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## STABILIZED-PLATFORM WEIGHING SCALE OF NOVEL DESIGN

BY

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# STABILIZED-PLATFORM WEIGHING SCALE OF NOVEL DESIGN [1]

By Frederick J. Schlink

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## I. INTRODUCTION

This paper treats of the theory and design of a new type of check-stabilized weighing scale, in which the usual pin-and-link stabilizing element is replaced by a flexible elastic tape or wire, a design which eliminates practically all the friction inherent in earlier stabilizing mechanisms, with the result that the total frictional resistance of the scale is sensibly independent of the position of the load on the platform.

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[1] The author has been granted letters patent No. 1 218 092, under date of Mar. 13, 1917, on the type of weighing scale which forms the subject of this paper. A copy of that patent is given as an Appendix. It is to be noted that the invention therein described and claimed has been dedicated for the free use of the Government of the United States, or any person in the United States, without payment of royalties, as is usual in the case of patents granted on inventions within the field of work of staff members of scientific bureaus under the Government. This paper was submitted as a thesis in partial fulfillment of the requirements for the degree of Mechanical Engineer, at the University of Illinois, June, 1917.

By this expedient, which insures through suitable disposition of the platform, that the stress in the stabilizing element continues constantly in the sense of tension—the function of a stabilizing link being then satisfactorily and sufficiently fulfilled by a flexible connector—the utility and application of the check-stabilized scale are greatly broadened and the accuracy of the device is much increased.

The earlier types of stabilizing elements are illustrated and the limitations of each set forth. The equilibrium conditions of the platform and stabilizing element are derived, and the methods to be used in adjusting the scale are outlined. The paper includes a discussion of the effects of static friction on the indications of scales and shows how the elimination of this friction enhances the accuracy of weighings.

## II. FUNDAMENTALS OF DESIGN OF STABILIZED SCALES

### 1. TYPE OF WEIGHING SCALES

For the purposes of this paper, weighing scales may be grouped into two broad classes—those having suspended platforms or weighbridges and those having stabilized platforms. In the first of these two classes is found the suspended-pan balance, familiar in the equal-arm balance used in analytical and scientific work; in the second class appear most of the weighing scales used in industry and commerce, where a suspended platform or weighbridge would be inconvenient and cumbersome. This inconvenience arises principally from two sources. In the first place, the suspended platform involves the use of chains or rods by which to hang the weighbridge from the weighing system; these rods limit the shape and dimensions of the load to be applied, and tend generally to interfere with the convenient and easy handling of the load. In the second place, the suspended platform acts as a pendulum, tending to swing about its point of suspension, due to the restoring moment which is introduced when its center of gravity is displaced from the vertical line containing the center of suspension.

The effect of this harmonic motion of the platform is to interfere with the reading of the indications of the scale, since these oscillations of the platform and its superposed load are communicated to the lever system and added to the natural oscillation of the weighbeam or pointer, causing an irregular distortion of the normal sine-wave vibration of the weighbeam. The effect of this distortion is to obscure the estimation of the rest point or plane of balance of the scale.

On this account, in the use of a suspended-pan balance, it is essential to damp out by hand the swinging of the pans, so that the vibration of the pointer can be accurately observed, and read without the error which would result from the inclusion of the attendant vibrations of the platform. The necessity of thus damping the motion of the pans would cause much inconvenience, so that this type of scale is very little used industrially, in spite of its simplicity, accuracy, and reliability, and has been largely replaced by the various forms of stabilized-platform scales in practically all applications except those requiring the highest precision. This latter type of scale is very common; examples in great number are found in the so-called platform scales, in letter balances, wagon and track scales, etc., so widely employed, in all of which the weighing platform commonly lies above the plane of the lever system.

### 2. STABILIZING MECHANISMS

Two principal arrangements for stabilizing the platform have been commonly employed. The term "stabilizing" is used to denote the constraining of the platform to motion in a properly defined path, independently of the position of the load upon such platform. The first type of stabilizing mechanism is shown in Fig. 1, which illustrates the weighing mechanism of the four-point-support type, this mechanism being a very common one for scales of moderate and large capacity.

It will be seen that the platform is supported on two pairs of pivots or knife-edges, each of the triangles below the platform feet representing one pair of collinear knife-edges. As the platform bearings are held in contact with these pivots by the weight of the platform and the load it carries, the two pairs of bearings must assume the motion of the corresponding pairs of pivots. In this manner the motion of the platform is determined at all phases of its vibration, and the platform is therefore stabilized.

Now, it will be noted that this type of scale requires four pivots (or two pairs of collinear pivots) to support the platform, and in order that the motion of the platform proceed always into planes parallel to any assumed initial position (which is the necessary criterion for accuracy of weighing independent of the position of the load on the platform), the lever arms of which these knife-edges form the pivots must be accurately adjusted to equality with each other.

Such adjustment being somewhat difficult and too expensive to permit the making of this type of scale at the low cost needful for scales of small and moderate capacity in some applications, another type of stabilizing element has long been used, in which the platform is carried on but one knife-edge, or one pair of collinear knife-edges, the parallel motion of the platform being provided for by a linkwork so adjusted that every part of the plat-

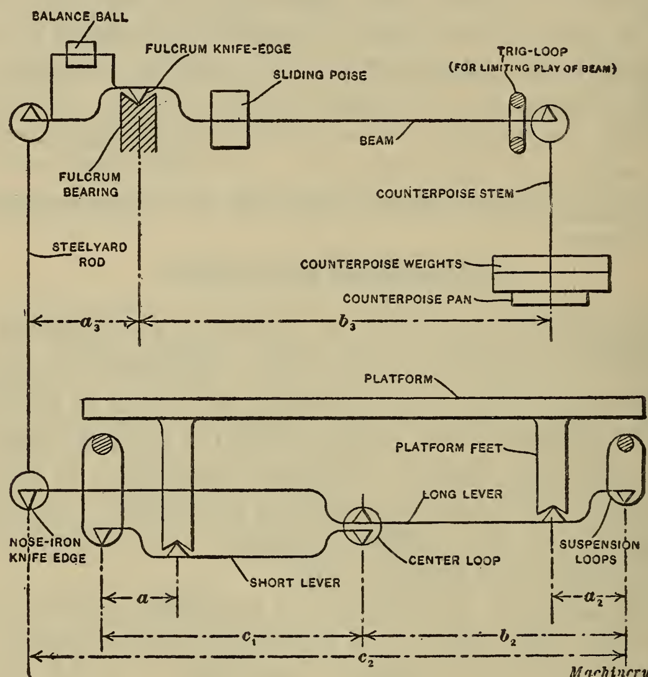


FIG. 1.—*Common form of platform scale, the platform of which is stabilized by being supported at four points in a plane*

Reproduced from the author's paper, "Weighing scales," in Machinery, January, 1916.

form describes, when oscillated through a small excursion, identically the same vertical displacement. This is equivalent to a statement that the linkwork is so designed as to resist only horizontal forces arising from noncentral placement of the load, or unsymmetrical weight distribution in the platform itself, all vertical components of forces due to the weight of the load being transferred, unchanged in amount, to the weighing mechanism of the scale.

### 3. FORCE RELATIONS IN THE CHECK-STABILIZED SCALE

Fig. 2 illustrates the construction of a scale having the properties set forth above. From this it may be seen that the total vertical component of the load on the platform and the weight of the platform itself is supported on the load knife-edge, the lower bar *2* of the linkwork assuming only the horizontal component which appears when the center of gravity of the platform load and of the platform itself, combined, lies outside the vertical plane containing the axis of the load knife-edge.

