NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546

REPLY TO ATTN OF: GP

October 15, 1970

TO: USI/Scientific & Technical Information Division
Attention: Miss Winnie M. Morgan

FROM: GP/Office of Assistant General Counsel for Patent Matters

SUBJECT: Announcement of NASA-Owned U.S. Patents in STAR

In accordance with the procedures contained in the Code GP to Code USI memorandum on this subject, dated June 8, 1970, the attached NASA-owned U.S. patent is being forwarded for abstracting and announcement in NASA STAR.

The following information is provided:

U.S. Patent No.	:	3,295,377
Corporate Source	:	Manned Spacecraft Center
Supplementary Corporate Source	:	
NASA Patent Case No.	:	XMS-05936

Gayle Parker

Enclosure:
Copy of Patent

N70-41682

(ACCESSION NUMBER) (THRU)

8 (PAGES) 0 (CODE)

(NASA CR OR TMX OR AD NUMBER) 14 (CATEGORY)

FACILITY FORM 602

NASA-HQ

N70-41682

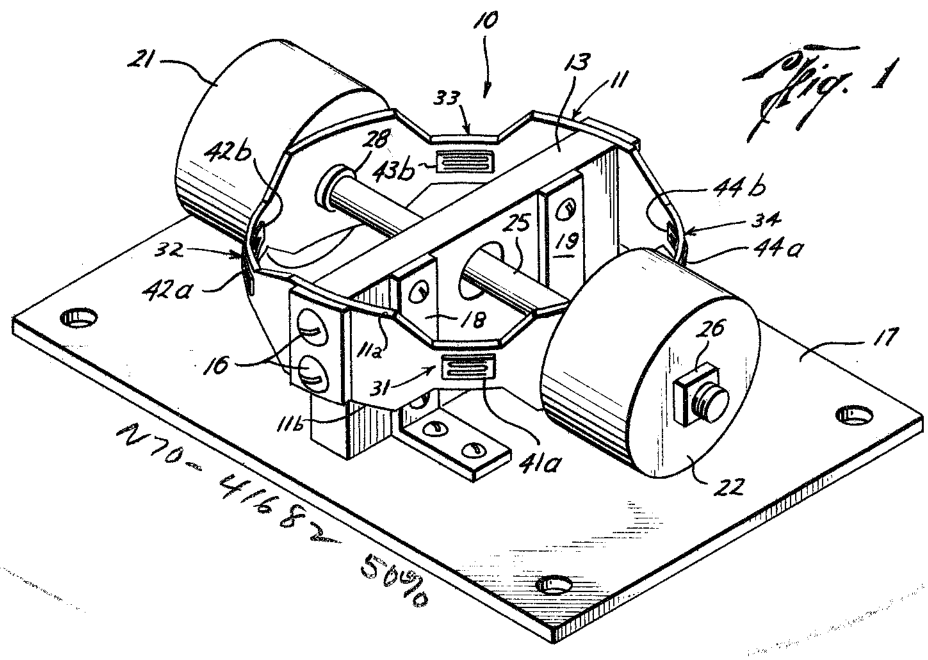


Fig. 1

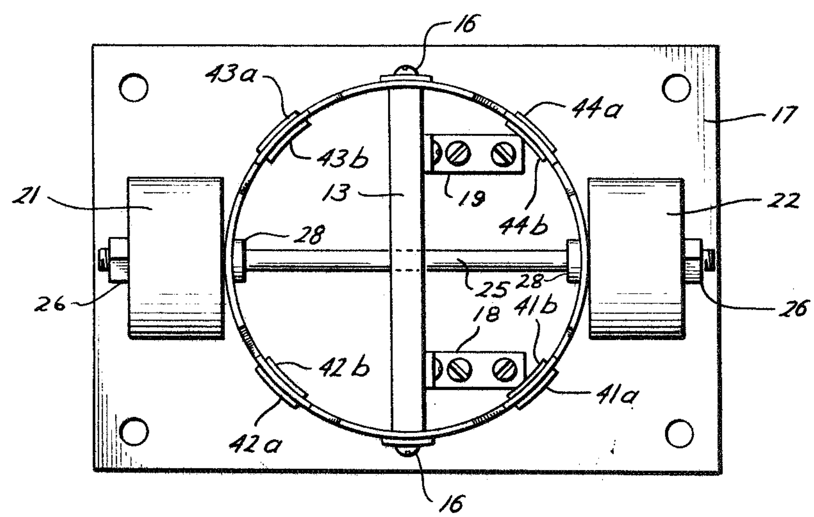


Fig. 2

Richard R. Richard
INVENTOR

BY G. T. McCoy
M. J. Marnock
ATTORNEYS

669

Jan. 3, 1967 R. R. RICHARD 3,295,377

ANGULAR ACCELEROMETER

Filed June 13, 1966 2 Sheets-Sheet 2

Fig. 3

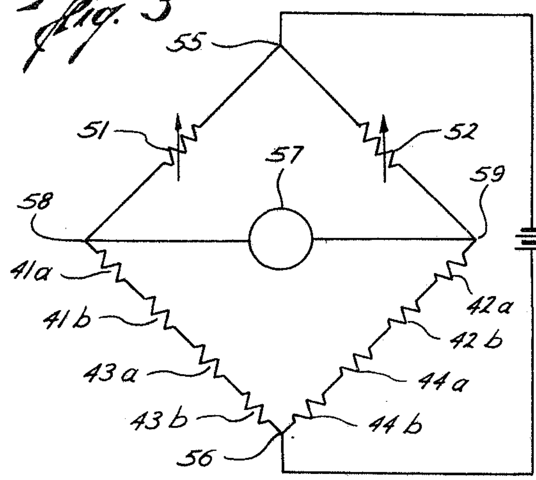
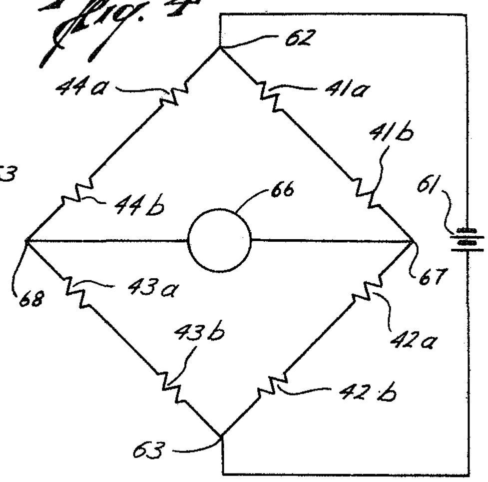


Fig. 4



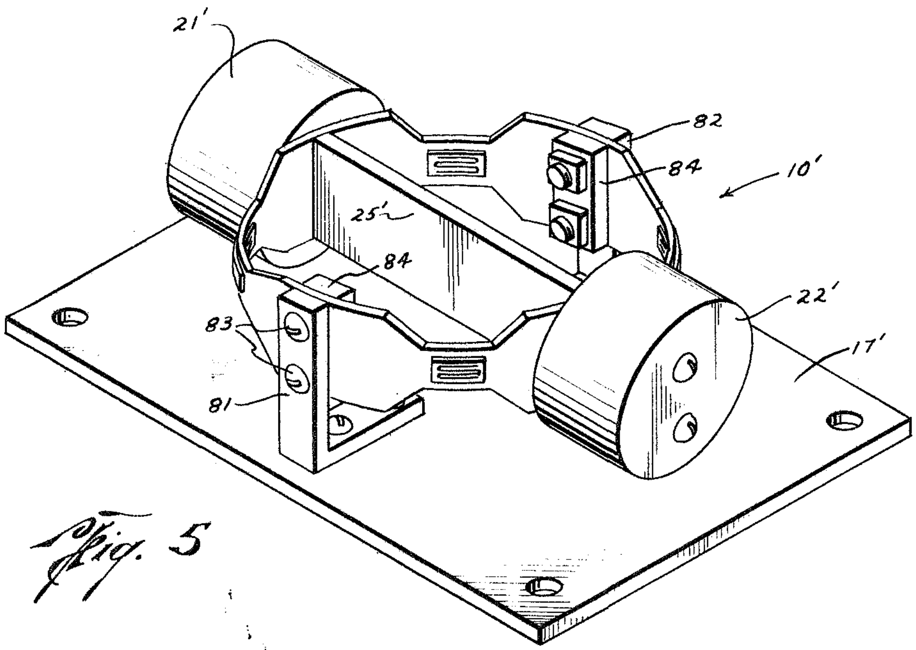


Fig. 5

Richard R. Richard
INVENTOR

BY [signature] [signature]
ATTORNEYS

United States Patent Office

3,295,377
Patented Jan. 3, 1967

3,295,377

ANGULAR ACCELEROMETER

Richard R. Richard, Houston, Tex., assignor to the United States of America as represented by the Administrator of the National Aeronautics and Space Administration

