In the representative embodiment of the apparatus of the present invention disclosed herein, a plurality of outwardly-biased centralizer bow springs are disposed around a tool body with their upper ends being pivotally secured to an intermediate portion thereof and their lower ends coupled together for longitudinal movement in relation to the lower portion of the body. To maintain the bow springs at a uniform spacing from the tool body when the new and improved centralizer is in a deviated wellbore, a corresponding number of rigid arms are pivotally coupled to the midportion of each spring and extended upwardly to a pivotal connection on a collar which is slidably mounted on the tool body and biased downwardly.

8 Claims, 3 Drawing Figures
WELL TOOL CENTRALIZER

This application is a division of U.S. application Ser. No. 485,059 filed July 1, 1974 and still pending.

It will, of course, be appreciated that many so-called “wellbore” logging tools and various well-completion tools must be maintained in substantial alignment with the central axis of a well bore during their operation. Ordinarily, such centering functions are accomplished by typical bow-spring centralizers having three or more elongated bow springs which are lightly biased outwardly against the well bore wall to center the tool without unduly impeding its travel through the well bore. It is recognized, however, that such minimal centering forces are inadequate for centralizing a well tool of even limited weight in a highly-deviated well bore interval.

Accordingly, as fully described in U.S. Pat. No. 3,555,689, one highly-successful bow-spring centralizer for aligning various wireline tools in deviated or non-vertical well bores includes circumferentially-spaced pairs of pivotally-interconnected longitudinally-disposed arms which are arranged along the tool body to respectively position their interconnected ends against the middle of each of the centralizer springs. By pivotally connecting the upper and lower ends of these arms to the spaced collars on the body also carrying the upper and lower ends of the centralizer springs, the outwardly-disposed interconnected ends of each set of these arms will always be equidistant from the longitudinal axis of the tool thereby preventing any one of the centralizer springs from moving any closer to the tool body than permitted by the interconnected arm ends.

A centralizer such as this is best arranged, however, with the spaced collars carrying the centralizer springs; and the pivotally-interconnected positioning arms being slidably mounted on the tool body for limited movement as an assembly between longitudinally-spaced stops. In this manner, regardless of which direction the tool is moving, the centralizer assembly will shift accordingly along the tool body; and, upon encountering a well bore restriction, the collar which is then trailing will be capable of shifting along the tool body as required for retracting the centralizer springs.

Although there is no particular problem presented by awning centralizers such as these to float or shift in a limited span along the tool body, various problems are presented when the centralizer assembly is also intended to perform an additional function. For example, as shown in the Cubberly patent, the lateral motion of the centralizing springs can be readily translated into electrical signals representative of the well bore diameter by means of an electrical transducer such as a potentiometer such as depicted in FIGS. 3A and 3B of that patent. However, since such a potentiometer must also move back and forth with the sliding collars, it is particularly difficult to reliably isolate the potentiometer from the well bore fluids. Those skilled in the art can, of course, envision other difficulties which could be readily solved if a centralizer assembly which is also to be used in a control or measuring function could be retained in a selected longitudinal position on the tool body.

Accordingly, it is an object of the present invention to provide new and improved centralizer assemblies which are particularly adapted for operation in non-vertical well bores as well as being specifically arranged for selectively operating various control elements or measurement transducers on a well tool in response to diametrical variations in a well bore.

These and other objects of the present invention are attained by providing new and improved tool-centralizing means including a plurality of elongated outwardly-extendible centralizing members which are distributed longitudinally about the body of a well tool with each member having one end pivotally secured to the body and its other end longitudinally movable in relation to the tool body. A longitudinally-slidable member is arranged on the tool body and cooperatively biased away from the pivoted ends of the centralizing members toward a location on the body between the mid-portions of the centralizing members and their pivoted ends. A corresponding number of rigid arms are respectively pivotally intercoupled between about the mid-portion of each centralizing member and the sliding member so that its movement toward its selected location will respectively pivot the arms from a steeply-inclined or generally-longitudinal position toward a generally-lateral position for extending the mid-portions of the centralizing members.

