effect of irregularities in the base.

It is sometimes desirable to further free the operator by providing an automatic link between the slope sensing means and the slope correcting means, and such mechanism is included in schematic form in FIG. 4. For that purpose the switches T1 and T2 are typically constructed as relay switches of a polarized relay 150. A center tap of the relay winding is grounded, and the end terminals of the winding are connected via the lines 151 and 152 to the direct current power source 156 via the series switch 157 and the respective switch contacts 154 and 155 of a double-throw switch 158. That switch is actuated by a slope-responsive device mounted on the screed, shown typically as pendulum 94 of FIG. 3. Contacts 154 and 155 may be mounted on bracket 98 for convenient adjustment of the zero slope angle. Switch 158 is then an illustrative form of transducer 100. If preferred, the pendulum may, of course, drive a transducer 100 of proportional type, the resulting signal being typically amplified and utilized to control relay 150 or its equivalent. If the slope error exceeds a definite threshold value, determined by the switch contacts 154 and 155 in the present instance, switches T1 and T2 are actuated in the proper direction to correct the error and also to reduce the chance of its recurrence. That automatic trimming control may be disabled, if desired, by opening switch 157; the slope may then be monitored by the operator and corrected by manipulation of switch handle 140 as already described. And while switch 157 is closed, the operator may, if he so desires, over-ride the automatic action by manual control of switches T1 and T2.

The slope control of FIG. 4 may be viewed as operating alternately in two different manners, in accordance with the magnitude of the error in the existing slope. When that error is small, so that switch contacts 154 and 155 are both open, the system responds solely to twist transducer R3. Motor 72 is then so driven as to maintain the screed twist constant. That action has the important advantage of isolating the machine operation from irregularities of the base.

If the actual slope error increases above a definite threshold, one of switches 154 and 155 closes. The system then acts under joint control of two variables, the screed twist and the existing slope. The system continues to control the screed twist, isolating it from irregularities of the base, but at a value that is modified in accordance with the sign of the measured slope error. In the present embodiment that modification includes both a temporary and a permanent factor, as already explained. The temporary modification is typically large enough to correct the existing slope error rather rapidly. The pendulum switch then opens, returning the screed motor 72 to effective control solely by the screed twist. The cycle of corrective action corresponds closely to the operator's action, already described, in monitoring the existing slope and adjusting the equilibrium twist value accordingly.

Smoother action may sometimes be obtained by returning the system of FIG. 4 to sole control by the screed twist before the existing slope error has been completely eliminated. In accordance with another aspect of the invention, that can be accomplished by causing the system to shift between its two manners of operation intermittently, partly or wholly independently of the actual magnitude of the slope error. Such a system is shown illustratively in FIG. 5. FIG. 5 also illustrates how the present invention may be embodied in a system employing a combination of screed twist and slope as the normal control variable. The grade control aspect of the system is omitted from FIG. 5 for clarity of illustration, but may be as shown in FIG. 4.

In FIG. 5 twist signal S6 is derived as in FIG. 4. However, that signal is not used directly, but is combined in the summing circuit 163 with a signal S10 which represents the error in transverse slope. Signal S10 is typically derived by developing an actual slope signal S8 by pendulum transducer 100, represented by the potentiometer R8 driven by the linkage 95. Signal S8 is then compared to a reference slope signal S9. Signal S9 may constitute a mechanical angle, as set at dial 101 in FIG. 3. As shown in FIG. 5, however, S9 is developed by the balance potentiometer R9, manually adjustable at the dial 101a. S8 and S9 are compared by difference device 160, which may be of conventional type, and the resulting slope signal S10, representing the slope error relative to the desired reference slope for which R9 is set, is supplied via the line 165 to adder 163.

Adder 163, which may be of any suitable type, is represented illustratively as comprising a resistance network R6, R10 and R11. The relative weight given to the component signals S6 and S10 may be varied, as by adjustment of variable resistor R6 of the adding network. The resulting combined control signal S11 is supplied to the servo amplifier 168, which controls screed drive motor 72. That motor controls the right end of screed 30 via screw 52, driving the screed to such position that the signal S11 is maintained at a definite equilibrium value, typically zero. That is, the linear combination of screed twist and mat slope represented by S11 is maintained at zero.

The system of FIG. 5 as thus far described will be seen to provide continuous drive of one end of the screed, under joint control of the existing slope and the existing screed twist, which control is functionally similar to that provided by the systems of the above identified copending applications. More particularly, the present signal S11 corresponds directly to the signal on line 44 of FIG. 6 of the above identified Bowen application. And it is functionally similar to the signal on lines 110 and 111 of FIG. 4 of the above identified Shea application. In the illustrative system of Shea, the latter signal depends upon both transverse slope and screed twist due to the mechanical linkage whereby pendulum 90 is supported and operated.

In accordance with the present invention, the operation of a system of either of those general types is rendered more accurate and reliable by providing means for monitoring the system performance under dominant or sole control of the existing transverse slope. As illustratively shown in FIG. 5, such monitoring action utilizes a pure slope error signal that is already present in the system as S10. That signal is tapped from line 165 and is supplied via the line 167 and the intermittently actuated switch 168 to a suitable trimming control mechanism represented schematically at 170. In the system disclosed in the above identified Bowen application, a corresponding signal is obtainable from lines 137 of FIG. 6. In a system of the type disclosed in the above identified Shea application, pendulum 90 does not provide a pure slope signal. However, a signal equivalent to the present S10 may be provided, for example, by mounting a second pendulum on the screed, typically in the manner shown

in FIG. 3 of the present application, with a suitable transducer with reference adjustment such as 100.

Monitoring control device 170 may, for example, comprise the servo amplifier 171 for discriminating the sign and magnitude of the input signal, and the reversible motor 172. That motor may be a stepping motor of conventional type, like 136 of FIG. 4; or may be arranged in known manner to drive reversibly at a rate proportional to the magnitude of the input signal. The motor is typically coupled to any suitable system component, variation of which causes a corresponding variation in the control action of the system. As illustratively shown at 173, device 170 drives twist balance potentiometer R4. A differential 175 is preferably inserted in that drive to provide parallel manual control of R4 via the knob 174, and a variable ratio device 179 is preferably included for adjusting the increment in S4. Alternatively, the corrective drive from motor 172 may be applied to another component of the control system which modifies the value of twist for which the control system is in equilibrium.