Filed June 13, 1966, Ser. No. 557,868
8 Claims. (Cl. 73—517)

The inver..on described herein was made by an employee of the United States Government and may be manufactured and used by or for the Government for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates to accelerometers, and more particularly to an accelerometer for measuring angular accelerations.

In the guidance and control systems of spacecraft and missiles it is particularly important and desirable that angular accelerations be measured with extreme precision. While a variety of angular accelerometers have heretofore beer devised, they are generally undesirable for use in harsh environments since their operation in adversely affected by large temperature variations and vibrations which induce unwanted signals.

In one method which has heretofore been used for measurement of angular acceleration, two accelerometers of the type having a linear sensitive axis, and normally responsive to linear acceleration, are disposed with their sensitive axes parallel. The two linear accelerometers are electrically connected and so oriented that their outputs are additive for angular accelerations, but are cancellative f r linear accelerations. In this arrangement, however, t.e geometry is critical, and extreme caution must be taken to assure equal sensitivities in the accelerometers. The arrangement is vexed by structural flexure problems and vibrations which may be induced in the two linear accelerometers are usually nonuniform, thus complicating the problem of nulifying vibrational effects. Furthermore, the accelerometer pair is generally sensitive to an angular velocity about an arbitrary axis lying in or parallel to the plane of the sensitive axes.

Another apparatus which has been used for measuring angular acceleration comprises a metal arm which is pivoted at its center point and provided at each end with a mass connected thereto. Angular acceleration tends to cause rotation of the arm about its pivotal axis. This motion is sensed by electronic means which supplies an input to a servo -ystem adapted to provide a proportional restoring torque. A measurement of the current supplied to the torque motor of the system provides a signal proportional the angular acceleration. In this type of servo-controlled apparatus, frequency response is often sacrificed, and the associated electronic circuitry is complex. Also, the nature of the sensing element requires difficult and tedious manufacturing processes.

Another apparatus which has been used for measuring angular acceleration comprises a continuous circular tube of fluid with a paddle disposed within the fluid. Angular acceleration causes the fluid to displace relative to the container wall, and thus induces a paddle movement which is converted to an electrical output signal proportional in magnitude to the acceleration. Construction tolerances are critical in this type of apparatus, however, and for many applications the device is objectionably heavy and large. Furthermore, vibrational effects and complications resulting from zero gravity environment limit its desirability for aerospace applications.

The angular accelerometer of this invention, which has been devised to overcome attendant disadvantages in the prior art devices, is of relatively lightweight rugged construction with uncomplicated measuring circuitry. The invention comprises a sensing ring with a pair of

masses supported on the ring in diametrically opposed locations. The masses are joined by a rigid connecting rod which is also fixed to the ring at these locations. The ring is secured at diametrically opposed points to a rigid support means which is fixed to the body to be subjected to angular accelerations. Preferably, the points of support for the sensing ring are disposed in a ninety degree relationship to the rod which joins the masses.

The sensing ring is also provided with strain intensification areas in four locations which are equiangularly disposed about the ring. The strain intensification areas are produced by notches in the ring which reduce the cross-sectional area of the ring at four locations. The arrangement is such that a strain intensification area is located between each mass and point of connection of the ring and support member. At each strain intensification area a strain gauge is bonded to the sensing ring on its external surface, and a corresponding strain gauge is attached on its inner surface so that the strain gauges are arranged in diametrically opposed pairs. The gauges are electrically connected in a bridge circuit arrangement which becomes unbalanced by variations in the electrical resistances of the gauges when they are subjected to tension or compression forces. In the event of an angular acceleration, the inertia of the ring-supported masses results in the transmission of forces along the sensing ring and subjection of each of the several gauges to either tension or compression forces, with a consequent imbalance of the bridge circuit proportionate to the magnitude of angular acceleration.

