Dec. 7, 1971 E. LAIMINS 3,625,053

ON-BOARD AIRCRAFT TRANSDUCER

Filed Jan. 14, 1970 4 Sheets-Sheet 1

FIG. 1

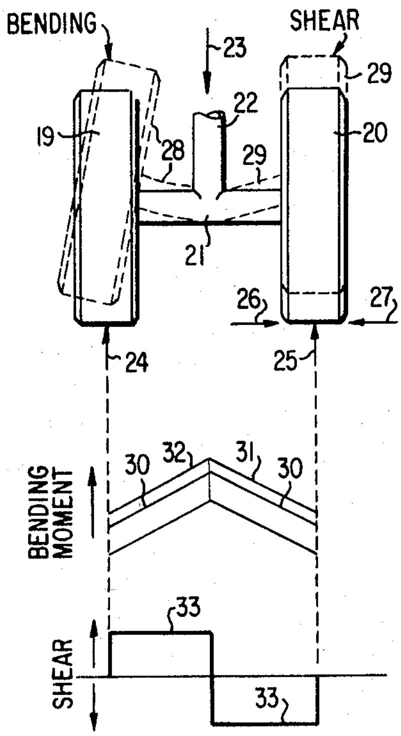
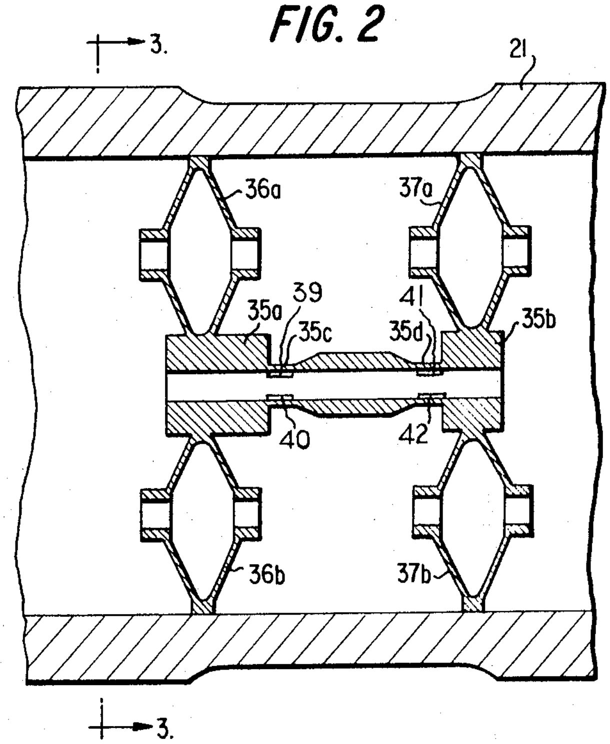