The novel features of the present invention are set forth with particularity in the appended claims. The invention, together with further objects and advantages thereof, may be best understood by way of the following description of exemplary embodiments of apparatus employing the principles of the invention as illustrated in the accompanying drawings, in which:

FIG. 1 depicts a preferred embodiment of a new and improved well tool centralizer incorporating the principles of the present invention as the tool is being operated in an uncased well bore interval;

FIG. 2 is an enlarged cross-sectional view of the intermediate portion of the new and improved tool shown in FIG. 1; and

FIG. 3 is a schematic diagram illustrating certain design principles of the present invention.

Turning now to FIG. 1, a new and improved centralizer assembly 10 employing the principles of the present invention is schematically shown as it, for example, may be arranged for utilization with a well-calibring tool 11. As illustrated, the calibring tool 11 is depicted suspended from an electrical logging cable 12 which is spooled in the usual fashion on a winch (not shown) at the surface and arranged to move the tool through a well bore interval 13 below a typical production string 14 for obtaining a diameter survey of this uncased interval.

In its preferred arrangement, the calibring tool 11 includes an elongated body 15 carrying the new and improved centralizer assembly 10 that is coupled between an upper body 16 and a lower depending body 17 which are cooperatively arranged for enclosing typical circuitry as required for providing electrical signals representative of the diameter of the well bore interval 13 as well as of any other downhole measurements which the tool may also be equipped to obtain. To record the various output signals of the well tool 11 obtained at the successive depth positions of the tool in the well bore 13, typical surface indicating-and-recording apparatus, such as a CRT or galvanometer recorder 18, is electrically connected to the cable 12 and adapted to be proportionally driven in response to its upward and downward movements by means such as a calibrated cable-engaging measuring wheel 19 that is
operatively coupled to the recorder as by a pulse generator or a suitable mechanical linkage 20. Turning now to FIG. 2, an enlarged cross-sectional view is shown of a preferred embodiment of the new and improved centralizer assembly 10 as it is preferably arranged on the well-caliper tool 11 and will appear in its fully-extended position. As illustrated, the new and improved centralizer 10 includes at least three elongated and somewhat-arcuate or outwardly-bowed leaf springs, as at 21 and 22, which are distributed uniformly in upright positions around the body 15 and coupled thereto by transversely-oriented upper pivots, as at 23, which respectively fix the upper ends of the springs to an enlarged upper portion 24 of the body and transversely-oriented lower pivots, as at 25, which respectively secure the lower ends of the springs to a collar 26 that is slidably disposed on the lower portion of the body. Since it may be desirable to adjust the extended portions of the bow springs, as at 21 and 22, one or more movable abutments or steps 27 are preferably coupled to the body as by threads 28 of a sufficient length to allow the upper travel limit of the slidable collar 26 to be established as required. To coordinate the lateral movements of the bow springs as at 21 and 22, the lower or outer ends of a correspondingly number of rigid arms, as at 29 and 30, are each movably coupled to the spring members as by transversely-oriented pivots 31 and 32 which are preferably located slightly above the mid-points of each of the bow springs; and the arms are respectively extended upwardly and have their upper and inner ends movably coupled, as by individual transversely-oriented pivots 33, to a collar 34 which is slidably mounted around the intermediate portion of the body 15. In the preferred manner of imposing a downwardly-directed force on the rigid arms as at 29 and 30, a stout compression spring 35 is coaxially mounted around the body 15 between the enlarged upper body portion 24 and the collar 34 and cooperatively arranged for biasing the collar downwardly toward a selected operating position as best defined by a stop or shoulder 36 on the intermediate portion of the body. It will, of course, be understood that the shoulder 36 could also be conveniently arranged as a threaded-coupled abutment on the body 15 which would either supplement or replace the lower abutment 27 as a means for selectively limiting the outward extension of the bow springs as at 21 and 22. Accordingly, with the new and improved centralizer 10 arranged as depicted in FIG. 2, it will be appreciated that as the bow springs, as at 21 and 22, are expanded outwardly against a wall of a well bore such as the uncased interval 13 (FIG. 1), the collar 34 will be correspondingly