Although the accelerometer of this invention is operational with only the external strain gauges, the strain gauges located on the inner surface of the ring enhance the over-all sensitivity of the device since they serve to cancel vibrations in the sensing ring and any forces other than those yielding angular acceleration data which may be applied to the ring. The rigid rod which joins the masses on the sensing ring also tends to insure uniformity in vibrations which may be induced in opposing halves of the sensing ring so that compensation of vibrational effects is greatly simplified. In addition, the arcuate configuration of the sensing ring increases the strength of the mass supporting means and is less subject to vibration than elongate linear structures.

Other objects and many of the attendant advantages of this invention will be readily appreciated as the same become better understood by reference to the following detailed description when considered in connection with the accompanying drawings in which like reference numerals designate like parts throughout the figures thereof and wherein:

FIG. 1 is a perspective view which illustrates the mechanical features of a preferred arrangement of the invention;

FIG. 2 is a top planar view of the apparatus shown in FIG. 1;

FIG. 3 is a schematic diagram of a simple measuring circuit of the invention;

FIG. 4 is a schematic diagram of an alternative form of the measuring circuit for the invention; and

FIG. 5 is a perspective view of an alternative arrangement of the mechanical features of the invention.

Referring more particularly to the drawings, there is shown in FIG. 1 an angular accelerometer **10** which constitutes a preferred embodiment of the invention. The accelerometer **10** comprises an annular sensing ring **11** of aluminum which is carried by a diametrically disposed support member **13**, also of aluminum. The sensing ring in the form of a circular cylinder is bolted to the ends of the support member **13** by bolts **16**, and carried thereby a uniform distance above a base plate **17** to which the support member is secured by L-shaped braces **18**, **19**.

The base plate **17** is adapted to be bolted to the body or vehicle which is to be subjected to angular accelerations.

Supported on the ring in diametrically opposed locations thereon are a pair of masses **21**, **22** in the form of steel disks. The masses **21**, **22** are threaded on the ends of an aluminum connecting rod **25** which extends through an opening provided in the support member **13** and through openings provided in the sensing ring for this purpose. The steel disks are held clamped against the external surface of the sensing ring by nuts **26** on the threaded ends of the rod **25**. In addition, clamping nuts **28** are disposed internally of the ring on the rod **25** and clamp against the inner surface of the ring. The nuts **28** are provided with curved faces which conformingly engage the curved surface of the ring so as to provide uniform clamping surfaces.

The edges **11***a* and **11***b* of the cylindrical sensing ring are each notched at four locations equiangularly disposed about the ring to provide strain intensification areas **31**, **32**, **33**, and **34**, as best shown in FIG. 1. The arrangement is such that a strain intensification area is located between each mass **21**, **22** and point of connection of the ring and support member. At each strain intensification area a strain gauge is bonded to the sensing ring on its external surface, and a corresponding strain gauge is attached on its internal surface. The ring is, therefore, provided with external strain gauges **41***a*, **42***a*, **43***a*, and **44***a* located respectively at strain intensification areas **31–34**, and also with strain gauges **41***b*, **42***b*, **43***b*, and **44***b* located respectively on the inner surface of the ring at the strain intensification areas **31–34**.

The strain gauges used in the accelerometer of this invention are of the strain wire transducer type, of which many kinds are commercially available, although piezo resistive type gauges are also satisfactory. As is well known, the electrical resistance of a strain gauge element undergoes a change when there is a change in magnitude or direction of force applied to the element, as for example an increase in electrical resistance when the element is placed in tension and a decrease in electrical resistance when the element is placed in compression. Each of the gauge elements is therefore oriented with its conductors parallel to anticipated strain, and is provided with electrical leads which connect the element in a measuring circuit in which the resistance variations of the strain gauges can produce electrical variations indicative of the stresses to which they are subjected.