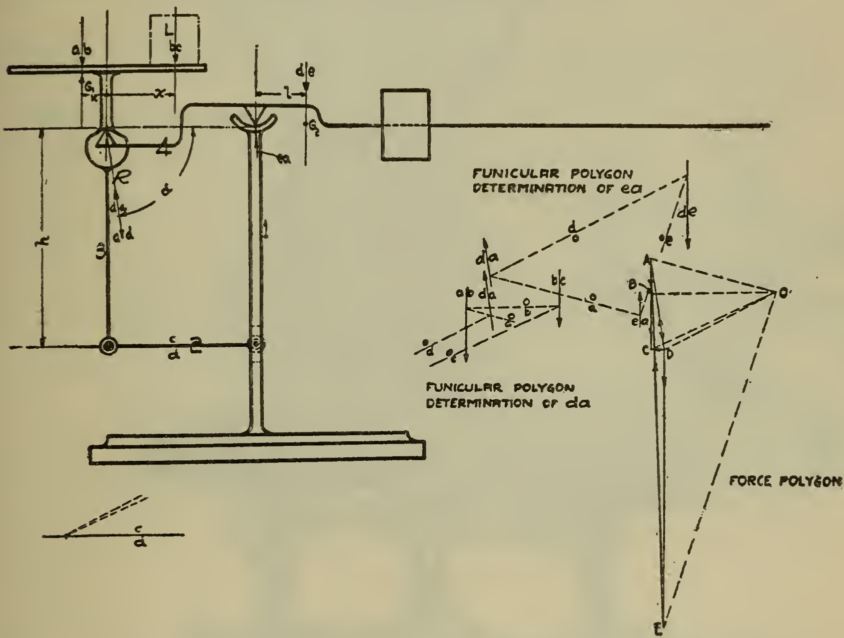


FIG. 2.—*Ordinary check-stabilized postal scale, having the pin-and-link type of check rod*

The force diagram at the right gives the solution for the stress in the check rod, and for the reactions at the load and fulcrum knife-edges.

It is to be noted here that, as actually constructed, scales of this type are usually characterized by compactness, portability, ruggedness, and durability, while their manufacture is not expensive and their adjustment is easily performed and not easily deranged.

However, a study of the mechanics of the scale, and experience in its use, leads diréctly to a knowledge of certain serious defects, and it was in the experimental investigation and analysis of these defects that the present invention, which forms the subject of this paper, was evolved. The nature and causes of the difficulties, to which allusion is made above, are shown analytically in the following derivation:

The dotted lines in Fig. 2 show a load the weight of which is equal to $L$, its center of gravity being located at a distance $x$ from the vertical through the load knife-edge (*3, 4*). Given the nomenclature of Fig. 2, and calling $T$ the stress in the link *2*, we obtain, by summation of moments, about (*3, 4*)—

$$\Sigma M = Lx - G_1 k - Th = 0$$

$$T = \frac{Lx - G_1 k.}{h} \qquad (1)$$

Let $R_x$ and $R_y$ be the components of the reaction $R$ at (*3, 4*) in the $X$ and $Y$ directions, respectively.

By summation of forces in the $X$ and $Y$ directions, we obtain—

$$\Sigma F_y = -L - G_1 + R_y = 0, \text{ or } R_y = L + G_1 \qquad (2)$$

$$\Sigma F_x = -R_x + T \qquad \text{or } R_x = T \qquad (3)$$

$$\tan \alpha = \frac{R_y}{R_x} = \frac{L + G_1.}{T} \qquad (4)$$

Substituting the value of $T$ from (*1*) in (*4*), we obtain—

$$\tan \alpha = \frac{(L + G_1)h}{L_x - G_1 k} \qquad (5)$$

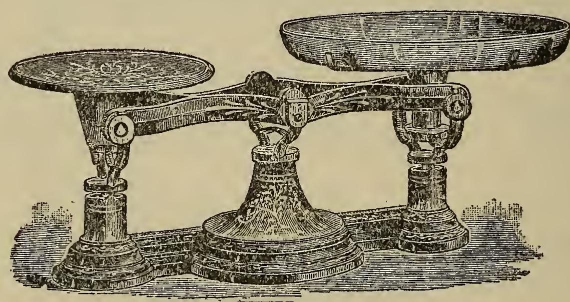

FIG. 5.—*Check-stabilized, equal-arm beam scale*

With this type, loose weights are required, in amount equal to the weighing capacity. Being inexpensive and, on account of simple construction, long wearing and reliable, it has been much used in small business of every sort. When the loads are carefully centered on the pans, the scale will weigh with very satisfactory accuracy.

To all of the familiar commercial forms illustrated in Figs. 3, 4, and 5, the invention which forms the subject of this paper is directly applicable.

This solution is given graphically in Fig. 2, and the force diagram is there extended to include also a solution for the reaction at the fulcrum pivot. As is shown by the above derivation, in all cases in which the resultant of the weights of the platform

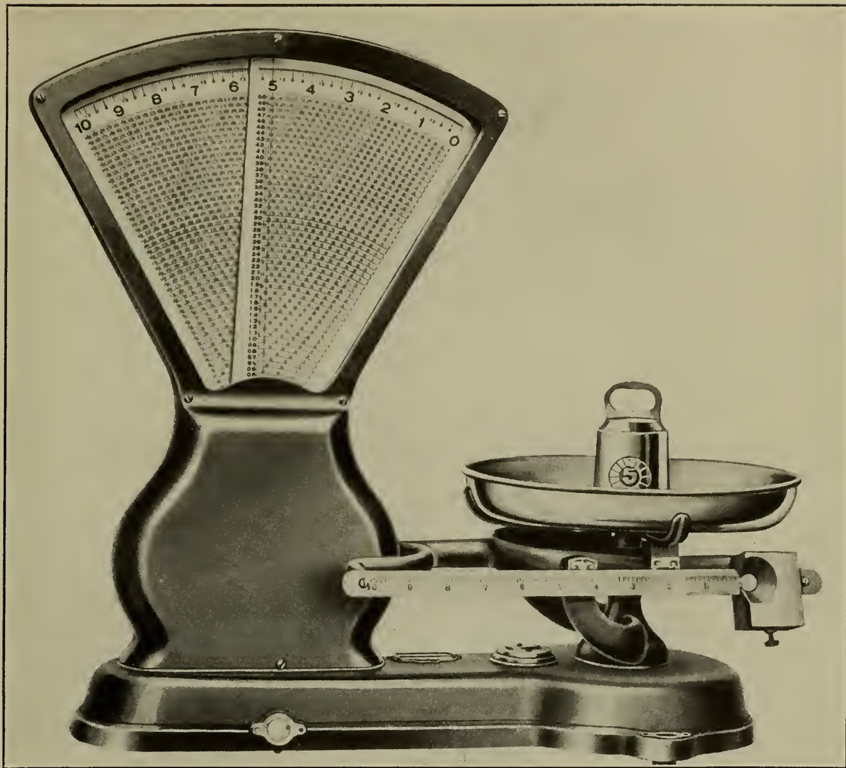

Fig. 3.—*Check-stabilized computing scale of a sort in common use in retail trade*

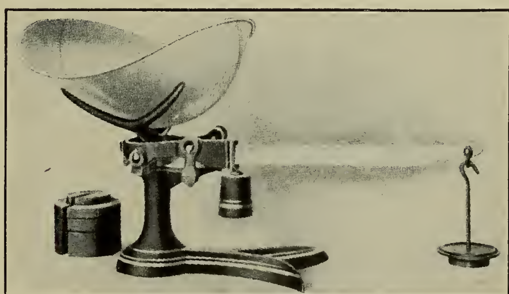

Fig. 4.—*Check-stabilized, unequal-arm beam scale (nonautomatic)*

This convenient and compact type of scale is much used in the hardware trade and in similar lines of business

and the superimposed load does not lie in the plane of the load knife-edge, a stress is introduced into the link *2*, which is called the stabilizing link, stabilizing check, or check rod, this stress being longitudinal, and in magnitude varying directly as the distance of the combined center of gravity of the load and platform from the vertical plane containing the load pivot, and, inversely, as the length of the link *3*.

