April 3, 1951 G. N. LEVESQUE 2,547,647

STRAIGHT EDGE

Filed Feb. 15, 1946 4 Sheets-Sheet 1

Fig. 1

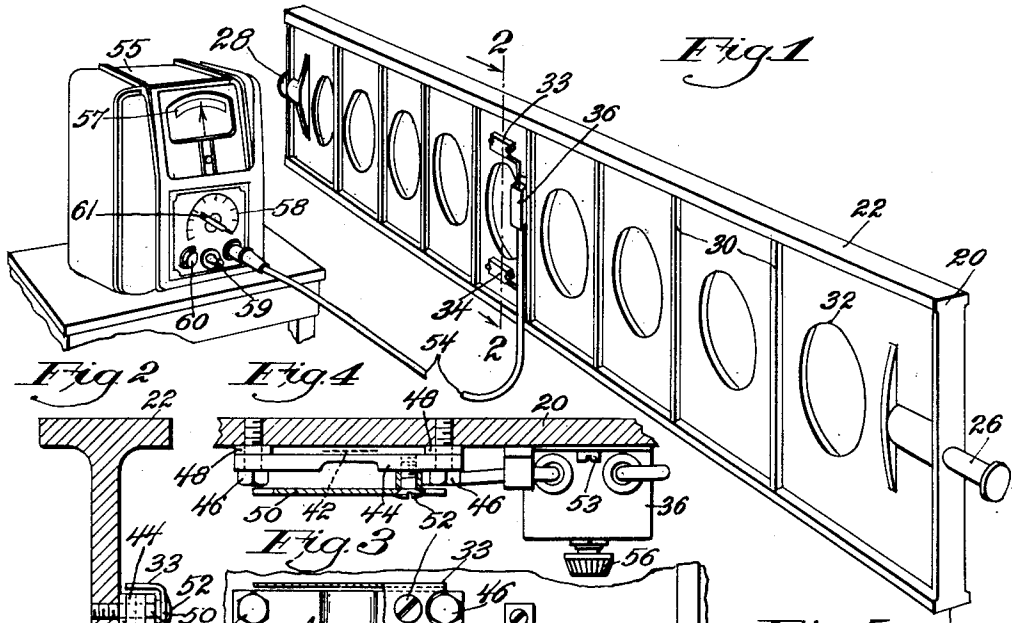


Fig. 2

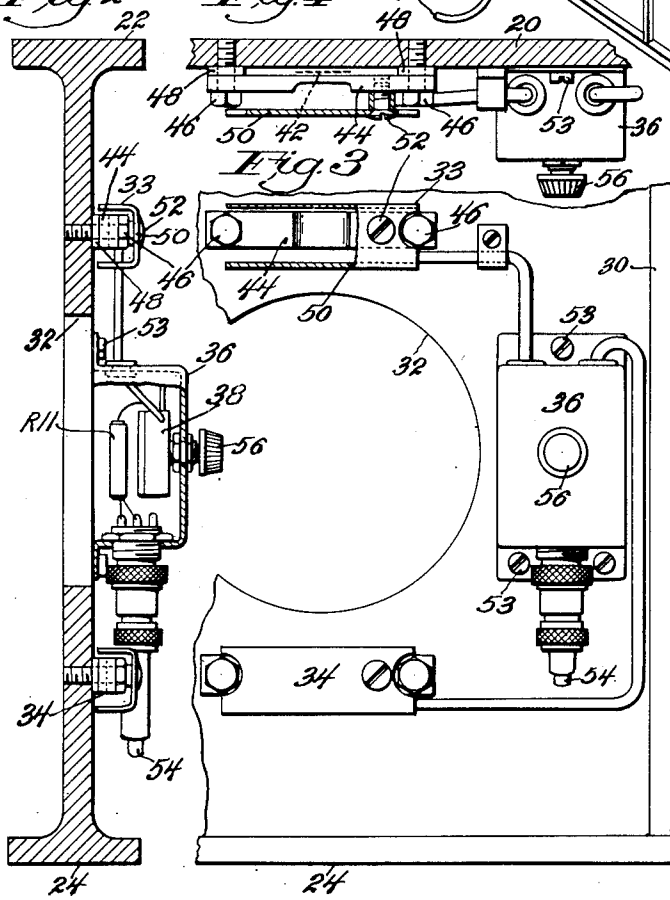


Fig. 4

Fig. 3

Fig. 5

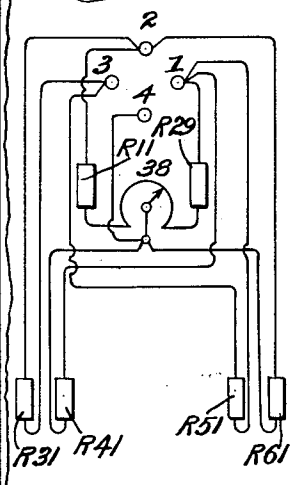
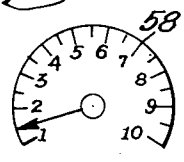


Fig. 6



Witness
Jas. J. Maloney.