FIG. 2



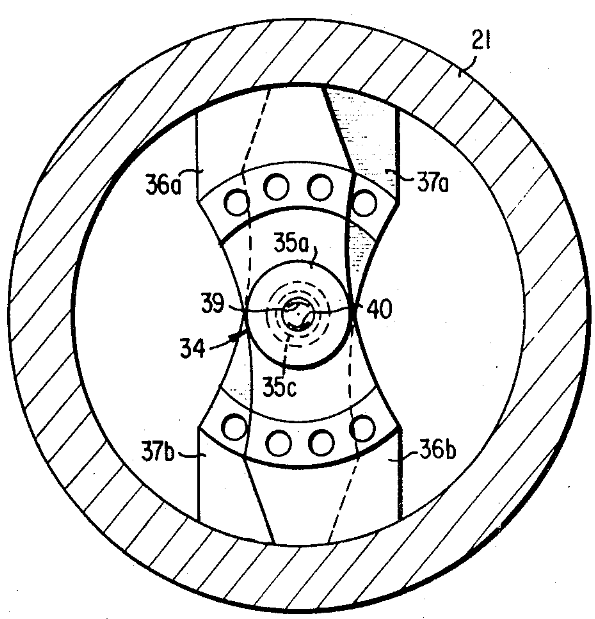


FIG. 3

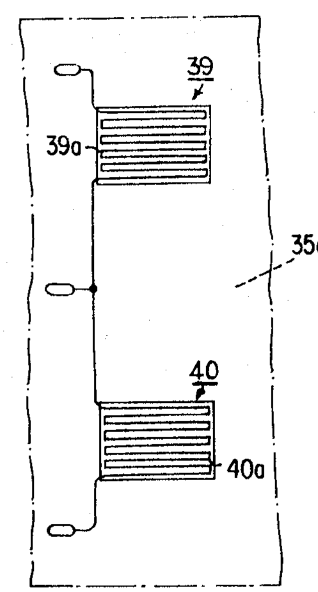


FIG. 4

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FIG. 5

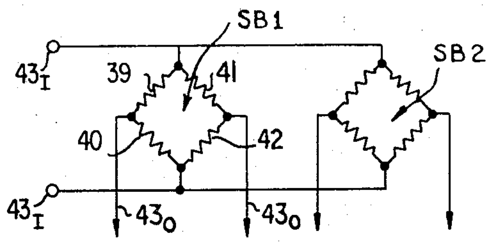


FIG. 6

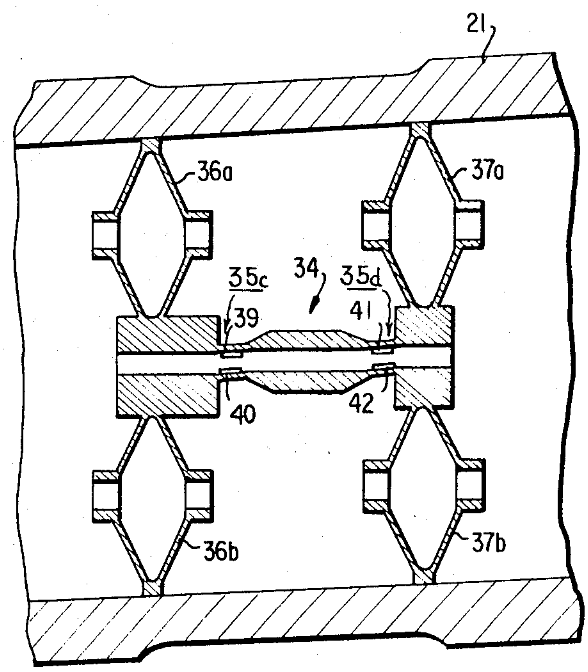
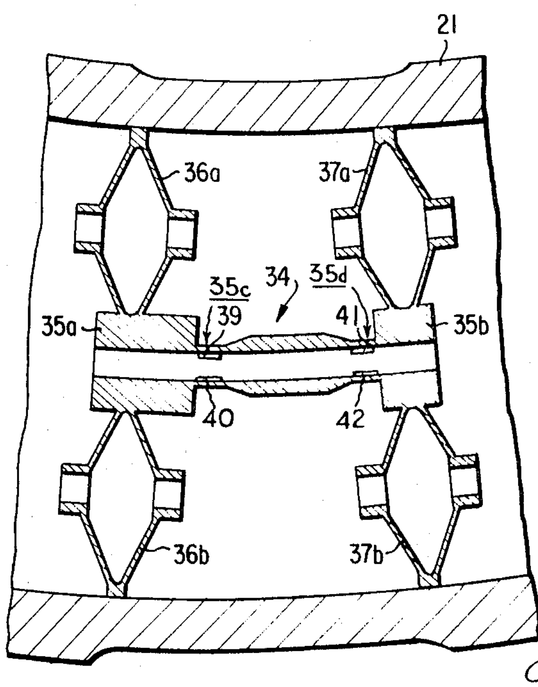


FIG. 7



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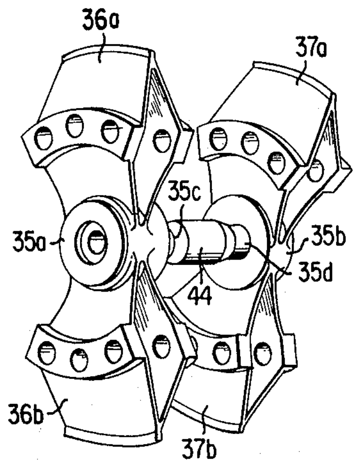

FIG. 8

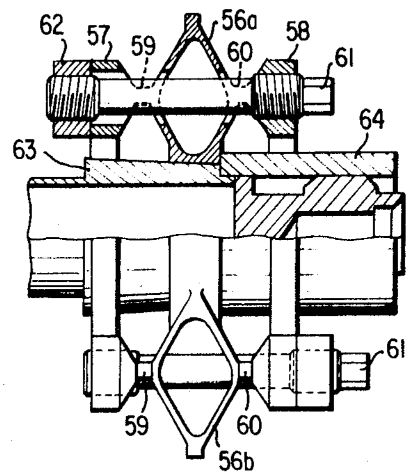

FIG. 11

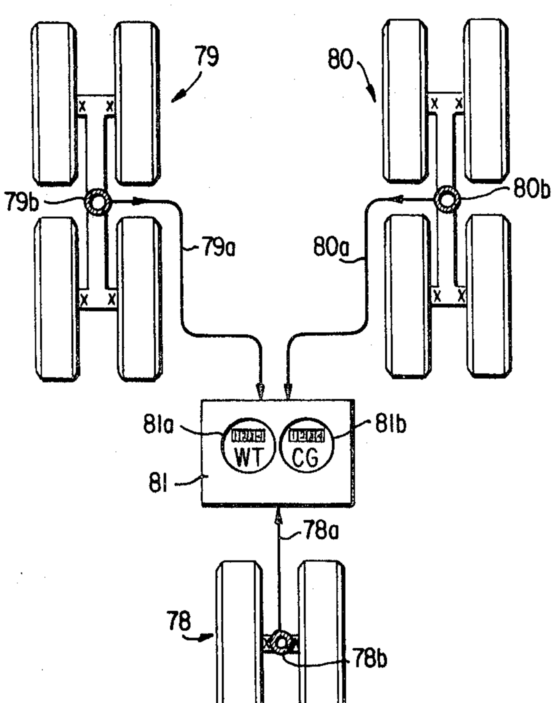

FIG. 12

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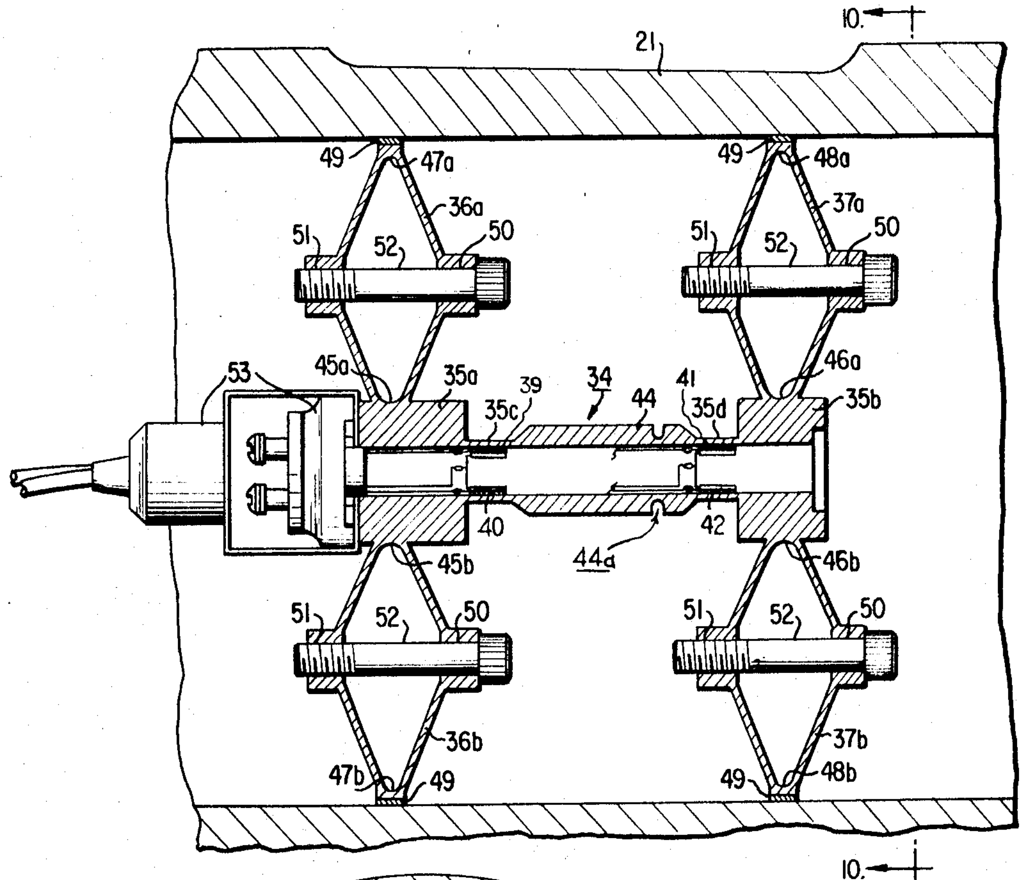