Switch 168 in FIG. 5 may be operated manually if desired, but is preferably operated automatically in accordance with some definite program. As illustrated, an interval mechanism 176 drives the cam 178, which periodically closes the switch at a frequency that is adjustable at 177. Interval device 176 may represent a conventional timer; or may represent an odometer driven typically with crawler tracks 24 (FIG. 1) and arranged to close switch 168 at uniform but adjustable intervals of travel of the paving machine. The switch actuating mechanism as shown holds switch 168 closed during a definite fraction of its operating cycle, that fraction being determined by the form of cam 178 and the radial spacing of the switch from the cam axis. That fraction is typically quite small, for example of the order of $\frac{1}{2}$ to $\frac{1}{10}$, and may be made adjustable if desired. If preferred, the interval mechanism may be arranged in known manner to hold the switch closed for a definite time period that is adjustable independently of the operating frequency for which it is set.

Each cycle of closure of switch 168 supplies slope signal S10 to device 170. If the existing transverse slope is correct, so that S10 is essentially zero, device 170 does not respond. If S10 represents an appreciable slope error, device 170 modifies the system, as by limited drive of R4, in a direction to cause the error to decrease. Such monitoring cycles are repeated periodically, the degree of correction being increased or decreased during each cycle as required to eliminate any slope errors that may occur. In this way cumulative errors of slope are positively prevented from building up, despite changes in the equilibrium value of angle of attack or other factors of machine operation.

In FIG. 5 as shown, the shift in R4 produced at each cycle of monitoring action is permanent, in the sense of continuing after the monitoring cycle is terminated by opening of switch 168. That shift of R4 may be supplemented by a temporary shift in the control system balance, which may be produced, for example, by electrical means such as that associated with switch T1 in FIG. 4. Such circuit means can be controlled, for example, by a polarized relay similar to 150 of FIG. 4 and actuated by the amplifier 171. Suitable means are provided for supplying to amplifier 171 a zero signal whenever switch 168 is open. That can be accomplished, for example, by suitable biasing means of conventional type within amplifier 171.

Intermittent monitoring of the existing slope can also be obtained in the system of FIG. 4. For example, the switch 157 of FIG. 4 may be controlled intermittently in any desired manner, for example as already described for switch 168 of FIG. 5. The monitoring action in FIG. 4 is then as already described except that it is limited to the periods of switch closure. In presence of such limi-

tation it is usually desirable to increase correspondingly the magnitude of the temporary modification of the system produced by switch T1, as may be done, for example, by reducing the resistance of R5.

It is sometimes desirable to control the trimming or monitoring action so that each increment of corrective drive is proportional to the magnitude of the existing mat slope error at the time of the monitoring cycle. An illustrative manner of obtaining such action in accordance with the invention is represented schematically in FIG. 6. In that system, twist signal S6 on line 135 and slope signal S10 on line 165 are typically produced as in FIG. 5. A relay 180 with double throw switch normally supplies S6 via switch contact 181 to amplifier 168b which controls screed motor 72 and screed screw 52. That servo loop normally maintains the screed twist at a value corresponding to the setting of twist balance potentiometer R4 essentially as already described.

A transducer, represented illustratively as the potentiometer R12 is coupled via the magnetic clutch 184 to screed drive screw 52, as indicated by the dashed line 185. A variable ratio drive device 183 is preferably included in coupling 185. R12 is supplied with reference voltage from E, and its wiper is yieldingly biased toward zero position, as by the springs 188. When clutch 184 is released, the output signal S12 on the line 189 is reset to zero, due to action of springs 188, whereas clutch engagement causes the signal to vary in accordance with the drive of screw 52. Many other configurations may be employed for providing the described reset action. For example, the wiper of potentiometer R12 may be driven continuously from screed drive screw 52, the potentiometer case being rotatably mounted by means of a magnetic clutch and yieldingly centered relative to the wiper by springs corresponding to 188. Clutch engagement then causes the transducer to be driven as in FIG. 6, while clutch release permits the case to rotate back to zero position.

Screw 52 is similarly coupled via the electric clutch 186 to the wiper of twist balance potentiometer R4 or some effectively equivalent component, as indicated schematically at 187. Coupling 187 preferably includes also an adjustable ratio drive device 198 and a differential 175 and manual dial 174 to facilitate manual adjustment of R4 independently of the clutch drive if desired. Clutch 186 is operated synchronously with clutch 184. As shown, the two clutches are connected in parallel between the line 195 and ground.

Signal S12 is compared with slope signal S10 by the difference device 190, typically of conventional type, which produces on the line 192 a control signal S13 proportional to their difference. That signal is supplied to the other switch contact 182 of relay 180. Relay energization causes screed drive motor 72 to operate under control of S13 rather than S6. The relay is energized intermittently in any desired manner. For example, the relay may be energized from a power source E' via the line 194 and the switch 168a, which is actuated by cam 178 and interval device 176 as already described in connection with FIG. 5. Clutches 184 and 186, already described, are energized simultaneously with relay 180, as by connection of clutch line 195 to line 194.

In operation of the system of FIG. 6, as long as cam switch 168a is open the screed twist is maintained at the constant value corresponding to the setting of R4. On closure of switch 168a, relay 180 shifts control of motor 72 from twist signal S6 to signal S13. Since R12 is then at center, due to the reset action of springs 188, S13 equals S10 and represents the existing departure of the transverse slope of the mat from the desired value, set on R9. If S10 is not zero, motor 72 is actuated, driving screw 52. Screw transducer R12 is thereby driven through energized clutch 184 until its output S12 balances the error signal S10. The servo drive then reaches equilibrium and stops. The drive increment is proportional to the magnitude of the

error, the constant of proportionality being conveniently adjustable by varying the drive ratio at 183. That same drive produces a proportional shift in R4, via energized clutch 186. That change is ineffective while switch contact 181 is open. The constant of proportionality for the drive of R4 is conveniently adjustable at 198.