Inventor
George N. Levesque
by his Attorney
Maxwell Fish

April 3, 1951 G. N. LEVESQUE 2,547,647

STRAIGHT EDGE

Filed Feb. 15, 1946 4 Sheets-Sheet 2

Fig. 7

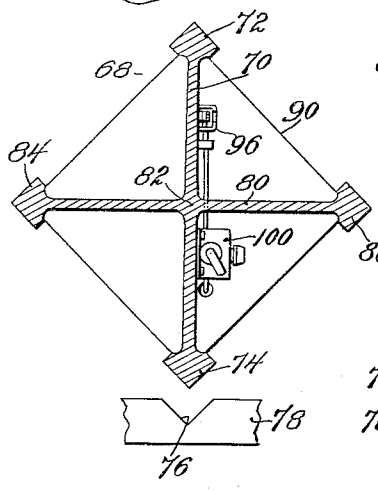


Fig. 8

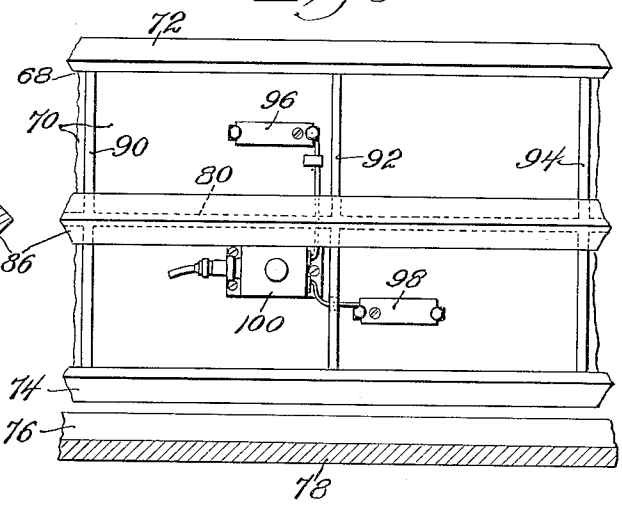
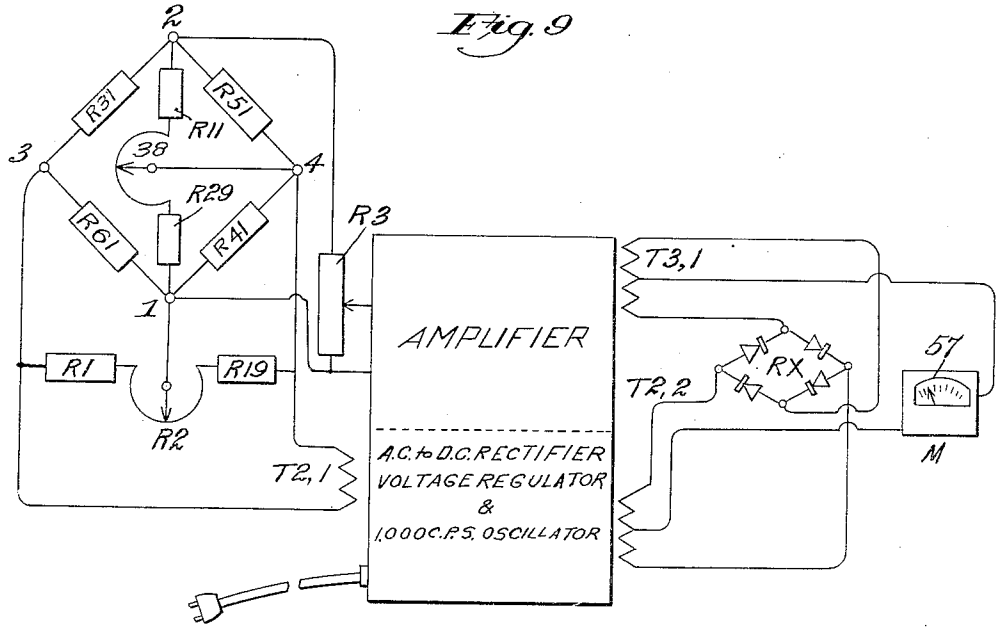


Fig. 9



Witness
Jas. J. Maloney.

Inventor
George N. Levesque
by his Attorney
Mayhall Fish

April 3, 1951 G. N. LEVESQUE 2,547,647

STRAIGHT EDGE

Filed Feb. 15, 1946 4 Sheets-Sheet 3

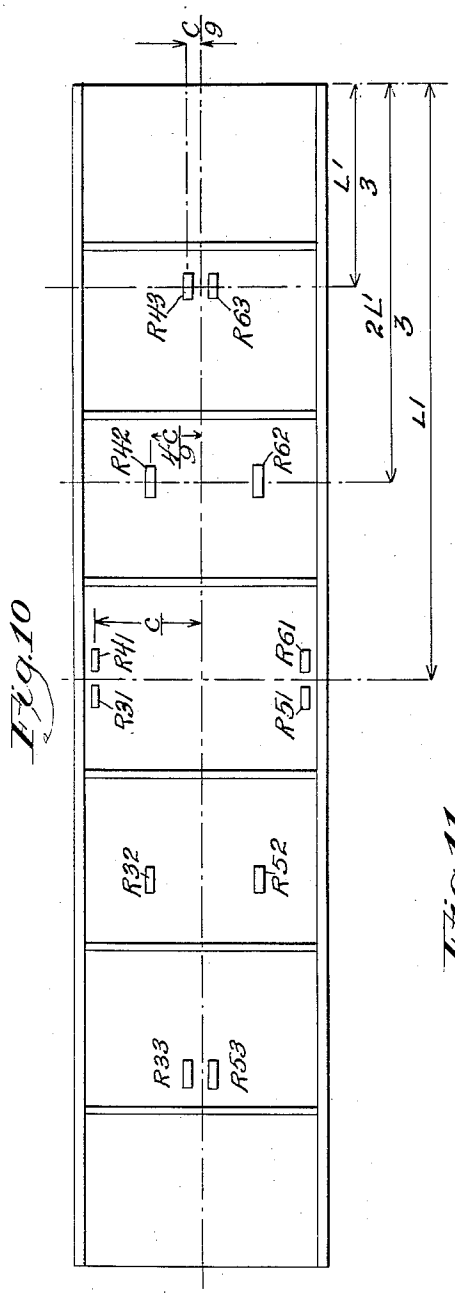


Fig. 10

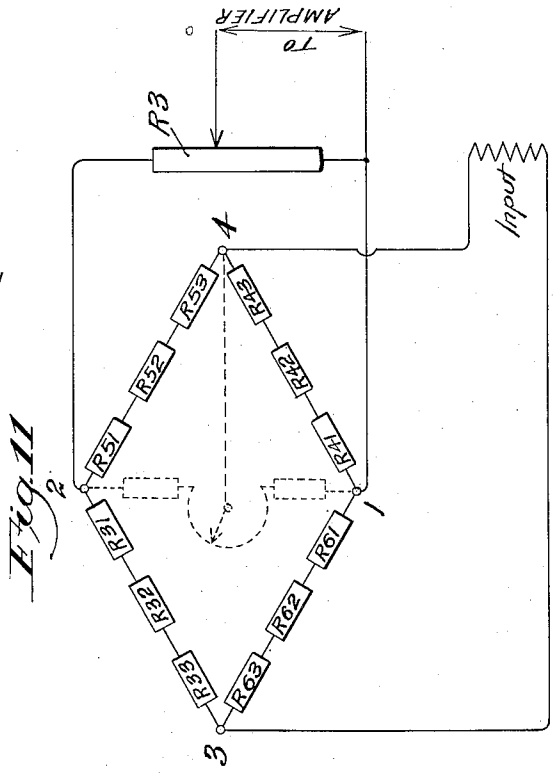


Fig. 11

Witness
Jas. J. Maloney.