Now, this introduction of a stress in the bar *2*, with the appearance of reactions at the journals (*1*, *2*) and (*2*, *3*), involves frictional resistance to turning at those journals. It is a fact that in check-stabilized scales as commonly constructed, this friction is detrimentally large in amount, resulting from the necessity of making the platform dimension in the $X$ direction reasonably large, and of keeping the length of the bars *1* and *3* of the linkwork rather short, in order that compactness be not sacrificed.

#### 4. DYNAMICAL CONSIDERATIONS

The motion of a vibrating scale beam is given by an equation of the form—

$$\theta = Ae^{-at} \sin \omega t, \qquad (6)$$

in which $\theta$ is the angular amplitude of the vibration at any phase; $t$, the time; $\omega$, the angular velocity; and $A$ and $a$ are constants.

This equation is derived under the assumption of frictional resistance proportional to the first power of the velocity, an assumption which the writer's experiments have shown to be reasonably accurate for a weighing scale at moderate and large amplitudes of oscillation, where the preponderating portion of the damping is that due to the fluid friction of the medium (air) in which the scale parts oscillate. At very small amplitudes the air resistance becomes small in comparison with the inelastic resisttances of deformation of the knife-edges and bearings, and the wave form deviates in an irregular manner from that above defined, owing to a distinct change in the type of friction.

It may be stated as a general principle that in any weighing scale all frictional resistances which do not vanish at zero velocity of the moving parts are disadvantageous and productive of error, in that they cause uncertainty or variability in the readings of the apparatus. Fig. 7, which is an actual time curve of the excursions of a vibrating scale beam, indicates the cause of these errors. It will be seen that the final rest point is subject to variation, depending upon the amplitude of the initial excursion and the direction or sense in which that excursion is made. The curves of Figs. 7 and 8 are reproduced from actual oscillograms taken by photographic means on a scale of the type illustrated in Fig. 2.

We may neglect for the present the effect produced by varying the position of the load upon the platform and the concomitant effect of such variation upon the absolute value of the frictional resistance at any given phase. It will be readily understood without special illustration here that for a given magnitude and sense of the initial excursion such change of load position alone would alter the final rest point.

(*a*) Means of Determining Rest Point.—A weighing scale may have its indications read in one of three ways. If the damping is slight, as in the case of precision balances, the position of the rest point is closely approximated by taking the mean of two, three, or more excursions of the pointer over a graduated scale or arc; or second, by waiting for the balance to come to rest, reading then the final position of the pointer; or third, by damping the balance artificially so as to make it approximately dead beat. It can easily be shown that none of these methods can give accurate results on a balance which has any appreciable static friction.

If the first method be used, the mean of three excursions will lie to one side or the other of the virtual rest point, according to the direction in which the first recorded swing was made. Similarly, if the second method be used, the rest point of the balance will not be definite, but will depend upon the total number of excursions it has executed before coming to rest, and if the balance is read in this way, every slight difference in the manner in which the balance is set in motion will result in a different rest point. In the third method, when the balance has static friction, the rest point will lie invariably on a determined side of the true point of balance, depending upon the direction in which the one excursion has been made; in other words, the excursion, no matter from which direction executed, will be consistently too short, and the final reading will be in error either in excess or deficiency, according as the reading has been taken at decreasing or increasing load.

We have seen, then, that in no case can a balance which has static friction give correct readings of the rest point. No proof is needed to show that upon the determination of the true rest point the accuracy of all weighing depends. In the ordinary platform scale we adjust by trial the equilibrating forces until the end of the beam plays, as closely as can be judged, in the center

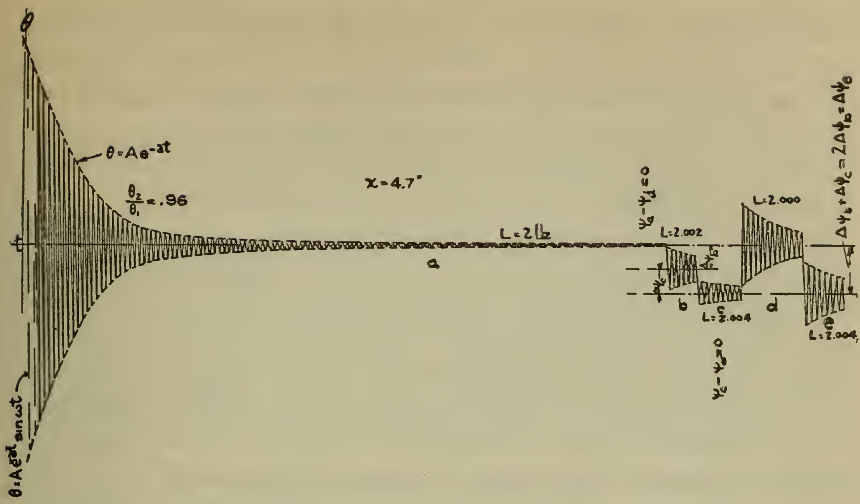


FIG. 6.—*Curve of damped oscillations, reproduced from photographically recorded oscillogram*

This is a vibration of the form,

$\theta = Ae^{-at} \sin \omega t.$

The horizontal axis is that of time, while the vertical axis is that of angular displacements from the initial plane of balance. The value $\frac{\theta_1}{\theta_2}$ gives a measure of the amount of the damping. The values of the load corresponding to each oscillogram are recorded in each case. For example, in the curves of this figure, *a* is the oscillation for the scale with a load of 2.000 pounds, the distance *x* from the vertical plane through the load knife-edge being 4.7 inches. In *b*, an increment of 0.002 pound has been added, and in *c*, an additional 0.002 pound. At *d* both increments have been removed together, and at *e* both have been readded, together. Note the accuracy with which the axes of *a* and *d*, and of *c* and *e*, are collinear, respectively. The curves of this figure are taken from a scale having the type of stabilizing link presented for the first time in this paper.

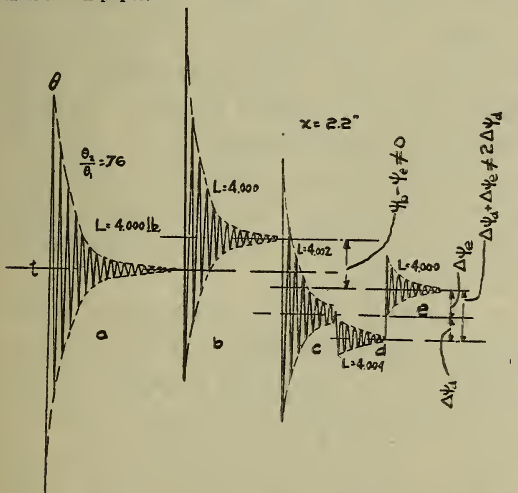


FIG. 7.—*Curves taken in a manner similar to those in Fig. 6, but on the old type of scale, having the pin-and-link check rod*

Curves *a* and *b* are for identical conditions, the scale simply being allowed to come to rest at the end of *a* and restarted for *b*. Note the variability of rest point here exhibited, and expressed analytically in the equations accompanying the figures.

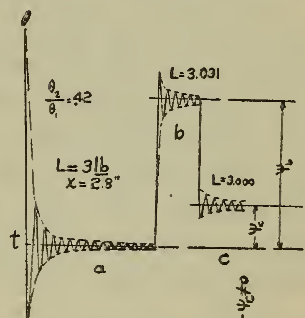


FIG. 8.—*Scale of same type as Fig. 7, but a different specimen*

The capacity of this scale is 20 pounds, and yet a large damping and variability occur with a load of only 3 pounds, displaced but 2.8 inches from the platform center, which lies in the the vertical plane through the load knife-edge.