moved downwardly toward the abutment or shoulder 36. This movement of the collar 34 will, therefore, swing the arms, as at 29 and 30, to a less-inclined or nearly-lateral position for respectively imposing an outwardly-directed centering force against each of the bow springs, as at 21 and 22, which increases as the rigid arms are swung outwardly by the downward displacement or travel span of the sliding collar. Since the centralizing force provided by each of the bow springs, as at 21 and 22, will proportionally decrease as they expand, it will be recognized that the overall centering force developed by the new and improved centralizer 10 will be equal to the summation of the centering forces respectively provided by the individual biasing forces of the bow springs as at 21 and 22 as well as of the compression spring 35. Those skilled in the art will recognize, therefore, that by selectively establishing the several relevant design parameters for the bow springs, as at 21 and 22, and the biasing spring 35, the overall centering force of the centralizer 10 can be made sufficiently large to maintain the tool 11 closely centered in even highly-diverted wells. Moreover, by using design principles similar or analogous to those described in U.S. Pat. No. 3,097,433, the overall centering force of the new and improved centralizer 10 can be established at a selected substantially-constant level within the travel span of the bow springs as at 21 and 22. By designing the centralizer 10 to provide a substantially-constant centering force, movement of the tool 11 through a well bore will, of course, be facilitated. It must be appreciated that in keeping with the objects of the present invention, the new and improved centralizer 10 should be capable of readily retracting as required to pass various well bore obstructions. There is, of course, no particular problem where the centralizer 10 is moved into a gradual diametrical reduction in a well bore. The most serious condition is, however, where the centralizer 10 encounters an abrupt reduction in diameter such as a ledge, as at 37 in FIG. 1, when the tool 11 is being lowered into the uncased interval 13. Similarly, as the tool 11 is being raised in the well bore interval 13, the centralizer 10 must also be capable of readily retracting as it enters the lower end of the production string 14 without dangerously increasing the tension in the suspension cable 12. It will be recognized, therefore, that the new and improved centralizer 10 must be capable of retracting without undue resistance whenever one or more of the several bow springs, as at 21 and 22, are subjected to either an upwardly-directed force or a downwardly-directed force. Thus, to examine the effects of such longitudinal forces on the centralizer 10, FIG. 3 is presented to schematically represent the responses of one of the bow springs, as at 22, and its associated rigid arm, as at 30, when the bow spring is subjected to either a downwardly-acting force, F1, or an upwardly-directed force, F2. Taking the situation first of all where the new and improved centralizer 10 is moving upwardly in the uncased interval 13 and encounters the lower end of the production string 14, it will be appreciated that a downwardly-directed force, as at F1, will be imposed on the upper portion of the bow spring 22 at some point between the pivots 23 and 32. It will be recognized, however, that since the upper end of the bow spring 22 is pivoted, as at 23, to the tool body 15, the upper portion of the bow spring must pivot downwardly and inwardly about this upper pivot. As this occurs, the lower and outer end of the rigid arm 30 will also be swung downwardly and inwardly toward the body 15 along a relatively-flat arc of travel and thereby cause the collar 34 to shift slightly upwardly along the tool body as required to accommodate the changing angular position of the arm. It will be seen, therefore, that the normal response of the new and improved centralizer 10 is to retract readily whenever it encounters a downwardly-acting force as at F1. Ordinarily, the rigidity of the bow springs, as at 22, between the pivots 23 and 32 is sufficient to preclude a downward force, as at F1, from
buckling the upper portion of the spring inwardly or downwardly so as to resist any tendency to the outer pivot to move outwardly instead of inwardly. Should it be found, however, that such buckling may occur, the upper portions of the bow springs, as at 21 and 22, could be further stiffened by respectively securing a reinforcing member, as at 38 in FIG. 2, on the upper end of each bow spring. As shown there, this may be done most conveniently by arranging these reinforcing members, as at 38, to serve as the upper end connections for the bow springs, as at 21 and 22, for cooperation with the upper pivots as at 23. Similarly, it is also preferred to provide identical or comparable end connections, as at 39, for the lower ends of the bow springs as at 21 and 22.