Inventor
George N. Levesque
by his Attorney
Maxwell Fish

April 3, 1951 G. N. LEVESQUE 2,547,647

STRAIGHT EDGE

Filed Feb. 15, 1946 4 Sheets-Sheet 4

Fig. 12

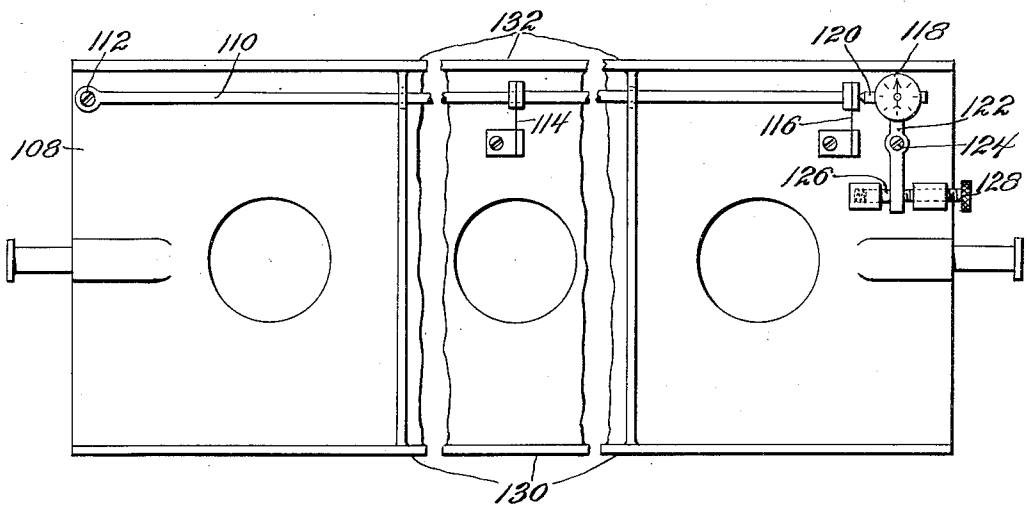
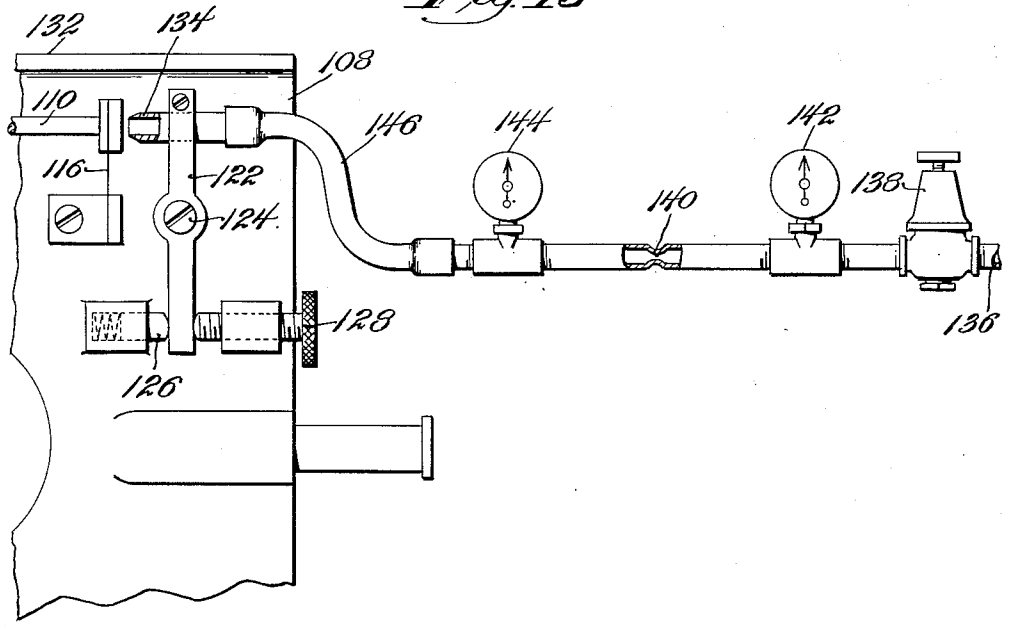


Fig. 13



Witness
Jas. J. Maloney.

Inventor
George N. Levesque
by his Attorney
Maxwell Fish

Patented Apr. 3, 1951

2,547,647

UNITED STATES PATENT OFFICE

2,547,647

STRAIGHTEDGE

George N. Levesque, Cranston, R. I., assignor to Brown and Sharpe Manufacturing Company, a corporation of Rhode Island

Application February 15, 1946, Serial No. 647,923

8 Claims. (Cl. 33—75)

1

The present invention relates to improvements in straight edges for indicating the error in flatness of nominally plane surfaces. The straight edges herein disclosed by way of example, as embodying in a preferred form the several features of the invention, are constructed and adapted for gauging respectively the flat and V-shaped ways in the bed of a grinding machine to receive the reciprocable work table of the machine. Grinding machine ways of this character may be ten feet or more in length for large size machines, and must be trued within an extremely small margin of error.

Straight edges of the general type referred to, are manufactured from a good grade of cast iron, and are shaped to provide a high degree of rigidity along the length of the straight edge. The straight edge shown in Fig. 1, for gauging the flat ways, is finished to provide opposite trued gauging surfaces on opposite sides of a neutral axis running lengthwise of the straight edge. The box-shaped straight edge shown in Figs. 7 and 8, for gauging the V-way is formed with two sets of trued V-shaped surfaces, the two edges of each set being formed on opposite sides of a neutral axis, and the two sets of edges being set at a 90° angle from one another. The box-shaped straight edge is further braced by means of transverse trusses or webs to provide rigidity of the straight edge for gauging the V-way in a transverse plane as well as in a vertical plane. In the illustrated embodiment of the invention, the opposite trued gauging surfaces on the opposite sides of the neutral axis of the straight edge are constructed and arranged to be in exactly parallel relationship. Such parallel relationship while greatly to be preferred, is not essential to the construction and operation of the straight edge in accordance with the invention.

Under the usual conditions of use, the master straight edge is placed on the way to be gauged which is coated with any suitable medium such as red lead, and the high spots thus indicated are removed by scraping. Experience has shown that the master straight edge employed in this manner is subject to certain errors which have in the past seriously limited the usefulness of the master straight edge, particularly for gauging the flatness of the way along its length.

It is a primary object of the present invention to provide a novel and improved master straight edge which is well adapted for indicating the error in flatness of nominally plane surfaces to an extremely narrow tolerance of error over their

2

entire length, and in which correction is made automatically for errors resulting from any out-of-line distortion of the straight edge along its length when in use.

It is a further object of the invention to provide a novel and improved straight edge having means for indicating out-of-line deflections of the gauging surfaces, which is capable of use in such a manner as to cancel out or eliminate errors which may be built into the straight edge, or which may arise as a result of variations in temperature conditions or from other causes, so that quick and accurate readings indicating the out-of-line error of the surface being gauged may be taken which are unaffected by change of operating personnel or lapse of time between readings, and are not subject to the delays previously found necessary to permit temperature conditions to become equalized in the work and in the straight edge.

With these and other objects in view as will hereinafter appear, a principal feature of the invention consists in the provision of a straight edge having associated therewith strain sensitive gauging means including strain sensitive gauges which are disposed upon the straight edge in such a way that the degree of strain registered is proportional to the out-of-line distortion of the straight edge. In the preferred form of the invention, the strain indicating device referred to, includes amplifying means and a visual inspection meter which is calibrated in such a manner as to provide an indication of the out-of-line error of the gauge surface in terms of linear dimension, preferably ten thousandths of an inch.