As shown in FIG. 3, the strain gauges in the accelerometer **10** are electrically connected in a bridge circuit in which the several strain gauges are represented schematically of resistances of corresponding reference number. In one arm of the bridge the strain gauge elements **41***a* and **41***b* located at one strain intensification area of the sensing ring are serially connected to the diametrically opposed strain gauge elements **43***a* and **43***b*. In like manner, strain gauge elements **42***a* and **42***b* are serially connected with strain gauge elements **44***a* and **44***b* in a second arm of the bridge. The remaining arms of the bridge are provided with balancing resistors **51**, **52**, respectively. For circuit operation, a direct current voltage from a voltage source **53** is applied across the bridge at the junctions **55** and **56** between the balancing resistors **51** and **52** and the resistors **43***b* and **44***b*, respectively.

In the absence of an angular acceleration or any other unsettling forces on the strain gauge elements, the bridge circuit is balanced by means of the adjustable resistors **51** and **52**. For indicating the condition of bridge balance or imbalance, a null detector meter **57**, preferably of the "zero-center" type, is connected across opposing corners of the bridge to the junctions **58** and **59**.

By referring to FIG. 1 it will be noted that clockwise rotary acceleration of the angular accelerometer **10** will result in the strain gauges **43***a* and **43***b* being placed in tension, and the strain gauges **42***a* and **42***b* being placed in compression, due to inertia of the mass **21**. Also, due to inertia of the mass **22**, the strain gauges **41***a* and **41***b* are placed in tension, and the gauges **44***a* and **44***b* are subjected to compression forces. Since all of the strain gauges in one arm of the bridge are in tension, and all of the gauges in another arm of the bridge are in compression, the resistance ratios of the bridge arms are no longer equal, so that there is a resulting imbalance of the bridge circuit indicated by a voltage across the junctions **58** and **59**. The magnitude of the voltage is proportional to the magnitude of the angular acceleration, and the direction of the angular acceleration is indicated by the polarity of voltage across the junctions **58** and **59**.

It is readily apparent that the angular accelerometer **10** is operational with only use of the external strain gauges. However, the location of strain gauges on the inner surface of the sensing ring enhances the over-all accuracy and sensitivity of the device, since these gauges serve to cancel vibrations which might be induced in the sensing ring and any forces other than those yielding angular acceleration data. For example, an undesirable flexing of the sensing ring in the area of the strain gauges **44***a* and **44***b* would result in one of the gauges, either **44***a* or **44***b*, being placed in tension, and the other gauge being placed in compression. Consequently, the electrical effects on the gauges are nullified since the increase in electrical resistance of the gauge placed in tension is balanced by the decrease in electrical resistance of the gauge which is placed in compression, and there is an effective cancellation of the undesirable flexure.

An alternative form of bridge circuit for measuring angular acceleration is shown in FIG. 4. In this simpler form of circuit the serially connected strain gauge elements **41***a* and **41***b* associated with the strain intensification area **31** are placed in one arm of the bridge, and the gauges **42***a* and **42***b* at strain intensification area **32** are connected in series in a second arm. The third bridge arm comprises the strain gauges **44***a* and **44***b*, and the fourth arm comprises the strain gauges **43***a* and **43***b*. A direct current voltage from a voltage source **61** is applied across the bridge at the junctions **62** and **63**. The condition of bridge balance or unbalance is indicated by a null meter **66** connected across the junctions **67** and **68** between the gauges **41***b* and **42***a*, and between the gauges **43***a* and **44***b*, respectively. The several strain gauges are carefully calibrated and adjusted to have identical resistances so that the bridge is normally in balance.

It will be noted that a clockwise rotary acceleration of the angular accelerometer **10** in FIG. 1 places the gauges **41***a*, **41***b*, and **43***a*, **43***b* in tension, and the gauges **42***a*, **42***b* and **44***a*, **44***b* in compression. Since there is a change in the resistance ratios of the bridge arms, there is a resulting imbalance of the bridge and a corresponding indication of acceleration. The direction of the acceleration is determined by the voltage polarity across the junctions **67** and **68** which is indicated by the direction of the meter deflection. A counterclockwise acceleration, of course, results in a similar imbalance of the bridge with a reversal of tension and compression forces resulting in a voltage polarity reversal.