These figures illustrate clearly the conception of "uncertainty of indication," discussed in the text.

of the trig loop. (See Fig. 1.) In another group of scales, similar to that illustrated in Fig. 2, the reading of the balance is made with reference to an estimated horizontal plane, the arc of oscillation of the beam being purposely made rather large so that deviations from the horizontal plane can be observed and varied by suitable alteration of the load or counterpoise weights.

(*b*) Limitations Imposed Upon Sensibility.—On account of this factor of uncertainty in the indications of scales of certain types and especially in the case of check-stabilized scales, it has necessarily been the regular practice, in order to give such a scale a satisfactory and practical definiteness of rest point, to tolerate a low sensitiveness, since, when a scale is very sensitive, uncertainties of indication appear as distinct deviations of the pointer or weighbeam from a given plane of balance in repeated weighings of the same load. The reason for this condition lies in the fact that in a very sensitive scale the restoring forces—that is to say, those forces which tend to propagate the oscillations—may be actually smaller than the resisting force of the static friction opposing the motion. When this condition obtains, the scale may even take up any rest point indifferently, appearing to be in neutral equilibrium, while in point of fact the mechanism is geometrically stable, and capable of executing harmonic vibration if the frictional forces could be withdrawn.

The inherent sensibility of a scale apart from the effects of static friction is usually capable of adjustment to almost any desired value; but it is obvious that if the virtual sensibility be so high that the scale is sensitive to a far smaller quantity than it will *repeat* to in successive weighings, no advantage is had. Rather, the result is disadvantageous in that the user will be confused, and not knowing the cause of the discrepancy he will distrust the scale for any work, even work of a requisite precision sufficiently low that the scale may be entirely suited to it.

On this account scales of this sort having considerable static friction are commonly adjusted to be so insensitive that the deviations from constancy of rest point can hardly be detected by the eye unaided by some special means adapted to magnify the deviations of the indicating element. It has hitherto been erroneously assumed that this low sensitivity was a fault inherent in the general type of check-stabilized scales, but as here indicated it has been necessitated solely by the failure of the scale, on account of friction, to return to the same position of balance under a constant value and disposition of load.

## III. ELIMINATION OF FRICTION IN THE STABILIZING CHECK

### 1. PRIOR TYPES OF FRICTION-REDUCING STABILIZING CHECKS.

The generality of application of this principle of uncertainty of rest point in a scale having appreciable static friction now being recognized, it will be well to note briefly the expedients which have been devised in attempting to reduce the friction arising in the stabilizing check. In Figs. 9, 10, and 11 the principal means which have been resorted to with the object of reducing this friction are shown and described. None of these expedients has proved thoroughly satisfactory; the reasons will appear upon a study of the figures and the legends which accompany them.

### 2. THE PRESENT DESIGN OUTLINED AND APPLIED.

Figs. 12 and 14 illustrate the application of the present invention to two common kinds of check-stabilized scales, the so-called postal type with sliding poise and the equal-arm, stabilized-pan counter scale. It will be seen that the platform has been so disposed as to lie entirely to one side of the load knife-edge. The effect of this is that stresses in the stabilizing check are always in the sense of tension. The usual stabilizing check is replaced by a flexible elastic tape or wire (or a plurality of such tapes or wires) having a free length between the faces of the clamps at its ends, equal to the distance between the contact lines of the fulcrum and load knife-edges. Now, since provision has been made that the stabilizing check will always be under tensile stress, the tape will be taut and the mechanism "force-constrained."

Furthermore, since the tape is elastic, the energy absorption in it as the scale oscillates is practically zero, and this condition will hold for any position of the load on the platform, so long as such position of the load does not induce in the tape a stress in excess of the elastic limit of the material.

General Principles of Design.—The displacement of the load to be weighed, from the position of minimum stress in the check rod to the position of maximum stress, will have practically no effect on the flexural elasticity of the tape, and the only friction attendant upon the stabilizing device is the very small molecular friction which has usually been termed "mechanical hysteresis." As is well understood, this is very small in amount in the case of more elastic metals and in scales constructed in the manner illustrated,

PRIOR TYPES OF FRICTION-REDUCING STABILIZING-CHECKS.

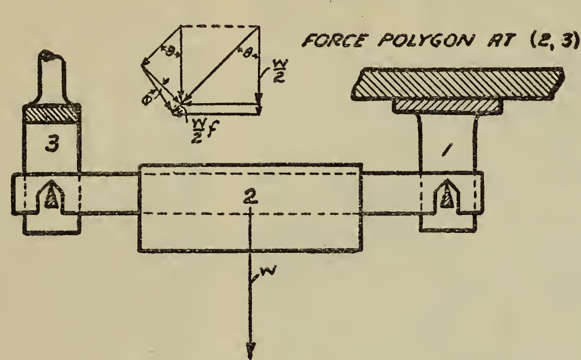


FIG. 9.—*This type of check rod has a V-bearing at each end, engaging with a knife-edge having its axis vertical*

Its capacity to sustain longitudinal loads is determined as in the force diagram shown; this capacity is very small, making the device useful only in one or two restricted applications.

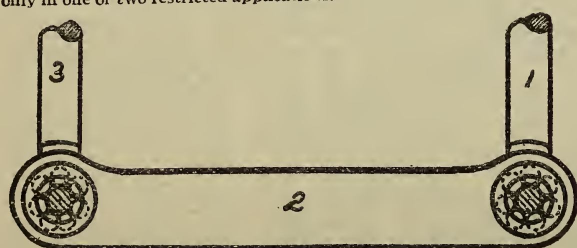


FIG. 10.—*Ball bearings used for the pivots (1, 2) and (2, 3)*

Requires accurate machine work and careful adjustment, and is susceptible to the effects of dirt and corrosion. Moreover, the friction of ball bearings, under the best conditions, is much greater than that of analogous knife-edge or flexure-plate constructions.

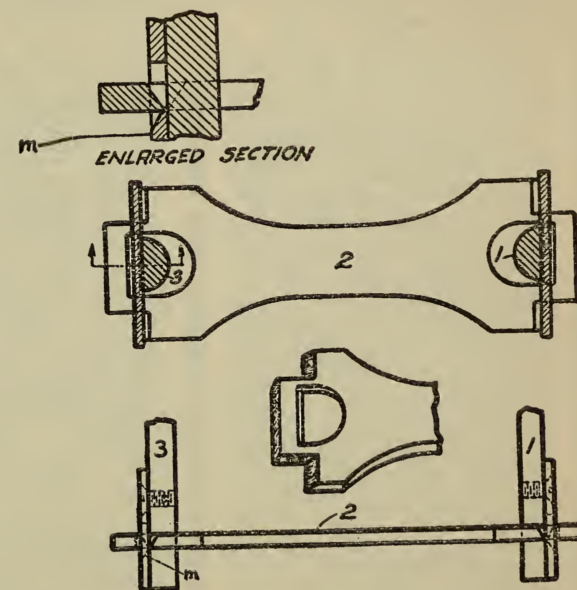


FIG. 11.—*Pairs of opposed knife-edges at each end, in contact with coplanar vertical bearing faces*

An additional knife-edge at each end must be provided at *m* to support the weight of the check rod at the proper center of rotation. The enlarged section shows the effect of end shake and wear in introducing a cramping or binding action.