When switch 168a opens, control of motor 72 is returned to twist signal S6. That signal, however, has been modified by the described corrective drive of R4. That change in R4 typically corresponds to only a small part of the change in screed twist that was needed to balance the system during the monitoring action. The screed twist is therefore typically returned nearly, but not quite to its original value after each corrective action. The corrective action thus includes a relatively large temporary correction and a relatively small permanent correction. Adjustment at 183 changes both corrections in the same proportion; while adjustment at 198 changes only the permanent correction.

The overall action is thus functionally similar to that previously described except that the corrective action varies in magnitude with the slope error. Transducer R12 may be considered to measure the excursion of the corrective drive, which is then compared with the existing slope error.

A simplified form of control system, with correspondingly reduced functions, is useful for many purposes, and may be illustrated by FIG. 6 by considering that twist transducer R3, twist reference transducer R4 and their associated equipment are omitted. Relay switch terminal 181 is then typically grounded, so that when interval switch 168a is open the screed motor 72 is maintained stationary. The action of such a simplified system is to monitor the transverse slope intermittently and to adjust the screed twist by an increment that is proportional to the error of transverse slope. The twist is thus corrected intermittently in a direction to cause the slope to be restored gradually to its proper value. Each cycle of corrective action applies a further twist increment based upon the slope error at the time. With this simplified system, however, the screed twist is not isolated from irregularities of the base during the periods between corrective adjustment.

In FIG. 6, as shown, a single servo drive, comprising an amplifier 168b and drive motor 72, is switched between two functions which may be described as maintaining the screed twist in accordance with the setting of R4; and modifying that setting of R4 in accordance with the pendulum error signal from R8 and R9. Alternatively, those functions may be performed by separate servo drives, eliminating the need for time sharing between them. The screed twist can then be isolated from irregularities of the base even during periods of slope monitoring, as in the system of FIG. 5. Such a modified system may be derived from FIG. 5 by introducing a potentiometer like R12 of FIG. 6, driven from motor 172 via a clutch like 184 of FIG. 6. The signal S12 from the potentiometer is summed with the slope error signal on line 167. Such a system differs from that of FIG. 5 particularly in that the monitoring action varies with the magnitude of the slope error.

In FIGS. 4 to 6 the grade, twist and slope reference signals comprise electrical signals which are compared electrically to the actual grade, twist and slope signals, respectively. Alternatively, that comparison may be made in other ways, for example essentially mechanically. It is often convenient to drive one member of a transducer in accordance with the actual value of a variable and drive the other member in accordance with the adjustable reference value of that variable. The position of the second member may then be considered to constitute a signal representing the reference value; and the output of the transducer then directly represents the deviation of the variable from the reference value.

In FIG. 4, for example, grade reference potentiometer R2 may be omitted, the winding of grade potentiometer

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R1 being movably mounted and coupled to manual knob 120 for adjustment of the reference value of the grade, as indicated schematically in FIG. 4A. Difference device 124 may then be considered to be incorporated in the potentiometer structure. The output signal from the wiper of R1 then corresponds to S5 of FIG. 4 and may be supplied directly to amplifier 128. Correspondingly, twist reference transducer R4 of FIGS. 4 to 6 may be incorporated in transducer R3; and slope reference transducer R9 of FIGS. 5 and 6 may be incorporated in R8.

When the transducer is of any type comprising two relatively movable members, as is true, for example, of an electromagnetic transducer having relatively movable winding and armature members, and of a hydraulic transducer with relatively movable valve and seat members, the two members of the transducer can similarly be driven in accordance with different values to be compared. Moreover, two or more signals in mechanical form can be combined mechanically in known manner, for example by means of one or more differentials, and the resulting single mechanical signal used to drive a transducer in conventional manner to produce a difference signal.

The system of FIG. 7 is in many respects similar functionally to that of FIG. 4, but utilizes electromagnetic transducers of differential transformer type, and illustrates the drive of one member in accordance with the existing value of a variable and of the other member in accordance with the reference value. FIG. 7 also illustrates a particularly convenient manner of switching control functions between ends of the screed by means of suitably arranged connectors. FIG. 7 further illustrates particularly convenient and effective circuit means for supplying a temporary trimming or corrective signal increment in an alternating current system.

The system of FIG. 7 utilizes four transducers, T1 to T4, typically all of identical basic structure. Each transducer comprises a core member 201 of E-form and an armature or I-core 210. The E-core carries a primary winding 202 on the center leg and secondary windings 203 and 204 on the side legs. The primary windings of all the transducers are excited with alternating current of suitable frequency, such as 1000 cycles per second, for example, which is typically derived from an oscillator powered by direct current. In FIG. 7 a source of direct current power is indicated at 212, connected via the main switch 214 to the oscillator indicated schematically at 200. Oscillator 200 may be of conventional construction, and only the secondary winding 216 of its output transformer is shown explicitly. Alternating current, typically having a substantially square waveform, is supplied from oscillator 200 via the lines 220 to the primary windings of the four transducers.

The I-core and E-core of each transducer are independently rotatable about axes indicated schematically at 206 and 207, respectively, which may coincide but are shown mutually spaced for clarity of illustration. Rotation of either core member alters the spacing between the ends of the I-core and the respective side legs of the E-core, thereby altering the relative magnitudes of the currents induced in the respective secondary windings. When the two core members are aligned, the two secondary currents are typically equal, which will be referred to as zero signal condition. The two secondaries may be series connected in opposition to give a single output signal that is actually zero under that condition. In the present system, however, separate output connections are provided for the signal from each secondary winding, and the two signals are compared in magnitude only after demodulation. That arrangement has the advantage that the demodulation can be accomplished by a simple rectifier, requiring no reference phase. Hence shifts of phase in one or both component signals produce no error in overall response. All connections to transducer T1 pass through a connector indicated at M1.