Another feature of the invention consists in the provision of electrical strain indicating devices in the form of one or more bonded electrical strain sensitive gauges which are rigidly secured or bonded to the straight edge away from and preferably at opposite sides of the neutral axis, and which are arranged in a Wheatstone bridge circuit having at least one such gauge as a variable element thereof to provide an extremely sensitive indication of variation in strain to which the straight edge is subjected. In the illustrated form of the invention, the Wheatstone bridge circuit is connected through a transformer and amplifying unit to a visual inspection meter having a pointer adapted for movement in opposite directions from an intermediate neutral or zero position. The arrangement of the Wheatstone bridge circuit and intervening connections is such that a strain imposed upon the strain

gauges as the result of a tendency of the straight edge to sag in one or the other direction, will cause the pointer to move correspondingly in one or the other direction from the neutral position. In order to obtain a balance of the Wheatstone bridge circuit which will bring the pointer roughly to a zero position, a potentiometer with appropriate resistances is connected across the Wheatstone bridge circuit. A further fine adjustment of the pointer to zero position is obtained by means of a second potentiometer which is connected with the Wheatstone bridge circuit and is arranged to be controlled by a knob mounted on the amplifier and visual inspection meter unit.

A further feature of the invention consists in the method of use of applicant's improved straight edge for the detection and correction of out-of-line error of a machine tool way along its length. The steps of the method consist in the placing of the straight edge with one side thereof resting upon the way to be gauged, adjusting the potentiometers referred to, to cause the pointer of the visual inspection meter to be brought to a zero position, re-positioning the straight edge with the opposite edge thereof in engagement with the way, and finally noting the direction an dextent of movement of the pointer from its neutral position. The movement of the pointer is controlled to provide a direct indication of the out-of-line error.

Further in accordance with the invention, in order to provide such direct indication of the existing error, the position of the strain gauges on the straight edge, the degree of amplification achieved by the amplifier unit, and the calibration of the meter dial are related to one another in a definite manner and preferably in accordance with a formula hereinafter to be more fully described.

Specifically in accordance with the invention, I have found that either one strain sensitive gauge placed away from the axis of the straight edge at its middle, or preferably a group of strain sensitive gauges placed substantially equi-distant from the two ends of the straight edge and upon opposite sides of the neutral axis, in the direction of increasing strain, will register degrees of strain which are in proportion to the out-of-line displacement of the straight edge along its length. While the arrangement of one or more strain sensitive gauges at the mid-section of the straight edge has been found to provide satisfactory results, I have found that an alternative arrangement of a relatively large number of strain sensitive gauges along the length of the straight edge is capable of providing a still more accurate measurement of the out-of-line errors of the straight edge.

Another feature of the invention consists in the application of strain indicating devices such as those previously described, to a box-type straight edge adapted for the gauging of V-ways, so that the straight edge may be readily employed for the gauging of the V-way in both the vertical and horizontal plane.

The several features of the invention consist also in the devices, combinations and arrangement of parts hereinafter described and claimed, which together with the advantages to be obtained thereby will be readily understood by one skilled in the art from the following description taken in connection with the accompanying drawings, in which Fig. 1 is a perspective view of a straight edge of the general type employed for the gauging of a flat way, and provided with strain indicating devices with the amplifier and visual inspection meter unit in accordance with the present invention; Fig. 2 is a section taken on the line 2—2 of Fig. 1, substantially through the middle of the straight edge, and illustrating particularly the position of the electrical bonded strain gauges and associated rough balancing potentiometer; Fig. 3 is a fragmentary view in front elevation illustrating substantially the parts shown in Fig. 2; Fig. 4 is a sectional plan view of the parts shown in Fig. 3; Fig. 5 is a diagrammatic view of that part of the electrical circuit comprised by the strain gauges and potentiometer secured to the straight edge; Fig. 6 is an enlarged detail view of the sensitivity adjustment dial on the amplifier and visual inspection meter unit illustrated in Fig. 1; Fig. 7 is a sectional view looking from the left of Fig. 8, taken through substantially the mid-section of a master straight edge adapted for gauging a V-way, and illustrating the position of the the electrical bonded strain gauges and potentiometer secured to the straight edge; Fig. 8 is a fragmentary view in front elevation of the mid-section of the straight edge shown in Fig. 7; Fig. 9 is a diagrammatic view of the electrical connections including the electrical bonded strain gauges, and the Wheatstone bridge circuit therefor, together with the amplifier and visual inspection meter units; Fig. 10 is a view in front elevation of a master straight edge similar to that shown in Fig. 1, for gauging a flat way, but showing a different arrangement of the strain gauges thereon; Fig. 11 is a diagrammatic view of the Wheatstone bridge circuit embodying therein the twelve strain gauges shown in Fig. 10 of the drawings; Fig. 12 is a view in side elevation of a straight edge illustrating a mechanical form of strain sensitive gauging means including a gauge bar and adjustable dial indicator attached thereto; and Fig. 13 is a fragmentary view of the straight edge and gauge bar shown in Fig. 12, with a pneumatic gauge in place of the dial indicator shown in Fig. 12.

Referring to the drawings, the master straight edge shown in Fig. 1, for the gauging of a flat way, comprises the straight edge 20 which may be of ordinary description having a trued straight edge surface 22 and a similarly trued straight edge surface 24, which surfaces are made dead parallel and equi-distant from a neutral axis which passes through the supporting handles 26, 28 provided at opposite ends of the straight edge. The straight edge 20 is in the form of an iron casting, and is assumed to be 120 inches in length, and approximately fifteen inches deep, although it will be understood that straight edges of this description are commonly made in different lengths and with proportionately different depths and weights. The straight edge is designed for a high degree of rigidity, being for this purpose constructed in the form of an I-beam with vertically extending ribs 30 at spaced intervals along its length. A series of circular holes 32 are formed in the body portion of the straight edge primarily for manufacturing reasons to simplify the problem of casting.

The master straight edge shown in Fig. 1, has mounted thereon two electrical bonded strain sensitive gauge units 33 and 34, each housing two strain gauges (see Figs. 1 to 4 inclusive), the wiring for a Wheatstone bridge circuit incorporating said strain gauges, and a potentiometer unit 36 comprising a potentiometer 38 and resistances R11, R29 connected across the Wheatstone bridge

circuit. The unit 33 consists of two electrical bonded strain gauges R31, R41, illustrated in the electrical diagrams in Figs. 5 and 9. Figs. 2, 3 and 4 illustrate the construction of the electrical bonded strain gauge unit 33 in some detail. In accordance with the usual practice, the two strain gauges R31, R41, in the form of fine wire resistances, are mounted in a paper bond indicated at 42 in dotted lines (Fig. 4), the paper bond 42 being cemented to the under side of a bar 44 rigidly secured by screws 46 and washers 48 to the straight edge adjacent the upper edge surface 22 thereof. With this arrangement, any strain set up in the straight edge is transmitted to the bar 44, and is then recorded in terms of variations in resistance of the strain gauges R31, R41, secured thereto. A cover plate 50 secured by a small screw 52 serves to protect the strain gauge unit from damage which might result from contact with moisture or any solid object. The unit 34 secured to the lower portion of the straight edge adjacent the straight edge surface 24 houses two electrical bonded strain sensitive gauges R51, R61. This unit 34 being identical in construction with unit 33 previously described, has not been illustrated in detail. The potentiometer unit 36 consists of a casing which is bolted to the straight edge by means of screws 53, the potentiometer 38 which is of ordinary design, the resistances R11 and R29 in Figs. 5 and 9, and the terminals of a four line cable 54 which connects the Wheatstone bridge and potentiometer circuits above described to the amplifier and visual inspection unit 55 (see Fig. 1). Manual adjustment of the potentiometer 38 is effected by means of a knob 56 as best shown in Figs. 2 and 3 of the drawings.