By the arrangement shown in FIG. 1, it is to be noted that a linear acceleration of the accelerometer **10** will be effectively nullified by the nature of forces applied to the various strain gauges. For example, due to inertia of the masses **21** and **22**, a linear acceleration of the accelerometer **10** is in the longitudinal direction of the support member **13** and to the right in the figure will result in compression of the gauges **42** and **41**, respectively, and subjection of the gauges **43** and **44** to tension forces. The balance of the bridge circuit therefore remains undisturbed since the resistance ratio of the bridge arm containing the gauges **41***a*, **41***b*, and the arm containing the gauges **42***a*, **42***b* remains equal to the resistance ratio of the arm containing gauges **44***a*, **44***b* and the arm containing gauges **43***a*, **43***b*.

In like manner, a linear acceleration in the direction of the mass connecting rod **25** and to the right in FIG. 1 results in a compression of the gauges **41** and **44**, and subjection of the gauges **42** and **43** to tension forces. It will therefore be readily seen with reference to FIGS. 4 or 5 that the measuring circuit balance remains undisturbed, and the linear accelerations are effectively nullified in the accelerometer.

An important feature of the accelerometer **10** is provision of the rigid aluminum rod **25** which is clamped at each end to the sensing ring. The presence of the rod tends to insure that any vibrations which are induced in the two halves of the ring opposite the supporting member **13** are in correspondence and identical, so that the electrical balance of the measuring bridge is undisturbed. It is also to be noted that by the novel arrangement wherein the strain gauges are mounted on an annular sensing ring, impedance matching of strain gauges and their symmetrical arrangement is made far simpler due to the simple geometry of the system.

It is to be understood, of course, that although the principal parts of the angular accelerometer of this invention are described as being fabricated of aluminum, with the exception of the steel disk masses, other metallic materials could be used in lieu thereof. Also, while the annular sensing ring of the accelerometer **10** is in the form of a circular cylinder, other annular shapes could be employed.

A modification of the invention using an alternative form of support means for the sensing ring is shown in FIG. 5. In this embodiment **10′**, the support is provided by a pair of L-shaped braces **81**, **82**, each of which is bolted to the base plate **17′** and to the external surface of the sensing ring. The bolts **83** through the ring are held by fastening plates **84**. This form of the invention is more susceptible to structural flexures than is the accelerometer **10** and presents problems in alignment of the graces and in avoiding pre-loading strains in the sensing ring. However, by eliminating the diametrically disposed supporting member for the ring **11′** permits a reduction in weight of the device and has particular application where weight is especially critical. It also permits use of a more rigid connecting rod **25′** between the masses **21′** and **22′** than can normally be used with the accelerometer **10**.

The sensitivity of the device is a function of several variables such as the radius of the annular sensing ring, the size of the masses, and the size of the strain intensification areas. The sensitivity is also readily adjustable by replacement of the masses on the annular ring with masses of a different size. In this respect an annular sensing ring of smaller radius would require the use of larger masses to maintain a comparable sensitivity. Furthermore, while it would be possible to reduce the width of the annular sensing ring, that is, the dimension parallel to the cylindrical axis, this would render the device more susceptible to vibrations and flexures in this direction, so that the provision of strain intensification areas as in the accelerometer **10** is to be preferred.

The unique structure of the angular accelerometer of this invention provides a very sturdy and reliable device which exhibits a very precise high and low frequency response and one which is insensitive to constant angular velocity. It would be possible, of course, to modify the structure described herein as by the use of strain gauges other than the bonded strain wire resistance type, for example, piezo resistive gauges. It would also be possible to fabricate the accelerometer of this invention by using two separate semicircle shapes with aligned centers of curvature for supporting the masses in lieu of the annular sensing ring. However, the feature that all of the strain gauges are mounted on the same sensing ring provides for accurate temperature compensation since heat conduction in the sensing ring insures that all of the gauges are of uniform temperature. Temperature compensation, of course, is not so reliable in a device in which the strain gauges are mounted on separate structures and the problem of structural flexures would also be more critical.

It should also be understood that the foregoing disclosure relates only to preferred embodiments of the invention and that it is intended to cover all changes and modifications of the examples in the invention herein chosen for the purposes of the disclosure and which do not constitute departure from the spirit and scope of the invention.