As previously noted, the most-severe operating condition will be when the centralizer 10 is moving downwardly and encounters a landing nipple or some similarly abrupt reduction in diameter in a well bore. Thus, as schematically illustrated in FIG. 3, the lower portions of the bow springs will be subjected to an upwardly-directed force, as at F2, which, would, at first blush, appear to induce spreading or expansion of the springs as at 21 and 22 and shift the lower collar 26 upwardly along the tool body 15. As diagrammatically illustrated in FIG. 3, however, it can be shown that by virtue of the unique arrangement of the new and improved centralizer 10, it will be retracted so long as the force F2 is acting above the instantaneous or momentary center of rotation, as at 40, of the lower portion of the bow spring 22 (i.e., that portion thereof which lies between the pivots 25 and 32).

To understand this conclusion, it should first of all be recognized that when the force F2 is initially imposed on the lower portion of the bow spring 22, its upper end (i.e., at the intermediate pivot 32) can move only inwardly or outwardly along an arc 41 whose center is the upper pivot 23. Secondly, at the same time, the lower end of the lower portion of the bow spring 22 (i.e., at the lower pivot 25) can move only upwardly or downwardly along the tool body 15. The initial infinitesimal increment of the longitudinal travel of the lower pivot 25 can, however, be considered as being along an arc, as at 42, whose center, as at 43, lies along a normal or radius 44 perpendicular to the axis of the tool body 15 and passes through the lower pivot.

Accordingly, whenever an upwardly-directed force, as at F2, is imposed on some part of the lower portion of the bow spring 22 lying between the pivots 25 and 32, there will be an initial tendency for this lower portion to rotate infinitesimally about a momentary center of rotation, as at 40, which is geometrically defined by a line 45 that intersects the normal line 44 and perpendicularly intersects the lower portion of the bow spring. Thus, a rudimentary statics analysis will demonstrate that if the force, F2, is acting on the lower portion of the bow spring 22 at some point below this momentary center of rotation 40, the lower pivot 25 must move upwardly along the arc 42 while the intermediate pivot 32 swings outwardly along the arc 41 as the lower portion of the bow spring momentarily turns about this center of rotation. Conversely, as illustrated in FIG. 3, if the force F2 is applied above this momentary center of rotation 40, the lower pivot 25 must shift downwardly along the tool body 15 as the intermediate pivot 32 swings inwardly along its arc of travel 41.

It will be realized, therefore, that for a given well bore diameter, this momentary center of rotation, as at 40, for the lower portion of the bow spring 22 will be moved closer to the tool body 15 as the length of this lower portion of the bow spring is increased. Thus, in the usual situation, it is preferred that the lower portions of the bow springs, as at 21 and 22, be at least somewhat longer than their upper portions so that the lower portions will be steeply inclined in relation to the tool body 15 so as to keep their momentary centers of rotation, as at 40, fairly close to the tool body 15 and the lower pivots, as at 25.

It should also be appreciated that the new and improved centralizer 10 is particularly suited for operating various control elements of a well tool or measurement transducers which could not otherwise be conveniently or reliably operated if the centralizer was free to shift longitudinally along the tool body 15 as does the aforementioned Cubberly centralizer. As one example of this significant feature, the diameter-measuring means 46 of the new and improved well tool 11 are most conveniently located on the upper portion of the tool body 15. It will, of course, be recognized that since the bow springs, as at 21 and 22, move in unison and that the operating position of any one of them is directly proportional to the diameter of the well bore in which the centralizer 10 is then situated, the diameter-measuring means 46 can be readily operated by sensing the position of any movable part of one of the springs.