Transducer T1 corresponds to transducer 82 of FIG. 1.

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It is driven in accordance with the angle between the screed surface and the grade follower arm 84, as already described, and is also adjustable manually to vary the reference value of that angle, that is, to vary the value of that angle for which the output signal is zero. In the system as shown, the E-core 201 is coupled to the end portion of screed 30, as indicated schematically by the dashed line 222, with the angular relation between the E-core and screed adjustable by the manual knob 224. The I-core 210 is coupled to vertical movement of ski 83 or its equivalent, as indicated by the dashed line 226. That line may represent grade follower arm 84 of FIG. 1, for example. The output signal from transducer T1 on the lines 230, comprising the two related signals from the respective secondaries of that transducer, then represents the deviation of the angle B (FIG. 2) from the reference value for which dial 224 is set.

Transducer T2 is typically identical to T1 in construction, with an identical connector M2. It is similarly coupled to the screed and grade following mechanism, but at the other side of the paving machine. An important feature of the present structure is that transducers T1 and T2 are mounted in symmetrical relation with respect to the longitudinal mid-plane of the machine, one transducer being rotated 180° relative to the other. Similar errors of grade on the two sides of the machine then produce signals in the respective transducers of opposite sign. In FIG. 2, for example, an increase in reference grade at ski 83 rotates the transducer shaft clockwise about axis 85. The corresponding view of the other side of the machine appears as the mirror image of FIG. 2. Increasing grade of the ski on that side produces counterclockwise rotation of the transducer shaft as seen in that view. If the transducers are identically wired and then mounted back to back their output signals thus have opposite significance. Or if one transducer is mounted alternatively at either side of the machine with the same face always toward the midplane of the machine, a grade error of given sign produces opposite signals from the transducer under those two conditions.

In FIG. 7 the two screed drive motors 70 and 72 coupled to the respective ends of the screed by the screws 50 and 52, are provided with respective electrical control units D1 and D2. Those control units have respective identical input connectors N1 and N2, adapted to receive transducer connectors M1 and M2. They typically comprise, as shown explicitly for unit D1 only, the demodulators 232 and 234 for the respective signal components produced by the transducers just described; circuit means 236 for comparing the magnitudes of the direct current outputs of those demodulators; and switching means indicated schematically at 238 and 240, respectively, with output lines 239 and 241 by which the motor is driven in opposite directions. The switching means are so controlled by comparison circuit 236 that the motor is idle when both input signals are equal, and is driven in one direction or the other when the signal difference exceeds a small threshold value, the direction of drive corresponding to the polarity of the difference. The term "switching means" is not intended to imply necessarily that mechanical switches are involved, since the switching action can be controlled entirely by electronic amplifying means if desired. However, the final stage ordinarily comprises a conventional motor contactor. The demodulators, comparison circuit and switching mechanism may be of conventional design, and are therefore not described in detail.

The two motors 70 and 72, or their control units D1 and D2, are wired oppositely, so that an input signal of given polarity at the input connectors N1 and N2 produces opposite driven direction of the motors that they control. That is indicated schematically in FIG. 7 by the crossed input leads between connector N2 and control unit D2. However, the difference in wiring can actually occur within the unit or in the wiring of the respec-

tive motors, 70 and 72. The wiring is such that left control unit D1, for example, causes motor 70 to increase the angle of attack at the left end of the screed in response to the signal from transducer T1 that represents an increase in angle B (FIG. 2). Right control unit D2 then also causes the angle of attack at the right end of the screed to increase in response to an input signal from transducer T2 that represents increasing angle B, since the polarity of that signal is opposite with respect to the signal from T1, and the response of the control unit D2 is also opposite with respect to D1. Hence in both instances, the angle of attack is automatically modified in a direction to bring the actual grade of the freshly laid mat into agreement with the reference grade. Thus, either or both ends of the screed may be controlled in accordance with grade, if desired, by connecting M1 to N1 and M2 to N2; and if only a single grade transducer is provided, say T1 with connector M1, it may be mounted interchangeably on either side of the machine and plugged into the appropriate connector N1 or N2.

Transducer T3 in FIG. 7 corresponds to twist transducer 110 of FIG. 1, and produces a signal representing the difference between the actual screed twist and a reference value. Thus T3 takes the place of both R3 and R4 of FIGS. 4, 5 and 6. As illustratively shown, the E-core of T3 is mounted on one end of screed 30 in a rotational position that is adjustable by means of the stepping motor 136; and the I-core of the transducer is driven from the other end of the screed by a linkage represented schematically at 112 and typically corresponding to the twist shaft 112 of FIG. 1. The transducer output then corresponds directly to the signal S6 of FIG. 4, for example. An additional manual adjustment of the reference value of twist may be provided, as indicated by the knob 174, coupled via a differential device 175 to the E-core of T3. Elements 174 and 175 thus correspond functionally to the elements identified by those numerals in FIG. 6.

The two output signal components from the respective output windings of T3 are supplied to the connector M3 via the lines 250 and 252, respectively. Each of those signal circuits includes in series a secondary winding of the transformer 262. The primary winding 263 of that transformer is connected in an increment control circuit indicated generally at 260. Circuit 260, which corresponds generally to the circuit containing resistance R5 of FIG. 4, produces a temporary signal increment whenever the stepping motor 136 is actuated.

Connector M3 may be plugged into connector N2 of control unit D2, as indicated in FIG. 7, to control right screed motor 72 in accordance with screed twist. Alternatively, M3 may be plugged into connector N1 of control unit D1 to control left screed motor 70 in accordance with screed twist. The wiring between transducer T3 and connector M3 is such that the signal delivered to either control unit causes screed drive in a direction to bring the actual screed twist into agreement with the reference value, that is, in a direction to reduce the difference between the two signal components. That is feasible because the two control units D1 and D2 produce opposite screw rotation, and thereby alter the screed twist in the same direction, in response to a given input signal.