The amplifier and visual inspection unit 55 as shown in Fig. 1 and in the diagram Fig. 9, comprises a casing having mounted thereon an indicator dial 57 from which is read the amplified indication of out-of-line error of the straight edge and surface gauged thereby, a sensitivity adjustment dial 58, a sensitivity adjustment knob 61, an off-on switch 59 and a zero adjustment knob 60. As will be evident from an inspection of Fig. 1 and Fig. 9, all of the electrical connections and apparatus other than the bonded electrical strain sensitive gauge units, the potentiometer unit 36 and Wheatstone bridge connections are contained within the amplifier and visual inspection unit housing 55.

The two electrical bonded strain gauge units 33, 34 are mounted equi-distant from the neutral axis extending through the handles 26, 28 toward the respective straight edge surfaces 22, 24, and at a point midway between the two ends of the straight edge. The wiring of the Wheatstone bridge circuit including the strain gauges R31, R41, R51 and R61, potentiometer 38 and resistances R11, R29, is shown in Fig. 5. The arrangement of the several elements of the Wheatstone bridge circuit will be best understood in connection with the diagrammatic view of the electrical connections Fig. 9. The potentiometer 38 provides means under the control of the operator for effecting a rough adjustment of the pointer associated with the visual inspection unit hereinafter described, in its intermediate neutral position.

A preferred form of electrical amplifier circuit for use with applicant's comparator gauge is illustrated in somewhat diagrammatic form in Fig. 9 of the drawings. Since certain devices employed and electrical circuits embodying these devices are well known in the art and form specifically no part of the present invention, only such description is included herewith as is believed necessary to enable one skilled in the art to understand the connection of the present invention therewith. Referring more specifically to Fig. 9, applicant has shown the four electrical strain sensitive gauges indicated respectively at R31, R41, R51 and R61, arranged in the form of a Wheatstone bridge balanced circuit. The potentiometer 38 above noted, is arranged with its variable resistance and the associated resistances R11, R29 connected between terminals 1 and 2 of the bridge circuit, and the variable connector extending from the terminal 4 of the bridge circuit. Current is supplied to the strain gauge Wheatstone bridge circuit from an A. C. supply through a conventional rectifier circuit which serves to supply a filtered direct current voltage. Part of the D. C. current is regulated by a gaseous regulator tube which, being a piece of ordinary equipment is not shown, to supply a 1000 cycles-per-second triode oscillator and the last amplifier tube of the amplifier circuit which is again of ordinary description. The 1000 cycles-per-second oscillator supplies the Wheatstone bridge through secondary T2, 1 of the oscillator transformer, and also the rectifier RX through secondary T2, 2 of the same oscillator transformer. Forming part of the Wheatstone bridge circuit are two resisters R1 and R19 which, together with the potentiometer R2, afford a means for electrically adjusting the balance of the strain gauge bridge circuit. Any unbalance voltage appearing across two of the terminals designated at 1 and 2, respectively, is fed to the potentiometer R3 which, by means of the conventional knob 61 and graduated scale 58 on the front of the amplifier, is used to vary sensitivity of the device. Any desired fraction of the unbalance voltage is selected by the potentiometer R3, and is impressed on the grid of the first amplifier tube of the amplifier. The unbalance voltage is amplified and appears in the secondary T3, 1 of the output transformer associated with the last amplifier tube. The output current is rectified by the circuit consisting of the ring connected copper oxide rectifier RX, the transformer windings T3, 1 and T2, 2. A current flows through the meter M which is proportional to the strength of the output voltage, hence to the degree of the strain gauge bridge unbalance, and in a direction determined by the relative phase relations between the voltage in the transformer winding T2, 2 and the voltage in the transformer winding T3, 1 which is in turn determined by the direction of the strain gauge bridge unbalance.

I have made the discovery that highly sensitive strain indicating devices can be located on a straight edge in such a manner as to provide an indication of bending stresses set up in the straight edge which is accurately in proportion to the out-of-line displacement of the straight edge along its length. Experience has shown that a characteristic fault in ways of this character may consist of a slight curvature along the length of the way with high points at each end and with a low point about midway between the two ends. This fault may be of slight extent and less than the sag of the straight edge when supported at its two ends so that the straight edge conforms to the curvature of the way along its length. The characteristic fault referred to may be caused, for example, by the use of the ordinary master straight edge for rough gauging and scraping of the way.

In a preferred form of the invention, groups of strain gauges are placed at the mid-section of the straight edge at opposite sides of the neutral axis to provide an indication of strain which is substantially in proportion to the out-of-line displacement of the straight edge when placed on a way having this characteristic fault.

For convenience in calculating the amount of the out-of-line error of the straight edge from the reading of the visual inspection meter, the location of the strain gauge units at the mid-section from the neutral axis and other factors involved in the adjustment of the amplifier and visual inspection unit can be stated in terms of a general formula applicable to straight edges generally as follows:

$$\text{Error in work} = K\left(\frac{L^2}{C}\right) \times \text{meter reading}$$

where the error is in decimals of an inch, L is the length of the straight edge, C is the distance of the strain gauges from the neutral axis, and the meter reading is in terms of divisions on the meter scale. In this formula, K is a constant depending on three factors comprising the amplifier sensitivity, the strain gauge sensitivity, and the type of error. In the preferred form of the invention illustrated, this error is assumed to be a curve between one having constant curvature and the curve which is obtained when a uniformly loaded beam is supported at its ends. It has been found that the three factors above enumerated are practically uniform for different amplifiers, strain sensitive gauges and work, so that for a group of straight edges it is necessary only for the factor

$$\frac{L^2}{C}$$

to be constant in order to have the meter graduations of equal value. In the illustrated example, it is assumed that the straight edge is 120 inches long. The gauges have been arbitrarily located so that C is five inches

$$\frac{L^2}{C} \text{ thus equals } \frac{120^2}{5} = 2880$$

The apparent error may then be determined as follows:

$$\text{Error in work} = K2880 \times \text{meter reading}$$

It will be understood that the five inch dimension above mentioned is chosen in such a manner as to permit the use of this formula without change for the location of strain gauges on longer and shorter straight edges. Using the formula

$$C = \frac{L^2}{2880}$$

C can be figured for any length of straight edge.