Accordingly, in a preferred manner of arranging the diameter-measuring means 46, the tool body 15 includes an enlarged axial chamber 47 in which a longitudinally-movable tubular member 48 is slidable mounted and operatively coupled to the bow spring 22 by means such as an extension or crank arm 49 on the movable end fitting 38 which is projected through an opening 50 in the body and pivotally coupled, as at 51, to the slidable member. To prevent well bore fluids from entering the chamber 47, sealing members, as at 52 and 53, are cooperatively arranged around the opposite ends of the slidable member 48 and engaged with the walls of the chamber above and below the body opening 50. A position-sensing transducer, such as potentiometer 54, is mounted within the chamber 47 and cooperatively coupled, as at 55, to the slidable member 48 for providing a varying electrical characteristic which is indicative of the longitudinal position of the slidable member. It will, therefore, be recognized that the transducer 54 can be readily calibrated to provide accurate measurements which are representative of the lateral positions of the bow springs, as at 21 and 22, which are, in turn, directly related to the diameter of the well bore interval which the centralizer 10 is then situated.

Another type of transducer which may be effectively operated by the new and improved centralizer 10 of the present invention is one which will also provide depth-correlation signals. Thus, as also shown in FIG. 2, the well tool 11 may also include a collar locator 56 such as fully described in U.S. Pat. No. 3,267,365 which is incorporated by reference herein. To accomplish this, at least an intermediate portion of the tool body 15 is made of a non-magnetic material and cooperatively arranged to enclose a sensing coil 57. Magnets, as at 58 and 59, are appropriately located on the rear of the bow springs, as at 21 and 22, for inducing electrical sig-
nals in the sensing coil 57 which are indicative of the movement of the tool 11 past magnetic anomalies such as collars in the production string 24. Since U.S. Pat. No. 3,267,365 fully describes the arrangement of such anomaly-responsive devices, it is, of course, unnecessary to describe the further details of the collar locator 56.

Accordingly, it will be recognized that the new and improved centralizer 10 of the present invention is particularly suited for efficient operation even in highly-deviated well bores. By virtue of the outwardly-biased pivoted arms which are coupled to the rear of each of the centralizing members or bow springs, these members will always be positioned at a uniform lateral spacing away from the tool body so as to maintain the tool closely centered in the well bore. Moreover, since new and improved centralizers incorporating the principles of the present invention are cooperatively arranged so that the theoretical or momentary centers of rotation of the lower portions of the several bow springs are always close to the tool body and near the lower ends of the springs, an upwardly-directed impact on the springs will cause the springs to retract in all but very unusual situations. Similarly, the upward inclination of these positioning arms serves to effect retraction of the centralizer springs in response to downwardly-directed impacts. As previously described, the unique arrangement of the new and improved centralizer of the present invention is particularly useful where the centralizing members are also to be employed for operating various auxiliary devices in keeping with the principles of the invention set out in the aforementioned pending application.

While only a particular embodiment of the present invention has been shown and described, it is apparent that changes and modifications may be made without departing from this invention in its broader aspects; and, therefore, the aim in the appended claims is to cover all such changes and modifications as fall within the true spirit and scope of this invention.