Stepping motor 136 and increment circuit 260 are controlled by the pendulum transducer T4, which corresponds to transducer 100 of FIG. 3, for example, and takes the place functionally of R8 and R9 in FIGS. 5 and 6. The E-core of T4 is typically mounted on bracket plate 98 of FIG. 3 for angular adjustment by the dial 101 relative to the actual transverse mat slope; and the I-core is driven by pendulum 94 via the shaft 95. The output signal from T4 then represents the departure of the actual transverse mat slope from the desired value, set in at knob 101. That signal is supplied via the lines 254 to the control unit D3, which typically is essentially identical to units D1 and D2 except for adaptation of its output circuit

to drive the relatively low power stepping motor 136. Control unit D3 energizes one or other of the output lines 256 and 257 according as one or other of the two input signal components is the greater. Those lines are connected to stepping motor 136 in such a way that the motor produces an output step function in one direction or the other in response to each energization of one of the lines. That movement is communicated to the E-core of T3 via the differential 175 and the coupling indicated at 259. The resulting drive of transducer T3 has the effect of modifying the reference value of screed twist, and is in such direction that the slope error that initiated the drive is progressively reduced, as already described in connection with previous embodiments. Stepping motor 136, like the other stepping motors already referred to, may be a reversible motor, or may actually consist of two motors so connected as to drive the controlled element in opposite directions. For purposes of the present description it will be assumed that the energization of lines 256 and 257 is by positive direct current.

Increment circuit 260 may be of any type that energizes primary 263 of transformer 262 in one phase relation to the alternating current output of oscillator 200 whenever stepping motor 136 is driven in one direction, and in the opposite phase relation when that motor is driven in the other direction, the phase relations being so arranged that the resulting signal increment at the transformer secondaries modifies the output from twist transducer T3 in the same direction as the stepping motor action. That is typically accomplished by connecting one end of transformer primary 263 via the line 267 to the center tap of oscillator transformer secondary 216; and connecting its other end via the line 264 and the two controlled rectifiers 265 and 266 in parallel to the opposite end terminals of the oscillator transformer secondary. The control terminals of controlled rectifiers 265 and 266 are connected to the junctions of respective voltage dividers, R15, R16 and R17, R18, which are connected between ground and the respective stepping motor lines 256 and 257. When the stepping motor is idle, controlled rectifiers 265 and 266 do not conduct in either direction, and no signal increment is produced. However, when one of the lines 256 and 257 is energized, the corresponding controlled rectifier becomes conductive, passing half-cycles of current in corresponding phase to transformer 262. The series capacitance 268 and shunting resistance R14 may be provided for phase control. Transformer 262 is connected in suitable polarity to produce signal increments in the output of T3 having the phase relation already described.

A manual control is preferably provided for actuating stepping motor 136 and for simultaneously producing a temporary signal increment via circuit 260 independently of pendulum 94 and transducer T4. Such a control is represented by the double throw switch 280, with manual handle 282, whereby positive direct current power may be selectively supplied to either one of the lines 256 and 257. Suitable means of any desired type are preferably provided for disabling the normal control of motor 136 by pendulum 94 whenever manual switch 280 is operated. As illustratively shown, normally closed switches 284 are provided in the respective lines 256 and 257 and are linked to handle 282 in such a way that closure of switch 280 to either of lines 256 or 257 automatically opens the switch 284 in the other line.

In accordance with a further aspect of the invention, FIGS. 8 to 10 represent illustrative structure for mounting the grade, slope and twist transducers in suitable relation to the screed 30. Left and right bracket assemblies 210 and 230 are mounted on the screed assembly adjacent the respective screed ends in such a way that they accurately reflect changes in angle of attack of the screed, while accommodating its torsional and crown movements. In the typical conventional paving machine

structure shown schematically in those figures, the forward edge 31 of screed 30 is secured to the lower edge of compacting mechanism 32, by which it is rigidly defined. The rear edge of the screed is defined by vertical frame structure that includes the channel member 202. That member, like the compacting mechanism, is formed in two sections which are effectively hinged together in conventional manner, not explicitly shown, on the fore-and-aft midplane axis 36 (FIG. 1) to permit crown adjustment of the entire screed assembly by the screw mechanism 37. When the crown adjustment is altered, the right and left halves of the screed, together with its supporting structures, fold slightly about axis 36. For any given setting of that adjustment, the two sections of channel 202 form an effectively rigid unit which defines the rear edge of the screed, while the forward edge is similarly defined by the effectively rigid unit formed by the two parts 33 and 34 of compacting mechanism 32. The compacting mechanism and forward screed edge 31 are pivotally mounted on draft arms 40 and 41 by the main support pivots 54; whereas the channels 202 and the rear screed edge are adjustably defined relative to the draft arms by the screed drive screws 50 and 52. Differential adjustment of those screws, or differential movement of the draft arms themselves alter the screed twist. The bracket structure to be described has the important characteristic of accommodating those screed movements without loss of accuracy in the desired definition. The bracket structure also clears the shelf 204, which is conventionally mounted on channel 202 and provides a walkway for the operator; and the partition 206, which defines a conduit 207 for conducting hot air from a heater, not shown, in thermal contact with the screed surface.

Each of the bracket assemblies 210 and 230 comprises a rigidly welded assembly of structural elements which is supported on the upper edge of channel 202 by an angle member 212. That member is of relatively thin sheet material and acts as a flexure pivot, permitting limited pivotal movement of the bracket assembly about an axis parallel to the length of the screed, indicated at 211. The rotary position of each bracket assembly about pivot axis 211 is defined with reference to the forward edge of the screed by a tubular strut 214. That strut is fixedly mounted on the bracket assembly and extends forward above partition 206. Its forward end is received by an aperture 217 in a bracket structure 216, fixedly mounted in any convenient manner, as by welding, on the rigid structure associated with compacting mechanisms 32. Aperture 217 is sufficiently large to permit torsional movement of the screed assembly and the resulting play is taken up by resilient means, shown as the coil spring 218 extending vertically between the strut and an arm of bracket 216.