FIG. 9

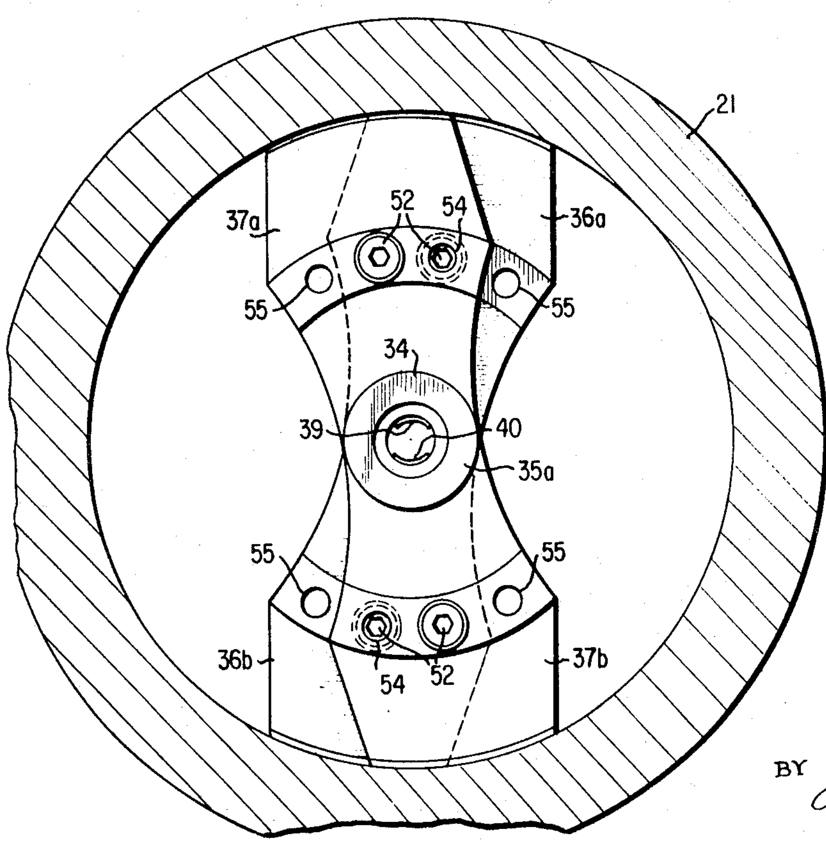

FIG. 10

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ON-BOARD AIRCRAFT TRANSDUCER

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Filed Jan. 14, 1970, Ser. No. 2,892
Int. Cl. G01l 7/16, 5/12
U.S. Cl. 73—88.5 19 Claims

ABSTRACT OF THE DISCLOSURE

Weight supported by a wheeled vehicle such as an aircraft is detected inside hollow axles by strain-gage transducers which are locked in place by individually adjustable spring-type collets making substantially line-contact connections with interior axle surfaces; the collets for each transducer are carried by rigid end portions of a sensing section including at least one deformable tubular portion equipped internally with strain gages arranged to characterize shear effects caused by the weight; and, in appropriate cases where installed within axles having non-uniform thickness, the sensing section is of an asymmetrical construction introducing self-compensation for measurement errors induced by axle non-uniformity.

BACKGROUND OF THE INVENTION

The present invention relates to improvements in the measurement of loadings such as those which are effective at the wheels of aircraft and the like, and, in one particular aspect, to novel and improved on-board aircraft weighing transducers which cooperate with axle structures of even non-uniform thickness to develop strain gage outputs characterizing weight-related vertical forces, and which incorporate unique readily-adjustable and highly-secure mounting provisions.

As has long been well known, measurements of aircraft weights at distributed sites such as those of the usual landing gear provide data from which total weight and locus of the center of gravity may readily be calculated as important aids to safe and efficient aircraft operation. Although accessory weighing jacks and platform-type scales are capable of determining these weights accurately, it offers obvious advantage to integrate the weighing instrumentalities "on-board" where they may be used at any ground location at any time without involving outside equipment and personnel. Accordingly, for the latter purposes, it has been proposed that the sensing techniques might include mounting potentiometer-type detectors or strain gages directly on the wheel struts or in association with deformable members responsive to pressures in the hydraulic wheel suspensions. As a practical matter, such techniques are found to be wanting in that have not succeeded in avoiding serious errors due to responses to forces other than those representing merely the craft weight; in hydraulic or pneumatic systems, for example, there are highly disturbing effects of friction between relatively movable parts, and in the strut-gaging systems the measurements unavoidably reflect unwanted responses to side loadings due to such factors as wind, apron discontinuities or slopes, and uneven tire wears or inflations. The allowable margin of error in calculations of aircraft center of gravity is very small, because of the great hazards which can result from faulty information as to its whereabouts in what invariably a very limited permissable range to begin with on any craft.