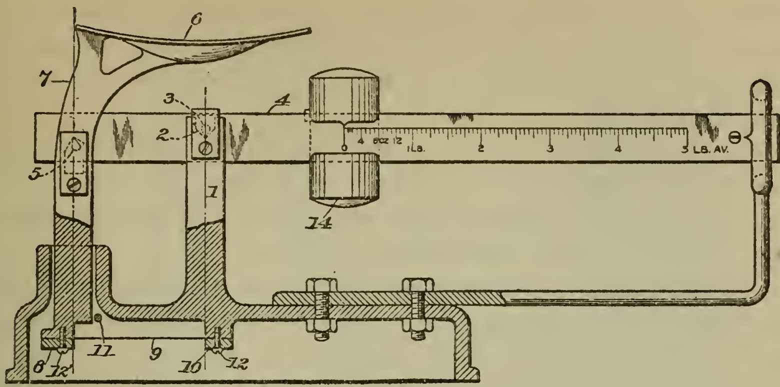

FIG. 12.—*Unequal-arm postal scale, similar in general design to that shown in Fig. 4, but equipped with the author's new stabilizing-check*

The pin *11* is for the purpose of detaining the lower end of the platform stem, so as to prevent buckling of the tape, in case the scale is violently jarred, or handled in such a manner as to turn the platform structure in the counterclockwise sense.

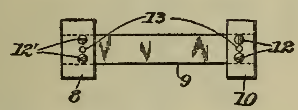

FIG. 13.—*Plan view of tape and clamps*

At *13* are shown pins driven in to retain the tape permanently in position, independent of the friction of the clamps.

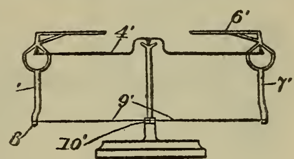

FIG. 14.—*Diagrammatic representation of an equal-arm beam scale, equipped with the new stabilizing-check*

This is similar to the scale shown in Fig. 5.

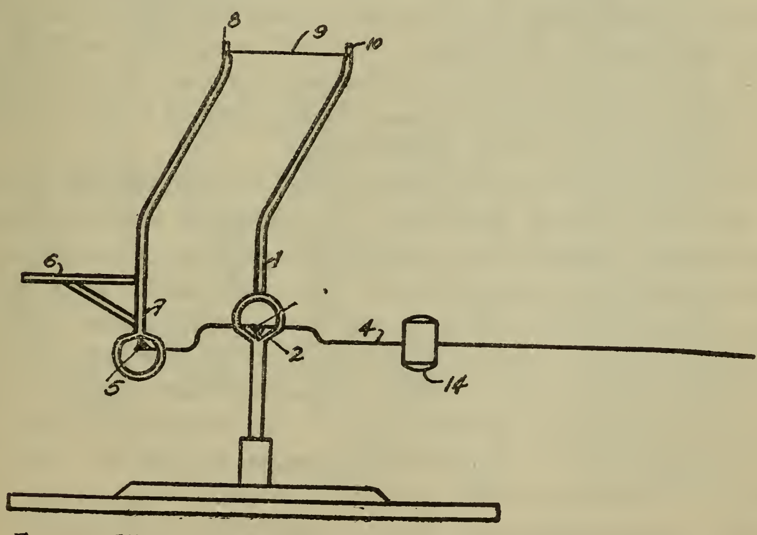

FIG. 15.—*Illustrating the application of the elastic stabilizing link to a scale in which the stabilizing element is above the plane of the beam*

certainly of an order not greater than the knife-edge friction. At any rate, this friction will be entirely negligible for any commercial application of the scale and probably in any ordinary laboratory application as well.

A study of the information at present available on the phenomena of mechanical hysteresis enables us to suggest the direction in which designers of weighing scales may seek to obtain a minimum energy absorption from this cause, as follows:

The tape should be thin in proportion to its width, in order that purely flexural stresses may be small, that the effective center of relative motion at each of the joints (*1*, *2*) and (*2*, *3*) of Fig. *2*, may be as definite and as near to the clamp faces as possible, and that the effect on the sensitiveness of the scale of the temperature coefficient of Young's modulus may be negligible. The opposing faces of the clamps which secure the tape are to be straight and parallel to the knife-edges of the beam, while the tape should be so adjusted in its clamps that its whole width is under approximately uniform stress.

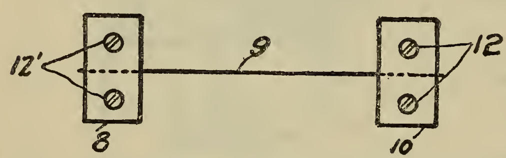


FIG. 16.—*Illustrating the use of a wire in place of a tape, as the stabilizing link*

This construction may be desirable in scales of very small capacity.

The tape should be of most elastic material—e. g., tempered carbon steel—unless for certain commercial applications incorrodibility be so essential that the highest elasticity may be sacrificed for endurance in humid or acid atmospheres, in which case any of the strong and elastic bronzes will serve well. Steel tapes, of thickness from 0.001 inch up and of various widths, are available commercially at low cost.

*Knife-Edge Reactions Inclined.*—It will be seen in Fig. 17 that the load and fulcrum knife-edges are somewhat inclined toward the quadrant opposite the platform, the purpose of this being to approximate the mean position of the reactions at these knife-edges so that the scale will be as nearly as possible immune against slipping of the knife-edge on its bearing in a direction perpendicular to the line of the pivot. No rational method can be given for the choice of the angle of inclination of the knife-edge, since the determination of the most favorable angle will depend upon the manner of weighing and the bulk of the material weighed; but it is hardly to be recommended that the knife-edge be inclined in the

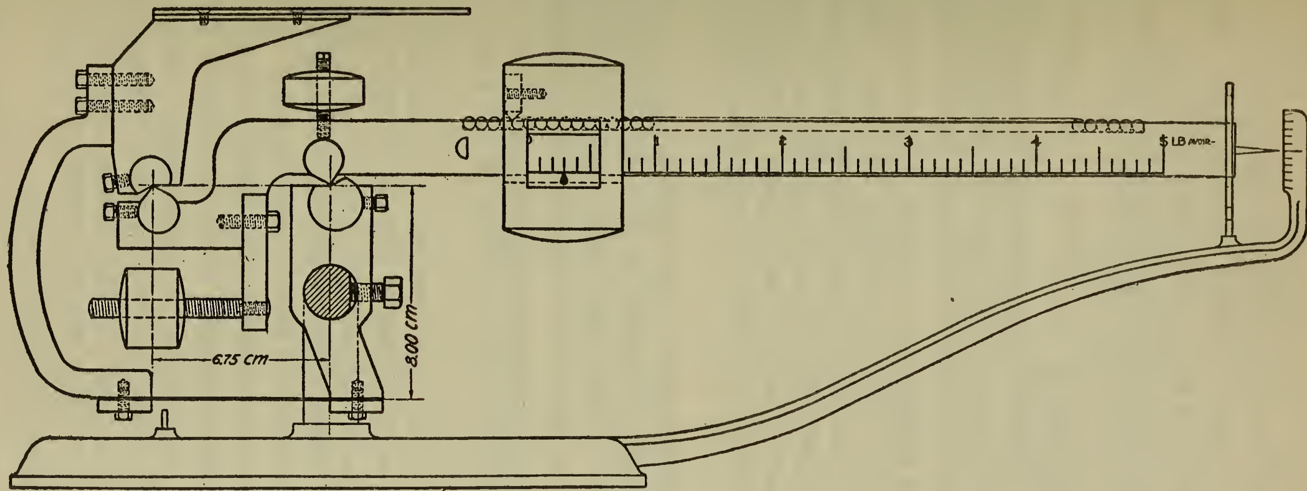


Fig. 17.—*Unequal arm beam scale with sliding poise, comprising the present invention*

This scale was built for experimental purposes in the shop of the Bureau of Standards. In this scale the knife-edges and bearings have been made adjustable to various inclinations, so as to permit of studying the slipping of knife-edges in their bearings in a direction transverse to the knife-edge axes. The beam of this scale comprises a novel form of notch provision devised by the author, to establish with exactitude the increments of motion of the sliding poise, the notches being constituted by the contiguous surfaces of the upper hemispheres of a row of steel balls set in a straight line and making contact with each other along that line. The extremely high accuracy of commercial bearing balls to equality of diameter and sphericity affords an ideally accurate notching, which will not require the tedious, point-by-point adjustment by hand, which has formerly been requisite in the case of accurate weighing scales having notched beams. It has been impossible in the case of track scales, for example, to machine the usual triangular notches accurately enough to eliminate the necessity of subsequent hand adjustment.

direction of the mean reaction for the full load of the scale displaced to the extremes of the platform, since the full load equivalent to the capacity of the scale would commonly be of such bulk in relation to the dimensions of the platform that it could not be so far displaced from the center. A better basis will be to determine the mean or mid-direction of the reaction for a load equal to one-half the capacity of the scale, when the center of gravity of the load is displaced from the extreme left edge of the platform to the extreme right edge of the platform, taking proper account of the weight of the platform itself.