What is claimed is:

1. A well tool centralizer comprising:
   a body adapted for movement through a well bore;
   a plurality of elongated bow springs circumferentially spaced around said body;
   means cooperatively securing one end of each of said bow springs to a first portion of said body for only pivotal movement relative thereto as intermediate wall-engaging portions of said bow springs respectively move laterally between extended positions and retracted positions adjacent to a second portion of said body;
   a slidable member cooperatively arranged on said body and adapted for longitudinal movement therealong between one position located between said first and second body portions and another position located between said one position and said second body portion;
   biasing means cooperatively arranged between said body and said slidable member for normally biasing said slidable member toward its said other position; and
   a corresponding number of rigid arms circumferentially spaced around said body and respectively pivotally intercoupled between an intermediate-located portion of each of said bow springs and said slidable member for movement relative to said body between generally-upright arm positions along and adjacent to said body when said bow springs are in their said retracted positions and outwardly-inclined arm positions for retaining said wall-engaging spring portions at a uniform lateral spacing from said second body portion when said bow springs are in their said extended positions.

2. The centralizer of claim 1 further including:
   means cooperatively coupling the other ends of said bow springs together for longitudinal movement relative to said body as said bow springs move between their said retracted and extended positions.

3. The centralizer of claim 2 wherein said other ends of said bow springs are at a distance from said body and said coupling means are longitudinally spaced from said second body portion.

4. The centralizer of claim 2 wherein said coupling means include:
   a second slidable member cooperatively arranged for longitudinal movement along a third portion of said body; and
   stop means on said third body portion cooperatively arranged for determining the travel span of said coupling means to at least define the outer limits of said extended positions of said bow springs.

5. A well tool centralizer adapted for movement through a well bore and comprising:
   a body having longitudinally-spaced upper and lower portions and adapted for suspension in a well bore;
   at least three elongated outwardly-bowed springs circumferentially spaced in upright positions around said body with the wall-engaging portion of each of said bow springs being laterally disposed from an intermediately-situated location on said body;
   means pivotally securing a first end of each of said bow springs to a selected one of said body portions for limiting said first spring ends to only pivotal movement in relation to said one body portion as said wall-engaging portions respectively move between a laterally-extended position and a retracted position adjacent to said intermediate body location;
   means cooperatively intercoupling the second end of each of said bow springs for longitudinal movement together in relation to the other of said body portions; and
   means cooperatively arranged for maintaining said wall-engaging portions equidistant from said intermediate body location and including a coupling member slidably disposed on said body for longitudinal movement thereon between said first spring ends and said intermediate body location, a corresponding number of rigid links pivotally interconnecting said coupling member to about the midpoints of each of said bow springs, and biasing means normally urging said coupling member toward said intermediate body location for coordinating the lateral movements of said bow springs and for imposing a progressively-increasing lateral force thereon as said wall-engaging portions move outwardly toward their respective extended positions.

6. The centralizer of claim 5 wherein said intercoupling means are axially spaced from said other body portion.

7. The centralizer of claim 5 wherein said intercoupling means include:
a collar slidably mounted for longitudinal travel on said other body portion, means pivotally coupling said second spring ends to said collar, and stop means cooperatively arranged on said other body portion for limiting at least the longitudinal travel of said collar toward said intermediate body location to establish said extended positions of said bow springs.

8. A well tool centralizer comprises:
a body having longitudinally-spaced upper and lower portions and adapted for suspension in a well bore; at least three upright outwardly-bowed springs uniformly spaced around said body with their wall-engaging mid-points laterally disposed from an intermediately-situated location on said body; means pivotally securing a first end of each of said bowed springs to a selected one of said body portions for limiting said first spring ends to only pivotal movement in relation thereto as said spring mid-points are respectively moved laterally between inward and outward positions as determined by well bore diameter variations; means cooperatively intercoupling the second end of each of said bowed springs for longitudinal movement together in relation to the other of said body portions; and means cooperatively arranged for maintaining said spring mid-points equidistant from said intermediate body location and including a coupling member slidably disposed on said body for longitudinal movement thereon between said first spring ends and said intermediate body location, a corresponding number of rigid links pivotally interconnecting said coupling member to about said mid-points of each of said bowed springs, and biasing means normally urging said coupling member toward said intermediate body location for coordinating the lateral movements of said bowed springs and for imposing a progressively-increasing outward force thereon as their said mid-points are moved outwardly against an adjacent well bore wall.