In accordance with certain aspects of the recognitions and teachings of the invention of U.S. Pat. No. 3,426,586, assigned to the same assignee as that of the present application, on-board transducers of a strain-gage type may be caused to respond with extraordinary precision to loading forces which produce shear in wheel axles of aircraft landing gear, with the result that their responses accurately characterize true weight reactions which are essentially isolated from the usual error-inducing effects differently evidencing themselves as bending. Isolation of shear is promoted by mounting a gaged shear-responsive element upon a wheel axle by way of spaced fitted collets which are in line contact with the axle, and the outputs are preferably improved through use of a sensing section including at least one deformable tubular portion equipped internally with strain gages intended to characterize only shear effects caused by the weight. However, it has been found that prior colleting has been difficult to install and adjust into secure locked positions, particularly within the confines of hollow axles which are expected to withstand extremes of shock, vibration, temperature, contamination and like environmental conditions. Moreover, the sensing portions of such transducers must be carefully and precisely oriented or zeroed within the axles, and prior multi-part adjustment provisions do not offer the ease and security of adjustments which would be optimum in many installations. In addition, transducers which suffice for measurements within axles exhibiting uniform cross-sections along the regions of the transducers, are found to be subject to errors, mainly due to unwanted responses to bending rather than shear effects, when the axles are non-uniform or are effectively non-uniform because of influences of other members. The present teachings enable difficulties of the aforesaid character to be overcome, by way of transducer structure of low-cost manufacture which is exceedingly rugged, easily installed and adjusted, readily adaptable to uses with non-uniform axles, and, further, is tunable to improve precision of measurements by offsetting unwanted bending responses.

SUMMARY OF THE INVENTION

It is one of the objects of the present invention, therefore, to provide novel and improved transducer apparatus of low-cost rugged construction which is uniquely adjustable to provide accurate measurements of vehicle loadings in response to axle deflections.

Another object is to provide new and advantageous strain-gage transducers having improved collet mounts capable of supporting a sensing section securely within a hollow axle under extreme environmental conditions of use, and which are nevertheless readily installed and finely adjustable in situs.

An additional object is to provide shear-responsive strain-gage transducers which may be installed in initial stress-free or zeroed relationship within hollow vehicle axles, and which are uniquely proportioned for precise measurement of wheel reactions in vertical directions independently of side loadings and related bending-moment effects, even with axles of non-uniform cross-section.

Further, it is an object to provide unique onboard aircraft weight transducers of essentially one-piece construction which may be quickly and reliably mounted and precisely adjusted within tubular wheel axles by way of individually-expansible portions of line-contacting collet members, and which involve shear-responsive strain-gage sensors which advantageously promote maximum outputs and effect cancellations of unwanted bending-moment reactions which would otherwise result from axle non-uniformities.

A still further object of the present invention is to provide an improved onboard aircraft weight transducer having tubular shear-responsive sensing sections which involve deformable portions separated by a more rigid portion to promote optimum outputs, and which are supported asymmetrically to promote suppression of unwanted bending-moment effects not related to the weight under measurement.

By way of a summary account of practice of this invention in one of its aspects, the weight supported by each wheel of an aircraft is detected by a strain-gage transducer mounted within the usual hollow axle associated therewith, the sensing section for the transducer including at least one relatively flexible tubular portion asymmetrically disposed to a predetermined degree in relation to mounts for relatively rigid end portions united therewith, such that unwanted bending effects do not produce erroneous outputs from the circuitry of strain gages housed within the sensing section. Each of the rigid end portions of the sensing section is supported by a pair of diametrically-opposed radially-expansible collet members, and each of the collet members is of a bowed form rendering it individually adjustable, radially, by way of axial compression via an adjusting member. The said collet members are radially expansible to make secure and essentially line-contact connections with the interior of the axle, and to provide stable and rigid internal suspensions for the rigid ends of the sensing section. Further, they act as somewhat resilient supports which will compensate for internal dimensional changes in the axle due to environmental effects, and, because of the individual radial adjustabilities, the collet members provide an important convenient means for eliminating or adjusting the orientation of and pre-load forces experienced by the sensing section when it is first installed. Strain gages bonded to the tubular members at diametrically-opposite positions respond to both bending and shear effects, but due to the combined effects of properly locating the gages and mechanically adjusting the unique collets, unwanted responses due to bending effects are eliminated and the outputs are related substantially to shear alone. The latter outputs are, in turn, accurately related to the wheel reactions due to craft weight, without including error-inducing components resulting from side loadings, and with minimized shifts due to exposures to environmental extremes.

BRIEF DESCRIPTION OF THE DRAWINGS

Although the aspects and features of this invention which are believed to be novel are expressed in the appended claims, additional details as to preferred practices and embodiments, and as to the further advantages, objects and features thereof, may be most readily comprehended through reference to the following description taken in connection with the accompanying drawings, wherein:

FIG. 1 illustrates an aircraft landing gear assembly in which dashed linework characterizes bending and shear deflections, together with related bending moment and shear diagrams;

FIG. 2 is a cross-section of an improved axle-mounted shear transducer in a neutral or undeflected condition, and without radial adjustments;

FIG. 3 is a cross-section taken along section line **3—3** in FIG. 2;

FIG. 4 represents an inner cylindrical surface of the transducer of FIGS. 2 and 3 together with strain gages carried thereon;

FIG. 5 schematically illustrates bridge circuit connections for gages such as those of FIG. 4;

FIG. 6 provides a cross-section of the same axle-mounted transducer in a condition of substantially pure shear;

FIG. 7 provides a cross-section of the same transducer undergoing bending;

FIG. 8 is a pictorial illustration of a preferred embodiment of an improved transducer, without radial adjustment members;

FIG. 9 comprises a longitudinal cross-section of the transducer of FIG. 8 together with a surrounding axle of non-uniform cross-section in axial directions;

FIG. 10 is a view of the transducer in FIG. 9, taken along section line **10—10** in FIG. 9;