From equation 1 on page 8 it is deducible that the pan structure need not lie entirely to the one side of the vertical plane through the load knife-edge, since, in order that the tape remain in tension for all loads and for all positions of any load, it is necessary only that the center of gravity of the pan element and load combined, lie on the proper side of the vertical plane through the load knife-edge, to produce a moment of such sense that it can be resisted by a finite tensile stress in the stabilizing tape. In equation (1) this is equivalent to a requirement that $T$ be positive and greater than zero.

For the designing of this type of scale (and the same applies to many other sorts as well) it should be said that the graphical method will ordinarily be the most useful, being the simplest, and suggestive of the true sense of the several forces and moments involved. Fig. 2 shows the graphic analysis of the forces, giving solutions for the magnitudes and directions of the reactions at (*3*, *4*) and (*4*, *1*).

Since in the present design the constancy of direction of the reaction in the check rod is assured, it will be possible and practicable, if for any reason it appear desirable, to use knife-edges in the stabilizing mechanism; and the difficulty to which attention was directed in the legend of Fig. 11 will not exist. A single pair of opposed, horizontally directed knife-edges, acting at each extremity of a simple flat bar slotted so as to establish suitable V-bearings, will serve to provide a mechanically satisfactory stabilizing link. It is doubtful, however, whether such an arrangement will show any advantage over the flexible tape, the latter being easier to adjust and assemble and not liable to derangement by the accidental disengagement of the parts.

## IV. ADJUSTMENT OF THE SCALE

The adjustment of this type to correctness of reading may be considered to comprise the following individual adjustments:

1. Adjustment of the ratio of lever arms of the beam if the beam has three knife-edges; or adjustment of the weight of the sliding poise to correspond correctly to the distance between the load and fulcrum knife-edges in case the beam has but two knife edges.

2. Adjustment of the linkwork so that the *accuracy of indication* is independent of the position of the load on the platform.

3. Adjustment of the linkwork so that the *sensibility* of the scale is independent of the position of the load on the platform.

### 1. ADJUSTMENT OF RATIO OF LEVER ARMS

The first of these adjustments is common to all types of lever scales, and consists merely in adjusting the spacing of the pivots or knife-edges so that the actual arm-ratio of the beam is in agreement with the figured arm ratio, the details of the adjustment depending upon whether the scale is equipped with a hanging counterpoise suspended on a pivot at the end of an invariable arm or is equipped with a fixed-weight sliding poise establishing a variable lever arm. This adjustment is a matter of manufacturing detail and needs no discussion here.

### 2. ADJUSTMENT OF PARALLELISM OF LINKS.

The second and third of the adjustments named above are not of equal importance. Clearly, since the load to be weighed can in practice never be exactly centered on the platform, it is the first essential that the scale be so adjusted that the reading of the weight of the load obtained is independent of the position of the load. This adjustment requires that the two horizontally directed[2] bars (Fig. 18) of the figure *1234* be exactly parallel. Fig. 18 shows the reason for the variation in reading obtained when these bars, *2* and *4*, are not parallel. It will be seen that, under these conditions, the stabilizing check is subjected to a force which has a vertical component depending in magnitude upon the position and value of the load upon the pan. The effect of this vertical com-

[2] In the following discussion the beam and the bars *2* and *4* of the quadrilateral are for convenience spoken of as horizontal, and the bars *1* and *3* as vertical; this is, however, nonessential, being adopted because of the usualness of this design, and for simplicity. The reasoning can be generalized to include any definite, recurring null position, whether inclined or not.

ponent is to increase or decrease the apparent weight of the load as the vertical component of the reaction is directed upwardly or downwardly. If the links *2* and *4* were parallel, no upward or downward component would appear in the reactions at the points of connection of the stabilizing link when the scale beam was in its horizontal or null position.

We may now consider the third requirement of adjustment. It will be appreciated that this requirement is not of paramount importance in the case of commercial scales, since practically all such are read by the null method, the beam being equilibrated in the process of weighing so as to come to rest at or swing in equal arcs about the horizontal position. This being the case, no moderate variation in sensibility can have serious effect, provided that all values of the sensibility are high enough to meet the requirements of the work for which the scale is to be used.

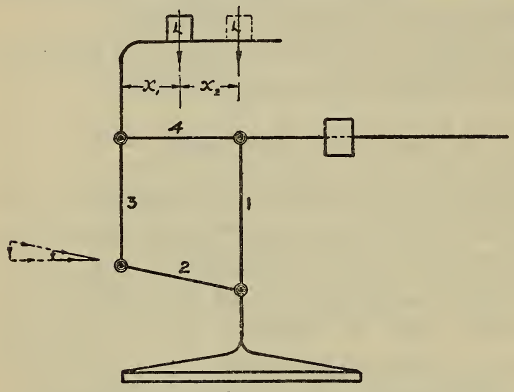


FIG. 18.—*Faulty adjustment, links 2 and 4 not parallel*

The effect of this condition is to introduce at the joint (*2, 3*) a reaction having a vertical component, as resolved in the force triangle shown in the figure, the value of this component depending upon the magnitude and position of the load on the pan and upon the sense and amount of the inclination of the link *2*. This vertical component acts to increase or decrease the apparent value of the load being weighed, according as the component acting on link *3* is directed downwardly or upwardly.

It will be seen in Fig. 19 that, so long as the beam is read in the horizontal position, the reaction at the point of connection of the stabilizing check is horizontally directed; since no vertical component exists, the force at the load knife-edge imparted by any increment of load when the beam is in that position is independent of the position of the load. Moreover, it will be seen that as soon as the beam is deflected from the horizontal position, the bars *2* and *4* being unequal in length do not move in parallel paths but become inclined to each other so that a vertical component of the reaction is set free. This, it is to be understood, affects the restoring moment of the weighing system, of which the sensibility is the direct function, and if the scale were to be read by deflections, as is a precision balance, serious error might result, since the load equivalent of a given angular deflection from the position of balance would depend upon the position of the load on the platform. It will be seen, also, that if the load and counterpoise weights are varied by trial, as in the ordinary process of weighing, so that the beam finally comes to rest in the horizontal position, no error will result, as in this position no vertical component of the tension in the tape exists.

In a very sensitive scale of this type, difficulty might rarely be encountered on account of the above-described deviation from constant sensibility, in that, for certain positions of the load on the pan, the scale might become unstable or accelerating, which is merely a condition of negative sensibility occurring when the point of neutral equilibrium (infinite sensibility) has been passed.