The meter of the electrical system is calibrated in the following manner. First the deflection at the center of a particular straight edge when it is supported at its two ends is calculated. The meter is then set so that the needle associated with dial 57 swings through the correct number of divisions with each division of the scale equalling .0001 inch. For example, if the total deflection of the straight edge when supported at its ends is .0015 inch, the meter needle should swing through fifteen divisions total reading when the straight edge is turned from a position with edge 24 down to a position with edge 22 down (see Fig. 1). It will be noted that the meter is thus calibrated to read only one-half the total deflection obtained when the straight edge with the meter set at zero is turned from a position with one edge down to a position with the other edge down, and this is a true reading of the actual out-of-line error of the way. The adjustment above noted is made in the factory.

The operator is instructed to use the meter at a specified sensitivity dial setting which is normally ten, and is in accordance with a standard degree of magnification of the electrical system. In order to verify the degree of magnification, the operator first sets the sensitivity knob 61 controlling the potentiometer R3 of the meter at one, and then adjusts the set zero knob 60 which controls potentiometer R2 of Fig. 9 through its full range. This should swing the pointer through five divisions over the meter dial 57. If the swing is too large or too small, correction may be made through an auxiliary magnification adjustment located in the back of the visual inspection and amplifier unit. The auxiliary magnification adjustment referred to, is a magnification adjusting potentiometer similar to that designated at R3, being a usual element of the conventional amplifier generally indicated but not here shown in detail. It will be noted that when the strain gauges are located in accordance with the formula

$$C = \frac{L^2}{2880}$$

an electrical amplifier system having the same maximum magnification may be used with every straight edge irrespective of size. It is only necessary to adjust the sensitivity of the amplifier to a standard value by means of the set zero knob 60 and the meter dial 57 as previously described, and the amplifier is then correctly calibrated for straight edges of all sizes.

Figs 10 and 11 illustrate a modified arrangement of strain gauges comprising the Wheatstone bridge circuit on the straight edge which is capable of producing a theoretically more accurate determination of the out-of-line error of the straight edge. The arrangement of the strain gauges illustrated in Figs. 10 and 11, is of particular value when gauging surfaces where the slight curvatures may reverse or be otherwise abnormal. In this form of the device, a group of twelve strain gauges has been employed, noted respectively at R31 to R33 inclusive, R41 to R43 inclusive, R51 to R53 inclusive, and R61 to R63 inclusive. In this case the strain gauges are set at spaced intervals along the length of the straight edge in accordance with a formula $D=(L^d/L')^2 \times C$, where D is the distance of the gauge or gauges out from the neutral axis, C is the distance at which the center gauge or gauges are spaced from the neutral axis, L^d is the distance of a particular gauge from the nearer end of the straight edge, and L' is the distance from the end to the center of the straight edge. As noted in these figures, the strain gauges are arranged so that the bridge unbalance is proportional to the actual error in straightness. It will be noted that gauges R31, R41, R51 and R61 are disposed from the end of the straight edge by a distance L' and from the neutral axis by a distance C. The gauges R42, R62, and R32, R52, are disposed from the end of the straight edge by an amount

$$\frac{2L'}{3}$$

and a distance from the neutral axis of

$\frac{4C}{9}$

The resistances R43, R63 and R33, R53 are disposed from the end of the straight edge by a distance

$\frac{L'}{3}$

and are disposed from the neutral axis by a distance of

$\frac{C}{9}$

Figs. 7 and 8 of the drawings, illustrate another embodiment of the invention in a master straight edge adapted for gauging the straightness of a V-way in both the horizontal and vertical planes. The straight edge generally indicated at 68 in Figs. 7 and 8, is a box-like structure comprising a vertical flange 70 which extends along the length of the straight edge, and is formed along its upper and lower edges with two V-shaped rails 72, 74 having trued surfaces shaped to correspond exactly with the surfaces of the way 76 in the grinding machine bed 78 indicated in fragmentary form in these figures. The flange 70 and rails 72, 74 extend along the length of the straight edge which in the present instance may be assumed to be 120 inches in length. This straight edge 68 is also provided with a second flange 80 shown in Figs. 7 and 8 as extending in a horizontal plane, and intersecting the flange 70 along a neutral axis designated at 82. The horizontally disposed flange 80 is similarly formed with rails 84, 86 along its outer edge, the flange 80 and rails 84, 86 extending along the length of the straight edge. The rails 84, 86 are provided with trued surfaces which conform exactly to the surfaces of the V-way 76. The straight edge is further strengthened and stiffened by means of transverse webs such as those designated at 90, 92 and 94 in Figs. 7 and 8, which are cast integrally with the flanges 70, 80 and provide an extremely rigid construction of the straight edge. Inasmuch as the straight edge for gauging V-ways as thus far described, is in accordance with the usual construction of such straight edges, fragmentary views only of this straight edge have been included herewith, both ends thereof being broken away. The transverse web 92 marks the exact middle of the straight edge lengthwise thereof.

In accordance with the invention, two sets of strain sensitive gauges are mounted on the vertical flange 70 of the straight edge at the midsection of the straight edge. These comprise a strain gauge unit 96 containing two bonded electrical strain sensitive gauge resistances which may be assumed to be resistances R31, R41 of electrical diagram Fig. 9, as previously described in connection with the embodiment shown in Figs. 1 to 5 inclusive, and strain gauge unit 98 in which are housed the bonded electrical strain sensitive gauge resistances R51, R61 as shown in Fig. 9. It will be noted that the strain gauge units 96, 98 are mounted on the flange 70 at equal distances from the neutral axis 82 of the straight edge, and are further symmetrically disposed with respect to the middle web 92 of the straight edge longitudinally thereof. Also mounted on the flange 70 is the rough adjustment potentiometer unit 100 which is identical with that designated at 36 in Fig. 1, and illustrated in greater detail in Figs. 2 and 3. The unit 100 contains the potentiometer 38 together with the resistances R11, R29 connecting the cross terminals 2, 1 with the Wheatstone bridge, and with the adjustable element of the potentiometer connected to the terminal 4 of the Wheatstone bridge.

While in the preferred embodiments of the invention above described and illustrated, a plurality of groups of strain sensitive gauges have been employed mounted at opposite sides and equi-distant from the neutral axis, it will be understood that the invention is not limited to the specific arrangements of these strain gauges shown. It is, for example, possible to employ a single strain sensitive gauge which is placed away from the neutral axis at any desired point along the length of the straight edge, this strain gauge being incorporated into a Wheatstone bridge circuit having as the other three legs thereof, fixed or dummy resistances. It is essential only that the strain sensitive gauge or gauges employed be disposed away from the neutral axis, and that its position lengthwise of the straight edge be determined with reference to the characteristic form of the error to be expected in the surface to be gauged and the resultant distribution of strain along the length of the straight edge when placed upon said surface.