FIG. 11 is a view, partly in section, of another collet arrangement; and,

FIG. 12 comprises a partly pictorial and schematic diagram of an on-board weight-responsive system into which the improved transducers may be incorporated.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The paired aircraft wheels **19** and **20** appearing in FIG. 1 represent part of a landing gear unit which bears some of the loading typically shared by a plurality of units in a landing gear array. Conventional tubular forms of an axle **21** and strut **22** communicate downward force **23** of the ground-supported aircraft to the wheels and thence to the underlying apron surfaces. Wheel reactions to the vertical loading are characterized by force arrows **24** and **25**, and normally are about equal. In addition to the downwardly-directed forces representing the aircraft weight which is of interest for measurement purposes, the wheel reactions can be expected to involve lateral components, such as are designated by arrows **26** and **27**, as the unavoidable result of such factors as wind loading, apron slope or irregularities, parking stresses, uneven tire inflations or wear, and the like. Resulting deflections of the halves of axle **21** reflect the effects of both bending moment and shear; bending moments tend to cause the kind of deflections designated by dashed linework **28**, and shear deflections tend to be of the nature designated by dashed linework **29**. Bending moment varies with position along the longitudinal axis of axle **21**, of course, and represents the vertical load multiplied by the distance between that position and the center of pressure of the tire on the underlying apron, plus any lateral loads multiplied by the tire radius. As has already been referred to, the side loads may vary and the radius and center of pressure, or "footprint," of the tire may change also. Bending moment plot **30** shows variations with distance, considering only the vertical load reactions **24** and **25** while they remain constant, and plots **31** and **32**, characterize the net bending moments due to the combined effects of these vertical load reactions with the horizontal side loads **26** and **27**, respectively. When transducers responsive to bending moments are employed, their axial positions are thus critical, and moreover, the contributions due to side loadings cannot be segregated and the measurement can be seriously in error if they are taken to represent craft weight. By way of important distinction, however, the shear plot **33** characterizes only the forces in the vertical direction, as desired, and is even essentially independent of the positions along each half of the axle.

Based upon recognitions of the latter advantages, a shear-responsive transducer **34** (FIG. 2) is disposed within each half of the hollow cylindrical axle **21** to sense and characterize only the shear effects which take place due to weight-related forces acting in the vertical direction. The sensing element includes spaced rigid end portions **35*a*** and **35*b*** and an intermediate sensing section including spaced relatively thin-walled flexible tubular portions **35*c*** and **35*d***, the rigid end portions each being separately suspended within the axle by diametrically opposed radially expansible collects **35*a*, 35*b*, 37*a*** and **37*b***, which are seen to be doubly-bowed and can be individually compressed laterally to cause firm substantially line-contact engagements with the inner axle surface **21*a*** as the result of toggle-like radial expansion of the collets. Electrical shear-responsive strain gages are bonded to interior surfaces (such as **35*c*'** in FIG. 4) of the relatively thin flexible portions **35*c*** and **35*d*** at each of two opposite upper and lower positions along a vertical diameter at the respective portions, where they also will unavoidably respond to certain tension and compression effects exhibited at these sites due to unwanted bending, such as that caused by side loadings mentioned above. Further important advantages result from the fact that this unique form of shear sensor well lends itself to construction as a small light-weight element which does not add significantly to the craft loading, which may be flexible and sensitive enough to develop large responses, and which may be machined simply and accurately. Collaterally, it is important that the preferred colleting, described in detail later herein, need not be adjusted in a manner which would tend to impose forces disturbing the lightweight construction of the sensing element. In FIG. 4, wherein the cylindrical inner sensor surface **35c'** is opened out flat for purposes of illustration, the top strain gage **39**, is shown to have its wire grid **39a** aligned substantially parallel with the longitudinal axis of the sensor, and the bottom strain gage **40** has a like wire grid **40a**, with its filaments similarly aligned. The companion gages **41** and **42** at the top and bottom of the interior of sensor section **35d** are arranged the same way.

One of the two strain-gage bridges, SB**1**, in FIG. 5 is shown to include the aforementioned gages, it being understood that the companion bridge SB2 for a transducer associated with an adjoining half axle, or the like, is of course similar. The strain-gage grid-wires for each half of the pair constituting the gage installation for each of the two sensor sections are connected in series in adjacent arms of the bridge SB1, and the two series-connected pairs are paralleled across the input electrical excitation leads 43_I. Output from the bridge is taken across the junctions of the respective series-connected pairs, via leads 43_O. Considering the pure shear condition depicted in FIG. 6, for example, the gages **39** and the diametrically-opposite gages **40** for sensor section **35c** respectively in compression and tension while the gages **41** and **42** for sensor section **35d** are respectively in tension and compression; hence the bridge is appropriately unbalanced and its output leads 43_O yield a desired electrical output signal characterizing the vertical forces related to weight. If undesirable forces cause bending of the axle, rather than shear-type deflection, the gages **39** and **41** would both be in compression, for example, while the other gages **40** and **42** would both be in the opposite state, tension, and the bridge would not be unbalanced, and would develop no erroneous outputs responsive to those forces which induce bending; this is highly desirable, of course. Typical results of unavoidable vertical bending forces portrayed in convenient exaggeration in FIG. 7; in that case, the two top gages experience compression and the lower gages tension, such that there is no related output from the aforementioned bridge. Other unwanted effects, such as those of torsion and axial elongation are simply ignored advantageously by the bridge because of the self-cancelling action.