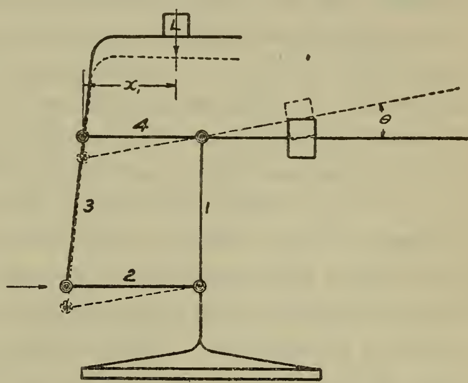


FIG. 19.—*Faulty adjustment, links 1 and 3 not parallel*

Since, under this arrangement, links *2* and *4* are parallel when the beam is horizontal, no error is introduced so long as the beam is read in this position, as no vertical component of the reaction at (*2*, *3*) appears. However, when the beam is deflected, links *2* and *4* no longer remain parallel, and the vertical components at the joints (*2*, *3*) and (*3*, *4*) are unequal, leaving a net free component either increasing or decreasing the effect of the load in returning the beam to its null position. As explained in the text, this status practically affects only the sensibility of the scale, when the position of the load on the platform is altered.

The above is of significance chiefly in showing that the adjustment of the bars *1* and *3* to exact parallelism is of minor importance and hardly of consequence in commercial scales. It is on account of this fact that in the new type of stabilizing element presented in this paper, the slight displacement of the centers of relative motion in the tape, toward its center, due to such rigidity as it possesses, is of little importance, and need not be more than approximately and empirically corrected for. This slight displacement of the centers (*1*, *2*) and (*2*, *3*) away from the faces of the clamps can be compensated for by making the distance between the inner faces of the clamps slightly in excess of the distance (*3*, *4*)–(*4*, *1*).

Some elastic effect will be introduced by the stiffness of the tape, especially when the tapes are made relatively thick to withstand large loads or hard usage, but no difficulty will be encountered on this account, as the additional restoring moment coming from the resilience of the tape can be compensated for by suitable reduction of the restoring moment of the beam, by adjusting its center of gravity closer to the fulcrum knife-edge, or even in extreme cases, should it prove necessary, by locating the center of gravity of the beam above the fulcrum knife-edge.

#### 3. MAKING THE ADJUSTMENT SECURE.

After the adjustment of the tape is completed so that the effective length between centers of flexure is equal to the distance between the load and fulcrum knife-edges of the beam, some means should be applied to maintain this adjustment permanently against the shocks of handling incident to use. While, during the process of adjustment, the tape is firmly held by the friction of the clamps, the permanency of the adjustment after its completion may be assured by tightening the clamping screws or bolts, then grinding off the screw-driver kerfs or locking the nuts in some convenient way. Next, holes are drilled through both jaws of each clamp, and into these holes are driven tightly fitting pins, the outer ends of which are ground off flush with the surfaces of the lower clamp jaws. This arrangement will serve to secure the tapes against gradual slippage or sudden release under the friction of the clamps. Other means of performing the same service are familiar to makers of cam scales, in which the ends of the tapes must be securely attached to the cams upon which the tapes wind.

## V. CONCLUSIONS

The stabilizing device described in this paper has many useful applications. Its elements are of the utmost simplicity, and its construction and adjustment offer no peculiar difficulties. Its manufacturing cost should be little, if any, in excess of that of the earlier types, while the broadness and utility of the applications of check-stabilized scales are thereby much enhanced.

#### 1. LIMITATIONS ON SENSIBILITY LARGELY REMOVED.

On account of the fact that the designer is not limited to a low sensibility by the presence of a considerable friction which will mask the indications of the scale and make a high virtual sensibility of no practical value, the present design permits the application of the convenient and compact check-stabilized scale to uses from which its deficiencies have hitherto excluded it.

For example, druggists' counter scales and even prescription scales can be made in accordance with the designs herein set forth; while in the laboratory, where the unsatisfactory "trip scale" and the combination check-stabilized and four-point-support stabilized scale, long known as the "union" scale, have been much used for the weighing of large samples outside the capacity range of the available suspended-pan analytical balances, the present design will perform a useful service.

Moreover, its utility is not limited to these relatively large capacities, for, by making the stabilizing element of very flexible and elastic construction, as will be attainable by the use of a quartz fiber, or a plurality of such fibers, the utmost delicacy of action can be secured without sacrifice of accuracy, provided only that the finish and accuracy of adjustment of knife-edges and bearings be of the same high order as would be required in a suspended-pan balance for work of equal precision.

Most of the computing and other automatic scales used in retail trade, except the common hanging-pan spring scale, are of the check-stabilized type, and the friction of the old type check rod has been a source of serious difficulty on account of the limits it imposed on the delicacy of action of the scale, preventing the scale from accurately repeating the reading at a given load. The present design can be readily applied in the construction of these scales, as well as to the nonautomatic types hereinbefore discussed. In many of these computing scales, in order to obtain as great a length as possible for the vertically disposed sides of the parallelogram, the check rod has been placed high above the platform, so that the greater space available in the upright structure of the scale could be used to house the long platform stem and the fixed link. The present design lends itself quite as well to this arrangement, using the above-platform disposition of the stabilizing link, and such a modification of the mechanism is illustrated in Fig. 15; for simplicity, the application there shown is a nonautomatic scale.

### 2. IMMUNITY FROM EFFECTS OF DIRT AND CORROSION

In cases where the scale is exposed to much dirt or moisture or corrosive fumes the tape can be made of some nonrusting material of suitable elastic properties, or, if it is found desirable to use steel, it can be perfectly protected by a strong coating of elastic varnish or lacquer or perhaps by electroplating. The scale will be better protected against deterioration under these severe conditions than any of the previous types, in any of which latter a slight accretion of rust or foreign matter upon the turning pairs of the check rod may easily cause a serious binding and derangement of the scale. An examination of Figs. 9, 10, and 11 will show the susceptibility of these earlier types to the effects of dirt and corrosion.

### 3. INCREASE IN CAPACITIES FEASIBLE

The scale we have described can be used for higher capacities than the old type; in fact, its use can be extended into the field usually considered solely satisfied by the four-point-support type of stabilized platform scale, the reason being that the practical absence of friction in the stabilizing element will permit scales of large capacity to be produced without restriction to the very small platform dimensions that would be requisite in the older forms in order to keep the frictional moments reasonably low.

In this connection, attention should be called to the fact that the general type of stabilized scale here considered, whether using the rigid or the elastic stabilizing link, is exposed to derangement when the platform load is large and far displaced, due to the slipping of the load knife-edge (or less probably the fulcrum knife-edge) within its bearing, destroying the parallelism of the linkwork. The effect is, of course, due to the growth of the component of the knife-edge reaction in the direction of the contiguous face of the bearing to a value larger than the static friction of the knife-edge against sliding in a direction perpendicular to the pivot axis. Two means are suggested for reducing the likelihood of this occurrence, although it should be borne in mind that the condition named will not ordinarily arise except in the case of abnormally large platforms or large weighing capacities.

Assuming that the angle of the bearing has been well adapted to the angle of the knife-edge, and the knife-edge properly inclined in accordance with the mean obliquity of the reactions, the most useful expedients to eliminate the appearance of the difficulty named appear to be the following:

1. The use of an arrestment, as is common in foreign-made scales of every sort, adapted to return the load and fulcrum knife-edges accurately to their proper contact lines before each weighing. Such a device also has the effect of greatly increasing the life of a scale, in that it protects the knife-edges from wear, except at such times as loads are actually being weighed.

2. The use of flexure plates instead of knife-edges, similar to the designs of A. H. Emery, as used in his testing machines and railroad track scales. By the use of this form of pivot, the relation of pivot to bearing, and consequently the constancy of the parallelogram adjustment, would be definitely assured under all conditions of loading. So constructed, the scale would have flexural pivoting throughout for both load-supporting and load-stabilizing functions, an interesting generalization from the device which forms the subject of this paper.

The commercial advantages of the scale described may be recapitulated as follows: The limitations hitherto imposed on the attainment of a high sensibility have been practically set aside, whereby the convenient and compact check-stabilized scale has been made available for a wider range of use; the new type of construction is less susceptible to the effects of dirt and corrosion; and finally, it can be used for scales of greater capacities and greater platform dimensions than was possible in the case of antecedent forms of the check-stabilized scale.