The method of using the straight edge 68 for gauging V-ways is the same as that employed for the gauging of flat ways with the straight edge 20 previously described, except that an additional gauging operation is required for the gauging of the V-way in the horizontal plane. The straight edge position shown in Fig. 7 is in position to be lowered onto the V-way in order to gauge the way in the vertical plane. In accordance with the procedure previously outlined, the potentiometers are adjusted to a zero reading of the visual inspection meter, and the straight edges rotated 180° to bring the rail 72 into engagement with the V-way 76. The reading thus obtained upon the visual inspection meter dial 57 provides a direct measure of the out-of-line distortion of the straight edge in the vertical plane. In order to gauge the V-way in the horizontal or transverse plane, the straight edge is rotated on its neutral axis through 90° from the position shown in Fig. 7, so that the rail 86 is disposed in the V-way 76. Again, the position of the pointer in the visual inspection meter is positioned through adjustment of the potentiometers above described, to bring the pointer to the neutral position. The straight edge is then rotated through 180° to bring the rail 84 into engagement with the V-way 76, and the reading upon the visual inspection meter dial 57 thus obtained provides a direct measure of the out-of-line distortion of the straight edge and of the V-way engaged thereby in the horizontal plane.

While in the preferred form of the invention, bonded electrical strain sensitive gauges are employed in combination with electrical amplifier and visual inspection means calibrated to provide a direct indication of out-of-line distortion of the straight edge, it will be understood that the invention in its broader aspects is not limited to the particular form of strain sensitive gauge employed, and that the use of other types of strain sensitive gauges is contemplated within the spirit and scope of the invention. Other such forms of strain sensitive gauging means which might be employed would include the armature and coil or

condenser types, pneumatic means and mechanical means.

One such alternative form of the invention employing a mechanical strain sensitive gauging device for determining the out-of-line distortion of the straight edge is illustrated in somewhat diagrammatic form in Fig. 12 of the drawings, which discloses a straight edge 108 similar to that shown in Figs. 1, 2 and 10. In this form of the straight edge, the strain sensitive gauging device employed comprises a gauging bar 110 which extends along the length of the straight edge at one side of the neutral axis and adjacent one of the straight edge gauging surfaces. The gauging bar 110 is rigidly secured at one end to the straight edge by means of a pin 112, and is supported along its length by means of reeds 114 and 116 so that any distortion or bowing of the straight edge along its length will be reflected by movement of the right hand end of the gauging bar 110 with relation to the adjacent portion of the straight edge. For indicating the extent of such movement, a dial indicator 118 is provided, having a plunger 120 which is arranged for engagement against the abutting end of the gauge bar 110. The dial indicator 118 is carried on a lever 122 which is mounted on a pivot 124 on the straight edge and is adjustably supported at its lower end between a spring-pressed plunger 126 and a zero adjustment adjusting screw 128. The straight edge shown in Fig. 12 is used by placing the straight edge with one of the edges as, for example, the edge 130 in engagement with the surface to be gauged, whereupon the adjusting screw 128 is manipulated to bring the pointer of the dial indicator 118 to zero. The straight edge 108 is then turned over and is placed with the other gauging surface 132 in contact with the surface to be gauged. Assuming that the dial indicator 118 has been properly calibrated, a direct reading is now obtained of the out-of-line error of the surface to be gauged along its length.

Fig. 13 of the drawings, illustrates still another form of strain sensitive gauging means which may be provided in accordance with the present invention. In this form of the device, the gauge bar 110 shown in Fig. 12, is retained, and a pneumatic gauge is employed in place of the dial indicator illustrated in Fig. 12, in order to provide a more highly sensitive indication of the degree of strain and consequent out-of-line distortion of the straight edge along its length. In this form of the device, a gauging nozzle 134 is mounted on the pivoted arm 122. A fluid which may be air is supplied under pressure through a supply line 136 through a pressure regulator 138. Thence the fluid passes through a fixed orifice 140 having at either side thereof pressure gauges 142 and 144, through a flexible tube 146 to the fixed gauging nozzle 134. In this form of the device, the pressure gauge 142 at the right of the fixed orifice 140 is maintained at a constant reading. Variations of pressure at the nozzle will cause variations of back pressure which will be indicated on the pressure gauge 144 at the left of the fixed orifice. As with the form of the device shown in Fig. 12, the straight edge is located with one engaging surface in engagement with the surface to be gauged, the indicating means comprising the pressure gauge 144 is adjusted to the zero position by means of the adjusting screw 128, the straight edge is then turned over to bring the other gauging surface against the surface to be gauged, and the reading of the pressure gauge 144 is again taken. This gauge is calibrated to provide a direct reading of the out-of-line error of the surface to be measured.

The invention having been described, what is claimed is:

1. A straight edge having straight edge gauging surfaces arranged in opposite relation at opposite sides of a neutral axis, and strain sensitive means for gauging strains set up in the straight edge by out-of-line distortion of said gauging surfaces, which comprises at least one bonded electrical strain sensitive gauge mounted on the straight edge away from said neutral axis and substantially midway of the length of the straight edge to provide a response to such strain substantially in proportion to the extent of out-of-line distortion of said gauging surface, a Wheatstone bridge circuit embodying said gauges, a manually adjustable potentiometer connected across said circuit for balancing the circuit, electrical amplifying means, visual inspection means including a zero indicator dial, and indicating means actuated by said electrical amplifying means indicating any unbalance of said circuit and the direction thereof on the dial, said strain sensitive gauges, said electrical amplifying means and visual inspection means being arranged and proportioned for the out-of-line distortion of the straight edge in accordance with the formula

$$\text{Out-of-line error} = K \times \frac{L^2}{C} \times \text{meter reading}$$

where L is the length of the straight edge, C is the distance from the neutral axis to the strain gauges, and K is a constant.

2. A straight edge having straight edge gauging surfaces arranged in opposite relation at opposite sides of a neutral axis, and strain sensitive gauging means for gauging strains set up in the straight edge by out-of-line distortion of said gauging surfaces, which comprises bonded electrical strain sensitive gauges grouped in units on the straight edge at opposite sides of said neutral axis and along the length thereof, a Wheatstone bridge circuit embodying said gauges, and electrical amplifying and visual inspection means connected to indicate the extent and direction of unbalance of said Wheatstone bridge circuit, wherein said units are located in accordance with a formula wherein the distance D of any designated unit from the neutral axis $=(L^d/L^1)^2 \times C$, where L^d is the distance of a particular gauge from the nearer end of the straight edge, one pair of units being located at a point substantially midway of the length of the straight edge at a distance L' from the end thereof and a distance C from the neutral axis, a second pair of units at a distance

$$\frac{2L'}{3}$$

from the end and a distance

$$\frac{4C}{9}$$

from the neutral axis and a third pair of units a distance

$$\frac{L'}{3}$$

from the end and a distance

$$\frac{C}{9}$$

from the neutral axis.