In a preferred embodiment appearing in FIGS. 8 through 10, an on-board axle type transducer is shown as having a pair of collets **36** and **37** each of which includes a pair of diametrically-opposite spring members **36a**, **36b**, **37a** and **37b**, respectively. Collets **36** and **37** are of unique lightweight construction which will reliably and securely secure and retain the transducer in a fixed position despite irregularities in unfinished inner surfaces of an axle, and despite extremely severe shock, vibration and temperature cycling. Each half collet, that is, each of the metal spring members **36a**, **36b**, **37a** and **37b** is independently adjustable, such that each collet may be independently radially expanded to lock in place the associated rigid end portion (**35a** or **35b**) of the sensor section without undesirably stressing that sensor section. For such purposes, each spring member is fashioned in an open bowed configuration, which in the illustration is diamond-like and has the "sides" thereof joined together or formed integrally to provide a resilient doubly-bowed structure having its radially innermore "corners" united with the respective rigid end portions **35a** and **35b** of the sensor section, as shown at **45a**, **45b**, **46a** and **46b**. The opposite radially-outermore "corner" **47a**, **47b**, **48a** and **48b** of spring members **36a**, **36b**, **37a** and **37b** are disposed and shaped to engage the inner surface of axle **21** over narrow "line" contact arcuate regions, and preferably include an outer edge coating **49**, of material which is softer than the axle material, such that the axle surface will not be scored or scratched by the spring members. Undesirable stress concentrations in the axle are thus minimized, while secure fitting is assured. Enlarged and relatively stiff portions about radially midway along the bowed spring members are provided as part of the axial-compression adjustments for the desired radial expansions. At least two, and preferably three, angularly-spaced apertures are provided in each of the aforesaid enlarged portions of the spring members with the centrally-disposed axially-innermore aperture **51** associated with each spring member being internally threaded. An adjusting screw **52** is provided for each of the spring members, and extends through the forward unthreaded aperture **50** into engagement with the rearward threaded aperture **51**; adjustment of the radial expanse of the associated spring member accompanies axial compression of the doubly-bowed spring member, as the screw is tightened. As is shown in FIGS. 9 and 10, the adjusting screws **52** are all adjusted from the out-board end of the axle **21**, whence the transducer is accessible. To make the adjusting screws **52** associated with the inner collet **36** readily adjustable from the outer end of the axle, an otherwise-unused aperture **54** is provided in each of the spring members **37a** and **37b**, and, further, collet member **36** is angularly offset somewhat in relation to collet member **37** to align adjusting screws **52** associated with collet member **36** with the access-apertures **54** in collet member **37**. Adjusting screws **52** associated with collet member **36** are readily accessible from the outside of the axle by way of a tool inserted through the apertures **54** and into turn-inducing engagement with the appropriately-shaped heads of the screws **52**. Each of the spring members **36a**, **36b**, **37a** and **37b** is also shown to be provided with apertures **55** which serve the purpose of imparting symmetry to the spring members which promotes even loading and avoids undesirable stress concentrations.

When the screws **52** are loose and the spring members **36a**, **36b**, **37a** and **37b** are unexpanded, the transducer assembly with which they are associated may be slid into the axle from the out-board end thereof to a desired axial position. Once in the proper position, the individual spring members may be radially extended by tightening the individual adjusting screws **52** to a predetermined torque by long-handled tooling such that the spring members will make narrow-area contact with the axle and bind the transducer so tightly in place as to preclude significant displacement. The spring members are capable of storing sufficient energy to compensate for such dimensional variations in the interior of the axle as will be caused by environmental conditions. Undesirable bending of the relatively delicate sensor section tends to develop during the mechanical mounting of the transducer within the axle, due to the need for mounting it at axially-spaced positions, and because of possible inaccuracies in the fabrication of the transducer and/or irregularities in the shape and surface characteristics of the axle. Because the spaced collets are formed by individually-adjustable spring members, the aforementioned undersirable bending can be eliminated readily and the sensor section can be secured in place substantially stress-free. By observing the outputs of the bridge circuitry associated with the sensor section gaging, using convention instrumentation, undesirable bending effects are immediately detected, and selected ones of the screws **52** are then adjusted, while making such observations until the unwanted bending effects are cancelled; this affords a highly advantageous and convenient means for obtaining a zero balance with respect to bending characteristics. The same kind of practice also enables any desired pre-loading effects, or the like, to be introduced, very simply and accurately. By way of distinction, prior fastening mechanisms have involved circumferential locking by way of simultaneous expansions essentially all around a sensor axis, such that the axis itself could not be shifted radially; the individual radial adjustments provided on opposite sides of a sensor axis, by way of the present teachings, instead permit each end of the generally-centralized sensor section to be centered or shifted, as necessary, without affecting the integrity of the structure or the setting at the opposite end.

The illustrated preferred sensor section includes a pair of axially-spaced, thin-walled and relatively flexible shear-sensing portions, **35*c*** and **35*d***, spaced by an enlarged and relatively rigid axially-extending mid portion **44**, and joined at their axial extremities with rigid end portions **35*a*** and **35*b***. The lengths of the relatively flexible shear-sensing portions **35*c*** and **35*d*** are shown to be sufficient to accommodate the internal gaging **39** and **40**, and to accommodate certain deflection-induced elastic deformations. In FIG. 9, the locus of gaging is shown to be close to the rigid end portions **35*a*** and **35*b***, where optimum measured elastic deformation effects are experienced. A hollow cylindrical shear-sensing section is preferred, and conveniently and economically lends itself to precision manufacture, although it should be appreciated that the cross-section may be other than of perfectly circular tubular form. Conveniently, the internal strain gaging of the sensor unit may be hermetically sealed by a cover plate for electrical connection leads, and an end housing **53** filled with potting compound (not shown) accommodates a cable connector and other desirable auxiliary items.