Washington, June 28, 1917.

## Appendix.—COPY OF PATENT

### UNITED STATES PATENT OFFICE

FREDERICK J. SCHLINK, of Washington, District of Columbia.

### WEIGHING-SCALE.

[1,218,902. Specification of Letters Patent. Patented Mar. 13, 1917. Application filed July 22, 1916. Serial No. 110,804.]

*To all whom it may concern:*

Be it known that I, FREDERICK J. SCHLINK, a citizen of the United States, and an employee of the Bureau of Standards, United States Department of Commerce, a legal resident of the State of Illinois, residing in the city of Washington, in the District of Columbia, (whose post-office address is 1425 T street, NW.,) have invented new and useful Improvements in Weighing-Scales, and have made application by petition of even date herewith, under the act of March 3, 1883, chapter 143, (22 Stat., 625,) praying that Letters Patent therefor may be granted to me.

The invention herein described and claimed may be used by the Government of the United States or by any of its officers or employees in the prosecution of work for the United States, or by any person in the United States, without payment of any royalty thereon.

The following is the specification of the invention:

My invention relates to an improvement in stabilizing devices for weighing scales.

The object of my invention is to provide a stabilizing mechanism for a scale pan or platform sensibly free from friction and not subject to the relative large and variable frictional resistances which occur in scales equipped with the usual forms of stabilizing devices.

The stabilized scale is usually distinguished by having a platform or pan located above the knife edges in the weighing beam or lever, and the mechanism for stabilizing said pan and constraining it to move in parallel planes is called the stabilizing mechanism. In the ordinary forms which are familiar in the numerous postal and package scales of small and moderate capacity the stabilizing link or element is a simple flat bar provided at each end with holes through which respectively pass pins connecting the bar at one end to a fixed part of the scale and at the other to the vertical stem supporting the platform. The length of this link between centers of pin holes, in order that the weight indicated shall be independent of the position of the load on the platform, is required to be equal to the distance between the load and the fulcrum knife edges of the beam. The pins at either end of the link form pivots. When the load on the platform is displaced from the center of said platform in the direction of the longitudinal axis of the beam, a stress is set up in the stabilizing link accompanied by reactions at each of the pivots above mentioned, and for all such non-central placement of the load a considerable and variable friction will be introduced at these connections, this friction being much greater in amount than that existing between the usual knife edge and bearing, thus acting to reduce the accuracy of the scale, and to limit the sensitiveness which is attainable under the given construction. My invention relates to a means of overcoming this difficulty by providing a stabilizing element which is sensibly free from friction and which leaves the scale unaffected as to accuracy and sensitiveness by variation in the position of the load upon the platform.

The nature, characteristic features, and scope of my invention will be more readily understood by the following description taken in connection with the accompanying drawing.

In the drawings: Figure 1 is an elevation in partial section of a typical postal scale embodying my invention. Fig. 2 is a view from below of the elastic tape used as the stabilizing element, in connection with the clamp at each end thereof, by means of which the tape is secured. Fig. 3 illustrates schematically the application of my invention to the so-called "trip scale" or equal-arm stabilized pan balance such as is in common use in trade.

Referring more particularly to the drawing: 1 indicates the post which supports the fulcrum bearing 2 in which the fulcrum knife edge 3 of the beam 4 is pivoted. The beam carries a sliding poise 14 and the usual scale of graduations. The load knife edge is shown at 5 and may if necessary be somewhat inclined in a direction away from the scale platform 6, the latter being carried on a supporting stem 7, which at its lower end receives by a suitable clamp member 8 one end of the tape (or wire) 9. The clamp member 8 is secured to the stem by means of the screws 12′. The other end of the tape is received beneath the clamp member 10 which is secured to the base of the scale by means of the screws 12. The pan or platform 6 is so located as to lie entirely to the one side, namely, that nearest the fulcrum knife edge, of the load knife edge 5. It thus results that tensile stresses only are produced in the tape 9 for all positions of the load on the platform. The distance between the proximate faces of the clamp members 10 and 8 is substantially equal to the distance between the contact lines of the fulcrum knife edge 3 and the load knife edge 5 while the distance between the contact line of the fulcrum knife edge 3 and the line of entry of the tape beneath the clamp member 10 is equal to the distance between the line of contact of the load knife edge 5 and the line of entry of the tape beneath the clamp member 8. A pin may be provided as at 11 to prevent buckling of the tape, in case, by accident or from any other cause, the lower portion of the stem supporting the pan should be displaced toward the member 10.

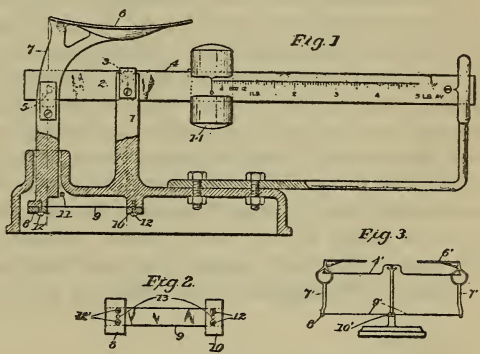

FIG. 20.

Suitable means may be added for permanently securing the tape after adjustment so that it may not be subject to the danger of displacement through accident or shock. In Fig. 2 the screws by which clamp members 8 and 10 are held in position may pass through close-fitting holes in the tape or may act to secure the tape ends by friction between the clamp jaws alone. The pins 13 may after final adjustment of the tape be driven tightly into holes drilled completely through clamp jaws and tape so as to provide a positive, and not easily alterable, means of preventing slippage or displacement of the tape during use of the scale.

The thickness and width of the tape are chosen so as to be suitable to the loads and service the scale will be subjected to. I do not wish to be limited to the use of a single tape for the purpose.

It is to be noted that some elastic effect will be introduced by the stiffness of the tape, especially if the tape be made relatively thick in order to withstand large loads, but no difficulty will be experienced on this account as the additional restoring moment provided by the elasticity of the tape can be compensated for by suitable reduction of the restoring moment of the beam, by adjusting its center of gravity close to or even, if it should in rare instances prove necessary, by locating it above the fulcrum knife edge.

In Fig. 3 in which an equal-arm balance is shown, 4′ is the scale beam having the load knife edges at either end, each of which support the stem 7′, a tape 9′ being connected to the lower end of each stem.

It is understood that it is not essential that the stabilizing tape be below the plane of the beam. The arrangement may be such that the stabilizing tape is above the plane of the beam or in fact in any plane except that defined by the load and fulcrum knife edges. In case the stabilizing tape lies above the plane of the load and fulcrum knife edges, the particular side toward which the scale platform is disposed may differ from the arrangement illustrated in the drawings. In any case the disposition of the platform will be such that the stress introduced in the tape will be in the sense of tension.

Although but two specific embodiments of this invention have been herein shown and described, it will be understood that numerous details of the construction shown may be altered or omitted without departing from the spirit of this invention as defined by the following claim:

In a weighing scale, the combination with the scale beam of a load supporting member pivotally connected to the beam at one side of the fulcrum of the beam, said member having its load receiving platform so disposed with reference to said pivot that the center of gravity of the system including the said member and the load placed upon its load receiver will always lie on a given side of the vertical plane through the pivot axis, said member extending away from the plane of said load pivot and fulcrum and a flexible tape so connected at one end to said member at a point outside the plane of said pivots and at the other end to a stationary part of the scale as to afford a free portion of the tape between the points of connection substantially equal in length to and, under tension parallel with, a straight line terminating in the axes of the above-named pivot and fulcrum and perpendicular to such axes.

Signed at Washington, D. C., this 21st day of July, 1916.

FREDERICK J. SCHLINK.

Witnesses:
C. A. BRIGGS,
LOUIS A. FISCHER.