3. A straight edge having straight edge gauging

surfaces arranged in opposite relation at opposite sides of a neutral axis, and strain sensitive gauging means for gauging strains set up in the straight edge by out-of-line distortion of said gauging surfaces, which comprises bonded electrical strain sensitive gauges grouped in units on the straight edge at opposite sides of said neutral axis and along the length thereof, a Wheatstone bridge circuit embodying said gauges, and electrical amplifying and visual inspection means connected to indicate the extent and direction of unbalance of said Wheatstone bridge circuit, wherein said units are located in accordance with a formula $D=(L^d/L^1)^2\times C$, where D is the distance of the gauge or gauges out from the neutral axis, C is the distance at which the center gauge or gauges are spaced from the neutral axis, L^d is the distance of a particular gauge from the nearer end of the straight edge, and L' is the distance from the end to the center of the straight edge.

4. A straight edge having flanges intersecting at right angles to one another and two pairs of V-shaped gauging surfaces, the gauging surfaces of each pair being adapted for use successively when testing a single surface, the two surfaces of each pair being disposed at the outer edges of said flanges in opposite relation at opposite sides of a neutral axis and with the two pairs with their supporting flanges disposed in planes intersecting one another at right angles along the line of said axis for gauging a V-way in vertical and horizontal planes respectively, and strain sensitive gauging means for gauging strains set up in the straight edge by out-of-line distortion of the gauging surfaces thereof when the two surfaces of a pair are successively engaged with the surface to be tested, said strain sensitive gauging means comprising a strain sensitive gauge disposed on the straight edge away from said neutral axis on the supporting flange for one of said pairs of V-shaped gauging surfaces to provide an indication of such strain of each pair of the V-shaped gauging surfaces in said latter plane in proportion to the extent of out-of-line distortion of said gauging surfaces in said plane.

5. A straight edge having flanges intersecting at right angles to one another and two pairs of V-shaped gauging surfaces, the gauging surfaces of each pair being adapted for use successively when testing a single surface, the two surfaces of each pair being disposed at the outer edges of said flanges in opposite relation at opposite sides of a neutral axis and with the two pairs with their supporting flanges disposed in planes intersecting one another at right angles along the line of said axis for gauging a V-way in vertical and horizontal planes respectively, and strain sensitive gauging means for gauging strains set up in the straight edge by out-of-line distortion of the gauging surfaces thereof when the two surfaces of a pair are successively engaged with the surface to be tested, said strain sensitive gauging means comprising at least one bonded electrical strain sensitive gauge disposed on the straight edge away from said neutral axis on the supporting flange for one of said pairs of V-shaped gauging surfaces to provide a response to such strains of each pair of the V-shaped gauging surfaces in the plane of said supporting flange substantially in proportion to the extent of out-of-line distortion of said gauging surfaces, a Wheatstone bridge circuit embodying said gauge, and electrical amplifying and visual inspection means connected with said Wheatstone bridge circuit.

6. A straight edge having flanges intersecting at right angles to one another and two pairs of V-shaped gauging surfaces, the gauging surfaces of each pair being adapted for use successively when testing a single surface, the two surfaces of each pair being disposed at the outer edges of said flanges in opposite relation at opposite sides of a neutral axis and with the two pairs with their supporting flanges disposed in planes intersecting one another at right angles along the line of said axis for gauging a V-way in vertical and horizontal planes respectively, and strain sensitive gauging means for gauging strains set up in the straight edge by out-of-line distortion of the gauging surfaces thereof when the two surfaces of a pair are successively engaged with the surface to be tested, said strain sensitive gauging means comprising bonded electrical strain sensitive gauges disposed on the straight edge at opposite sides of said neutral axis on the supporting flange for one of said pairs of V-shaped gauging surfaces to provide a response to such strains of each pair of the V-shaped gauging surfaces in the plane by said supporting flange substantially in proportion to the extent of out-of-line distortion of said gauging surfaces, a Wheatstone bridge circuit embodying said gauges, a manually adjustable potentiometer connected across said circuit for balancing said circuit, electrical means to amplify any indication of unbalance of said circuit, and visual inspection means to indicate the extent and direction of said amplified indication of unbalance.

7. The method of gauging the error in straightness of a surface by employing a straight edge having opposite straight edge gauging surfaces and equipped with strain sensitive means for gauging strains set up in the straight edge by out-of-line distortion of the straight edge and visual inspection means to indicate the degree of said distortion, which method comprises the steps of locating the straight edge with one edge in contact with a surface to be gauged, adjusting said visual inspection means to zero, locating the straight edge with the other edge against the surface to be gauged and thus obtaining a reading of the visual inspection means which is proportional to the error in the surface being gauged.

8. The method of gauging a straight surface with a straight edge having opposite straight edge gauging surfaces disposed at opposite sides of a neutral axis and strain sensitive gauging means for gauging strains set up in the straight edge by out-of-line distortion of said gauging surfaces, comprising bonded electrical strain sensitive gauges mounted as strain gauge units on the straight edge at opposite sides of said neutral axis at equal distances therefrom to provide an indication of strain including the direction of said strain substantially in proportion to the extent of out-of-line distortion of said gauging surface, a Wheatstone bridge circuit embodying said gauges, an electrical amplifier and visual inspection unit to amplify any indication of unbalance of said Wheatstone bridge circuit including the direction thereof including a visual inspection meter, and means for adjusting the balance of said Wheatstone bridge circuit, which method comprises the steps of locating the straight edge with one edge against the surface to be gauged, adjusting said Wheatstone bridge circuit to a zero reading of said visual inspection meter, locating the straight edge with the other edge against the surface to be gauged, and reading the meter to provide a measurement of out-of-line error of the surface to be gauged based

upon one-half the total out-of-line distortion of the straight edge.

GEORGE N. LEVESQUE.

REFERENCES CITED

The following references are of record in the file of this patent:

UNITED STATES PATENTS

Number	Name	Date
1,054,109	Gasparich	Feb. 25, 1913
1,383,979	Bryant	July 5, 1921
1,431,638	Dowling	Oct. 10, 1922
1,563,011	Brookes	Nov. 24, 1925
1,985,576	Menneson	Dec. 25, 1934
2,036,458	Carlson	Apr. 7, 1936
2,152,556	Messinger	Mar. 28, 1939
2,252,464	Kearns	Aug. 12, 1941
2,292,326	Lewis	Aug. 4, 1942
2,316,975	Ruge	Apr. 20, 1943
2,370,845	Davis	Mar. 6, 1945
2,381,283	Hathaway	Aug. 7, 1945
2,403,951	Ruge	July 16, 1946
2,423,620	Ruge	July 8 ,1947
2,423,867	Zener et al.	July 15, 1947
2,452,860	Mostertz	Nov. 2, 1948

FOREIGN PATENTS

Number	Country	Date
551,361	Great Britain	Feb. 18, 1943

OTHER REFERENCES

Publ.: Electronics, pages 106–111, Dec. 1943.

Publ.: Product Engineering, pages 443–449, July 1945.