Axle thickness may not always be uniform and may, in fact, be of a non-uniform cross-section such as that of the tapering construction shown in FIG. 9, resulting in normally troublesome non-uniform deflection characteristics for the axle. The same may also be true where an axle is of uniform thickness along the specific region occupied by the transducer but is surrounded or otherwise influenced by other portions of different cross-section or by other members, such as bearings, beam joints and the like. For such reasons, and as shown in FIG. 9, rigid end portions **35*a*** is caused to extend a greater axial distance than rigid end portion **35*b***, whereby sensing sections **35*c*** and **35*d*** are asymmetrically disposed with respect to the transverse planes of support defined by the outer edges of the collet members. Such asymmetrical disposition of the sensing sections functions to compensate for the asymmetrical deflection of the non-uniform thickness axle **21**. In this connection, references to FIGS. 6 and 7 serves to aid in understanding the behavior of the axle and sensor unit; where one part of an axle is thinner, it will bend more under loading, and the flexible sensor sections within thus will not bend in the same uniform way they would if the axle cross-section were uniform throughout. The presence of shear-responsive gages at two axially-displaced sites, i.e. at the two sensor sections **35*c*** and **35*d*** in the structure under discussion, is primarily for the purpose of enabling their unwanted bending responses to cancel one another in their bridge-circuit arrangement, yet such cancellation will not occur, and error will result, if they respond unequally to unequal bending because of the non-uniformity of the axle. Accordingly, the responses of these sensor sections to bending is intentionally caused to be different, by predetermined amounts, by the aforesaid asymmetrical dispositions of these sections. As shown in FIG. 9, the sensor section which is nearer the thicker cross-section, i.e., section **35*c***, is moved further from the plane of its collet support, to cause the wanted offsetting increase in its bending, so that its bending will then substantially match that of the other section **35*d***, and their respective unwanted gage outputs due to bending effects will cancel while their wanted outputs due to substantially pure shear will augment one another. It is not essential that the mid portion **44** be rigid for the aforementioned beneficial effects to take place, but the mid portion **44** has the advantageous action of effectively multiplying the consequences of axle deflections, whereby more pronounced responses are developed by the strain gages than would be the case if the tubular unit were of the same flexibility throughout the length between the rigid end portions **35*a*** and **35*b***. The rigid mid portion **44** may be disposed asymmetrically in relation to the rigid end portions **35*a*** and **35*b***, for purposes of causing the two sensing portions **35*c*** and **35*d*** to be of different lengths, and, in turn, to develop intentionally different responses for introducing certain compensations, such as those for non-uniform axle cross-sections referred to hereinabove. Similarly, like asymmetrical effects may be developed, or unintended asymmetrical effects may be overcome, by machining down selected parts of the mid portion to impart a desired degree of flexibility at a site such as that of the annular groove **44*a*** in FIG. 9. Comparable effects may be realized by precision machining outside of the appropriate one of the sensing portions to a diameter less than that of the other.

The transducer **34** including the sensor unit and associated collet members is illustrated as a unitary member with no relatively moving parts which would tend to create troublesome hysteresis or frictional effects causing errors which would be sensed by the gages and displayed in the measurements. However, where it is not possible to install a unitary transducer within an axle, because of unusual internal configurations in axle construction, for example, it may then be warranted to construct the transducer of several parts for assembly within the axle.

The collet arrangement shown in FIG. 11 includes spring members **56*a*** and **56*b*** which are attached to the rigid end portion **63** of the sensor unit by means of cooperating tapered surfaces and a locking member **64**. It is to be noted that the spring members **56*a*** and **56*b*** may be formed integrally with the rigid end portion of the sensor unit as in the aforementioned embodiment. A pair of ring members **57** and **58** are concentric with the sensor unit and are interconnected with spring members **56*a*** and **56*b*** by means of sections **59** and **60** which are formed integrally therewith. An adjusting screw **61** extends through and is threadedly engaged with an aperture in ring member **58** and is threadedly engaged at the other end thereof with an adjusting nut **62** such that by tightening the adjusting screw **61**, the spring member **56*a*** is radially extended and by loosening the adjusting screw **61**, the spring member **56*a*** is brought radially inward.

A typical installation is represented in FIG. 18, wherein an aircraft nose wheel unit **78** and right and left main wheel units **79** and **80** are each equipped with the improved transducers within the axles near each wheel at sites marked X. Cabling **78*a*–80*a*** couples the transducer measurement information through the struts **78*b*–80*b*** to an on-board instrumentation package **81**. The latter provides visual gross weight and center-of-gravity displays **81*a*** and **81*b*** in accordance with known techniques; total weight is determined by adding the weights detected at the sites of each of the wheels, and center-of-gravity is computed by considering the moments of the wheel reactions (longitudinal and/or lateral) in relation to reference positions. Landing and lift-off conditions may be established from the weight signals also, although the conventional measurements are made while the craft is stationary.

The specific embodiments and practices herein described have been presented by way of disclosure rather than limitation, and various modifications, substitutions and combinations may be effected by those skilled in the art without departure in spirit of scope from this invention in its broader aspects and as set forth in the appended claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. Transducer apparatus comprising a load sensor unit having surfaces which exhibit strain responsive to loadings thereof, collet means for fixedly mating said sensor unit radially and axially in relation to a cooperating load-supporting member to exhibit strain response to loadings whereby, said collect means including at least two radially-expansible portions arrayed in substantially the same plane at different angular positions to support said sensor unit radially about a center and in relation to said load-supporting member, each of said radially-expansible portions including members which cooperate to produce a toggle-like radial expansion in response to lateral pressure, and means independently adjustable to apply lateral pressure to said members of each of said portions, and gage means for producing electrical output signals characterizing strain responses of said sensor unit to loadings thereof transferred to such unit by said collet means.

2. Transducer apparatus as set forth in claim 1 including at least two of said collet means mounting said sensor unit at spaced positions therealong, each of said portions of each of said collet means having narrow peripheral edge surfaces which form a substantially line contact with at least one of the adjoining peripheral surfaces of the load-supporting member and the load sensor unit.

3. Transducer apparatus as set forth in claim 1 wherein said members which cooperate to produce a toggle-like radial expansion are spring members, and wherein each of said portions of said collet means comprises two of said spring members which are of bowed form.

4. Transducer apparatus as set forth in claim 3 wherein said two spring members of bowed form are arranged back-to-back with their radially outer and inner edges together and other portions spaced further apart.

5. Transducer apparatus as set forth in claim 3 wherein the two spring members of each of said collet portions are back-to-back with a generally diamond-shaped spacing therebetween and have a first corner edge thereof affixed to said sensor unit and a second opposite corner edge thereof radially displaced from said sensor unit and adapted to engage said load-supporting member.