Each of the bracket structures 210 and 230 includes a mounting plate 220 to which the grade transducer 82 or 84 can conveniently be releasably bolted. That plate is offset rearwardly from the vertical plane of channel 202 (FIG. 9) sufficiently to permit input shaft 86 of the transducer to pass behind the screed drive screw 50 or 52 and screed end plate 39. The grade transducers are preferably constructed with input shafts in the form of sleeves 224 journaled in the transducer housing. Shafts 86 are axially adjustable in those sleeves, and are clamped in the desired axial position by means of set screws or clamp means of any suitable type, indicated at 225 in FIG. 8.

Beam 90 and the twist transducer mechanism are mounted on brackets 210 and 230 by means of vertical left and right arms 236 and 238. Those arms are pivotally connected to the respective bracket assemblies as by means of pins which pass through two aligned bearings 232 on the bracket assemblies and bushings 234 on the lower end of the arms. One of the arms, shown as left arm 236, is fixedly connected to beam 90, and the bearings 232, 234 are loaded by the springs 235 to eliminate play. The other arm 238 carries a pivot pin 240 at its

upper end which defines the height of the right hand end of beam 90 and also defines the rotary position of the right hand end of twist transducer shaft 112. As shown, shaft 112 fixedly carries the block 242 with the coaxial bore 243. An offset transverse bore in block 242 fittingly receives pivot pin 240. A sleeve 244 is fixedly mounted on the end of beam 90 and is received in bore 243. Sleeve 244 is transversely slotted at 245 to provide clearance for pivot pin 240, defining block 242 axially of shaft 112, while permitting limited rotation. A single coil spring 248 extends between beam 90 and bracket assembly 230, effectively eliminating any play in lower arm bearings 232 and 234, the upper arm bearings at pin 240, and the bearing between sleeve 244 and block 242. The right end of shaft 112 is thereby positively driven with the angle of attack of the right end of the screed; while beam 90 is free to follow changes in angle of attack of the left end of the screed.

A mounting plate 250 for twist transducer 110 is fixedly mounted on the left end of beam 90, and carries the transducer in position to receive shaft 112 as input shaft. The rotary position of the transducer case is thus defined by bearing structure 232 and 234 on left bracket assembly 210, while that of its input shaft is defined by the corresponding bearings 232, 234 on right bracket assembly 230. Since those axes are, in turn, maintained by the struts 214 of the respective bracket assemblies parallel to the screed surface adjacent the respective screed ends, transducer 110 accurately responds to screed twist. Stepping motor 136 is typically mounted in the transducer case and drives one element of the transducer relative to the case. Electrical connections between the various elements of the control system are typically made by flexible cables, but are mainly omitted from the drawings for clarity of illustration.

As illustratively shown in FIGS. 1, 11 and 11A, the screed drive motors 70 and 72 are preferably mounted directly on the respective screed control screws 50 and 52 which they drive. The mounting structure illustrated has the further advantage of embodying clutch action whereby the motors may be disconnected from the screws when not required. As shown best in FIG. 11, the two mounting plates 264 and 266 are rigidly connected to the motor assembly and project transversely from the motor axis. Bore in the respective plates receive the drive screw 52 in a manner permitting screw rotation and also permitting limited axial movement. A sleeve 268 is fixedly mounted on the screed drive screw and provides a smooth cylindrical surface which receives the bushing 269, set in the bore in upper plate 266.

The motor proper is indicated at 72, with a conventional gear reduction mechanism at 260 adjacent lower plate 264. The motor gear 262 is mounted on the output shaft below plate 264 and normally engages the screw gear 272. The sleeve 270 is fixedly mounted on the lower portion of screw 52 and carries a radial flange on which the gear 272 is mounted. The sleeve 276 is rotatably mounted in fixed axial position on sleeve 270. Lower plate 264 carries the bushing 278, which is axially slidable on sleeve 276. Upward movement of the entire motor lifts motor gear 262 free of screw gear 272. The motor may be latched in its upper released position in any convenient manner, as by inserting a pin through the holes provided in the lugs 280 and 282, which are fixedly mounted on plate 264 and on sleeve 276, respectively. Rotation of the entire motor assembly about the screw axis is prevented in any convenient manner that permits the described axial clutching movement. For example, a link 284 may be loosely pivoted on a horizontal axis at one end on lower plate 264 and at its other end on a bracket, indicated schematically at 285, which is fixedly mounted on the machine frame.

We claim:

1. A control system for a paving machine that is movable forwardly over a base and that comprises a trans-

verse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means actuable to differentially adjust the angles of attack of the respective end portions of the screed to vary the screed twist and thereby to cause a corresponding progressive variation in transverse slope of the mat surface as the machine moves forward;

said control system being adapted to maintain a desired value of the transverse mat slope and comprising in combination

signal means operatively connected to the screed for response to the screed twist and acting to produce a signal having a predetermined relationship to screed twist,

servo means operatively connected to and controlled by said signal means for driving the screed setting means under control of the signal to maintain an equilibrium value of screed twist in accordance with said relationship independently of irregularities in the base,

said servo means including trimming means operatively associated with said signal means and actuable selectively in opposite directions to modify the equilibrium value of screed twist that is maintained,

sensing means responsive to deviation of the transverse slope of the mat surface from the desired value, and monitoring means operably connected to said trimming means and sensing means for actuating the trimming means under control of the sensing means in a direction to reduce said slope deviation.

2. A control system as defined in claim 1, and wherein said monitoring means includes interval means acting to define only intermittent intervals during which the monitoring means are effective.

3. A control system as defined in claim 1, and wherein said monitoring means includes means for actuating the trimming means intermittently only when the deviation of the transverse slope from the desired value exceeds a predetermined threshold value.

4. A control system as defined in claim 1, and wherein said trimming means is actuable intermittently and comprises first means acting in response to each actuation of the trimming means to modify the equilibrium twist value only during a limited time period, and second means acting in response to each actuation of the trimming means to modify the equilibrium twist value during an unlimited time period.

5. A control system as defined in claim 1, and wherein said trimming means includes means for adjustably varying the magnitude of the modification in the equilibrium twist value that is produced at each actuation of the trimming means.