What is claimed and desired to be secured by Letters Patent is:

1. An apparatus for measuring angular acceleration, said apparatus comprising:
- a ring member;
- support means for supporting said ring member at diametrically opposed points on said ring member, said support means being rigidly connectable to a body adapted to be subject to angular acceleration;
- a pair of masses supported on said ring member and mounted thereon at diametrically opposed locations which are equiangularly disposed relative to said support points;
- a rigid memer interconnecting said masses;
- a plurality of stress sensing means mounted on said ring member for sensing strains induced in said ring member by inertia of said masses when said apparatus is subjected to angular acceleration, at least one of said stress sensing means being located between each said mass and support point; and
- indicating means responsive to said plurality of stress sensing means for indicating magnitude and direction of angular acceleration of said apparatus.

2. An apparatus for measuring angular acceleration as described in claim **1** wherein said stress sensing means comprise electrical resistance type strain gauge elements, which are bonded to the wall of said ring and characteristically change electrical resistance when subjected to deforming forces, and said indicating means is an electrical circuit means electrically interconnecting each said strain gauge element and responsive to changes in electrical resistance of the strain gauge elements produced by tension and compression forces in said ring member for indicating the magnitude and direction of angular acceleration.

3. An apparatus for measuring angular acceleration, as described in claim **2**, further characterized in that said ring member is provided with a plurality of strain intensification regions, each produced by a reduction in cross-sectional area of said ring member; at least one of said strain intensification regions being located between each said mass and support point, and at least one of said strain gauge elements being bonded to the wall of said ring member at each said strain intensification region.

4. An apparatus for measuring angular acceleration, said apparatus comprising:
- a ring member;
- support means for supporting said ring member at diametrically opposed points on said ring member, said support means being rigidly connectable to a body adapted to be subject to angular acceleration;
- a pair of masses supported on said ring member and mounted thereon at diametrically opposed locations which are equiangularly disposed relative to said support points;
- a plurality of stress sensing means mounted on said ring member for sensing strains induced in said ring member by inertia of said masses when said apparatus is subjected to angular acceleration and wherein at least one of said stress sensing means is located between each said mass and support point; and
- indicating means responsive to said plurality of stress

sensing means for indicating magnitude and direction of angular acceleration of said apparatus.

5. An apparatus for measuring angular acceleration as described in claim 4 wherein said stress sensing means comprise electrical resistance type strain gauge elements, which are bonded to the wall of said ring and characteristically change electrical resistance when subjected to deforming forces, and said indicating means is an electrical circuit means electrically interconnecting each said strain gauge element and responsive to changes in electrical resistance of the strain gauge elements produced by tension and compression forces in said ring member to indicate magnitude and direction of angular acceleration.

6. An apparatus for measuring angular acceleration as described in claim 5 wherein said electrical circuit means comprises a Wheatstone bridge arrangement of the strain gauge elements, said bridge being normally in a balanced condition but becoming unbalanced when the apparatus is subjected to angular acceleration.

7. An apparatus for measuring angular acceleration, as described in claim 2, further characterized in that said ring member is provided with a plurality of strain intensification regions, each produced by a reduction in cross-sectional area of said ring member; at least one of said strain intensification regions being located between each said mass and support point, and at least one of said strain gauge elements being bonded to the wall of said ring member at each said strain intensification region.

8. An apparatus for measuring angular acceleration, said apparatus comprising:

a ring member;

support means for supporting said ring member at di-

ametrically opposed points on said ring member, said support means being rigidly connectable to a body adapted to be subject to angular acceleration;

a pair of masses supported on said ring member and mounted thereon at diametrically opposed locations which are disposed by ninety degrees relative to said support points, said ring member having a plurality of strain intensification regions, each produced by a reduction in cross-sectional area of said ring member and at least one of said strain intensification regions being located between each said mass and support point;

a rigid member interconnecting said masses;

a plurality of strain gauge elements mounted on said ring member for sensing strains induced in said ring member by inertia of said masses when said apparatus is subjected to angular acceleration, a pair of said strain gauge elements being located at each strain intensification region with one of said pair being bonded to the innermost surface of said ring member and the other of said pair being bonded to the outermost surface of said ring member; and

electrical circuit means electrically interconnecting each said strain gauge element and responsive to changes in electrical resistance of said strain gauge elements for indicating the direction and magnitude of angular acceleration, each said pair of gauge elements forming one arm of a bridge circuit.

No references cited.

RICHARD C. QUEISSER, *Primary Examiner.*