6. Transducer apparatus as set forth in claim 5 wherein third and fourth corner edges of the arrangement of said spring members have aligned apertures therein with surfaces surrounding at least one of said apertures being threaded, and wherein said independently adjustable means includes a threaded bolt member extending through said apertures and threadedly engaged with said surfaces.

7. Transducer apparatus as set forth in claim 6 wherein said third and fourth corner edges are substantially rigid.

8. Transducer apparatus comprising a load sensor having substantially rigid end portions and at least one relatively deformable portion between and joined as a unit with said end portions, collet means for mounting said end portions in relation to a load-supporting member at spaced positions therealong, at least one of said collet means including at least a pair of spring means arrayed in substantially the same plane and each individually radially expansible and each having narrow peripheral edge surfaces which form a substantially line contact in substantially the same plane with at least one of the peripheral surfaces of the load-supporting member and of the sensor end portion between which it is disposed, said spring means of each of said collet means being angularly displaced at different angular positions about said sensor to support said sensor radially in relation to said load-supporting member, and gage means for producing electrical output signals characterizing deformations exhibited by the load-supporting member and transferred to said deformable portions of said load sensor via the line contact of said edge surfaces of said collet means.

9. Transducer apparatus as set forth in claim 8 wherein each of said spring means includes members which cooperate to produce toggle-like radial expansion in response to lateral pressure, and means independently adjustable to apply lateral pressure to said members of each of said spring means, whereby said spring means provide secure connections with said load-supporting member while remaining yieldable radially to compensate for dimensional changes in said load-supporting member due to environmental effects.

10. Transducer apparatus as set forth in claim 9 wherein each of the spring means includes two of said members in a back-to-back arrangement with a generally diamond-shaped spacing therebetween and having a first corner thereof affixed to said rigid end portion and a second opposite corner thereof radially displaced from said rigid end portion and adapted to engage said load supporting member, and wherein third and fourth corners of said arrangement have aligned apertures, surfaces bordering at least one of said apertures being threaded, and wherein said means for applying lateral pressure and thereby adjusting the relative positions of said first and second corners including a threaded fastening member extending through said apertures and threadedly engaged with said surfaces.

11. Transducer apparatus as set forth in claim 10 including two of said collet means, one each at each of said spaced positions, aligned apertures through said third and fourth corners of one of said collet means being further aligned with aligned apertures of the other of said collet means and thereby affording access for adjustment of said adjusting means for said other collet means.

12. Transducer apparatus as set forth in claim 8 wherein said relatively deformable portion of said load sensor includes substantially tubular elastically-deformable material of substantially annular cross-section between and joined as a unit with said rigid end portions and exhibiting surface strains responsive to loadings thereof, said load-supporting member being hollow, and said collet means being disposed within said load-supporting member and applying loading forces to said end portions of said load sensor in directions substantially normal to the longitudinal axis of said tubular material, one of said rigid end portions being joined with said tubular material at a greater distance from the plane of line contact for the associated collet means therefor than is the other of said end portions, whereby said tubular material is asymmetrically disposed longitudinally with respect to the planes of said line contact of said collet means, said electrical strain gage means including at least one pair of electrical strain gages bonded respectively to diametrically-opposite surfaces of said tubular material at each of two positions axially spaced along said longitudinal axis.

13. Transducer apparatus as set forth in claim 8 wherein each of said collet means consists of two of said radially-expansible spring means substantially diametrically opposed to one another.

14. Transducer apparatus as set forth in claim 12 wherein said tubular material between said rigid end portions comprises two axially-spaced relatively-deformable sections joined with a relatively rigid mid-section axially therebetween, said pairs of strain gages each being disposed at a different one of said two spaced sections and responding to load-induced strains thereof.

15. Transducer apparatus as set forth in claim 12 wherein said load-supporting member comprises a vehicle axle, and wherein said strain gages at each of said positions are disposed along vertically-opposite surfaces.

16. Transducer apparatus as set forth in claim 15 wherein each of said strain gages includes electrically-conductive filaments extending substantially longitudinally along said surfaces of said tubular material, for response to shear-induced elastic deformations of said material.

17. Transducer apparatus as set forth in claim 12 where-

in said gage means includes electrical bridge circuitry having electrical excitation terminals and electrical output terminals, and means connecting said strain gages in said circuitry as arms thereof to unbalance said circuitry in response to deformations of said material induced by shear of said load-supporting member while preserving said circuitry substantially balanced in response to deformations of said material induced by bending of said load-supporting member.

18. Transducer apparatus as set forth in claim **12** wherein said load-supporting member is more rigid nearer one of the said planes of contact and tends to bend non-uniformly, said one of said end portions being further from said one of said planes and thereby being effective to induce correspondingly greater relative bending of the nearby tubular material in response to bending of said load-supporting member.

19. Transducer apparatus comprising a load sensing device including substantially rigid end portions and substantially tubular elastically-deformable material between and joined as a unit with said end portions and exhibiting surface strains responsive to loadings thereof, means for applying load forces to said end portions of said load sensing device in directions substantially normal to the longitudinal axis of said tubular material, first strain gages bonded to said tubular material nearer one of said end portions and responding to load-induced surface strains thereof, substantially parallel with said axis second strain gages bonded to said tubular material nearer the other of said

end portions and responding to load-induced surface strains thereof, substantially parallel with said axis said tubular material nearer said one of said end portions and said tubular material nearer said other of said end portions being united with and longitudially spaced along said axis by a substantially rigid elongated mid portion, electrical bridge circuitry having electrical excitation terminals and electrical output terminals, and means connecting said strain gages in said circuitry as arms thereof to unbalance said circuitry in response to deformations of said material induced by displacements of said end portions in shear while preserving said circuitry substantially balanced in response to deformations of said material induced by displacements of said end portions in bending.

References Cited

UNITED STATES PATENTS

3,272,006	9/1966	Eckard	73—141 A
3,327,270	6/1967	Garrison	338—2
3,426,586	2/1969	Kadlec	73—88.5
3,494,181	2/1970	Boelkins	73—88.5
3,521,484	7/1970	Dybvad et al.	73—88.5

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