6. A control system as defined in claim 1, and wherein said trimming means is variably actuable to produce a continuously variable modification in the equilibrium twist value at each actuation, and said monitoring means includes means for regulating the actuation of the trimming means in accordance with the magnitude of the deviation of the mat slope from the desired value.

7. A control system for a paving machine that is movable forwardly along a base and that comprises a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means actuable to differentially adjust the angles of attack of the respective end portions of the screed to vary the screed twist and thereby to cause a corresponding progressive variation in transverse slope of the mat surface as the machine moves forward;

said control system being adapted to maintain a desired value of the transverse slope of the mat surface and comprising in combination

servo means for driving the screed setting means and having means responsive to the twist in the screed

to maintain the screed twist equal to a definite equilibrium value independently of irregularities of the base,

said servo means including trimming means actuable to modify selectively in opposite directions the equilibrium value at which the screed twist is maintained,

sensing means responsive to deviation of the transverse slope of the mat surface from the desired value,

and monitoring means operably connected to said trimming means and sensing means for actuating the trimming means under control of the sensing means in a direction to reduce said slope deviation.

8. A control system for a paving machine that is movable forwardly along a base and that comprises a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means actuable to differentially adjust the angles of attack of the respective end portions of the screed to vary the screed twist and thereby to cause a corresponding progressive variation in transverse slope of the mat surface as the machine moves forward;

said control system being adapted to maintain a desired value of the transverse slope of the mat surface and comprising in combination

means operatively connected to the screed for developing a signal that is a function of both the existing value of screed twist and the existing value of transverse mat slope,

means operatively connected to said first mentioned means for driving the screed setting means in response to the signal to maintain a predetermined equilibrium value of the signal,

trimming means operatively connected to said second-mentioned means and actuable to modify selectively in opposite directions the relationship between said signal and the screed twist,

sensing means responsive to deviation of the transverse slope of the mat surface from the desired value,

and monitoring means operatively connected to said trimming means and sensing means for actuating the trimming means under control of the sensing means in a direction to reduce said slope deviation.

9. A control system for a paving machine that is movable forwardly along a base and that comprises a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means actuable to differentially adjust the angles of attack of the respective end portions of the screed to vary the screed twist;

said control system comprising in combination means operatively associated with the screed for developing a control signal that represents the screed twist,

second means acting to define a reference value for said signal,

control means operatively connected to said second means and actuable intermittently to modify said reference value only during a limited time period, means operatively connected to said second means and acting in response to each actuation of the control means to modify said reference value during an unlimited time period,

and means operatively responsive and connected to the first said means for driving the setting means under control of the signal to maintain the value thereof equal to the reference value.

10. A control system as defined in claim 9 and including also sensing means responsive to variations in transverse slope of the mat surface, and means operatively connecting said sensing means and control means for actuating said control means under control of the sensing means.

11. In a control system for a paving machine that includes a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means for differentially adjusting the angles of attack of the respective end portions of the screed to vary the screed twist; the combination of means for developing a signal that represents the difference between the actual and desired values of the transverse slope of the mat surface, means operatively connected to the setting means and actuable intermittently at predetermined intervals to initiate drive of the setting means, and means operatively connected to said last-mentioned means and said signal means for acting to terminate such drive of the setting means when the resulting change in screed twist corresponds to the magnitude of said signal.

12. In a control system for a paving machine that includes a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means for differentially adjusting the angles of attack of the respective end portions of the screed to vary the screed twist; the combination of means for developing a signal that represents the difference between the actual and desired values of the transverse slope of the mat surface, means operatively connected to the setting means and actuable intermittently to initiate drive of the setting means, means operatively connected to said last-mentioned means and said signal means for acting to terminate such drive of the setting means when the resulting change in screed twist corresponds to the magnitude of said signal, and means driven in accordance with the forward movement of the paving machine and operatively connected to said intermittently actuable means for actuating said intermittently actuable means at regular periods of said movement.

13. In a control system for a paving machine that includes a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means for differentially adjusting the angles of attack of the respective end portions of the screed to vary the screed twist; the combination of means for developing a signal that represents the difference between the actual and desired values of the transverse slope of the mat surface, means operatively connected to the setting means and actuable to drive the setting means under control of the signal, and means operatively connected to the last said means and driven in accordance with the forward movement of the paving machine for actuating the last said means intermittently at regular periods of said movement.

14. A control system for a paving machine that is movable forwardly over a base and that comprises a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means actuable to differentially adjust the angles of attack of the respective end portions of the screed to vary the screed twist and thereby to cause a corresponding progressive variation in transverse slope of the mat surface as the machine moves forward;

said control system being adapted to maintain a desired value of the transverse slope of the mat surface and comprising in combination

means for developing a slope signal that represents the deviation from the desired value of transverse slope of the pavement surface,

means for developing a twist signal that represents the deviation from the desired value of screed twist,

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and control means operatively connected to the screed setting means and both said signal means for driving the screed setting means alternately under control of the slope signal and under control of the twist signal.

15. A control system for a paving machine that is movable forwardly along a base and that comprises a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means actuable to adjust the angles of attack of the respective end portions of the screed;

said control system being adapted to maintain a desired value of the transverse slope of the mat surface and to maintain a desired grade of the mat surface adjacent either end of the screed,

said control system comprising two independently actuable drive means connected to the respective screed setting means, each drive means including connector means for supplying a control signal to actuate the drive means, the two drive means responding oppositely to such signal,

signal means for producing a grade signal responsive to the existing grade error of an end portion of the screed,

said signal means being interchangeable between the two ends of the screed and producing signals oppositely related to the grade error at the respective screed ends,

circuit means connectible selectively from said signal means to either one of the connector means to supply the grade signal as control signal to the associated drive means,

second signal means operatively connected to the screed for producing a twist signal responsive to the existing error in screed twist,

and circuit means connectible selectively from the second signal means to the other one of said connector means to supply the twist signal as control signal to the associated drive means.

16. A control system for a paving machine that is movable forwardly over a base and that comprises a transverse screed, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, and setting means actuable to adjust the angle of attack of an end portion of the screed at one end thereof;

said control system being adapted to maintain a desired value of the grade of the mat surface adjacent said end of the screed and comprising in combination a grade follower arm disposed adjacent said one end and extending forwardly of said screed,

structure mounting one end of the arm on the screed for relative rotation with respect thereto about an axis transverse of the direction of travel,

means at the other end of the arm for contacting a grade reference surface at a point spaced forwardly of the screed,

means operatively connected to said grade follower arm for developing an electrical signal that represents the angular position of the arm with respect to the screed surface,

and control means operatively connected to the last said means and the setting means operatively connected to said setting means for driving the setting means under control of the signal.

17. In a control system for a paving machine that is movable forwardly over a base and that comprises a transverse screed having two screed portions on respective sides of the machine midplane, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, crown adjusting means actuable to vary the angle between the screed portions to control the crown of the mat sur-

face, and setting means for adjusting the angles of attack of the respective end portions of the screed;

the combination of an elongated member,

two mounting means supporting the member at respective longitudinally spaced points thereof on the respective screed portions at substantially equal distances from the machine midplane, each of said mounting means positively defining the distance of the member from the plane of the screed portion on which it is mounted and comprising pivot means for limited rotational movement of the member about an axis parallel to the direction of machine travel, and one of said mounting means carrying the member for limited translational movement longitudinally of the screed, and

sensing means mounted on the member and responsive to the longitudinal inclination thereof, said sensing means producing a signal that represents the average transverse slope of the mat surface independently of the setting of the crown adjusting means.

18. In a control system for a paving machine that is movable forwardly over a base and that comprises a transverse screed having two screed portions on respective sides of the machine midplane, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, crown adjusting means actuable to vary the angle between the screed portions to control the crown of the mat surface, and setting means for adjusting the angles of attack of the respective end portions of the screed;

the combination of an elongated member,

two mounting means supporting the member at respective longitudinally spaced points thereof on the respective screed portions at substantially equal distances from the machine midplane, each of said mounting means positively defining the distance of the member from the plane of the screed portion on which it is mounted and comprising pivot means for limited rotational movement of the member about an axis parallel to the direction of machine travel,

shaft means mounted on said two mounting means with the shaft axis parallel to the length of the screed, means defining the angular position of the shaft means with respect to one of said mounting means, means defining the angular position of the member about the shaft axis with respect to the other mounting means,

first sensing means mounted on the member and responsive to the longitudinal inclination thereof, and second sensing means operatively connected to said shaft means and member and being responsive to the difference in said angular positions of the shaft means and member.

19. In a control system for a paving machine that is movable forwardly over a base and that comprises a transverse screed having two screed portions on respective sides of the machine midplane, means for depositing paving material adjacent the leading edge of the screed to form a mat on which the screed rides, crown adjusting means actuable to vary the angle between the screed portions to control the crown of the mat surface, and setting means for adjusting the angles of attack of the respective end portions of the screed;

the combination of an elongated hollow member,

two bracket assemblies mounted on the respective screed portions,

means mounting the ends of the member on the respective bracket assemblies, each of said mounting means positively defining the distance of the member end from the plane of the screed portion on which the bracket assembly is mounted and comprising pivot means for limited rotational movement of the member with respect to the bracket assembly about an axis parallel to the direction of machine travel,

a shaft mounted on said two bracket assemblies parallel to and within the member,

means defining the angular position of the shaft with respect to one of said bracket assemblies,

means defining the angular position of the member about the shaft axis with respect to the other bracket assembly,

and sensing means mounted on the member and responsive to the difference in said angular positions of the shaft and member.

20. In a control system for a paving machine that is movable forwardly over a base and that comprises a transversely extending screed assembly including screed plate means and spaced forward and aft elongated structures, the screed plate means having leading and trailing edges mounted on the forward and aft structures, respectively, means for depositing paving material adjacent the leading edge of the screed means to form a mat on which the screed means rides, and means actuable to adjust the relative heights of the structures at the respective ends of the screed assembly to vary the angle of attack with which the screed means engages said material;

structure for mounting a transducer in defined angular relation to the angle of attack of the screed means at a predetermined longitudinal position of the screed assembly, comprising in combination

a bracket assembly mounted on the aft structure for limited pivotal movement with respect thereto about a pivot axis parallel to the length of the screed,

coupling means interconnecting the bracket means and the forward structure at said longitudinal position and acting to define the angular position of the bracket assembly with respect to said pivot axis, and means for rigidly mounting the transducer on the bracket assembly.

21. In a control system for a paving machine that is movable forwardly over a base and that comprises a transversely extending screed assembly having two mutually adjustable portions on respective sides of the machine midplane, each of said portions including forward and aft elongated structures and screed plate means having leading and trailing edges mounted on the forward and aft structures, respectively, means for depositing paving material adjacent the leading edge of the screed means to form a mat on which the screed means rides, crown adjusting means actuable to vary the angle between the screed assembly portions to control the crown of the mat surface, and means actuable to adjust the relative heights of the structures at the respective ends of the screed assembly to vary the angle of attack with which the screed means engages said material;

the combination of two bracket assemblies mounted on the aft structures of the respective screed assembly portions for limited pivotal movement with respect thereto about pivot axes parallel to the length of the screed,

coupling means interconnecting the bracket means and the respective forward structures and acting to define the angular positions of the bracket assemblies with respect to said pivot axes,

an elongated support member,

mounting means mounting the ends of the support member on the respective bracket assemblies for limited pivotal movement with respect to pivot axes parallel to the direction of machine travel, said mounting means defining the rotational position of the support member about a longitudinal axis thereof with respect to one bracket assembly and the support means permitting limited rotation of the support member about said longitudinal axis relative to the other bracket assembly,

first sensing means mounted on the support member and responsive to the longitudinal inclination thereof, and second sensing means responsive to rotation of the

support member about said longitudinal axis with respect to said other bracket assembly.

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